HONESTY TO THE SINGULAR OBJECT

Roald Hoffmann

The theme before us is “Language, Lies, and Ethics.” As a scientist and a writer I could think of the way language is used in science, how it differs form the language of poetry. I could examine the claims of science to approach truth, and how its standards of evidence differ from those of, say, the law. But let me take another tack, and begin by a look at storytelling in science, clearly a process couched in language. The moral implications of narrative will then take me to another place, to consider what ethical lessons, if any, might emerge from normative science.

Stories

Science tells some rollickin' good stories. So why are scientists so unappreciative of the necessity of storytelling for the success of their own enterprise? Why do they beatify Ockham's razor rather than the rococo inventiveness of their hypotheses?

Because they are afraid of “just so” stories. The Kiplingesque allusion points to one of science’s historical antipathies -- to the teleological. Countered by a human proclivity for exactly that, the teleological, in the telling of scientific stories. Is there also a suspicion of the particularity of language, when scientists are ideologically committed to infinitely paraphraseable universals?

Consider first the stories that emerge out of science. So many to choose from -- the epics of continental drift, or the way one iron atom in hemoglobin communicates with another. Or amusing ones, like how the

amount of vanilla claimed to be natural in French ice cream exceeds by a factor of ten the quantity of beans shipped from Madagascar. Which led to a cat and mouse game between the forgers of vanillin (the flavor principle here) and the scientific detectives who learned to distinguish between the natural and synthetic form of one and the same molecule.[1]

Or take a triumph of molecular biology, the working out of the chemistry and function of the ribosome. In Figure 1 is a schematic illustration – not an atom in sight in this representation -- of this biomolecular "smart" factory. It is a complex of about 80 proteins and a few RNA molecules which takes a strand of messenger RNA (complementary to DNA) and initiates a process of linking, according to the RNA instructions, amino acids shuttled to site A by a transfer RNA to an already formed piece of the enzyme at another site P. And proofreading the enzyme coming off, at a rate of 20 amino acids a second.[2]

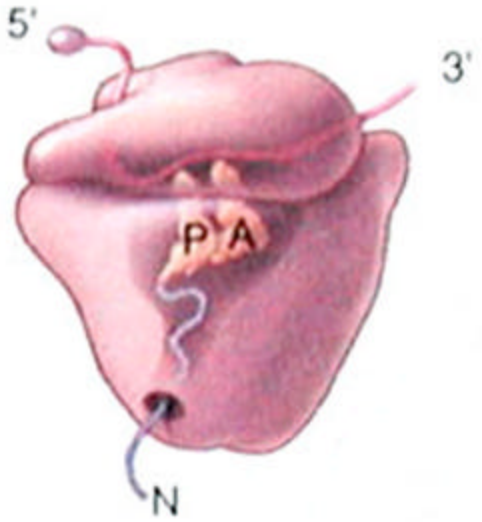

Figure 1. A representation of a ribosome, by Graham T. Johnson. Reproduced by permission from "Cell Biology" by Thomas R. Pollard and William C. Earnshaw, (Philadelphia: Saunders, 2002). The stand marked 5'----3' symbolizes the messenger RNA, the strand ending in N is the protein being synthesized.

Shall I compare thee to a Rube Goldberg machine[3] (Figure 2)? (In England it would be Heath Robinson.) And is there a gaping trap in this simplistic mechanism of mechanistic visions? Oh, yes. The way we envisage the ribosome is mechanical, linear, and… ephemeral. The representation, thrilling as it is, is transitory. Yet --- and this is what some critics of scientific knowledge miss – this most unfaithful representation doesn't hinder us from designing real, functional antibiotics that throw a wrench into the workings of microbial ribosomes.

