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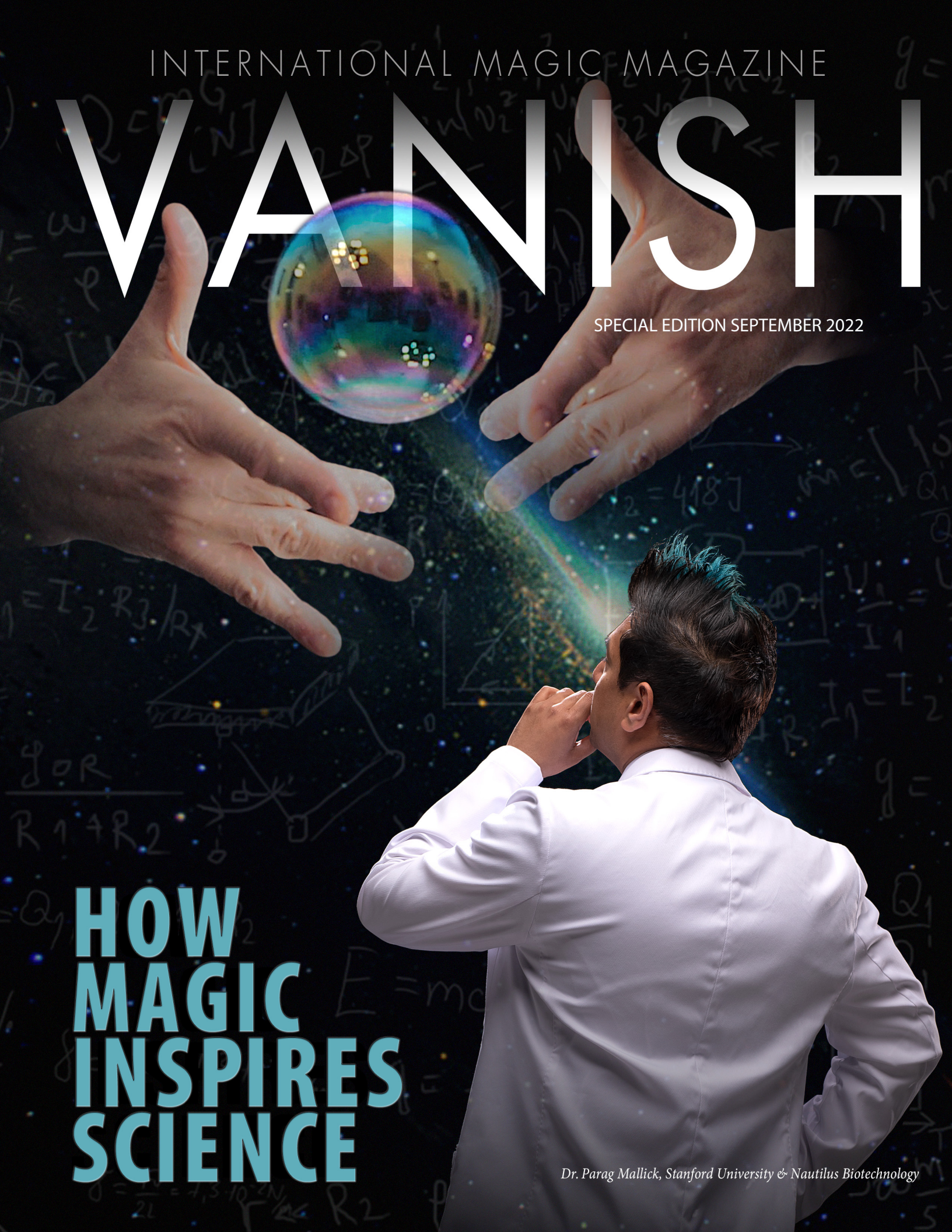

HOW MAGIC INSPIRES SCIENCE

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EDITOR'S **NOTE**

SCIENCE & MAGIC

The connection between Science and Magic has been a fascination of mine for many years. You can imagine how excited I was when a few months ago I got a call from Adam Fleischer. I knew of Adam from *The Magic Manuscript*, magic's first full-color glossy magazine that he launched and edited during the 1980s. It was a trend-setting publication and was part of what inspired my path in magic and in publishing and editing VANISH. During that period, Adam, along with America's first FISM Champion Vito Lupo, also produced *The New York Magic Symposium* conventions in the 80s. The New York Magic Symposium was known to set a new bar for the quality of talent and production for magic conventions. The event featured some of the last appearances by the likes of Slydini and Dai Vernon.

Now, 25 years since the last Symposium, Adam and Vito are launching a new event. *The International Magic Symposium* will be an academic conference on how magic inspires science, technology, teaching, and creativity to be held in Venice, Italy (dates for the first event have yet to be announced). While the event will feature a handful of the brightest minds in magic and a select group of top performers, the event's attendees will predominantly be scientists, academics, and technologists. Driven by their interest in this area, both Vito and Adam collaborated with me to produce this special issue of VANISH on how magic inspires science and creativity. I'm fascinated by the confluence of magic with science and academia, and I think we have an issue chock full of articles that will be of interest to both scientifically inclined magicians as well as magically intrigued scientists and academics.

