

Art & Science

[Talk and "recital" given by Assoc. Professor of Biology, Chris Bystroff, to the entering graduate students at the Heffner Alumni House, RPI, Troy, NY.
Aug. 26, 2005]

It's a pleasure to be here to greet the new graduate students and to have the opportunity to perform for you all. It is a special treat for me to be able to perform in public. I rarely get to do anything musical these days. In fact it's been more than two years since I played in public, and on that last occasion I was so distracted that I forgot to tighten my bow and didn't realize it until my accompanist had already started playing and it was time for me to come in. I lifted my bow to play the first long note in a bach sonata, and "clack", I heard the sound of wood on the string instead of the sound of horse hair. I stopped, tightened my bow quickly and we started over, but that experience reminded me of why I chose science over music as a career so long ago.

Today I will play for you a piece for solo viola. I wrote this piece 25 years ago when I was a music major (briefly) at Carleton College in Minnesota. I have never performed it in public, and in fact I had never even named it until now. This month I decided to call it "Art & Science", not because the music has anything to do with science but rather to give me an excuse to write an introduction having to do with the arts and the sciences. It's a 5 minute piece so I can afford to give it a 40 minute introduction.

I think I was chosen to do this talk because I was recently tenured in the Biology department and at the same time received an award from the National Science Foundation. I have also received three other grants, all within the last 2 years. So it's been a great time for me. Literally it feels like a great weight has been lifted from my shoulders. I think the reason I was so distracted that day and forgot to tighten my bow is that I was always nervous about my career and worried about whether my department and my university would recognize the value of my science. In fact I was convinced after four years and no grant funding (or very little) that I would be denied tenure and would have to move my family, again, and possibly change my career, again, and all of the blood, sweat and tears that I had spent on bioinformatics would be lost. I was distraught, disillusioned and depressed. Then one day, a few months ago, I got a call from the Provost, and suddenly all was well. Birds were singing in the trees and the sky was clear. I was

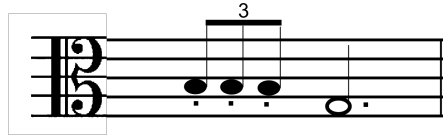
tenured. I was granted nearly infinite job security. Now I can be fired only under the most extraordinary of circumstances, such as a felony offense, or the failure to show up for class because I went to Fiji for a year. Tenure means I don't have to prove myself to anyone, anymore. I'm superman. I can relax now. (Ok, so they can still take away all of my money, but not my job!) But naturally, the last thing that you would want to do after you were told you were superman is to relax. When you are superman you want to save the world. You want to tackle the real hard problems. Tenure means I can talk about and do the things that I think really need to be talked about and done -- even if they are risky. I can talk publically about subjects previously taboo for a professor -- religion, politics, sex, even fortran. I can even play my viola in public in my official capacity as a professor. I can go out on a limb, as some professors do, and claim skills and knowledge beyond my immediate expertise, for expertise in one science often provides insights into other sciences and even non-sciences. In other words, at last I can live up to my title and "profess".

Of course, I should not burden you with my pipe dreams. I should really have decided to give you a talk about my research. For the record this hypothetical talk would have been titled "The underlying physical determinants of the protein sequence database: a statistical model for protein folding." I can see some of you nodding off already. I like my science, I really do. I like staring at protein structures all day and writing code (in fortran) that asks a well-structured question that can be answered by the sequence and structure databases, questions that involve the physical forces behind the amazing spontaneous self-assembly of protein chains. It's fascinating to me, but I also know that no matter what I say I can't get everyone to like bioinformatics in 45 minutes, and there's really no point to doing that in any case. You don't have to care about what I do. Instead, we should simply get to the bottom line, talk about something useful to you, and forget the details. The bottom line is: I did something that happened to get me some recognition from the NSF. And how I did it, in broad terms is: by resolving dissonance.

And, that's where the music comes in. To help you better understand the music, let be talk about the parallels between Art and Science.

