



Rockmore thinks computers can authenticate art better than any connoisseur can.

THE REMBRANDT CODE

Identifying true old masters – and spotting the fakes – is a rarefied art. Dan Rockmore wants to make it a science.

by Bijal P. Trivedi

photographs by Richard Ballard



In a photography studio nestled in the high attic of New York's Metropolitan Museum of Art, mathematician Dan Rockmore stands in front of *Flora*, rocking back and forth on his heels like a shy schoolboy. He leans close to the figure on the canvas to peer at her face. Unshackled from her heavy wood gilt frame, the beautiful Roman goddess of spring and flowers appears vulnerable. "It's like seeing actors backstage at Broadway, without their makeup, drinking beers, and smoking cigarettes," Rockmore says quietly, as if the mere vibration of his voice could send the



350-year-old painting, worth about \$40 million, crashing to the floor.

Flora is one of 25 works attributed to Rembrandt van Rijn that are now under intense scrutiny. Some of these paintings have dubious origins; experts believe that others, like *Flora*, are bona fide Rembrandts. She, for example, shows telltale signs of the 17th-century Dutch master: the cascading brushstrokes that create the decadent, billowing folds of her sleeve, the horizontal flow of light pouring from her flower-filled apron, the oversize hand. But these characteristics are in the eye of the beholder, and Rockmore, a professor of computer science at Dartmouth College, wants to bring digital technology to the art of authentication. Using hi-res digital cameras and software that he wrote himself, Rockmore aims to examine the brushstrokes from *Flora* and 24 other works to reveal Rembrandt's unique mathematical fingerprint.

"The fact that you can put everything on the computer means that everything is numbers," Rockmore says. "As soon as everything is numbers, it makes perfect sense to ask mathematical questions about what the numbers represent." If he's right – if computers can distinguish between artists more accurately than connoisseurs can – the art world is in for some high-stakes corrections. Rockmore's scientific approach will boost the value of some collections by millions of dollars – while devastating others that are tainted by imitations and fakes.

AUTHENTICITY IS A BUGABOO that plagues the art world in general but Rembrandt collectors in particular. Over three decades, Rembrandt had about 40 pupils in his studio who emulated his style. Many of these often-anonymous student works fell into the hands of Amsterdam dealers who resold them as the real thing, occasionally augmenting them with Rembrandt's signature – forever muddying the task of attribution.

A hundred years ago, about 700 works were attributed to Rembrandt. That number has now dropped by more than half, due in large part to connoisseurs who have spent years identifying features and nuances that distinguish master from student. Lousy luck for the owners of the mislabeled works, this smaller supply means bigger bucks for the possessors of authentic masterpieces. Today there is at least an order

of magnitude difference in price between a Rembrandt and a creation by one of his pupils, says Anthony Crichton-Stuart, head of old master paintings at Christie's New York. For example, a "sublimely beautiful" painting by Rembrandt pupil Willem Drost sold for \$2.6 million in 1997. Three years later, Rembrandt's *Portrait of the Old Lady*, which the same critic dubbed merely "wonderful," fetched \$28.6 million.

The Met owns 42 paintings that were once believed to be Rembrandts, but the attribution of more than half of them is now in question. Only two have original documentation and a reliable paper trail tracing passage from the artist's hand through various collectors over the past 350 years.

In 1995 the museum took the debate public when it mounted the exhibition *Rembrandt/Not Rembrandt*. The show contrasted works considered to be genuine Rembrandts with those done by pupils and admirers painting in his style. Each attribution was accompanied by an explanation of how the connoisseurs made their call. The experts don't agree on a handful of works, and the debate rages on. Walter Liedtke, a curator in the Met's European painting department and an expert on Dutch and Flemish art, believes that 20 of his museum's Rembrandts are real and says that the world's top Rembrandt scholars would agree with almost all of his choices. "There's a border zone of about five or six paintings that would be debated and probably will be for generations," Liedtke says. "This is not a hard science."