Paul Romhany
Editor

Science is magic that works.
– Kurt Vonnegut

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DR. PARAG MALLICK

Associate Professor at Stanford University
and Chief Scientist at Nautilus Biotechnology

Editor's Note: *By day, Dr. Parag Mallick is a professor at Stanford who runs a lab that uses systems biology and big data to develop cancer diagnostics. He also serves as Chief Scientist at Nautilus Biotechnology, a publicly traded biotechnology company that he cofounded. By night, Parag wears a very different hat, that of a professional magician. He is a member of the Magic Castle in Hollywood and has performed all over the world for audiences of thousands. This essay was based upon a lecture/one-man show he first created for a scientific symposium at MIT.*

Scientists and magicians both live in worlds full of unexplained phenomena and spend their days contemplating the impossible. Despite their mutual focus, modern scientists seldom look to magicians for inspiration or guidance.

The gulf between scientists and magicians is understandable. After all, a scientist's mission is to expand the frontiers of knowledge by asking questions about the nature of our world and finding evidence that either supports or refutes a posited perspective or explanation. By expanding the frontiers of knowledge, scientists help to make the impossible possible. Magicians have an entirely different mission. At their core, magicians are entertainers focused on engendering astonishment by making the impossible *appear* to be possible. In putting the impossible on display, magicians help audiences believe – if even for a moment – that there is magic in the world and that the currently accepted laws of nature are merely suggestions not shackles. Among the most important tools in a magician's toolbox is their understanding and awareness of cognitive deficits and biases. By exploiting these gaps in our perception, magicians make impossible phenomena appear possible.

Simply put, magicians help us believe that it is possible to challenge the impossible whereas scientists *actually* challenge the impossible.

While many may see the roles of magicians and scientists as irreconcilable, magic and science are historically interconnected. Below, I share examples of how closely intertwined the science and magic communities have been throughout history. I also discuss how much modern scientists have to learn from the deep investigation of perception and gaps therein that magicians have known about and exploited for centuries.

> "IT IS NOT OUR SENSES THAT DECEIVE US, IT IS OUR MIND."
>
> **- Alfred Binet, 1894**

I was motivated to share my perspective because I believe that NOW is the time to encourage more conversations and collaborations between scientists and magicians.

Magic was central to the emergence and popularization of modern science.

The story of magic and science is one of estranged siblings who were once extremely close, but then spent the last century drifting apart. In their younger days, the high-brow magic of the court and salons matured side-by-side with science, and each played a crucial role in shaping the other. Demonic and ceremonial magics, such as astrology and alchemy, ultimately evolved into astronomy and chemistry.

Additionally, there is evidence to suggest that another popular form of occult magic, necromancy, influenced modern medicine: the Court of Lorenzo de' Medici included noted necromancers like Giovanni Francesco Rustici alongside artists like Michelangelo who were pushing the boundaries of anatomy, and humanists like Lorenzo Marsilio Ficino who was the son of a surgeon and studied medicine.

From the 14th to the late 19th century, there was a close integration between magic and the sciences. Magic was not strictly the entertainment magic common today. Many of this period's magicians also worked at the forefront of scientific advances.

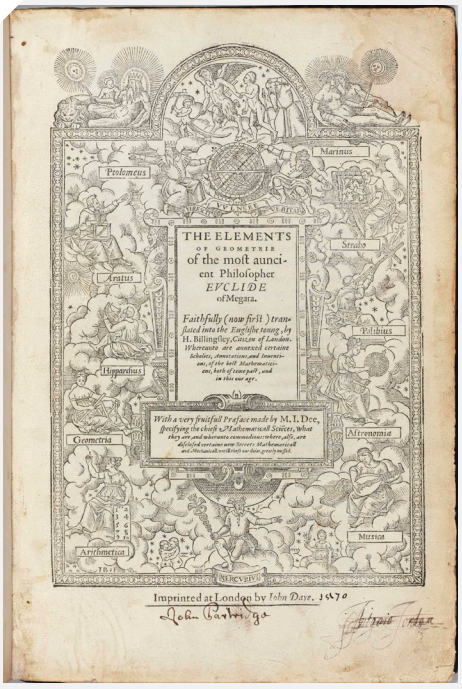
John Dee – "Celestial Necromancer" and Science Advisor to Queen Elizabeth I

Ideas surrounding perception are perhaps the most important links between magic and science. The works of one of the earliest scientist-magicians, John Dee, provides a perfect example of this linkage. Dee was an astronomer, mathematician, cartographer, alchemist, spy, and "celestial necromancer." He was also a scientific and medical advisor to Queen Elizabeth I.

One of Dee's most important achievements was his translation of *Euclid's Elements*, bringing geometry into the modern world. Geometry is the branch of math that is closest to providing a framework for describing how perception can alter observation. For example, projections and cross-sections allow us to think about how things appear when they are viewed from different perspectives. (see digaram on bottom of page 15).

Our perception and interpretation of the world is significantly impacted by how we choose to look at it. This is a fundamental principle common to both modern science and modern entertainment magic.

