Uncovering the human superpowers
Cognitive science researcher Mark Changizi explores how the brain works—discovering some remarkable answers to age-old questions
PACKED NEATLY ON THE bookselves in Mark Changizi's Carnegie Building office sit stacks of notebooks containing hundreds of questions. **WHY** do we have fingernails? **WHY** are organs packaged in such a specific way inside our bodies? **WHY** does skin wrinkle when it gets wet? **WHY** are our hands shaped the way they are?

These are among the questions in the notebooks—26 and counting—that Changizi fills with potential research ideas he poses as queries about the design and behavior of biological systems.

So far questions in the notebook have yielded highly acclaimed research findings, including why primates see in color and have forward-facing eyes, why optical illusions succeed at tricking our eyes, and why written characters across languages share common shapes.


An evolutionary scientist and theoretical neurobiologist, who joined Rensselaer’s Department of Cognitive Science as an assistant professor in 2007, Changizi focuses on research that often sets him apart from his colleagues in the field. **By Amber Cleveland**
“Mark is a theoretical neuroscientist of the first rank, and has an amazing ability to systematize a dizzyingly broad range of phenomena,” says Selmer Bringsjord, professor and head of the Cognitive Science Department. “We are profoundly fortunate to have him at Rensselaer. He is a key component of a department that, while not large, achieves great range across cognitive science.”

FINDING X, WHY, AND Z

While most cognitive scientists attempt to understand how the human brain performs specific tasks, Changizi focuses on uncovering why it works the way it does to begin with.

“What drives me is the opportunity to understand the basic reasons for why a biological system does what it does, looks the way it does, or is organized the way it is,” says Changizi. “My research is dedicated to carving out the fundamental work about why we are the way we are.”

Changizi says the “how” and “why” of research go hand in hand, and he often uses analogy to illustrate why both parts of the research puzzle must work in tandem to form a clear picture of human cognitive tasks. “If a group of people cut off from the everyday world were to stumble upon a stapler, and the object and its function was foreign to them, you can imagine how difficult it might be to figure out how it works,” Changizi says. “Without knowing what it’s used for, they might shoot staples through the air and say ‘this is the mechanism that causes that,’ or they might start breaking it or bending it in ways it’s not meant to move and say ‘if you bend it this way, it does this.’ They could be analyzing infinitely many mechanisms that the stapler could carry out that have nothing to do with what it’s designed for.”

That’s where Changizi’s research comes in.

“You can only talk about a mechanism once it’s understood what the intended function of the mechanism is,” he says. “If you can figure out what a biological system—like the visual system has been selected to do, you can start to work on how it does it.”

Changizi’s interest is in discovering why a particular mechanism gets selected to perform a task that a biological method could do. “My research focuses first on why a mechanism happens, and then on uncovering what makes that mechanism optimal.”

Just as optimization is inherent in the systems he studies, it’s also inherent in the process by which Changizi conducts his research, which differs in significant ways from the processes typically followed by many of his colleagues. “I’m cognizant that it’s not likely I will make multiple discoveries of the same magnitude in any given topical area, so in order to optimize my chances as a theorist, I have to constantly change the subject areas I focus on. And I take a specific approach to do that,” he says.

Changizi’s research questions are the product of more than a decade of frequent brainstorming sessions, during which he tries not to aim to solve a specific problem or confine his thinking to any particular discipline, because “the odds of getting a great idea in any given area are very low, so you need to allow your brainstorming travels to go anywhere.”

He says he may develop anywhere from 10 to 100 ideas before finding a good one, which he defines as “coherent, interesting, true, testable, and publishable.”

Changizi’s intense research focus extends to disciplining his own mind by avoiding too close associations with specific scientific communities, funding agencies, and academic conferences. This, he believes, minimizes any psychological constraint that might keep him from following the most promising research directions.
“This can make you less likely to go outside your own community to take up other kinds of problems,” he says, “even great, interesting, exciting problems—for fear of being rejected by your peers.”