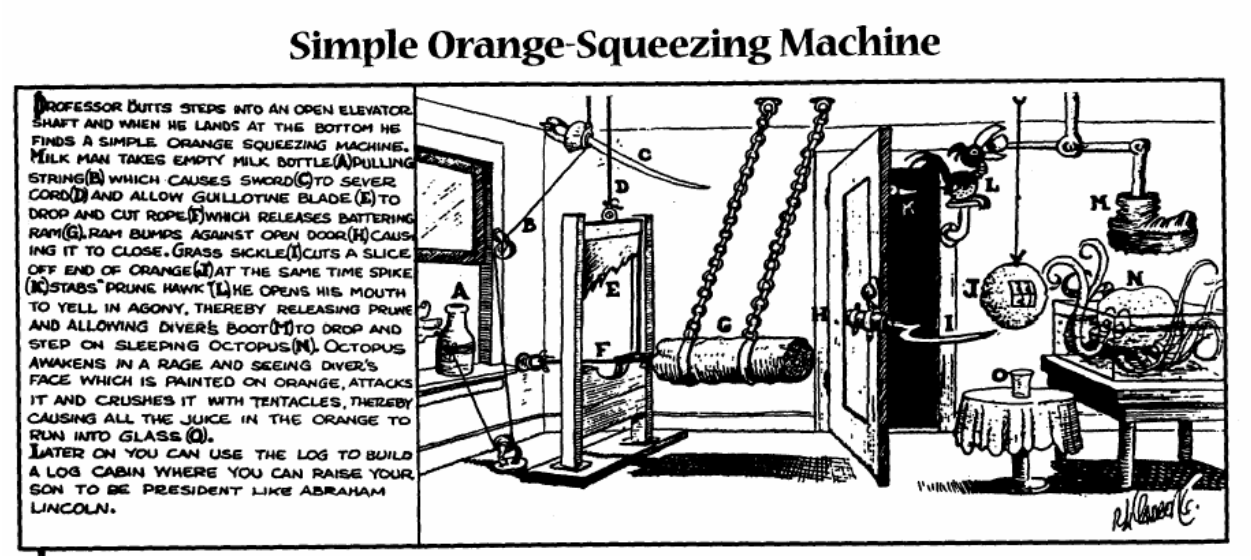

Figure 2. A cartoon by Rube Goldberg, one of the series of inventions by Prof. Lucifer Gorgonzola Butts. Reproduced by permission of King Features Syndicate.

The ribosome story allows me to shift to something much more interesting. This is the utility, nay necessity, of storytelling <u>for</u> practicing science.

Why should storytelling be essential for science? Well, every time the simple is proffered, human beings fall for it. So admiration for the symmetrical molecules, exemplified by the ones shown in Figure 3, or for a simple mechanism of a chemical reaction, the aesthetic imperative in physics (if an equation is beautiful, it must be right) seems….natural. And related to our falling for political ads, of any persuasion. But what if honest investigation of the real world reveal complexity, bound to be discovered in any biological or cultural entity that has been subject to inherently complexifying evolution? Even in a molecule. Take a look at hemoglobin, the oxygen carrier in our blood (Figure 4). This is already a much simplified representation, omitting the vast majority of the more than 9000 atoms in this $C_{2954}H_{4516}N_{780}O_{806}S_{12}Fe_4$ molecule. Where, and how, does one then find pleasure in such contorted complexity?

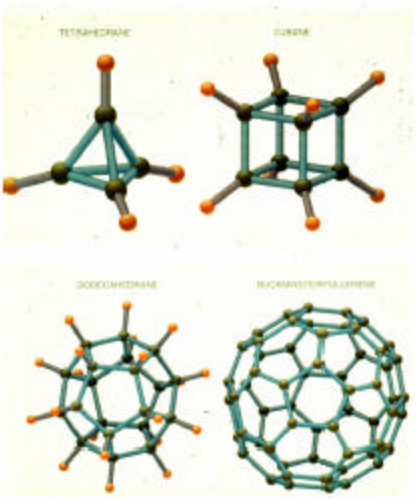

Figure 3. Some lovely symmetrical molecules, beautifully simple, simply beautiful, and … devilishly hard to make (except for buckminsterfullerene, the last to be synthesized).

Figure 4. A schematic, “ribbon” drawing of the structure of hemoglobin. There are four subunits in the molecule, roughly identical in pairs. The ribbon traces the backbone of the biopolymer; note the helices. The oxygen is held at the iron atoms that center the four platelet shapes nestled in the folds of the protein.

Storytelling seems to be ingrained in our psyche. I would claim that with our gift of spoken and written language, this is the way we wrest pleasure, psychologically, from a messy world. Scientists are no exception. We tell stories for they first satisfy, then keep one going. Stories “domesticate unexpectedness”, to use Jerome Bruner’s phrase.[4,5]

A Short Story of the Real World

Let me tell one such constructive story. Insects are the greatest chemists. They use pretty simple chemicals in communication, mating, defense and predation. In 1966 R. S. Berger identified the main sex pheromone of the cabbage looper moth, *Trichoplusia ni* (Noctuidae), shown

in Figure 5 in its caterpillar stage, as “(Z)-7-dodecenyl acetate,” a pretty simple molecule related to some fatty acids in all living things. This pheromone is also illustrated in Figure 5.