In one of Dee's most important collaborations – and one that many scientists will be familiar with – is a map which Dee collaborated with Mercator on in 1595, as shown in the center image. It represents one of the first projection map views of the



Dee's translation of *Euclid Elements*

Mercator, Gerhard, 1512-1594

"Septentrionalium Terrarum descriptio" From Mercator's posthumously published atlas, Atlantis pars altera

world. This perspective was quite different from other maps of the time.

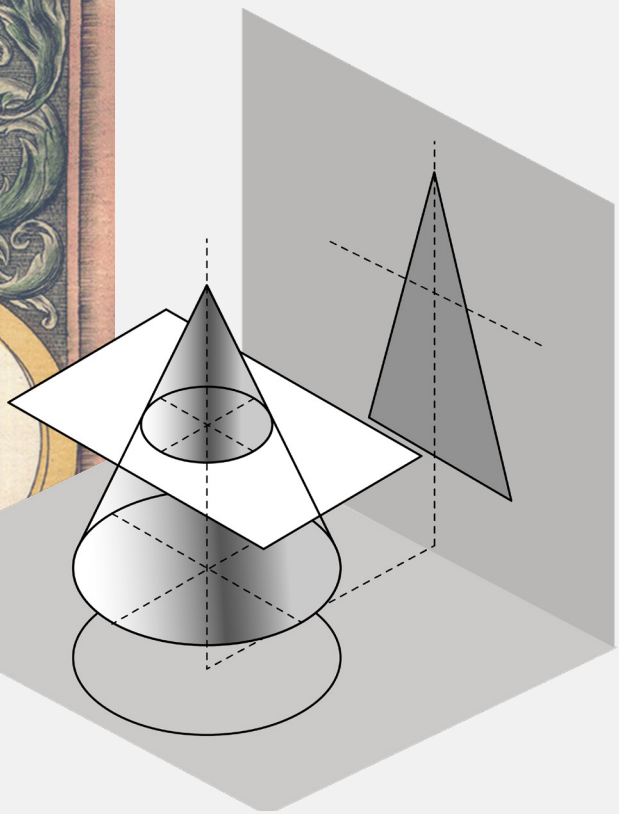
In the map, it looks incredibly easy to get from Europe to Asia and the Americas. It's possible these views of the world influenced people's perception and interpretation of the world, helping to make people believe that sea voyages across continents were attainable. Dee himself was an advocate of British exploration.[1] He helped lay the groundwork for several English voyages of exploration and played a role in teaching captains the foundations of mathematical navigation and preparing maps for their journeys.

With maps presenting a view that made it look like people could easily traverse the globe, the British empire did just that. In this instance, the magician's lens on the subtleties of and the importance of perception may have had very real impacts on the trajectory of world events.

The intersections of science, magic, and perception had – and continue to have – a huge role in shaping our world.

A great example of the magician-scientist of the 18th century went by the stage name Comus (his real name was Nicholas Filip Ledru). He was an accomplished physicist and a magician, an early advocate of bringing science and magic together, and much of his magic dealt with electricity. He was a professor

1. General and Rare Memorials Pertayning to the Perfect Arte of Navigation (1577)



Right: Projections and cross-sections allow us to think about how things appear when they are viewed from different perspectives.

of mathematics to the Duke of Burgundy and is quoted as saying, *"I want to both excite the curiosity of the people and extend the progress of physics."*

Nicolas-Philippe Ledru (Comus) – A "Charlatan of Science"

Nicolas-Philippe Ledru became one of his era's most successful "charlatans of science." His show, billed as "Experiences Physiques et Mathematiques," combined fortune-telling and sleight-of-hand with mental telepathy, electrical healing, and optical illusions. Catering to the popular taste for sound and light shows, his alter ego Comus produced lightning by discharging Leyden jars and thunder by lighting a mixture of saltpeter, sulfur, and tartar salt. He used electricity allegedly to extract powder from diamonds, and he claimed the ability to establish communication between two people separated by a barrier.

Despite all these theatrics, Ledru was also a serious purveyor of science. In 1783 his use of electrical shocks to cure people with epilepsy was so well regarded that he was able to establish a clinic for the treatment of nervous disorders. In 1784 Louis XVI conferred on him the title of Physician of the King and named him to the Faculty of Paris. With crown support, Ledru made the transition from street conjurer to electrotherapist. He was hailed by Paris' Faculty of Medicine for 'his marvelous cures.'

At the time it was challenging to differentiate true science from pseudo-science from outright fraud, as a diversity of shows emerged in which magicians were both scientists – pushing the frontiers of physics and bringing it to the masses – as well as performers doing magic tricks and illusions for entertainment.

There are many more examples of magicians being at the forefront of science and engineering. Another scientist-magician whose primary medium was electricity was Professor Georg Matthias Bose of the University of Leipzig. One particularly notable effect of his (shown in the image above), debuted in 1737, illustrating a process he termed beatification. A participant would be asked on stage and a crystal crown would be placed upon their head. And then, untouched, a 'fire' would appear inside the crystal crown, creating a halo around the person's head.

