Abstract Science?

Roald Hoffmann

Is there an analogue in science to abstract art? A riposte might be, "Why should there be? Why ask science, so strongly tied to reality, to mimic the aesthetic games of the world of art?" Well, both art and science are created by human beings, and both are creative endeavors. So it might be interesting to look at any correspondences. No one-to-one mappings will be found, but let's relax that criterion and search for non-literal, imaginative analogies.

Abstraction in Art

It is not easy to define abstraction. Is the incised design in a 3,500-year-old Japanese Jomon jar *(below)* abstract art? Are the colored shapes of pre-Colombian Huari textiles abstract? Yes and no. Their imaginative power over us derives from form, color, texture, juxtaposition—all certainly elements of abstraction. Although we may not be privy to the layers of meaning from different cultures that are implicit in these objects, they do not appear to have been made in willed opposition to representation.

The Metropolitan Museum of Art/Art Resource, NY

A Japanese bottle from the Late Jomon period.

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Abstraction, not just mathematics, has its place in science as it does in art

Although abstract art has been with us for only about 100 years, sometimes it seems that there are more abstract-art movements than there are scientific "-ologies." The list begins with cubism, and will not end with postmodern painting. Recognizing that there are degrees of the abstract, my perception of the essence of this artistic direction involves several factors.

First of all, abstraction is oppositional, wanting to be seen as alternative to such ideals as naturalistic representation and the figurative. I will not say "alternative to reality," for (to paraphrase Magritte) the two-dimensional surface of the most photorealist painting still is not its subject. Not unexpectedly, much theory of the abstract disclaims a definition by opposition. Art desires a broader conception of what stirs the imagination.

Abstraction is also reductive. By that I mean that abstract art often takes some element of the artistic universe and explores all the tensions that it can get out of that element. Mondrian's squares create visual jazz, Rothko's broad color swaths can evoke joy or destructive tension. And Calder's mobiles move, ever so slowly, around inner peace. The element abstracted may be a force, as in Elizabeth Murray's works that break out from a shaped canvas.

Here is a spirited early statement on abstraction by one of its founders, Kazimir Malevich. In his *From Cubism to Futurism to Suprematism: The New Realism in Painting*, published in 1915, he writes: "I have destroyed the ring of the horizon and left the circle of things … in which the artist and the forms of nature are confined … [The new art] moves to its own goal—creation." Like all reductive philosophies, abstraction from time to time lays claim to "purity." Such a claim is risky, as one might reflect where else in history such claims have been made, and for what purpose.

What Can Chemistry Be Against?

To be abstract, chemistry might thus have to be oppositional. But opposed to what? Nature, of course. Much good chemistry comes from imitating nature, because this ultimate tinkerer has been at it for a long time. At a chemical level in the biological universe, there is an almost bizarre seizing upon anything that works, and subsequent perfection of it by evolution: Here oxygen is carried by a red blood cell's heme group with iron (as in mammals), there it's a binuclear copper complex (as in mollusks and arthropods). So nature, among other things a chemist with lots of time on its hands, has found some effective strategies for making molecules and using their properties. It provides a "literature" that's worth reading, not exterminating.

Chemists in the laboratory are torn between emulating nature and doing things their own way. A protein, through its own curling and its tool kit of side-chain options, shapes a pocket where, say, a molecule with only right-handed symmetry fits. But it not only fits, it has something done to it—a specific bond in that molecule is cleaved, or an atom is delivered to it. The chemist's fun, much like abstract art, is in achieving the same (why not better?) degree of shape control that nature does, but doing it differently, perchance better, in the laboratory.

Here's an example, in the form of effective and specific delivery of hydrogen to an organic molecule. Nature does it, but Thomas R. Ward at the

Timothy A. Clary/AFP/Getty Images

"White Center (Yellow, Pink and Lavender on Rose)" by Mark Rothko.

"LPH#3," a sculpture in wood by Roberto Bertoia. (Photograph is courtesy of the artist.)

University of Basel in Switzerland and his coworkers have done it as well. As shown below, they attached a reactive inorganic piece (that's the Rh with its ligands) through a binding link (biotin, a type of B-vitamin) to a small "handed" protein (streptavidin). The latter is the equivalent of a baseball glove; the Rh piece a very lively deliverer of hydrogen, firmly ensconced inside. The close bond leads to a strongly "handed" chemical reactivity.