Rockmore thinks it can be. His mathematical analysis of drawings by a Flemish Renaissance artist last year intrigued the art community and art collectors alike. Curators at the Met didn't really believe that his work could supplant theirs. But they were intrigued enough to invite him to examine the museum's Rembrandts.

AS MATHEMATICIANS GO, Rockmore is something of a celebrity. He defies the stereotype of a calculator-wielding, tweed-jacketed, sedentary academic holed up crunching numbers all day.

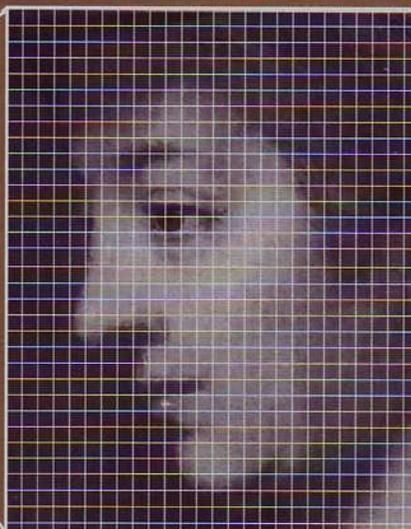
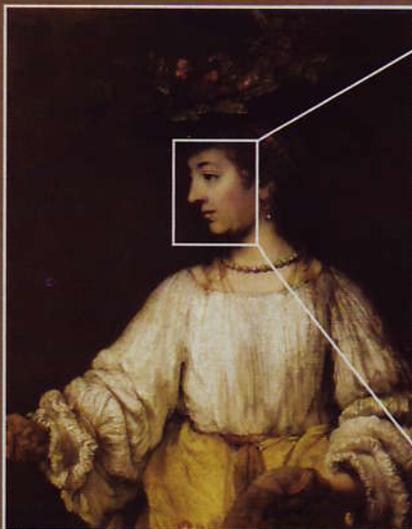
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Is This Rembrandt Real?

1

Digitize

Rockmore starts with a photograph taken with a Sinar 54 camera that spits out 20-megapixel images – about four times the resolution of a regular digital camera file.



2

Analyze

Software converts the picture to grayscale and divides it into squares. The pixels in each square are coded with a number between 0 (black) and 255 (white) – everything in between is a shade of gray. It does this so that it can see the distinctions caused by brushstroke style, not by color.

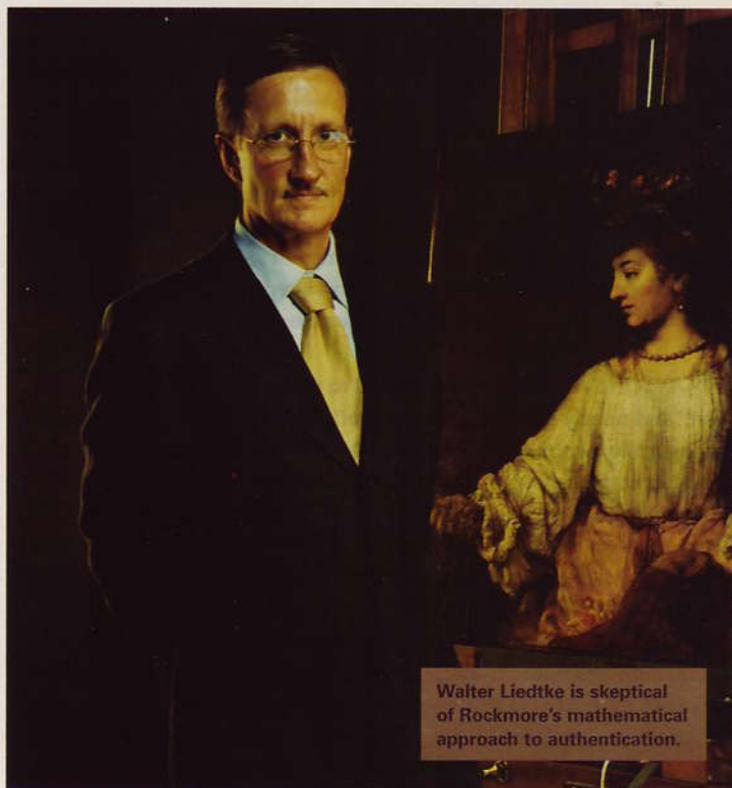
He's tan and lean. Laugh lines are etched deeply around his mouth. He's also busy. He spent last summer shooting math documentaries, puts a mathematical spin on everyday life for essays on Vermont's public radio station, and has written a book about Bernhard Riemann's 19th-century quest to discover the occurrence and distribution of prime numbers.