This effect was created through electrical currents being transmitted from the metal disk into the crown that had been filled with a gas, and it may have been one of the first demonstrations of something akin to a neon light bulb.

Disney's Pepper's Ghost at Haunted Mansion

Later, in the 1850s, Henry Dircks – an accomplished inventor, engineer, and scientist – created an effect known as the Dirksian Phantasmagoria that would enable the projection of a figure at a distance appearing like a hologram. A collaboration with John Henry Pepper, a lecturer and analytical chemist for the Royal Polytechnic[2] Institution, led to the Pepper's Ghost illusion that debuted in 1862 at the Royal Polytechnic. As the underpinning of all modern translucent ghost effects, Pepper's Ghost can now be found throughout the world and most famously at Disneyland's Haunted Mansion.

What scientists can learn from magicians regarding observation and perception

At the root of all scientific investigation lies observation. The scientific method depends upon it. Unfortunately, despite scientists best efforts, it is not always possible to objectively observe the world or to objectively analyze the data collected in scientific experiments.

Are we scientists incapable of objective observation because the lens of our perception – warped by our cognitive biases and blind spots – is so powerful that much scientific observation is flawed?

When looking through our microscopes and at our next-generation proteomics data, do we believe that we are looking at one thing – but is there really something completely different going on?

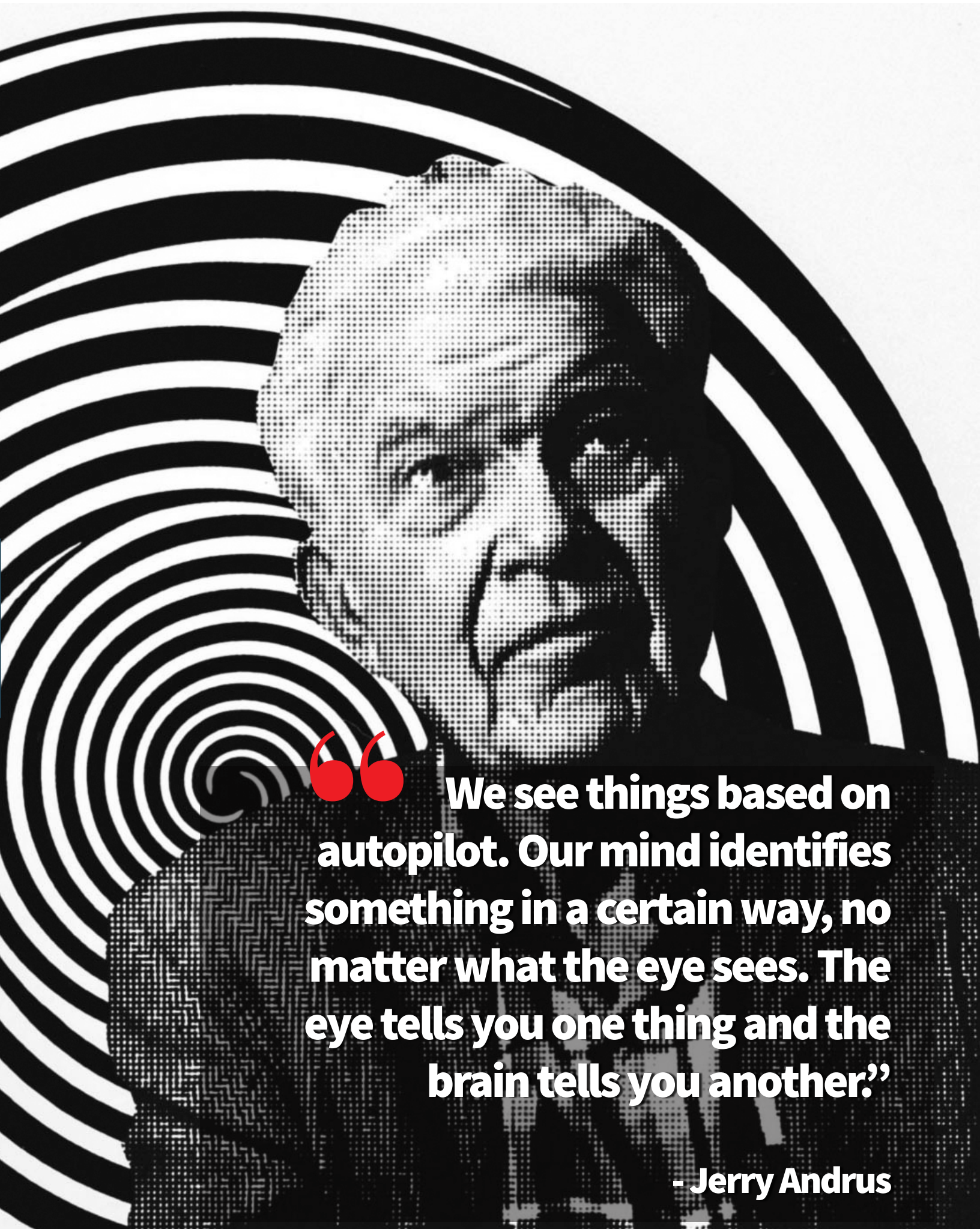
If the answer to these questions is "yes," a lot of science, as we currently know it, might require re-examining. As a scientist-magician, I can tell you that these holes in our perception prevent all of us, scientists and magicians alike, from seeing the world as it truly is.