Unnatural Products

Through synthesis, contemporary chemistry makes the objects of its own contemplation. In this way it comes close to art. For many molecules, utility is a distinguishing feature and a source of value, so that this science is poised between art and engineering. A kind of abstract-art movement within chemistry is the effort expended on the synthesis of molecules with (chemical) formal elements that are prominent, but without apparent utility. A cube made out of DNA, a $C_{20}H_{20}$ molecule dodecahedral in shape, an amine that is not basic at all, a molecule whose overall oxidation (or loss of electrons) paradoxically causes reduction (or gain of electrons) of one piece of it—these curiosities carry the elements of surprise, of violation of the given. But are such molecules not more like surrealist art? Surrealism works off transgressions of normal conventions—Dali's wilted watch, Magritte's play with reality.

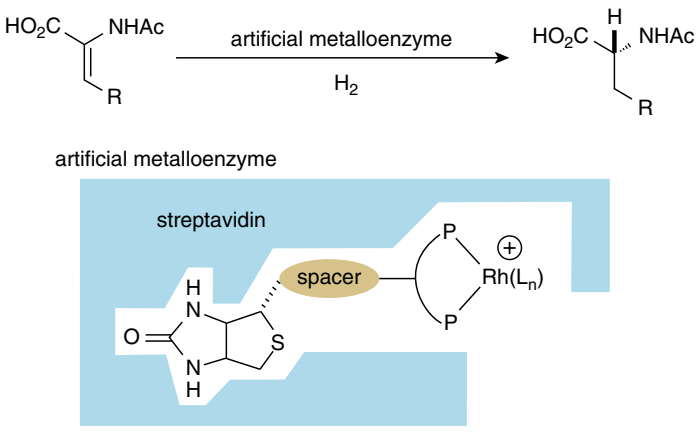
Analysis as the Path to Abstraction

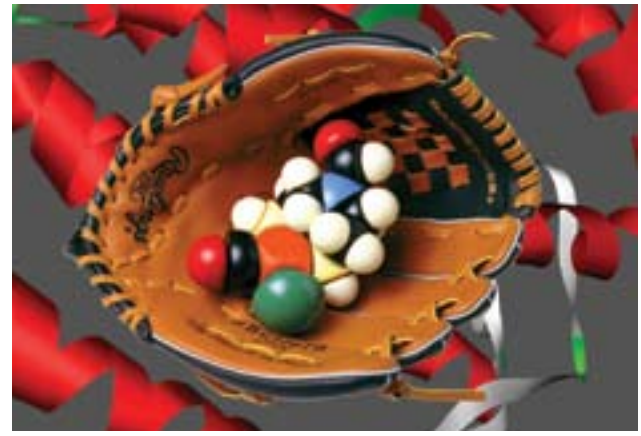
A characteristic modus operandi in abstract art, from Russian constructivist times, has been the concentration on one or another component of the artistic whole. Issues of form—the center or the periphery, inclusion or exclusion, see-through or opaque, balance, color—are isolated. Ad Reinhardt's beautiful all-red and all-black paintings are a fine example of this concentration. The contemplative process here can lead to an exploration of the emotional possibilities of just that formal element. One sees this motif at work in Klee's abstract paintings, or in Rothko's color fields *(above left)*. Roberto Bertoia, a colleague at Cornell, works out beautifully in small wood constructions the feelings of confinement, protection and communication *(above right)*.

Of course, science, from its Cartesian roots, has operated in just this way. If you want to understand something, take it apart, see how the pieces work, put it together (although too few people like to put things together …). Change only one variable at a time, if you can. If you want to see how a chemical reaction proceeds, write a mechanism, a sequence of elementary steps. Once the mechanism is recognized, have research programs develop on the pieces and extend the work. Taking things apart, as science does, is a move shared with abstract art.