Art and Science are generally believed to be separate areas of intellectual activity, mutually exclusive and non-overlapping. Symphonies are not peer-reviewed before publication, and scientific articles need not be put to music.

Singing a mathematical proof rather than simply stating it gives it no additional weight. And although a musical phrase or artistic motif may be a 'statement' in some sense of the word, no amount of logic can prove or disprove a musical statement. For example, consider the following "statement", originally posed by Beethoven in his fifth symphony:



True, or False? Anyone?

It's nonsense of course to ask whether it is true or false. It can't be true or false in a logical sense. It simply doesn't have that property. Can a rock be true or false? No. The letter 'x'? No. What about the statement "I married a werewolf"? Yes, it can be true or false, as long as the words "werewolf" and "married" are uniquely defined. It's false, by the way, by most definitions.

In the field of epistemology, a "statement" is something that has the property of being "true" or "false". Not both and not neither. Since the phrase from Beethoven's symphony is neither true nor false, it is not a "statement" in the sense understood by scientists and philosophers. In fact, we should be consistent and stop calling musical statements "statements". We can call them something else, such as "melodies", "riffs", or "phrases" instead.

This seems to say that music and science are mutually exclusive and one can never confuse one for the other. All we have to do to recognize a musical phrase from a scientific statement is to ask whether the 'statement' has the property of being true or false. I know this is not the whole story. There are statements that are not scientific, and there are non-statements that would not be regarded as art. But at least we can say that all scientific statements must be testable as true or false, and no artistic statement has this property. So we can say that Art and Science are mutually exclusive.

Nevertheless, Beethoven has communicated something to the audience in his Fifth Symphony. If the listener has received no sensation whatsoever from hearing the symphony, why did he or she pay fifty dollars to hear it? Statements communicate something, something that can be true or false. Music communicates something that cannot be true or false, but which can be good or bad, and has value when it is good.

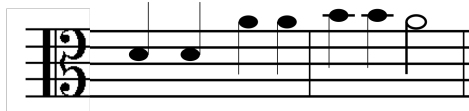
Let's put it this way, music can't be "true" but it can "ring true." It can be pleasing to the ear to the point of inspiring us to fork over fifty dollars, and all of the food and comfort that that fifty dollars implies, just to experience the sensation of orchestral sound without distractions. On the other hand, there are other sounds that we would pay not to hear, such as jackhammers, and maybe accordians, so obviously not all sounds have this property. Good sounds, musical sounds, "ring true". They follow some kind of self-consistent tonal pattern and predictable, intuitive rhythmic pattern that gives us a sensation of correctness, completeness and understanding, the same sensation we get from a solid scientific argument. Bad sounds offend our senses like lies and nonsense. Bad music is out of tune or out of step, tripping up our ability to build a mental model of the sound. Likewise bad science is not self-consistent and fits no complete model.

True, we don't often plop down fifty dollars to hear a mathematical proof or the complete explanation of the aerodynamics of helicopter flight. But that's just because few people are ready to hear and understand those types of "performances." A talk on aerodynamics would be gibberish to me and no matter how well structured. If I can't understand it, it gives me no sensation of correctness or "ringing true", even if it is revolutionary science. Likewise to most of you I'm sure, a bioinformatics talk might communicate nothing to you, and therefore be worth nothing, not even your time. I, on the other hand, would fork over more than fifty dollars and even travel across the country for the opportunity to hear a talk in bioinformatics by one of its greatest practitioners, and I have on many occasions done that. And this is not just because it is my job to go to conferences, although that is part of it.

I get a sensation of completeness and harmony from a scientific argument that is solid and well-supported. It must be true if all the bases have been covered and all the evidence is mutually reenforcing. I get a sensation of "dissonance" and dis-harmony from a talk or paper that is fallacious and incomplete. Holes in the science are like wrong notes or skipped beats. Unexplained incongruence between different scientific studies is like polytonality. Which key are we playing in anyway? In the 1980's, the prestigious journal Nature published a study by a group from a homeopathic medicine institute in Paris that showed an immune response to snake venom that had been diluted by a factor of 10^{23} . This result did not harmonize with the current understanding of how the immune system works, since there would surely not be even one molecule of snake venom in the diluted

solution. Sure enough, a retraction was published in a later volume. It turns out that the immunological data had been pruned on one side only, the side that showed no immune response. Whoops. Can't do that.