The information our senses receive is often ambiguous, incomplete, or misleading. Nevertheless, our brains attempt to stitch together a complex morass into a simple (but not always accurate) picture. Additionally, our brains try to filter out the vast amount of incoming data to drive focus towards the 'relevant' information. Our brains achieve this using prior information.

For example, when talking to someone, we decipher each word by considering not only the sounds and movements coming from

2. **The Polytechnic Ghost**
Pepper's Ghost, Metempsychosis and the Magic Lantern at the Royal Polytechnic Institution
Jeremy Brooker

Pages 189-206 | Published online: 07 Dec 2009


“We see things based on autopilot. Our mind identifies something in a certain way, no matter what the eye sees. The eye tells you one thing and the brain tells you another.”
- Jerry Andrus

the speaker's mouth but also the meaning of preceding words, the topic of the conversation, as well as our lifelong knowledge of language. When driving, our brains fill in the blanks of road signs that are partially obscured by shrubbery. Likewise, walking through a store, we focus more on the items we are considering purchasing than the background hum of the lights. All this inferring can happen because our brains are pre-cognitively filtering, focusing, and interpreting the gargantuan amount of information we are able to sense at any given moment. This is both amazing – and dangerous.

Every observation we make goes through the blurry lens of perception shaped by a mix of our experiences, biases, mood, and social identity. We are particularly shaped by cognitive biases – systematic errors in thinking that occur when people are processing and interpreting information in the world around them, affecting the decisions and judgments they make. All of these factors lead to massive gaps in perception, observation, and reality.

WATCH VIDEO

How can magicians help?

Magicians are the world's foremost experts in perception.

Magic exploits holes and idiosyncrasies in our perception that muggles, even scientist muggles, may not be aware of. I posit that these holes in our perception are potentially crippling our scientific investigations and standing in the way of our effective search for answers.

Many people believe that magicians operate through a complex web of lies. Ironically, this is entirely untrue. Most magic succeeds (fools the audience) not because of a lie a magician tells or conveys to the audience, but instead because the magician-performer exploits the audience's cognitive gaps, expectations, and biases that lead a person's brain to deceive itself. The most powerful and effective lie is the one you tell yourself! It is important to appreciate that these biases are normal and typically unconscious processes our brain uses to accelerate and improve the quality of decision making. There are literally hundreds of biases influencing us every day.

While it is challenging to overcome biases, through awareness one can attempt to examine conclusions to determine if they were the results of cognitive biases or are truly objective and logical conclusions from reliable evidence. From first-hand experience, I know that studying magic has helped me become more aware of common cognitive biases in others, and myself.

What magicians call misdirection is about encouraging the audience's brain to focus on the wrong thing, the wrong place, or the wrong time. Our brains like to do that naturally. At a magic show, this is totally acceptable. Unfortunately, in the context of a scientific inquiry, misdirection can be catastrophic. The term "inattentional blindness" was coined by Arien Mack and Irvin Rock and is defined as the failure to notice unexpected objects when attention is focused elsewhere. While we might like to believe that we are able to infinitely multitask, the reality is that our perception of the world is limited, not by our sensory organs (e.g., eyes and ears), but instead by our minds.

Perhaps my favorite example of inattentional blindness in a magic context is the classic card-under-glass trick. (Doc Eason and Jamy Ian Swiss have card-under-glass routines that are masterful. If you haven't seen them, I suggest seeking them out.) In this effect, a selected card routinely ends up under the magician's cocktail glass (that everyone is trying to focus on), seemingly impossibly disappearing from plain sight.

In reality, the magician is directing the audience's attention to the wrong place (typically the mat or to themselves) instead of where the action is happening. A related component of inattentional blindness is the common principle used in many magic effects that big movements obscure small movements. This is used extensively in tricks like 'Hot Rod' and other related paddle tricks.

Why do our brains do this? Why do we have these sorts of biases? I believe we have evolved to be as efficient as possible. We are constantly inundated with information. Just like our home computers, if we had to fully process every piece of input all the time, we would rapidly become paralyzed. Our brains do their best to focus on what we need and fill in the blanks with regards to missing information.

Inattentional blindness can readily occur in science (and is often coupled with confirmation bias, which we discuss next). For example, consider an experiment studying a gene that we believe is the driver of a given disease process. By focusing our attention on that gene, we may dedicate less of our awareness to the thousands of other genes that might actually be the drivers. Likewise, if we believe a process manifests on a time scale of weeks, we may overlook events that occur on a time-scale of seconds.

Combatting inattentional blindness is difficult. Modern 'discovery' science tools – like whole genome sequencing or broadscale proteomics profiling – can help because they effectively force us to take a wide lens on our experiments. Additionally, being critically aware of how much of a phenomena is not sufficiently explained by our hypothesis can also help us avoid the risks of inattentional blindness.