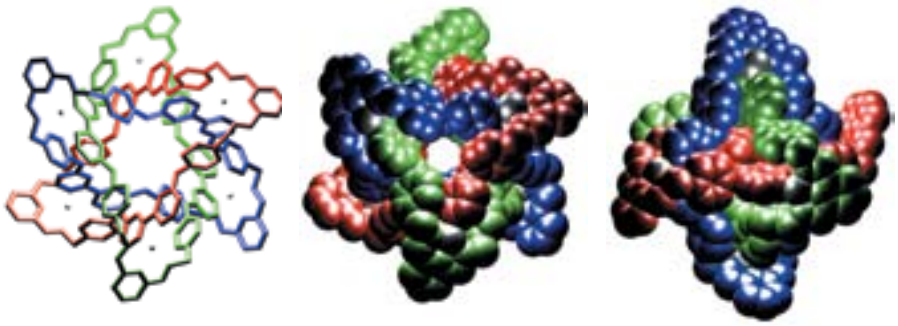
Games in a Simplified World

Just as in abstract art, what emerges in science after things are taken apart ranges from Hermann Hesse's *The Glass Bead Game* (where the rules are only alluded to) to real understanding. In chemistry, there are many examples of paring away to get at the essence of an idea (rather than a molecule). One can see this in stereochemistry, which intently explores all the ways in which a molecule can be distinguished from its mirror image.





Researchers have adapted a protein *(blue, left)* to deliver hydrogen. The protein's shape mimics a baseball glove *(right)*. (Illustration adapted from T. R. Ward, *Chemistry-A European Journal* 11:3798–3804. Image is courtesy of Wiley-VCH Verlag GmbH & Co. KGaA.)



Three views of the three interlocked molecular loops of Borromean rings. (From K. S. Chichak et al, *Science* 304:1308–1312. Image is courtesy of AAAS.)

As another example, consider the synthesis of the two interlocked rings of catenanes, or the three of Borromean rings *(above)*. The structures are real, and models of the molecules do look like physical rope knots or the Olympic symbol. But within chemistry I think there is a beautiful feeling of abstraction to them.

In another way, the small theoretical industry spawned by the work Charles Wilcox, Roger Alder and I did on stabilizing square-planar carbon also has an abstract feel to it. That molecule's geometry is about as far as possible from that of a normal carbon atom with four atoms bonded to it at the corners of a tetrahedron. Our transgressive whim could be seen as playing games with high-energy structures. However we, and others, immediately had therapeutic designs—for the molecules, not humans—to ameliorate the energetic suffering of such preposterous bonding configurations.

Giving the Aleatory Its Due

One recurring theme in 20th-century abstract art is the tension generated by seeming chance at work, seen famously in Jackson Pollock's action paintings, but also apparent in conceptual art. And randomness exists in another way in ceramics, for instance, in the studied interplay of clay with plant, wood material or interposed objects controlling reduction or oxidation in wood-kiln firing in Bizen and Shigaraki Japanese ceramics *(below)*.

A Bizen pottery piece by Jun Isezaki. (Photograph is courtesy of the artist.)

An interesting counterpart in chemistry is the recent growth of combinatorial chemistry or diversity-based organic synthesis. The idea is to come up with a set of facile reactions that generate not one, but millions of diverse molecules within one beaker. In part, but only in part, this work has a biomimetic motivation. For at some stages nature introduces steps that are dispersed, to populate niche-seeking molecules. Most do nothing, but a few succeed. The workings of the immune system and the diverse structures resulting out of terpene synthesis are examples. But the laboratory generation of vast "libraries" of potential enzyme inhibitors or fuel-cell catalysts has a feeling of seeing the aesthetic value in chance.

Organic Synthesis as Music

Music is the most abstract art form. Programmatic tone-poems and birdsong or burbling-brook mimicry aside, music is more than imitation. As Igor Stravinsky said, "For at the root of all [musical] creation one discovers an appetite that is not an appetite for the fruits of the earth."

On one level, music is a patterned sequence in time of audible tones varying in frequency and volume, with overtones and harmonics. What makes music so much more than this dry definition is the strong psychobiological resonance that sound sequences have for humans. No art form is more abstract, I think, and no art form has an easier way into the psyche.