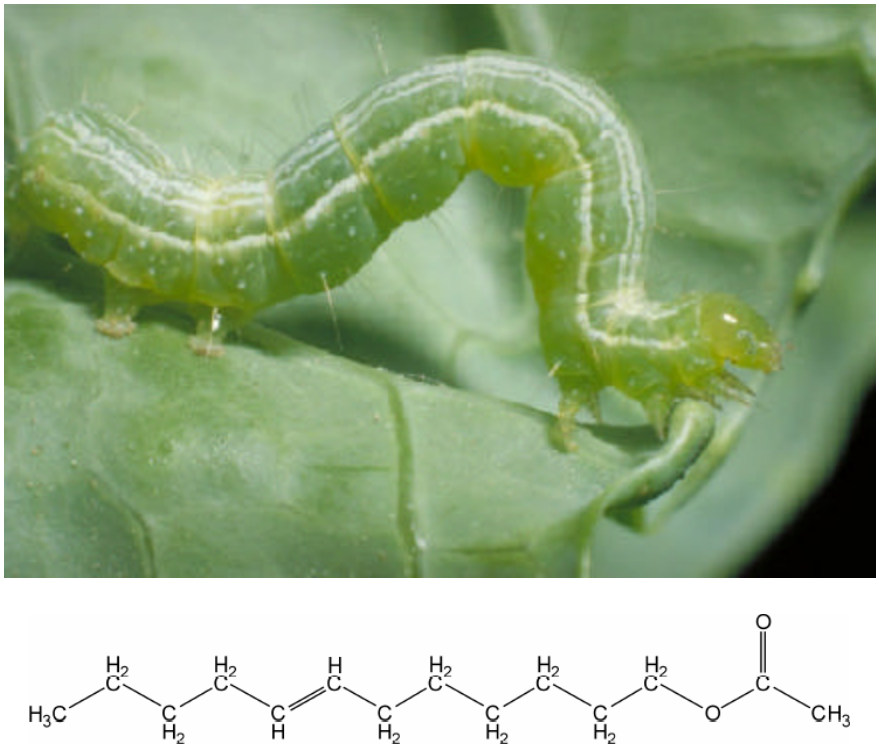

Figure 5. The cabbage looper moth in its caterpillar stage, and the first identified component of its sex pheromone, wafted by the female moth.

Those were the halcyon days of early pheromone chemistry; everyone was happy with one molecule (as they were with one gene for each trait). Thirteen years later L. B. Bjostad et al. identified a second component, important especially in close-range courtship behavior. Then the same group began to think through the biosynthetic relations between these two components and other molecules observed in the pheromone gland. Obviously, enzymes that do various transformations -- shorten molecules, remove hydrogens, add various atoms, all the wondrous machinery of the

living – are at work. I show below a complex graph from one of their papers, indicating the biochemical relations between the various kinds of fatty acids in the moth.[6] Here's the story, a biochemical story that moved Bjostad et al, which they confide to us. A blend of six components, suggested by their analysis, elicited complete courting flights against a stiff breeze in a wind tunnel. Clearly one needs six for sex. And would a human master perfumer be surprised?

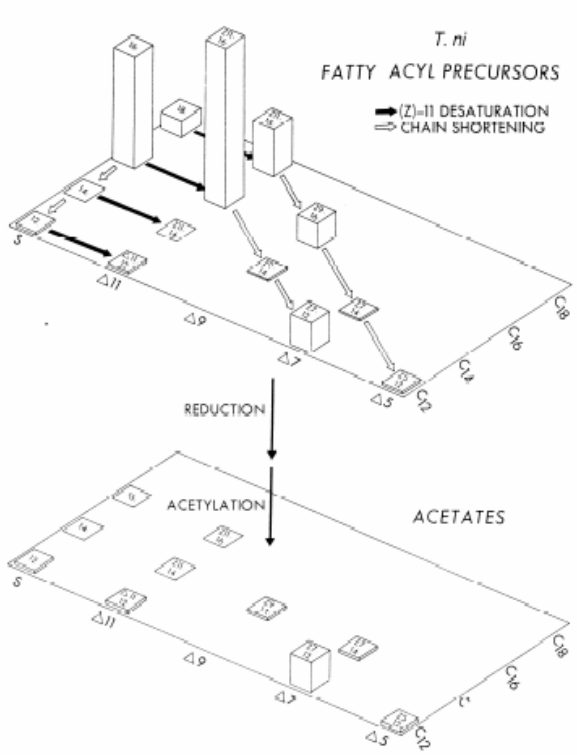

Figure 6. Biosynthetic clues to pheromone mixture. One axis is the length of the carbon chain, the other specifies the position of the double bond in the chain. This drawing is reproduced from Bjostad et al, ref. 6.