Occam's Razor and Simplicity Bias

Occam's razor[3] states, *"Non sunt multiplicanda entia sine necessitate,"* or "entities must not be multiplied without necessity." Attributed

3. https://science.howstuffworks.com/innovation/scientific-experiments/occams-razor.htm

to English Franciscan friar William of Ockham (1285-1347), a philosopher, logician and theologian, Occam's razor suggests that the simplest explanation is preferable. Einstein is attributed with a related aphorism: "Everything should be made as simple as possible, but no simpler." In scientific investigation, simplicity goes hand-in-hand with the scientific method as a common tool of the trade.

While the concept of simplicity in explanation is appealing, it is easy to overinterpret Occam's razor to suggest that the simplest explanation is not just preferred but actually correct.[4] Unfortunately, this line of thinking leads directly to yet another cognitive bias – simplicity bias. Our brains are wired to favor explanations with alluring narratives that are easy to explain. Explanations that include ambiguity, a large number of complex details, or are hard to understand are more likely to be questioned or dismissed. As covered above, we have a limited cognitive capacity. Consequently, simplicity bias allows us to save energy by avoiding explanations that tax or exceed our cognitive capacity.

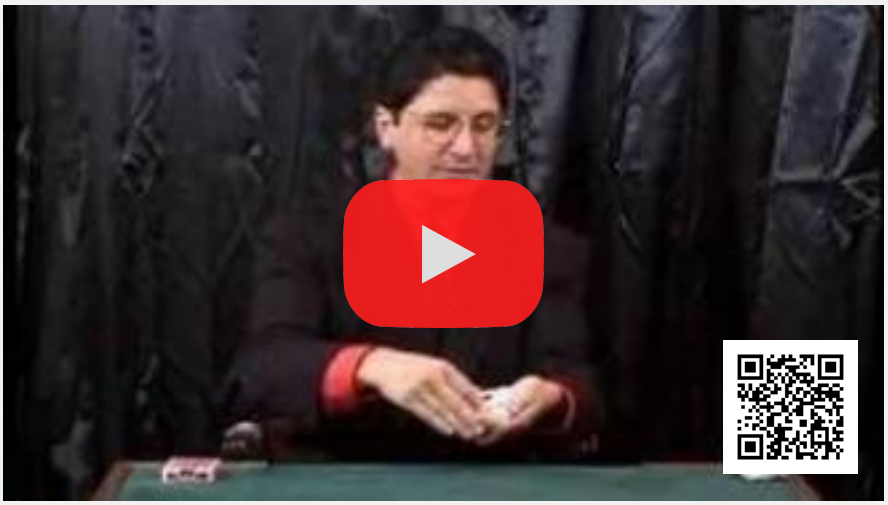
Magicians love to exploit simplicity bias. The most evident example where this arises is in effects in which a magician appears to be repeating something over and over again, such as in ambitious card routines. In this effect, a magician will typically show the audience a card, bury it in the deck, and then it will magically reappear at the top. The magician will repeat this process over and over again. While audience members appear to see the same thing happening each time, in reality the magician uses many different methods all throughout the routine, including a mix of one-way force decks, double lifts, passes, hold-outs, and other sleights and subtleties.

However, an audience member's inclination to generate a simple explanation would favor explanations reliant upon just one of these methods rather than a combination of all of them. The observed data would fit the simplest explanation (e.g., a one-way force deck) – right up until the point that the magician showed you a deck containing 52 different cards. Pigeon-holing the audience into a simple, but incorrect explanation provides a basis for fooling them.

In science, simplicity bias is prevalent. However, just because something is simple and pretty doesn't make it right. For example, for decades one of the primary characteristics that differentiated cancer cells from healthy cells was their shape. Cancer cells look distorted. Just like with the ambitious card, the simplest explanation would be that they are all distorted because of a common underlying mechanism and that, accordingly, they should behave similarly. At some level of detail this is true – they all behave badly. However, as the scientific community has dug deeper into the molecular underpinnings of cancers, it has learned that every individual cancer cell (billions of them) may have their own aberrations that govern the details of their behavior influencing not only minute details of their shape, but also other characteristics or behaviors, such as how they respond to drugs and move from place to place.

4 Feldman J. The simplicity principle in perception and cognition. Wiley Interdiscip Rev Cogn Sci. 2016 Sep;7(5):330-40. doi: 10.1002/wcs.1406. Epub 2016 Jul 29. PMID: 27470193; PMCID: PMC5125387.

> "AT THE CORE OF EVERY TRICK IS A COLD, COGNITIVE EXPERIMENT IN PERCEPTION." - TELLER



Combating simplicity bias and inappropriate reliance on Occam's Razor starts with recognizing how ingrained it is in our thought processes. Quantitative measures (e.g., the Akaike information criterion) can be used to compare models with respect to both how well they fit the data and how complicated they are. A few other tips – when trying to develop an understanding – challenge the thing that seems like the 'prettiest' explanation. Lastly, if you find yourself stuck in binary thinking – where there are exactly two explanations – call it out and ask why there are only two explanations. Also ask if parts of each of those explanations may be correct. One other excellent resource for combating simplicity bias is the book *Thinking, Fast and Slow* by Danial Kahneman.

