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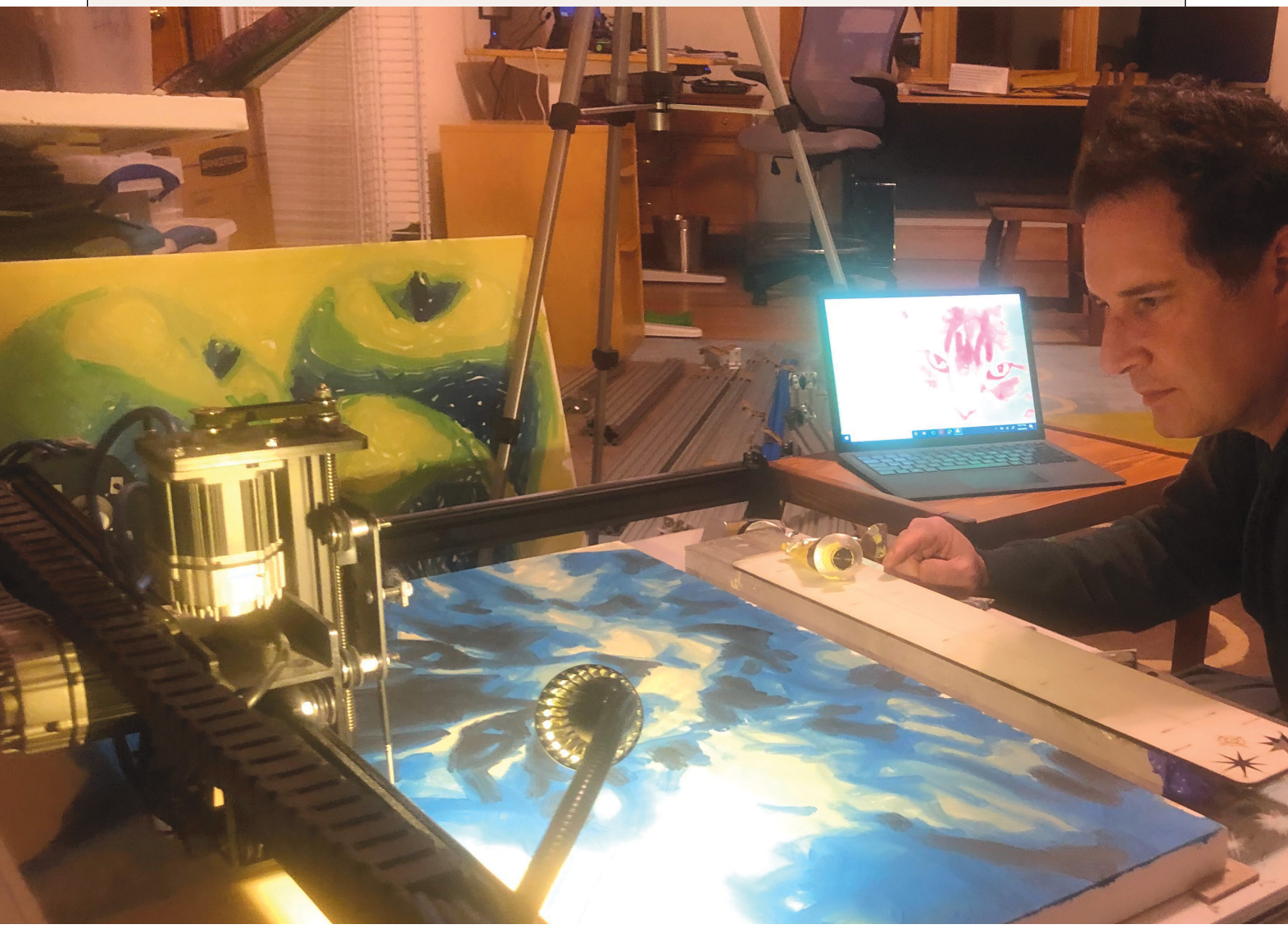
# Can AI Be Truly Creative?

*Computers and artificial neural networks are redefining the relationship between art and science.*

Arthur I. Miller



**QUICK TAKE**

**Art and science have always** influenced each other, but artificial intelligence (AI) provides a medium for these spheres to fuse and create new forms of expression and discovery.

**Artificial neural networks,** loosely modeled after how neurons process information, can generate novel art, which is sometimes indistinguishable from images created by humans.

**AI art offers an opportunity** for humans and computers to collaborate and for scientists to better understand how machines function.