Rockmore comes to art more through theory than through the works themselves. He says he first connected to art when he read manifestos written by mid-20th-century abstract expressionists. "It might be total bullshit," he says of the artists' writing, "but somehow it resonates." The process of creating art especially fascinates him, and he points to an interview he read with the contemporary American artist Chuck Close. "He certainly talks like a mathematician. He talks about getting the materials down, working on a piece like trying to prove a theorem, and sometimes it's wrong, so he tosses it out and starts again."

Rockmore's casual interest in art became something more serious in 2001 when he met George Goldner, chair of the Met's department of drawings and prints, while the two were walking their dogs in Central Park. Goldner, in turn, led the professor to Nadine Orenstein, who curated a Met exhibition of drawings by 16th-century artist Pieter Bruegel the Elder.

At one point, Orenstein explained to Rockmore how she figured out which works were real. She described distinctive features like the density of lines, their orientation, and specific sorts of curves characteristic of Bruegel. Hearing this, Rockmore's mind jumped to the work of two colleagues at Dartmouth who had used statistics to distinguish between real and fake photos. The similarities between his colleagues' work and Orenstein's led Rockmore to wonder whether a computer could analyze the linear content of the drawings and reach the same conclusion as a connoisseur. He tested his hunch using eight genuine Bruegel drawings and five sketched by other artists of the day.

Rockmore begins his procedure by analyzing the digital image pixel by pixel and creating statistical summaries of each painting or drawing. These summaries capture what Rockmore calls the



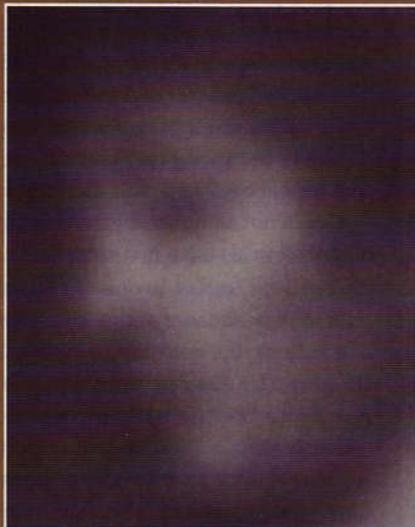
artist's mathematical signature, which in theory will be consistent from painting to painting. Just as everyone's handwriting is unique – with characteristic letter spacing, slant, and design – so is everyone's painting style, with characteristic brushstroke direction, thickness, and length.

At least that's what the software showed with the Bruegels. When the mathematical signatures of the 13 drawings were mapped, eight works clustered together – the same eight deemed by experts to be authentic Bruegels. The other five were scattered in space. The clarity of the results startled the art world, and holds out the promise that Rockmore will be able to work backward from his current analysis

3

Search

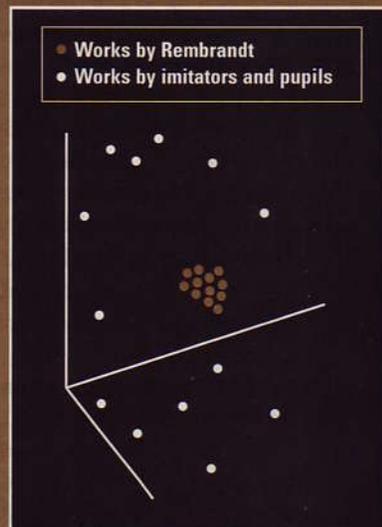
The software combs the image, identifying and stripping out the horizontal, vertical, and diagonal lines of the brushstrokes, searching for patterns that reveal the artist's style. With each pass, the software creates "a blurry version of the original," peeling away minute details and better exposing large-scale features. The computer does this five times, eventually gathering 72 pieces of data that statistically summarize each square.