He also tries not to let research funding exert too much influence over his work. “Funded research is important, and I do some, but I don’t ever want the dollars to dictate what I’m studying. I don’t want to forget what I was excited about doing before I got the money,” he says.

In fact, Changizi’s role as an outsider allows him to pursue projects that might sound crazy to other researchers. “Some of my best ideas seemed embarrassingly crazy when I first conceived of them,” he says. “[But] they have fueled my most important discoveries.”

His other unconventional practice is to rely on published data to verify his findings instead of conducting complex experiments, which can be time-consuming, difficult to conduct, and demand more specialized skills than a theorist like himself possesses. “I need the freedom to cut my losses if I’ve worked on an idea for a few months and then need to throw in the garbage and work on something new,” he says.

HUMAN “SUPERPOWERS”

Called “prolific” by Scientific American, Changizi has made four major discoveries in the last three years about the visual system’s “superpowers.”

His research both has uncovered uncanny abilities and overturned some longstanding erroneous explanations in each of the main subdisciplines of vision: color, object recognition, motion, and binocularity. His first research project, related to why we see in color, was conducted while he was a fellow in the Sloan-Swartz Center for Theoretical Neurobiology at the California Institute of Technology.

“Old-world primates, whose descendents include us, have a different cone receptor in their eyes than the rest of the animal kingdom, and thus they can see very slight color changes,” says Changizi. “For years scientists thought that our color vision had adapted to allow us to find the ripest fruits in the forest, but if you look at what these primates eat, the evidence isn’t extremely supportive.”

Changizi discovered that our ability to see in color is actually designed to allow us to detect subtle changes in the emotional states of our peers. A fluctuation in oxygenated blood could signal anything from embarrassment—through red cheeks—to going “white with fear.”

“Our ability to see subtle changes in color gives us the ability to read the minds and sense the emotions of those around us,” Changizi says. “We essentially have external sensing equipment for reading emotions, much like the Star Trek empath character [which had the psychic ability to sense the emotions of others].”

Changizi then turned his sights on object recognition by studying why letters across written languages share similar shapes. He discovered that our ancestors likely created their alphabets to mimic shapes that naturally occurred in their environment, exactly the shapes our visual systems have evolved to be great at processing.

“The letter Y, for example, is found on the corners of objects, and the letter T is found when a contour of an object is occluded by another object,” says Changizi. “And similar shapes are found throughout the alphabets of other languages.”

During the two years he’s been a faculty member in the Department of Cognitive Science, which Changizi says he joined because of its diversity of expertise in fields ranging from psychology and logic to artificial intelligence and neuroscience, he’s uncovered two more visual system superpowers.
He argues that our ability to anticipate the future is evident in everything we do, whether it's catching a football or maneuvering through a crowded room full of people.

It takes our brain nearly one-tenth of a second to translate the light that hits our retina into a visual perception of the world around us. While a neural delay of that magnitude may seem minuscule, imagine trying to catch a ball or wade through a store full of people while always perceiving the very recent (one-tenth of a second prior) past.

While many scientists hypothesized that optical illusions occur because they exploit the limitations of our visual processing, Changizi argues they occur when our brains attempt to perceive the future, and those perceptions don't match reality.

"We experience countless illusions in our lifetime. The most famous being geometrical illusions—those with converging lines and a vanishing point we often see in Psychology 101 classes or in entertaining optical illusion books," he says.

The Hering illusion, for example, looks like a bike wheel spoke with two vertical lines drawn on either side of the center vanishing point. Although the lines are straight, they seem to bow out away from the vanishing point. The optical illusion occurs because the human brain is predicting the way the underlying scene would project in the next moment if the individual were moving in the direction of the vanishing point.

"Evolution has seen to it that geometric drawings like this elicit our superpower ability to foresee the near future," says Changizi.

Changizi uncovered the final of the four superpowers in a paper published last summer. He claims the eyes have evolved to face forward in order to allow for "X-ray vision," or the human ability to see through the clutter in the world.