The other kind of scientific presentation that I don't like is the one that presents no new data, no new ideas, no particularly surprising or insightful conclusions. It's like the tune



I don't have to hear that. I know what's coming next. I've heard it before. The tonality is not in question here, the rhythm is very simple. It does not challenge me, regardless of the fact that it is harmonious and in-tune and has a perfect beat. A trivial song only holds the interest of a child who is just learning the meaning of tonality and rhythm. The same holds true in science. A talk can be trivial, even if it is logically sound, and such a talk holds the interest and gives a sensation of wonderment only for the uninitiated.

The best scientific talks I hear and the music that I most enjoy both have the quality of resolving dissonance, bringing dis-harmony into harmony, extracting a tonal and rhythmic framework where there was none before, or in the scientific sense extracting a complete and logical model where there was previously only data. Something is beautiful about that. And the parallels between musical and scientific dissonance are compelling to me enough to have fascinated me for many years. In fact, I named my computer cluster Bach because I believe the music of J.S.Bach more than anyone else explores dissonance and its resolution. In Bach's organ music and in his solo violin sonatas the musical phrases dance around each other and explore every corner of tonality, constantly setting up the expectations of the listener and then perversely twisting those expectations, without ever resorting to an illogical phrase or rhythm, until the final cadence neatly wraps up and explains everything in a short and decisive resolution. I wish I could do science the way Bach did violin sonatas. That kind of science would be non-trivial, exciting, drawing truth, simplicity and completeness from previously unrelated corners of knowledge. A fine example of a modeling experiment that "resolved dissonance" was the modeling of the structure of DNA by Watson and Crick in the 1950's for which they won the Nobel prize. The molecular basis of the gene was just a vague concept at the time. plenty of data. plenty of theories, but none of them harmonized well with the data.

None rang true. Watson and Crick collected disjoint knowledge from X-ray diffraction, mathematics, quantum mechanics and genetics and constructed a three dimensional model about which Watson said "it was so beautiful, it had to be right."

Beauty in both science and music is when the component parts of the system come together and harmonize with each other, mutually reinforcing, forming a new emergence -- a new model, a song or a symphony, or a new, more comprehensive theory. We get a good feeling, a feeling of truth and beauty, when we experience the resolution of dissonance. As a biologist, I wonder why it is so that harmony in such disparate fields as music and science should give us the same feeling. Perhaps there exists a "curiosity gene", a gene that drives us to resolve various forms of dissonance and rewards us with a good feeling when we do. But this is just conjecture, although it would make some sense in terms of human evolution. In any case, that's not where I want to go with this discussion.

In particular, I want to discuss confusion. Confusion is when we can't tell whether something is art or it is science.

Before I do that, let's review what we know so far about the similarities and differences between the arts and sciences. (1) They are fundamentally different in the types of statements they make. Science makes statements that can be true or false. Art does not. And (2) they both inspire the same good feeling when they resolve dissonance.

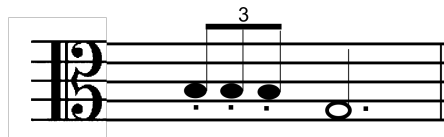
This says to me that logic has nothing to do with the feeling of truth. We can feel truth in a melody that "rings true" as easily as we can feel truth in a set of scientific data that are mutually reinforcing.