The story is told with sufficient verve in the Bjostad, Linn, Du and Roelofs paper that even I, an outsider to the field, am pulled in by it. More than just an analysis of pheromone glands, the biochemical relations are clever. I am intrigued by their tale and begin to think of its sequel – how do the females evolve that blend? How do the males evolve the receptors to it? Thomas C. Baker and his coworkers at Iowa State University have actually located separate compartments for the six components (and one so-called antagonist, a molecule that acts to negate the physiological reaction to the pheromone) near where the male antenna input is first processed. Extending the story is life-enhancing. And not just in the Thousand and One Nights.

John Polanyi has recently described the close relationship between science and storytelling:

> *Scientia is knowledge. It is only in the popular mind that it is equated with facts. This is, of course, flattering, since facts are incontrovertible. But it is also demeaning, since facts are meaningless. They contain no narrative. Science, by contrast, is story-telling. That is evident in the way we use our primary scientific instrument, the eye. The eye searches for shapes. It searches for a beginning, a middle, and an end.*[7]

The power of stories may indeed exceed that of facts. As Walter Benjamin has written:

> *The value of information does not survive the moment when it was new. It lives only at that moment; it has to surrender to it completely and explain itself to it without losing any time. A story is different. It does not expend itself. It preserves and concentrates its strength and is capable of releasing it even after a long time.*[8]

In telling the story of scientific discovery, we form a praiseworthy bond with literature and myth, all the other ways that human beings have of telling stories. Yes, there are times when the story has to be told simply, the fire engine sent the shortest route to the fire. But a world without stories is fundamentally inhuman. It is a world where nothing is imagined. Could a chemist be creative in such a world?

Ethics growing out of Science

Almost every story has a moral, explicit or not. As Hayden White asks: "When it is a matter of recounting the concourse of real events, what other "ending" could a given sequence of such events have than a "moralizing" ending?"[9] Emily Grosholz notes perceptively that "..when we hear a story, we evaluate the agents and the action. Maybe this is because of the irrevocability of human action (it only happens once, so it better be good), and intentionality (we always do things for an end or reason)…The very choice of beginning and ending confers meaning."[10]

In the endings I have seen, more often in scientific seminars than papers, there is a curious mixture of celebration of the human achievement, with serendipity coopted to serve design. And there's a double resacralization of the mundane, of what has just been demystified. In a spiritual process that I find refreshing, awe is expressed at what happens in nature or what human beings (OK, usually the author) can do. And the mysteries as yet to be resolved are articulated. With complete faith that they will be resolved.

This has led me to think not only about the morality emerging out of endings, but also of the potential of the process of science for constructing ethics. Here I follow, half a century later Jacob Bronowski's path. My landsman in more ways than one was much less tentative than I will be when he said " … the practice of science compels the practitioner to form for himself a fundamental set of universal values."[11]

Can ethics grow out of science? The very question may seem ludicrous to two communities of scientists: those who really believe that science is ethically neutral, and those who believe that scientists are inherently ethical. So let me first contend with these, as provocatively as I can.

To claim that science is ethically neutral ("I just worry about the technology of cloning. Someone else can decide if it's good for people.") puts scientists squarely in the company of anti-gun-control activists ("Guns don't kill; people do."). By contrast, I believe, and there is some philosophical tradition that supports this, that in any action by a human being, the instrument of that action (a gun, a molecule synthesized, yes, even a mathematical equation or a poem) must be accompanied by a

moral judgment. The judgment is: “will the use of that instrument by me (or by others) hurt people, or not?” The invention or implementation of a tool without consideration of the consequences of its use is deeply incomplete.

As for the claim that scientists are born with ethics – well, that’s just as likely as their being born with aesthetics or logic. That the latter is not true, you learn from reading the “peer review” referees’ comments on your paper. We scientists are smart people who have opted to engage in a remarkable social system for garnering reliable knowledge, that knowledge being of great practical and spiritual value. The critical components of that Western European social invention, science, are (a) normal, curious people, some of whom like mathematics; (b) people not afraid of getting their hands dirty -- experimenters; (c) an open system for dissemination of what one finds, and a communal urge to do so; and (d) a method that encompasses frequent dipping back and forth between approximations to reality (gauged by our occasionally misleading senses and our tools) and flights of imaginative fancy in hypothesis formation and theory building.