Most animals—fish, insects, reptiles, birds, rabbits, and horses, for example—exist in non-cluttered environments like fields or plains, and they have eyes located on either side of their head, allowing for panoramic vision.

Humans and other large mammals—primates and large carnivores like tigers, for example—exist in cluttered environments like forests or jungles, and their eyes have evolved to face forward, with a larger overlapping binocular field. Many have argued this was so primates could see in three dimensions as they jumped from limb to limb, but Changizi found these animals have been selected for maximizing the ability to see in leafy environments like forests.

"Our binocular region is a kind of 'spotlight' shining through the clutter, allowing us to visually sweep out a cluttered region to recognize the objects beyond it," he says. "As long as the separation between our eyes is wider than the width of the objects causing clutter—as is the case with our fingers, or would be the case with the leaves in the forest—then we can tend to see through it."

REVISION

Changizi discusses the four superpowers—emotion sensing, spirit-reading, future seeing, and X-ray vision—in his new book, The Vision Revolution. Changizi wrote the book for both a general audience and the scientific community.

"I really admire the work of [Harvard professor and author] Steven Pinker, whose books focus on scientific topics in a way that is accessible to all readers, not just scientists," says Changizi. "In that same vein, I was cognizant to try to write something that anyone could read, understand, and find interesting and inspiring—without compromising the
scientific explanations for why our visual systems have evolved to behave the way they do. Laymen like a trade science book most of all when they feel that the book is part of the scientific conversation, not something written just for laymen."

The book, which already has garnered mentions in The New York Times and Scientific American, is not the end of the literary road for Changizi, who has turned his sights to his next book. "I'm in the process of working on a proposal for a second trade book based on new research into how language mimicked nature, like how the sounds of speech sound like naturally occurring events," he says.

Changizi also has received accolades for his classroom teaching. The 2008 recipient of Rensselaer's Class of 1951 Teaching Development Grant awarded to faculty members for their outstanding accomplishments in education, Changizi has introduced innovative new coursework for undergraduate students. Last spring, for example, he taught The Cognitive Science of Art, an interdisciplinary course he developed for cognitive science and arts students that focused on uncovering various cognitive principles ingrained in artwork.

He also taught a daylong course to a digital circuits class focused on a new technique he created to harness the computing power of the visual system to carry out digital circuit and logic computations.

By visually representing a computer program in such a way that, when viewed by an individual, that person's visual system naturally carries out the computation and generates a perception, Changizi showed his students that it might be possible to one day glance at a complex visual stimulus (the software program) and have the visual system (the hardware) automatically generate a perception of the output of the computation.

He has begun to apply his approach by developing visual representations of digital circuits. A large and important class of computations used in calculators, computers, phones, and most of today's electronic products, digital circuits are constructed from assemblies of logic gates and have an output value of zero or one.

"A digital circuit needs wire in order to transmit signals to different parts of the circuit. The 'wire' in a visual representation of a digital circuit is part of the drawing itself, which can be perceived only in two ways," says Changizi, who created visual stimuli to elicit perceptions of an object tilted toward (an output of one) or away (an output of zero) from the viewer. "An input to a digital circuit is a zero or one. Similarly, an input to a visual version of the circuit is an unambiguous cue to the tilt at that part of the circuit."

Changizi says his students "loved the seminar," and he hopes to obtain financial support to create a semester-long course in visual circuits in order to measure the learning curve of this new way to teach digital circuits, compared with the traditional method.

"People are notoriously poor logical reasoners—someday visual circuits may enable logic-poor individuals to 'see their way' through complex logical formulae," he says.

And while he's succeeded at changing the way his students (literally) see digital circuits, and his scientific peers see the groundbreaking evolutionary reasoning behind the mechanisms of the visual system, Changizi is still hard at work. There are more questions to ask, more notebooks to fill, more answers to find.

"There is always more to discover about why we are the way we are," he says. "The tricky part is putting your finger on the right question—that crazy-sounding question—that allows you to uncover an important answer."