Art and science have always interacted—Galileo Galilei's seminal telescopic drawings of the Moon were informed by his studies at the Florentine Academy of Art—but popular interpretations of the relationship between the two have swung back and forth through the ages. In the 17th century, Isaac Newton's magisterial *Principia* set the foundations of modern physics and kick-started the Enlightenment: Science now held the answers to deep questions such as "What is reality?" whereas art seemed subjective and frivolous by comparison. By the 19th century, the pendulum was swinging back. Artist John Constable, for example, systematically recorded cloud formations for his paintings and frequented the Royal Society to discuss scientific developments with Michael Faraday.

Hod Lipson

**Robotics engineer Hod Lipson has created PIX18, a robot that uses artificial intelligence (AI) to create paintings. Lipson directs Columbia University's Creative Machines Lab where engineers, computer scientists, physicists, mathematicians, and biologists collaborate to explore the creative capacities of robots.**

At the beginning of the 20th century, Pablo Picasso and Albert Einstein broke down many of the conceptual barriers between science and art. Picasso looked beyond art to developments in mathematics, science, and technology. He incorporated emerging ideas about four-dimensional geometry, including a fourth spatial dimension, with technical aspects of cinematography into paintings such as *Les Demoiselles d'Avignon*, created in 1907. Thinking like a scientist enabled him to create this painting of otherworldly women depicted in increasing states of geometrization, differing in perspective and seen simultaneously in profile and frontal view, with their forms mysteriously interpenetrating. *Les Demoiselles d'Avignon* contained the seeds of cubism, the dazzling new style he founded with artist Georges Braque.

At almost the same time, while working in a Bern patent office in 1905, Einstein began developing a new theory of space and time. As he examined the major physical theories and underlying equations of his day, he saw asymmetries that did not exist in nature. He found this "unbearable" and wanted to eliminate them. He relied on symmetry and aesthetics—concepts usually associated with art—as he discovered the special theory of relativity.

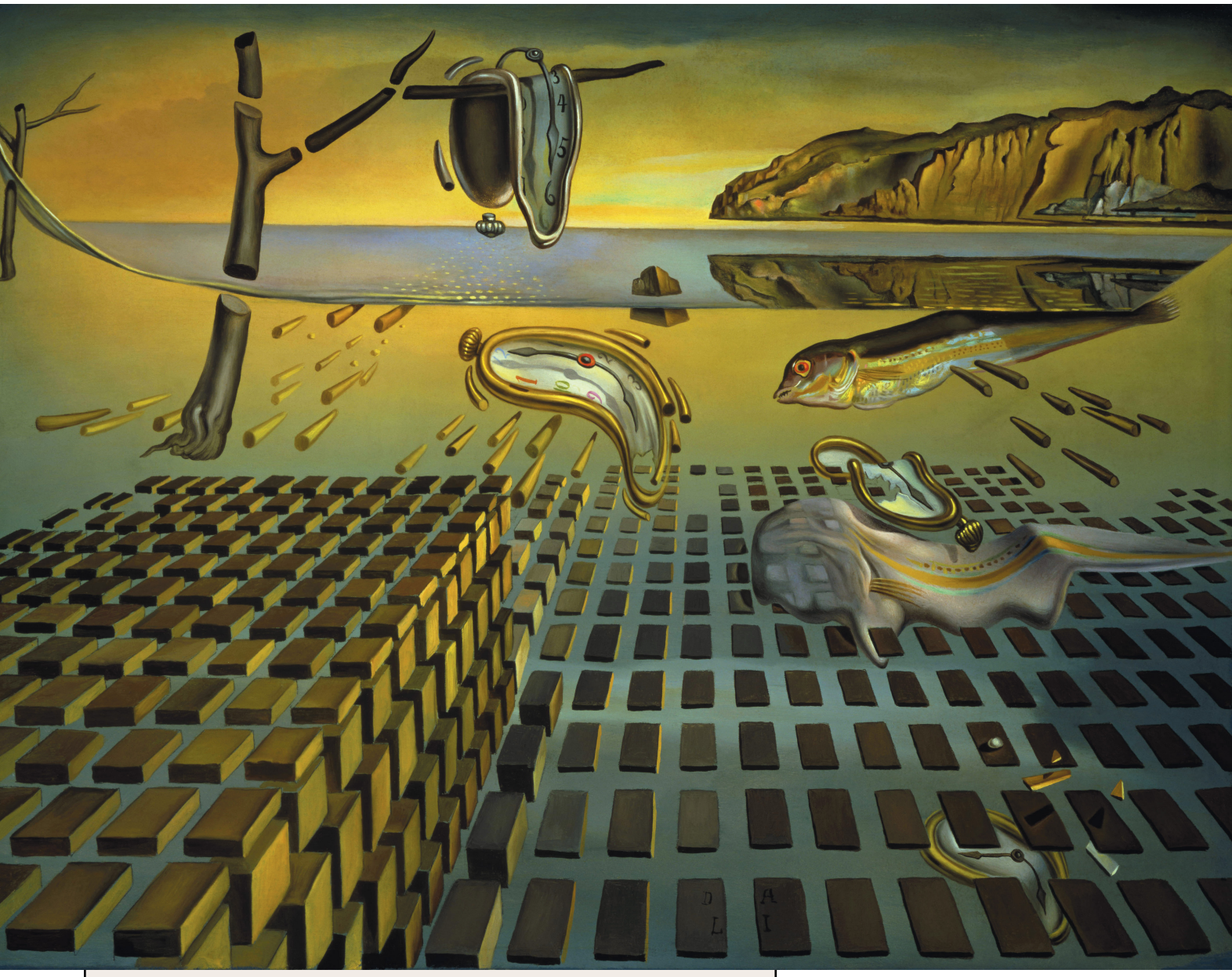
While Einstein's theory investigated the relativity of time, Picasso's cubism encompassed the relativity of space. They both replaced the earlier emphasis on *perception*, how we see and sense the world, with *conception*, how we abstract beyond what we see and sense. Salvador Dalí looked for ways to depict the fluidity of time, and Piet Mondrian developed his art into an abstraction of horizontal and vertical lines, basic structures within the dynamic equilibrium of nature. Historians and cultural critics predominantly focused on the influence of science on art during the 20th century. But artistic styles also made an impact on scientific ideas, well beyond Einstein's elevation of aesthetics.