So… is there is something in the practice of science that can enhance the ethics brought to it by scientists, or that possibly can engender an ethical outlook? As the above makes clear, I do not come to this because I think scientists are “better” than other people – far from it. Nor do I dare presume that a relatively late social invention, science, could provide a broad rationale for a human quality as fundamental as ethics. (Or is ethics itself a social invention? If so, it is older than science. But not as old as curiosity.)

When goods collide, where do we get our criteria for deciding among them? From the usual sources, like them or not: our socialization at home

and in our schools, i.e. from our parents and teachers. Perhaps from our genes, though not as much as E.O. Wilson would like us to believe. From churches and religions. From reading – novels are especially strong moral instruments. Not a tad diminished by deconstruction. By the time science enters a young person's moral consciousness, he or she is usually a pretty well-defined moral human being. For some, ethics may be a set of rigid schemata to be applied to any situation. Yet the web of life has a way of generating new quandaries; one's personal sense of what's right, how to act in difficult times, evolves even as it is moored in the past.

Two of the components I gave of science, publishing and the nervous motion twixt theory and reality, depend on texts, talks, and conversations. These generate narrative. And, even forgetting the moralizing endings, such acts of communication inevitably confront scientists with ethical choices – to be faced, evaded, negotiated. Let me expand on this.

An important part of the system of science is publication, with the potential of replication. How reproducible scientific findings are (and whether the reality of reproducibility is essential to belief) is a matter of contention.[12] It took several years for public questioning to surface of the all too novel measurements, a multitude of them, of Hendrick Schoen in solid state physics.[13]

Could it be that the primary emotional motivation for a scientist who does not falsify a synthesis or measurement is simply fear, rather than the psychoethical drive to report facts honestly? Perhaps; though I find definite positive value in fear in making us behave righteously. To a point. And fear of damnation, big and small, is certainly important in Christian ethics. It may be painful for most of us to see others, never ourselves, "…do the right

deed for the wrong reason.," as T.S. Eliot says in "Murder in the Cathedral."[14] But I accept the way we are: The "habit of truth," as Bronowski called it, is formed in many ways.

Ethics is like a limb that needs exercise to function. The importance of publication is that it provides exposure to potential testing. Time and time again. Fraud in science is ultimately unimportant. There is much prurient interest in it, for sure. With the same origins as our fascination with the sexual misdeeds of our ministers. Priests of the truth have a longer way to fall. But fraud is unimportant because the psychopathology of its perpetrators is such that their sense of fear of being proven wrong is somehow abrogated, and they never forge the dull, only the interesting. Thus, the normal workings of the system ensure that others -- out to prove the makers of the startlingly new wrong, not right -- will repeat the experiment.

So the system works, but is the individual scientist, motivated by loss of reputation if proven deceptive, likely to become more ethical? A cynical viewpoint is that he or she will learn to sanitize, embroider and manicure just enough to get away with what they can. And pile on the hype. A more charitable viewpoint is that we learn that data are not only not to be trusted, but that they are mute, and inherently conservative. That a human being must interpret them – yes, tell a story about them. And that it is OK (within a self-correcting system such as science) to risk an imaginative, ornate hypothesis which does an end run around Ockham's razor.

Something salutary takes place in the writing of an experimental part of a scientific paper. I have trouble in picking one of my own to show you,

for, sad-to-say, I'm just a theoretician. But here's a piece of a mixed experiment/theory paper in which I am a coauthor, ergo in part responsible:

> ***Crossover Experiments***. *In a 25-mL reaction flask was placed 0.050g (0.094 mmol) each of* $Cp_2^*Th(^{12}CH_3)_2$ *and* $Cp_2^*Th(^{13}CH_3)_2$. *The vessel was evacuated, and then 10 mL of* Et_2O *was condensed into the flask at -78°C. The suspension was stirred at this temperature until all of the material had dissolved and a colorless solution was obtained. The flask was then backfilled with 1 atm of CO and the solution stirred vigorously. After 4 h at -78°C, the solution was allowed to warm to room temperature whereupon a colorless solid (*$[Cp_2^*Th(\mu\text{-}O_2C_2\text{-}(CH_3)_2)]_2$*) precipitated. Next, 2 mL of degassed 1 M* H_2SO_4 *was added to the reaction mixture via syringe under a flush of argon. After the resulting suspension was stirred for 15 min, the mixture was centrifuged to remove a colorless, flocculent solid. The* Et_2O *layer was then separated from the aqueous phase. The aqueous phase was next washed with four 2-mL portions of* Et_2O, *and the washings were combined and then dried over* $MgSO_4$.[15]