WATCH VIDEO

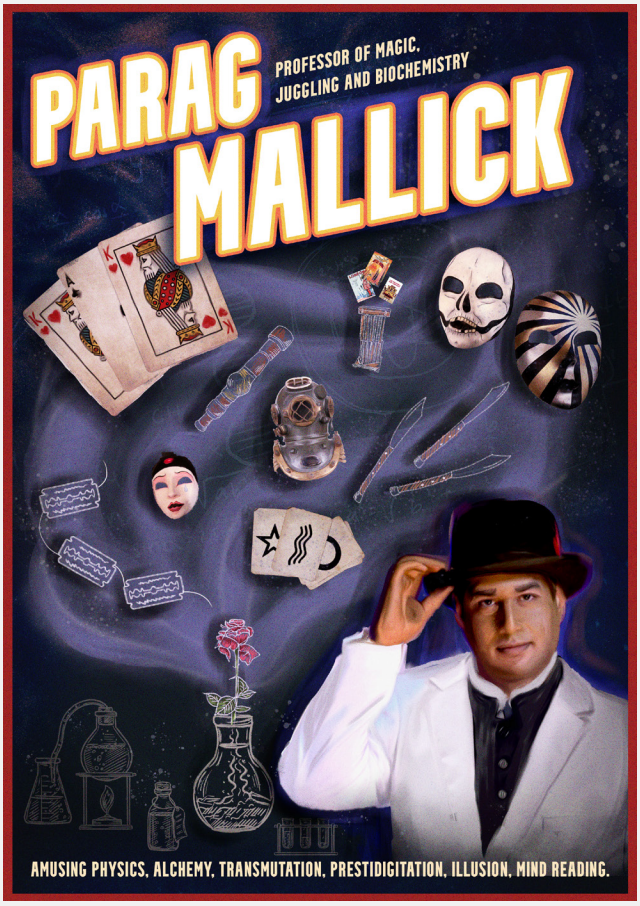
Confirmation Bias

Confirmation bias is the tendency to look for information that supports one's preconceptions. It impacts how we gather, interpret, and recall information – for example, when a person gives more weight to evidence that confirms their beliefs and undervalues evidence that could disprove it.

One of the early demonstrations of confirmation bias appeared in an experiment by Peter Watson in which the subjects were told to find a rule by which a series of numbers were generated.[5] This simple study showed that subjects chose responses that supported their hypotheses while rejecting contradictory evidence even though their hypotheses were not correct.

More recently, a study observed[6] researchers as they examined 165 lab experiments. In 88% of cases in which results did not align with expectations, the scientists blamed the inconsistencies on how the experiments were conducted, rather than on their own theories. Consistent results, by contrast, were given little to no scrutiny. This particular bias is sometimes known as asymmetric attention.

As magicians – we love to exploit confirmation bias. For example, audiences will typically assume basic things like decks of cards are 'normal' and that dice aren't loaded. In designing effects, magicians often bake in 'provers' that seemingly validate for the audience that their assumptions are correct. Once the audience has been assured that their assumptions are correct, magicians have set the boundaries of an audience's perception and awareness and are free to make the impossible happen. While this is fantastic for magic – it is extremely dangerous for science.



Fortunately, the study of ways to combat confirmation bias has drawn much attention in the scientific community over the past decade.[7] One approach, known as 'strong inference,'[8] suggests scientists make themselves explicitly list alternative explanations for their observations and debate the support for both the primary and competing hypotheses. An alternate approach gaining traction is known as blind data analysis. The general concept is to separate the data analyzers from the hypothesis generators. Under these circumstances, analyzers couldn't possibly over-interpret the data, as they have nothing to unconsciously look for.

I believe that deeper awareness and conversation around how effectively the magic community uses assumption blindness could help the scientific community develop new and more effective approaches to combat it.

Closing thoughts — bringing magic and science back together

My experiences as a magician have shown me both how malleable perception is, and how prevalent cognitive gaps and biases are. While, as a performer, I greatly enjoy taking advantage of these gaps and biases to delight audiences, I've become acutely aware of how these same biases may be impacting my scientific studies.

Ultimately the goal of science is to build a sufficient understanding of the world so that we can derive models that effectively predict future unknowns, such as what will happen when we drop a ball, or someone takes a cancer drug. To develop accurate, highly predictive models, we need to be able to observe and interpret the world around us as accurately as possible. These days, I try to make sure to look at my science through the lens of a magician – examining all the ways I might be fooling myself. This inquiry has become a routine part of everything from how I design experiments to how I analyze data, and I believe this has made me a better, and more cautious, scientist.