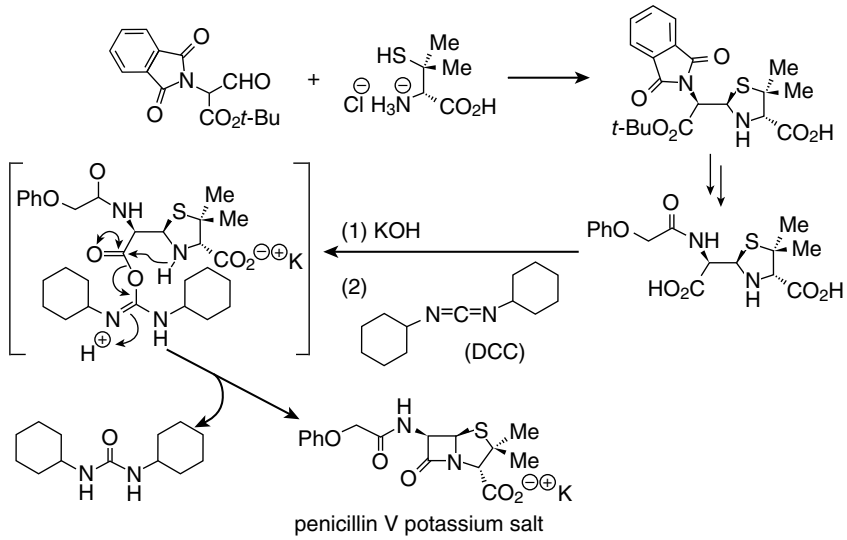
If time is the critical variable of music—in that for both melody and rhythm, the moment before and the moment after matter deeply—then perhaps organic synthesis proffers a rough scientific analogue. Take a sketch of the synthesis of penicillin by John C. Sheehan of MIT, made in the World War II era *(facing page)*. Note that an RNCNR (it's called DCC, for dicyclohexylcarbodiimide) piece is added in, in the center of the scheme, and then at the lower left of the reaction, the piece comes off again, carrying along the elements of water. DCC (now widely used in laboratory synthesis of peptides) is an "activator"; it makes possible the formation of the crucial four-membered ring in penicillin. The process is firmly embedded in time. If the steps were reversed at any stage, one would have a different reaction, a different melody. Or even a failed synthesis, a discordant descent into chaos, black gunk in the flask.

What makes a chemical synthesis, arguably the most intellectually developed part of chemistry, very different from a musical work is that the synthesis is motivated by its aim—to make one type of molecule, and no other. A movement of a Beethoven quartet will have its crescendo and coda. But in the end there is silence again; the emotionally wrenching, contrapuntal path in time to that silence is what remains, to be experienced only when the piece is played again.

Heating It Up

Abstract art is cold. And so is science. I put it this provocatively so as ultimately to work against this caricature, a prevalent one, I am afraid, of both abstract art and science. How can they both be "cold?" The way into emotion in abstraction (and the appreciation of science) is not direct. It has to be learned. Figurative portrayal, or even just the slightest evocation of the figurative gesture, may signal grief, tension, fear or love most directly. Sometimes it's done in just a few lines; this is how cartoons work. I've seen people cry in the Rothko chapel in Houston, but they came with some appreciation of abstract art, and a contemplative mood.

Science's cross is our insistence on depersonalizing experience, if it is to be crowned as reliable knowledge. The dehumanizing process has been enhanced in the past 200 years by the third-person, neutered language of that ossified ritual format of our stock-in-trade, the scientific article. What violence that dull language, that rigid format, does to the scientific imagination! How it dissipates in jargon the underlying thrill of feeling, say, the reactivity of a molecule turned upside down by clever substitution! Here science and abstract art have