Basta! You see a report of what was done, almost in iambic pentameter. Not the average run, but the best that was done, to be sure. It's there, this experimental part of a longer paper, for historical reasons: as evidence that it was done, that it can be done, with details reproducible by anyone (well, maybe). But why give the evidence? Isn't there trust in the community, aren't we all gentlemen? Or were, now that 35% of Ph.D.'s in chemistry in the US are women…

In citing another's experimental (or theoretical) work, there's a similar wrestling match on. To cite is an act of trust. Which can also be viewed as

an act of mistrust, for by citing someone else without questioning the result, one is protected should it be faulty. To say that the mistrust complicit in the statement of conditions of an experiment, or citing someone's work, negates the trust overtly expressed by using the work, and that that's all there is to science, is to miss the fertile tilled orchard of science – the creation of molecules as well as frameworks of understanding.

This is the essential tension of which Thomas Kuhn wrote, between trusting and not trusting.[16] I think writing an experimental part of a paper, or reading it in someone else's text, not once but many times (I have written five hundred such, not untypical) is an ethically productive action. In which both subconsciously and overtly the issues of trust and mistrust are negotiated by chemists. The important word here is "negotiation": the web of habitual description and citation subconsciously (and explicitly) forces the creator to confront the other. It is an inherently social web, built out of real and imagined interactions with other human beings. In it are the makings of a gift economy. And of empathy.

First Time Narratives

I see two other places where in an interesting way ethics emerges from normative science. The first is the responsibility taught by first time narratives, first time representations. I remember for instance, when Fred Hawthorne -- now at UCLA -- came one 1961 day to Harvard, when I was a graduate student there, and told us how he had made $B_{12}H_{12}^{2-}$, a molecule shaped like an icosahedron (see Figure 7)[17]. Nothing like it had been seen before; he described its properties with evident and appropriate excitement. Hawthorne knew instinctively that there was a story to be told of $B_{12}H_{12}^{2-}$,

that it sufficed to tell it straight. Das Ding an Sich was indeed beautiful enough; it was sacred even as it came to be in his profane hands. In another day, another time, Fred would have said that it was given to him by the grace of God. In 1961 he called it serendipity.

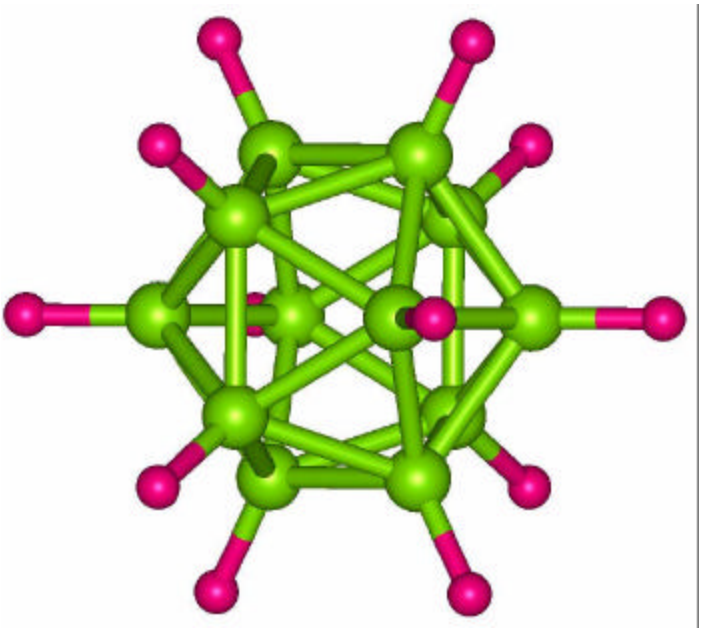

Figure 7. The structure of the $B_{12}H_{12}^{2-}$ ion synthesized by Pitochelli and Hawthorne, Ref. 17.

There was no more questions of Hawthorne making up a fib around $B_{12}H_{12}^{2-}$ than of Haydn writing a dissonant section in one of his piano trios.