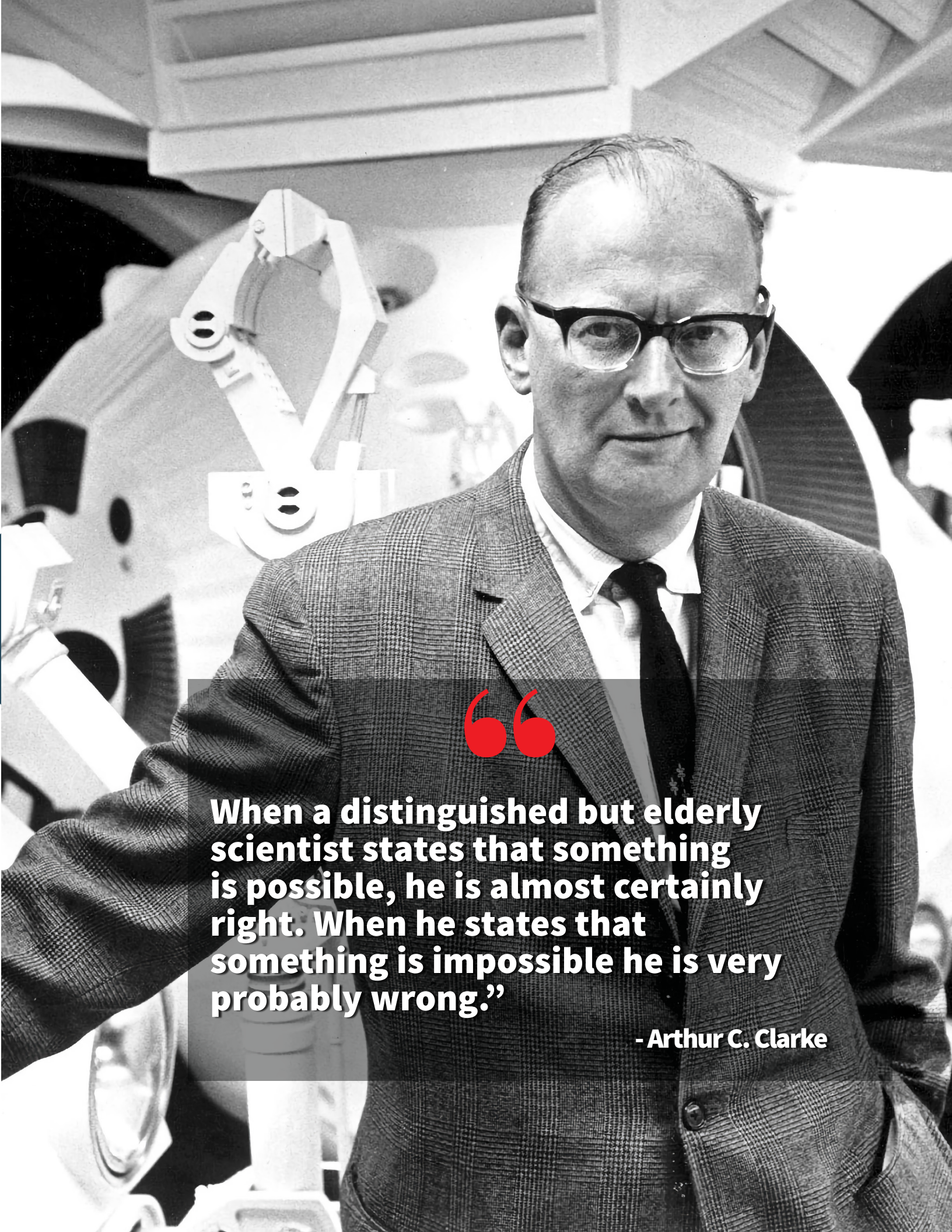
Magic lives between the improbable, impossible, and inexplicable.

In addition to examining biases, there are many other ways in which scientists might learn from magicians. Afterall, much like science, magic lives at the intersection between the improbable, the impossible, and the inexplicable. When developing a new magic trick, a magician often begins by thinking of something impossible. Next, they figure out a way to make it happen – or at least to make an audience perceive that it happened.

This willingness to wholeheartedly dive into the impossible, to not be afraid of it, and to explore utterly ludicrous explanations as part of the process, is something that scientists are often afraid of. Oftentimes we only allow ourselves a narrow range of explanations. For an educated and adept magician, no explanation (or possibility) is too hard, too complex, or too impossible to consider. Perhaps more interactions between scientists and magicians will embolden scientists to dream a little bigger, to explore a wide range of possibilities and hypotheses, and, ultimately, to accelerate the progress of science.

Arthur C. Clarke said it well in his second law – "***The only way of discovering the limits of the possible is to venture a little way past them into the impossible.***" I hope one day to be able to look back at the synergies that emerge from renewed conversations between scientists and magicians and see how magicians contributed to a new golden age of science filled with amazing breakthroughs. ■

5. P. C. Wason (1960) On the failure to eliminate hypotheses in a conceptual task, Quarterly Journal of Experimental Psychology, 12:3, 129-140, DOI: 10.1080/17470216008416717
6. Fugelsang, J. A., Stein, C. B., Green, A. E. & Dunbar, K. N. *Can. J. Exp. Psychol.* 58, 86–95 (2004).
7. ***How scientists fool themselves – and how they can stop***. Regina Nuzzo Nature volume 526, pages 182–185 (2015)
8. Platt, J. R. Science 146, 347–353 (1964).



“When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible he is very probably wrong.”

- Arthur C. Clarke