4

Plot

Rockmore takes this data, which describes the brushstroke elements like slant and thickness, and reduces the information into a point on a 3-D grid. This point is compared to points generated by other paintings. Works by the same artist should cluster together. Rockmore might then work backward to determine what differentiates master from pupil.



to figure out exactly what makes a Rembrandt real: perhaps the master had thicker brushstrokes than his pupils, or some characteristic shake in his hand.

Orenstein says she's impressed by the Bruegel results but doubts that Rockmore will have as much success analyzing more-complicated pieces. "I can't imagine that someday you will have something that will go around zapping images in an auction and saying, this is by Bruegel, this isn't, immediately on the spot," Orenstein says.

Other art connoisseurs are even more skeptical – most prominently Rockmore's colleague at the Met, Walter Liedtke.

ON MONDAYS, the Met is closed to the public. The galleries are silent, and nearly all of the lights are off. Most of the guards are absent. Roaming the tomblike chambers gives one the intoxicating sense of doing something illegal.

But adjacent to the silent galleries are little pockets of activity, where curators are busily poring over great works. One such pocket is Walter Liedtke's office, hidden within a maze of art on the second floor behind a pair of gray doors.

Inside is an industrial-style studio space with 20-foot ceilings. To one side are floor-to-ceiling hanging wire racks, heavy with priceless art and also some empty gilt wood frames. Liedtke is tall and trim, and, on this fall day, dressed in a charcoal-gray suit, pale-blue shirt, and a tie with narrow diagonal stripes of yellow and blue. Wireless spectacles are perched on his thin nose, and his slightly wet hair is parted neatly and combed to the left. A mustache hovers precisely over his lip.

Liedtke doesn't make small talk. He walks up to a captivating, if blandly titled, painting: *Portrait of a Woman*. A Rembrandt, no doubt. But Liedtke says, "Even through the dirt and varnish, I think this figure looks a bit like an awkward cutout. And in Rembrandt I would expect more of a sense of volume and easier transition to the background." Gesturing at the portrait, he adds, "Something you see frequently in Rembrandts, as opposed to pupils, is a sense of that arm under the costume. I mean, suppose she took her clothes off, what kind of arm would you be left with? What sort of shoulder? I'm not sure it would match that one. There's not a sense of something anatomical under the drapery. It's very flat." Well, yeah, now that he points it out, sure, it's obviously not a Rembrandt.

Liedtke navigates back to the Rembrandt gallery, flicks on the lights, and walks up to *The Auctioneer* – a painting whose provenance was not doubted until the early 1980s. He points to the sleeve. "What sort of material is this? It looks a bit like a *caffè latte*. It is pretty mushy and ill-defined," Liedtke says, his hand sweeping millimeters from the surface with the ease of someone who handles priceless works every day. He gestures to "fancy highlights" under the chin, adding that Rembrandt's imitators tended to copy his surface effects but missed the basics that are more characteristic of the person. Another clue is that the painter, whoever he was, used light to highlight the edge of a book and a piece of clothing, whereas genuine Rembrandts possess a more "generalized, subtle sense of light throughout."

Traditionally, art scholars have used a range of tools to determine attribution, but each has a caveat. Historical documentation is important, but extensive paperwork usually indicates fraud. "Signatures are nice," says Liedtke, but he adds that "the painting defends the signature and not vice versa." And the role of science – x-rays,

infrared imaging, autoradiography, pigment analysis – in authentication is far more limited than most people realize. Members of the public frequently bring in pictures or read about debated works and say, "Well, can't you take it to the lab and analyze it?" The answer, says Liedtke, is no.