Faced with the evidence that an electron behaved simultaneously as a wave and a particle, physicists Niels Bohr and Werner Heisenberg struggled with how to depict this seeming contradiction. Cubism influenced Bohr's discovery of the complementarity principle in quantum physics, which helped clarify the wave-particle duality. Bohr was struck by the way in which cubist artists interpreted their work: The perspective from which you view a cubist painting determines what it is. He realized that this idea could apply to the quantum domain, too. Depending on the way you look at an electron—the type of experiment you perform on it—it is either wave or particle. Similarly, chemist Harry Kroto used his experience as a graphic designer to visualize two-dimensional data in three dimensions when he co-discovered the structure of carbon-60 (better known as *buckminsterfullerene*) in 1985.

Today, art and science have entered another phase of extraordinarily fertile interactions. Computer science has distilled natural complexity into a digital language of 1s and 0s, and researchers have used that foundation to emulate the brain in machines known as *artificial neural networks*. In the 21st century—the Age of Artificial Intelligence—these advances are allowing computers to participate in the creative process. We are witnessing a new fusion of science and art as machine architectures and software help scientists and artists understand the world around us.

**The Artist Meets the Computer**

Throughout the first half of the 20th century, artists mainly used science and technology's ideas rather than their materials. But in the second half of the century, electronics and computers became widely available, changing the art-science nexus. Computer art first appeared in the early 1960s, developed almost simultaneously by A. Michael Noll, an engineer at that hotbed of ideas, Bell Labs, in Murray Hill, New Jersey, and artists Frieder Nake and Georg Nees in Germany (*see timeline on page 247*). But computer art's novelty opened up avenues of thought such as, "Will computers eventually be truly creative?" Some scientists began to call themselves artists and displayed their work in galleries. Newspapers snapped all this up.