Representation as Furniture

Much of what we do in science is to represent reality. Those representations, whether in language or not, are murky mirrors. But, as Emily Grosholz says, “representation is also generative: we say more than we know we are saying, and we induce order by our orderings, and good

representations, as intelligible things, add to the furniture of the world. So representations are both more and less than what they represent. By misrepresenting, they also allow us to know, and to create."[18]

Speaking of language and veracity, Oliver Sacks tells an interesting story in a film he made in the Mind Traveler series. In Eureka, CA he met a family of deaf Mexican farm laborers. Among the five children, the three older brothers, who did not sign, were suspicious of their younger siblings, who were learning sign language. Because they would learn to lie, the older ones said.[19]

When you see something for the first time, you don't know what it is. When you describe it for the first time, language will fail you. You grope for meaning. But there is no lie. Were we given more such moments!

Honesty to the Singular Object

A second experience is one shared by poets and scientists. Something is seen, felt, then described. Now not for the first time, but for the umpteenth. So love has fled, and it hurts to remember what was good. It has happened to others, though that thought seems not to comfort at all. A poem needs to be written – one is in the Luberon, in winter, one walks out in the morning into the vineyard, it's sad to face that beauty alone. But then there's a grape cluster, like no other grape cluster. It must be described:

RAISINS FOR BEING

They left small bunches
on the vine, green late-
comers; the farmers

knew the day to pick,
sugar rising in the
berries, rain offshore. But

four sunny days broke
the pattern; the vines free
of their luscious burden

filled out the stragglers.
And then I came, just
before pruning,

and walked out in
the morning frost, the sun
clearing the Luberon,

and a thousand droplets,
on a grape cluster,
muscat pavé, told me

that I had a latecomer's

right, to live life out
reflecting, free albeit

tethered, at an angle
to the sun, sweet to you.[20]

I describe, and I am not sad any longer. For a while.

Elsewhere there is a molecule I see in a journal (Figure 8)[21]. I talk about it to one of my graduate students, Pradeep Gutta. It has at its center a ring, with two tins and two nitrogens in it. But as you see, the environments of the two tins are strikingly different. Why? Could it be because of their different substituents, the chemical shrubbery hanging off the tin atoms? No, for the molecule with all substituents identical is calculated to have exactly the same geometry. "'tis a puzzlement," as Yul Bryner said. And could one exchange the environments of the two tins, as shown in Figure 9? We calculate the way the electrons move in this molecule, their orbitals, orbits writ large. And we reason out a reason, because … that's our métier. There's a story to be told, I tell it, as well as I can.

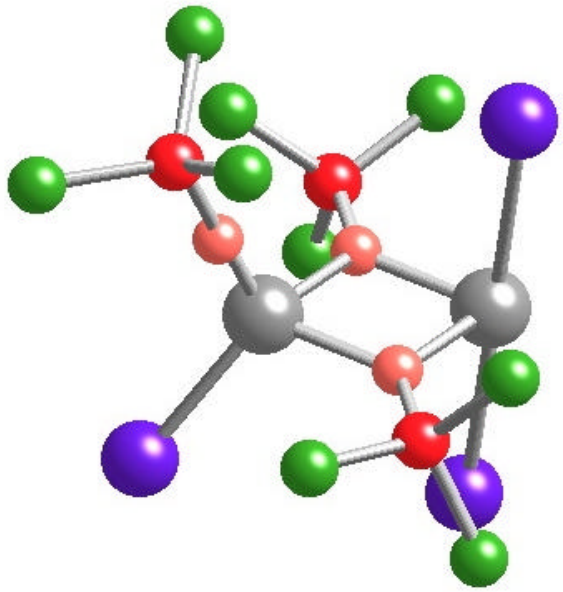

Figure 8. The structure of a molecule made Chitsaz et al, Ref. 21. Gray spheres = tin, orange = nitrogen, blue = iodine, red = phosphorus, green = C_6H_5 group.

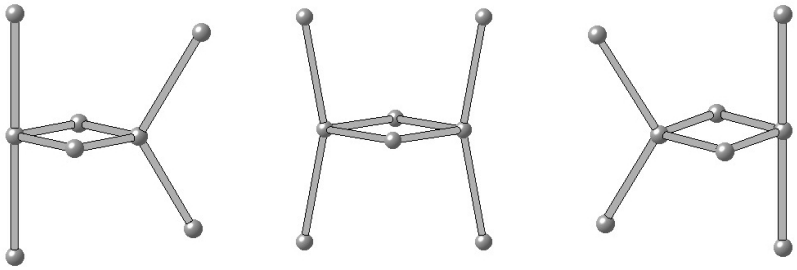

Figure 9. A drawing at left of the same molecule as in Fig. 8, now pruned to its geometrical essentials. The sequence of molecules, left to right, indicates a hypothetical way that the environments of the two tins could interconvert – a set of steps in a molecular ballet.