Pigment analysis might trace works to Rembrandt's studio, but he and his students used the same paints. X-rays revealing thread count matching that of a known Rembrandt canvas prove little, as the canvas dealer also likely supplied fabric to other artists. Dendrochronology – the dating of oak panels – could yield a match to wood panels from an authentic Rembrandt, but it doesn't pinpoint the artist, says Ernst van de Wetering, head of the Rembrandt Research Project, a group that has been continuously and systematically examining Rembrandt's oeuvre since 1968. "Scientific investigation very often will not lead you to a final conclusion, so you are doomed to also rely on connoisseurship," says van de Wetering. "The greater the artist, the less predictable is what he does."

"If I asked you to draw 100 lines," says Rockmore, "I could pick up some characteristic heartbeat or twitch." He explains that everyone, whether a great artist or a telephone doodler, has certain idiosyncrasies. Figuring out how to identify those idiosyncrasies is the core of what's known as visual stylometry. Rockmore's work is just one


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example of this growing field.

Analyses of Jackson Pollock's paintings also have hit on this physiological phenomenon. Richard Taylor, an associate professor with appointments in physics, psychology, and art at the University of Oregon, recently discovered an underlying pattern in Pollock's drip and poured paintings. After scanning Pollock's works and analyzing them at increasingly fine magnifications, Taylor found fractals – the naturally occurring geometric patterns, like the branches of a tree, that repeat over and over at every level of magnification.

This is not an inevitable consequence of pouring paint, says Taylor, who makes his case in a soon-to-be-published paper in *Pattern Recognition Letters*. In one experiment, he rigged about 40 people with motion sensors and asked them to flick, spatter, and pour paint à la Pollock. But contrary to the my-kid-could-do-that sentiment often triggered by abstract art, nobody could fake the fractals. "When you move your body to a posture where you are right on the edge of your balance, your motion becomes fractal," Taylor says. Pollock refined his technique over his career, increasing the fractal structure of the paintings – the key, says Taylor, for authenticating and dating Pollock works.



Rockmore and photographer Juan Trujillo in the studio, analyzing *Flora*. If Rockmore's method works, the art world is in for some high-stakes corrections.

A subconscious perception of the fractal quality may explain Pollock's popularity.

Taylor believes such investigations will be "huge in the future" for both abstract and figurative art, and he is already attracting attention. The Pollock-Krasner Foundation, established by Pollock's wife, abstract expressionist Lee Krasner, has commissioned Taylor to analyze several of the 32 potential Pollocks that were recently discovered in a storage unit. Twenty other collectors have commissioned him to analyze their art, and Taylor has established a company to handle the interest in his procedure.

Rockmore says he has received inquiries from museums and "at least 10" collectors interested in having works tested. All this suggests that science could make attribution faster and more objective.

Still, there are hurdles ahead. Rockmore's system worked well enough for the Bruegel drawings, Liedtke says. But drawings are simpler than paintings. Rembrandts sometimes have eight to 10 layers of paint, some conservation, some slight editing by later artists, and many other factors that could confound the analysis, he cautions. "Certainly, what Dan is doing is not going to solve anything by itself,"

Liedtke says. "I can imagine cases where his kind of analysis would help. But art historians are not going to be ringing up Dan saying, 'Did Rembrandt do that, or not?'"

Told of Liedtke's criticism, Rockmore shrugs and says, "I disagree." He admits that analyzing paintings might be tougher than analyzing drawings, particularly since he wants to include color data in his Rembrandt analysis. But to Rockmore, it's the difference between chess and checkers. Chess is more complicated and harder for computers to beat humans at – but they still can.

IN THE STUDIO at the Met, photographer Juan Trujillo makes some final adjustments. Lighting is critical. Even tiny ridges of paint, if unevenly lit, cast shadows that could interfere with the analysis. He peers at *Flora* through the viewfinder of the camera that's hooked up to live focus on the monitor, then he walks to the computer and clicks the mouse triggering a dull popping of the flash. The Roman goddess of spring and flowers has been translated into zeros and ones. Now it's time for Rockmore to figure out what makes her real. ■ ■ ■