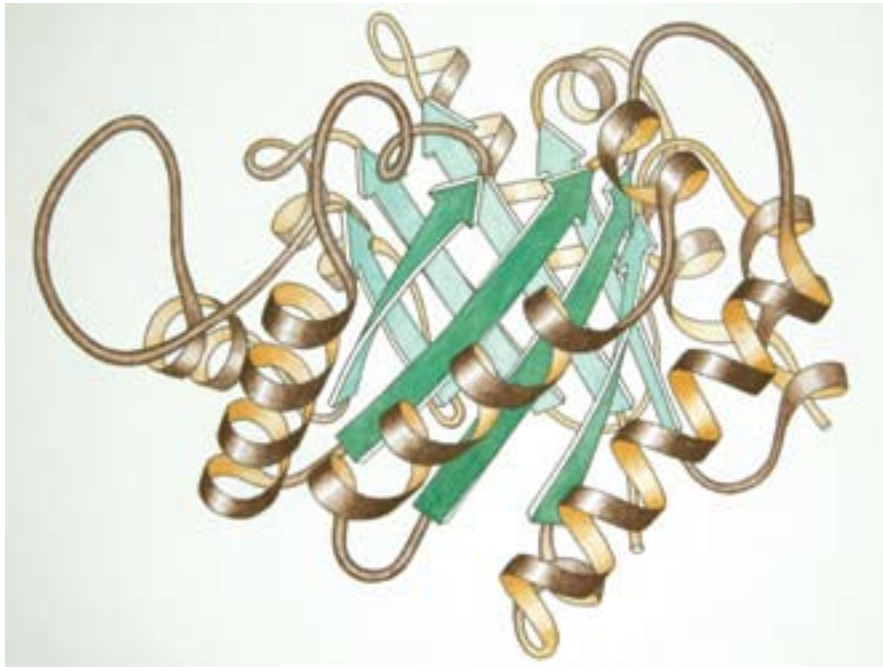


The synthesis of penicillin. (Illustration adapted from K. C. Nicolaou and T. Montagnon, 2008, *Molecules that Changed the World*. Berlin: Wiley-VCH.)

shared the consequences of dealing out the figurative and emotional.

Immanuel Kant understood that the artistic response is stirred by paired responses in us. These replies are both the instinctive emotional reaction to an object or a process, and the cognitive play with what we see or hear. One way to characterize the problem of perception that abstract art and science share is that when the figurative, natural or personal are pushed aside, the cognitive is emphasized. And thinking seems less warm. Oh, beauty comes back, no way of keeping its subversive pleasures out of the soul. But the initial impression of a shift in emphasis from the emotional to the cognitive is … coldness. Once again, music is the (magical) exception.

To restore emotion is harder for science than for abstract art. Form and color combine to make Kandinsky's compositions kinetic and joyful. The formal tensions at work in Bertoia's enclosures and Reinhardt's paintings reward the viewer with the feeling that something is at stake. We are drawn in to look intently and the thought emerging out of that contemplation carries emotional import, as the abstraction shapes a passage to the soul. As Reinhardt wrote, "May not one side of me speak up for the side of the angels?"



An illustration by Jane Richardson of a "ribbon" representation of proteins, to show the folding of the protein's biopolymer backbone. (Illustration is courtesy of the artist.)

The Obvious, Last

In science, we distance reality by representing it, in molecular models or mathematical equations. There is risk in that distancing, but also tremendous power—for instance, the calculus, along with a mathematical technique called perturbation theory, allows us to calculate the path of a Mars lander to a few meters.

The representations of science are both iconic and symbolic—they look like the thing and they are arbitrary. The lines in the ball-and-stick model of a molecule do give one a rough idea of the relative microscopic distances; the atom labels are just a convention. The representations are then manipulated on paper, on computer screens and in our minds with all the conventions of art—and that includes abstract art. So we focus in a cubist way on one part of a molecule, distorting it, and we indicate forces with Klee arrows. And when we need to represent essences, to focus in on what matters, we simplify, often in the way artists did in the beginning of abstract art in the 20th century.

Consider the problem of representing the essential backbone of proteins—biopolymers whose chains are sometimes helical, or sometimes stretched out with a pleated appearance. Its similarities and differences from protein to protein must be perceived. In the early 1980s Jane Richardson of Duke University invented a "ribbon" representation that is based on the reality of molecular structure obtained from experiment *(below left).* The ribbon representation, an abstraction I would say, was a genial idea. First done by hand, now computerized, this way of seeing has shaped the way we imagine proteins in our mind's eye.

Abstraction, both through equations and simplified representations of molecular structure, is an essential mechanism of science. But analogies to abstract art and music also enter in other ways—in the opposition to the natural, in playful and purposeful pursuit of essences, in the way time and chance are given their due. In science and art both, we create and discover meaning.

Acknowledgment

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