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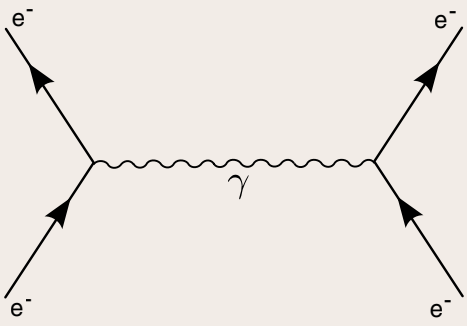
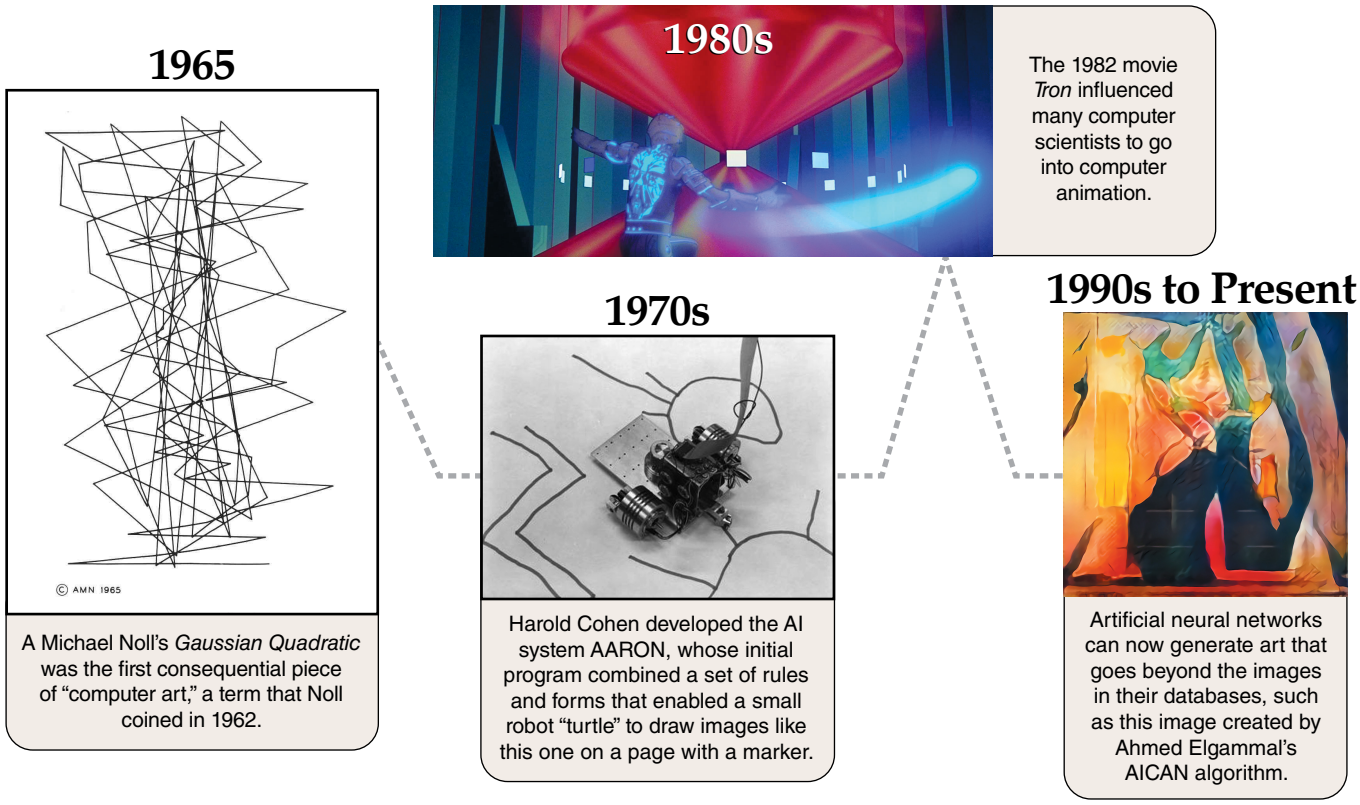



**In *The Disintegration of the Persistence of Memory* (1952–1954, *above*), surrealist painter Salvador Dalí explored quantum theory. The whole scene has been blown apart, reflecting the discontinuous and explosive features of the atomic world and the digitization of nature. At the same time, scientist Richard Feynman sought to visualize quantum theory with diagrams such as this depicting how two electrons collide and exchange a light photon (*left*).**

In 1966, Billy Klüver, an electrical engineer at Bell Labs whose interests crossed art, science, and theater, created *9 Evenings: Theatre and Engineering* in New York City. This was the first large-scale collaboration between artists, engineers, and scientists. For example, the artist Robert Rauschenberg used state-of-the-art electronics to subvert a game of tennis, and avant-garde musician John Cage generated "new" sounds using complex electronics.

The growing influence of electronics on art took off as software engineers explicitly sought to mimic the creative aspects of the brain. Over the past couple of decades, a new breed has emerged—artist and technologist rolled into one. In their hands, computer art has come into its own, thanks to the availability of tremendous processing power, huge amounts of data, and artificial neural networks.