You might say it's not the same feeling, that you enjoy music in a different way than you enjoy science, but I think there are strong parallels. Personal experience tells me this is the same sensation when I hear a musical piece as when I hear a science talk. If it's 19th century German 12-tone music, (Schoenberg for example) which I don't understand, or if it's let's say helicopter aerodynamics, which I don't understand, either way, I'm asleep. I tune it out because it doesn't flip the right switches in the brain. It's nonsense to me. If it's disco, a trivial monotonous machine-like musical form, or if it's Bill Nye the Science Guy, I turn it off. I feel a sense of impatience with trivial messages whether musical or scientific. (No disrespect intended for one of

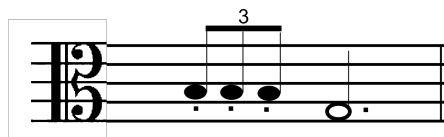
the greatest ever teachers of science to children. In fact, I do stay interested when Bill Nye raves about bouyancy or momentum, even though I learned that stuff in the third grade, but I'm interested in the teaching technique, not the science.)

A feeling is, in the end, something physiological. And humans don't have a large repertior of physiological sensations to work with. So it seems simpler to propose that this dissonance/resolution feeling is a single sensation (or a single gene) rather than many sensations (or many genes). I think this becomes clearer when we consider that intellectual stimuli span a whole spectrum of fields, not just science and art.

So, the confusion comes when we don't know what kind of truth we are experiencing. Is it logical truth, or is it artistic truth? The sensations are one and the same, but one is objective and the other is subjective. A scientific truth can be verified using logical means. An artistic truth cannot. In the case of the phrase



it is pretty clear that we are talking about a message that falls into the art category, so we don't try to prove it. Wouldn't you look ridiculous trying to prove Beethoven was right when he said:



?

...and Bach was wrong when he said



?

Yes, I think so. You would look ridiculous. Now. Would you look ridiculous if you tried to prove the statement

"The Earth was created in seven days?"

Maybe not.

"The Earth was created in seven days"

is a grammatically correct english sentence for which each word in the sentence has a conventional definition. This means that we should be able to look for evidence that supports this statement or refutes it. If our evidence is to the contrary then this statement is discordant, and we resolve the dissonance by accepting its falsehood, or by re-interpreting it. For example,

" a small lump of dust that was to become the Earth was created within seven days of the Big Bang."

So at first it does not seem utterly ridiculous to apply science to a religious tenet.

But consider other religious statements, drawing again from Christianity since that is the religion most familiar to me. Take for example,

"Jesus saves."

or

"Thine is the kingdom and the power and the glory forever."

Prove it. I can accept the definition of Jesus as a jewish leader of the first century, but what about the word "saves?" How is that defined? No, he is not saving money in a bank, which would have been my first guess. So, I asked a few people and they gave me the following clarification,

"Jesus saves your soul from eternal damnation."

But this statement simply adds more undefined terms. What is a "soul?" What is "eternal damnation?"

After a few more questions like this I generally get a squinty-eyed look that indicates that I must be mildly insane and a person to be avoided. I would get a similar look from the conductor of a symphony if I asked whether a musical phrase was "true." Maestro, is it true, sir? Is what true? Is it true that



And I would get exactly the same squinty-eyed, go-away look from the Maestro as I got the day before when I was kicked out of bible study.

It soon becomes clear that religious statements may be accepted as "truth" even when they are grammatically loose constructs and contain terms that are ambiguous or undefined. If so, and the truth we feel from these phrases comes in the absence of logic, then religious phrases and arguments are more akin to musical phrases which simply don't have the property of being true or false. Like music, they "ring true," meaning we can get a good sensation from these phrases. A good sermon can evoke a sense of beauty and completeness, of universality. But it is not science. Religious beliefs don't arise from the logic centers in the brain. Instead we can imagine a "faith center" in the brain perhaps that processes sermons and rituals. This brain center would be the appropriate recipient of the Sunday morning pastoral. But it would be inappropriate to treat a faith-based belief as you would a scientific hypothesis or theory.

Think, for example, how many scientific papers have you seen in reputable, peer-reviewed journals that have investigated "eternal damnation of the soul?" Given the obvious importance of the topic one would think science would have investigated it if investigation were allowed. But it is not. It is not truly a statement. Instead, it is more like a musical phrase. It is a phrase whose terms are not well-enough defined to have a true/false property assigned to it.