The language I use to tell my story is that of science, which is not the language of poetry, at least not much of the time. There is no premium on ambiguity in science. But that a word mean two things and sound like three other words, that … is the stuff of poetry. What science and poetry share,

even though they parted company, it seems centuries ago, is an honesty to the singular, determinate object. We tend to think science is after universals, the infinitely paraphraseable, to use again Guenther Stent's idea.[22] But science is not one thing, and maybe chemistry is different – we build shape, motion and reaction on specific, variably persistent group of atoms. Trends matter, general theories less. And individual molecules, examined up close, most of all.

Craving understanding, we circle around the object of our affections. In love with the particularity, the "thingness" of this powder, just this shade of turquoise, we study it. Here is what William Blake said:

> *He who would do good to another, must do it in Minute Particulars:*
> *General Good is the plea of the scoundrel hypocrite & flatterer:*
> *For Art & Science cannot exist but in minutely organized Particulars.*[23]

And A.R. Ammons, the American poet for whom art and science were not separated, in a section of his *Hymn*:

> *And I know if I find you I will have to stay with the earth*
> *inspecting with thin tools and ground eyes*
> *trusting the microvilli sporangia and simplest*
> *coelenterates*
> *and praying for a nerve cell*
> *with all the soul of my chemical reactions*
> *and going right on down where the eye sees only traces*
>
> *You are everywhere partial and entire*

You are on the inside of everything and on the outside

I walk down the path down the hill where the sweetgum
has begun to ooze spring sap at the cut
and I see how the bark cracks and winds like no other bark
chasmal to my ant-soul running up and down
and if I find you I must go out deep into your
far resolutions
and if I find you I must stay here with the separate leaves[24]

Fifteen million of the twenty million compounds known are white crystalline solids. I give you four vials – all white powders: one is sugar, another salt, the third penicillin, the fourth tetradotoxin – the poison of the fugu or pufferfish. Will you play Russian roulette with these? Your body knows the difference. The difference, and its definition by the fallible powers of our mind and hands, is as beautiful as it is essential. The description of difference is one task the scientist does as well as it can be done.

Does the ethical bent inherent in the precision of language sought by scientists and poets make scientists and poets better human beings? No, no more than it improves those who professionally lead the considered life. The ethical impulse is strong, inherently human. It can be suppressed, most alarmingly by crowds and power, to use Canetti's phrase. And, remarkably enough, it can be suppressed by the flush of first creation: I'm thinking of the susceptibility to this of the saints -- Sakharov and Bethe in science, Lowell and Sexton in poetry. Ethical thinking can be awakened, it

needs to be reawakened, by consideration of whether a molecule can harm, by advances in reproductive technology, and … just what one can invent in a historical play, and whether a poem hurts a lover. Even a soap opera can teach ethics. We should be grateful for these little (or big) prods to ponder ethical choice.

The First (Fruitful) Intersection of Science and Ethics

I want to make a final point that returns to our cultural roots. The tree in the Garden of Eden of our primeval religious narrative was the Tree of Knowledge of Good and Evil. I take the *etz hadaat tov vera* as… the tree of ethics (a word not in ancient Hebrew), and the first link between science, narrative and ethics. Let me bypass the question of why a just God would put ethics out of reach. He did. Continuing in my unrespectful/respectful midrash (which is similar to that of Zygmunt Bauman, Jean-Pierre Wils, and more recently by Leon Kass[25]), is not Adam and Eve's transgression implicit in the tale, serpent or no serpent? Without it there would be no narrative, no story of humankind. We'd still be between the four rivers still, right?

Even before eating of the fruit of the tree -- and the rabbis discuss whether it was wheat, grapes, or fig, with no apple in sight – Eve makes a decision: "When the woman saw that the tree was good for eating and a delight for the eyes, and that the tree was desirable as a source of wisdom, she took of its fruit and ate."[26]

The science in my mildly sacrilegious midrash is manifold. It sparkles in the knowledge that the tree conveys. Of what? Of oppositions and

polarities. Of matter particulate and continuous, opposites attracting each other or repelling, of analysis and synthesis. Of what is to be hidden and what is to be revealed, of the same and not the same (those four vials). And the verse speaks, directly, of experiment. For this is what Eve hazarded, isn't it? She saw, and thought, and acted. She acted on beauty, for wisdom. Kant would approve. Eve did what had to be done, not to end but to begin a story. In which curious human beings have the choice between good and evil.

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LITERATURE

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