An artificial neural network is loosely inspired by the way the human brain is wired, with layers of neuron-like nodes that process information. Like the brain, it needs to be trained on data to respond to what it hears and sees. Artificial neural networks can recognize faces, translate languages,




Graphic Barbara Aulicino; © 1965 A. Michael Noll; Computer History Museum; www.imdb.com/title/tt0084827/mediaviewer/rm4095316225; AICAN.io

**Starting in the mid-20th century, computers became a medium for humans to make art, fueling speculation that machines could eventually become creative. Decades later, with the emergence of AI, machines are becoming collaborators with artists and, in some cases, creators of new works of art.**

find patterns in huge data sets, and crack complex board games such as chess and go. They have also created spectacular works of computer art.

These artworks can offer insights into a scientific conundrum: We know that artificial neural networks work, but we don't know what goes on in the hidden layers of neurons within. Computer art is not just interesting or aesthetically pleasing software output. It could also guide researchers as they try to understand exactly what the algorithm and the machine running it are doing.

In 2015 Alexander Mordvintsev, an engineer at Google, created an algorithm called DeepDream to tackle this problem. He trained an artificial neural network on ImageNet, a database of more than 14 million images. He inserted a JPG image of a cat against a verdant background into the machine and stopped analysis partway into the neural network's hidden layers. Then he cycled and recycled the analyzed JPG, essentially asking the machine what that layer of neurons saw. This process resulted in a nightmarish version of the cat, with extra eyes on its head and haunches and canine features distributed across its body, and the background resembled a mosaic crawling with spiders. At that layer of neurons, the machine sees the world very differently from the way we do.

**Einstein's theory of relativity and Picasso's cubism replaced the earlier emphasis on *perception*, how we see and sense the world, with *conception*, how we abstract beyond what we see and sense.**

What this artificial neural network sees is an original creation, an image not in its database (*see* Computing Science, *November–December 2015*). When people come up with something that goes beyond the information we possess—our mental database—we call it *creativity*. I argue that we need to use this word for machines, too. Mordvintsev's code for DeepDream showed creativity, but the machine also showed creativity in producing the image, the work of art. Both human and machine jumped their databases. A variety of DeepDream images have now been produced by many computer artists and have been sold as fine art.

### Creating New Art

The year before Mordvintsev brought out DeepDream, Ian Goodfellow, now at Apple, created Generative Adversarial Networks (GANs), a significant technical advance in AI. Instead of

simply recognizing existing images as cats, dogs, or cars, GANs can generate entirely new images, and can then assess whether or not these images represent a real object, by themselves, without need of external input.

Mario Klingemann, a German artist and AI art pioneer, has created a series of portraits with a technique he calls "transhancement" using GANs. To make them, Klingemann used his own database, which he considers part of the creativity of making art with a machine. He describes these portraits as partway between the digital and the painterly. One of Klingemann's works, *Memories of Passersby I* (2018), runs a GAN algorithm that generates a constantly changing series of surreal male and female faces. Klingemann's ever-changing images have been compared to the works of British artist Francis Bacon. These faces of people who have never existed, dreamed up not in the human but in the computer's imagination, are at times beautiful and always disturbing.

In 2017, computer scientist Ahmed Elgammal at Rutgers University decided to develop an AI that could create brand-new styles of art. Style is of the essence for Elgammal, just as Paul Cézanne moved away from impressionism and created post-impressionism when he painted his masterpieces, while Picasso used post-impressionism as a springboard to cubism. Elgammal developed a new GAN called Artificial Intelligence Creative Adversarial Network (AICAN), which can not only judge its own work but also seek out styles that have never existed before. In other words, it can create. Elgammal trained his algorithm on a database of over 80,000 images representing Western art from 1400 to 2000. The machine produced its own style, not contained in the training set. This new, highly abstract style fits perfectly within the history of art, which has tended toward abstraction.

**When we come up with something that goes beyond the information we possess—our database—we call it creativity.**

Human judges assessed these AICAN images as novel, ambiguous, and surprising—all broadly recognized as characteristics of creativity. The judges also thought that the works had been produced by human artists, and actually preferred the AICAN images to many of the works by living artists shown at the 2016 Art Basel fair. But when a computer creates, who is the artist? That remains a contentious debate. These works have opened knotty issues of credit and even legal ownership.

At the moment, humans program all of these artistic machines: The process has to start somewhere. But credit for a machine's creativity need not necessarily be shared with the programmer. That would be like attributing Mozart's music to his father Leopold, who taught him the rules of composition. Machines have come a long way since the 1960s. They no longer need to be tied to their initial coding. DeepDream, GANs, the ingenious moves of game-playing programs such as AlphaGo, and AICAN all show a degree of autonomy.

This discussion has economic as well as philosophical implications, as AI art has entered the high-end market. Klingemann's *Memories of Passersby I* sold for $50,000 at Sotheby's in 2019; another work of GAN art sold a few months earlier for $432,000 at Christie's. Many people in the burgeoning field of cyberlaw lean toward human ownership. Elgammal, conversely, argues that AICAN is in control of both the artistic elements and principles, and he therefore credits the algorithm itself for the works it has produced. (*See "AI is Blurring the Definition of Artist," January–February 2019.*) Other artists consider their work with an AI a collaboration, and they sign the completed image with both their own and the AI's names.

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**AI algorithms such as DeepDream by Google engineer Alexander Mordvintsev can produce images that are interesting and aesthetically pleasing while providing a view of how the machines process information. This DeepDream image was generated from random noise using a machine that had been trained on images of buildings and places by the MIT Computer Science and AI Laboratory.**

### Computer Collaborators

Now that algorithms have demonstrated creative capacity, machine and human can collaborate. The visual artist can write new code to influence the machine's output and perhaps make changes in the database. In this way, machine and artist bootstrap each oth-

Mario Klingemann

**German artist and AI pioneer Mario Klingemann created *Memories of Passersby I* in 2018. The installation (*left*) constantly changes, revealing novel, surprising, and ambiguous portraits of male and female faces who never existed, including the two transient images at right.**

er's creativity. Mario Klingemann, for example, tinkers with GANs as well as using his own databases to produce some of his work.

Computer scientist and musician François Pachet, who directs Spotify's Creator Technology Research Lab in Paris, has produced a number of devices to aid musicians in composing and playing music. A keen jazz aficionado, he is also interested in finding ways to boost a musician's creativity when improvising. To that end he invented the Continuator, an AI that parses piano improvisation from a human musician into phrases, and then passes them on to a phrase analyzer that identifies patterns. The Continuator then improvises around the pianist's input, and the pianist goes on to respond to the AI's improvisation. Improvisation is a conversation between musicians and their instruments; here it's a conversation between a musician and an AI.

This same sort of collaborative effect occurs when scientists and artists work together on AI projects. In 2012, David Glowacki, a chemical physicist at the University of Bristol, brought together a team of scientists, artists, dancers, and engineers. Based on algorithms he had created for visually simulating the movements of molecules, the team came up with a dance performance that combined cutting-edge interactive digital art with rigorous molecular dynamics. In "Hidden Fields," dancers' movements create disturbances in projected patterns of molecules in motion, creating visually stunning effects.

"Hidden Fields" is more than an exercise in aesthetics. Its super-fast algorithms, created for dance, have since allowed researchers to interact with and optimize molecular dynamics simulations as they occur. Combining human scientific intuition and computation in this way helps researchers improve predictions of protein folding, for example. This outcome sits at the frontier of a fused scientific and artistic creativity.

In the Age of AI, no one can question the effect of art on science and science on art. Instead of a swinging pendulum of influence, they have melded into one—AI art—in much the same way that two black holes merge, first circling one another, becoming closer and closer, then coming together with repercussions felt throughout the universe.

AI art is a new form of science. Its algorithms can help reveal secrets of the hidden layers in artificial neural networks, potentially improving their use in complex, data-rich applications such as driverless cars and the internet of things. The machines that create AI art are also used in computer vision, which incorporates parallels to human vision. They can help us better understand how we see our world and how we respond to and reason about it. We can experiment with machines in ways not yet possible with the human brain and thus find deeper insights into our own creativity.

Machines are already showing glimmerings of their own artistic imagination and are accelerating scientific discovery. The output of these algorithms and our collaborations with them offer new vistas for expanding both creative expression and discovery.

*Arthur I. Miller is an emeritus professor of history and philosophy of science at University College London. He has published widely on creativity and on the interplay between art, science, and technology. His most recent book is* The Artist in the Machine: The World of AI-Powered Creativity *(2019). Email: a.miller@ucl.ac.uk*

## Bibliography

Miller, A. I. 2001. *Einstein, Picasso: Space, Time and the Beauty That Causes Havoc*. New York: Basic Books.

Miller, A. I. 2014. *Colliding Worlds: How Cutting-Edge Science is Redefining Contemporary Art*. New York: W. W. Norton.

Miller, A. I. 2019. *The Artist in the Machine: The World of AI-Powered Creativity*. Cambridge, MA: MIT Press.