This is not to say that religion is equivalent to music, which is uniformly illogical. There are some provably true statements in the Bible, so it is a mix of logical and illogical.

I do not in any way want to give you the impression that I do not value religion. Humans need religion like they need water. It satisfies a thirst of some sort for a higher completeness. It is natural that the sensations we feel upon hearing a good sermon that rings true get confused with the sensations we feel upon scientific discovery. Both give a sense of harmony and consensus, they both originate in the form of language, but they must be processed by two different centers in the brain, one of which is not driven by logic circuits but by a different set of rules, depending on the religion.

Language is the way we communicate our scientific findings and also the way we express our religious beliefs, and this contributes to the confusion. Some people recognize that the intellectual processes for these two modes of communication are separate and follow different rules, but some people

don't, and their confusion can be the source of a lot of grief, especially if these confused souls happen to be in positions of power in the government.

I'm talking of course about renewed efforts to re-introduce creationism into the schools by calling it "intelligent design." I don't want to go into the details, and I think many of you are probably already aware of this centuries-old and ongoing battle between the religious and scientific community. It rages on because religious zealots refuse to make a distinction between scientific and religious "beliefs" (and if I have made my point and you accept it, then you now realize that religious statements are like Art, not like Science, and therefore cannot be true or false.) At the same time, scientists fail to recognize that you can't disprove a religious belief and they go on trying to do so anyway, using science, of course. Perhaps a better approach would be for the scientists to preach, and therefore appeal for acceptance to the same logic-free higher brain centers that sense harmony in religious language.

Resolving this political issue is of utmost importance because if science and religion are taught by the same teacher in the same room, to a roomful of blank slates that are children, those young minds will develop cognitive centers that mix science and religion. They will grow up to be the adults who confuse the issue and try to prove the unprovable or seek scientific validation for a religious belief. Some may become practitioners of pseudo-science. "Pseudo-science" is the term applied to the mis-representation of faith as science.

Note that teaching science and art together would have no such confusing effect because they are clearly distinct. Religion is an art form that is not clearly distinct from science, especially to children, for the reasons I already stated. And this confusion represents a danger to our maturation as a society. And these days, our maturation as a society is becoming increasingly urgent.

Before I say why I think our maturation as a society is becoming increasingly urgent, let me introduce the fourth and final point, and this I believe this point will explain the music you are about to hear. The first three points were as follows.

(1) Artistic statements and scientific statements are fundamentally different. Scientific statements can be true or false. Artistic statements cannot be.

- (2) Both science and art can give a feeling of truth and harmony or discord and dissonance. Resolving dissonance produces a feeling that we value.
- (3) Confusion arises when we don't distinguish scientific language from artistic language. Religious language is art, not science.

My fourth point is that resolving dissonance comes in all sizes. When the dissonance is small we can easily resolve it. These are problems we solve every day. When dissonance is big, it is more challenging to resolve it, riskier, but perhaps more rewarding. This would be a problem worth granting you a Masters degree or a PhD. It is quite possible you will fail to solve the dissonance but you think it is worth the risk. When dissonance is too great, we flee from it. These are problems we feel that we cannot resolve so we shut them out, ignore them and generally wish they would go away without actually doing anything to make them go away.

An increasing willingness and ability to resolve greater dissonances is what I mean by "maturation as a society."

I'm going to try to describe the biggest, most dissonant and most widely-avoided scientific problem that I can think of. When I mention it, you will sink in your seats and start looking towards the door. Even if you have been paying full attention up to now, you will wish you were somewhere else when I ask you to pay attention to the biggest problem on Earth. After I say what it is, I'm going to ask you to gauge your personal dissonance on a scale of 1 to 3.

Ready? The problem is the human population explosion. Let me be perfectly clear on what I mean before you register your level of discomfort. If I had a chalkboard here I would draw a population curve going back to about 1700. The worldwide human population reached 1 billion in 1802, 2 billion in 1927 (a doubling time of 125 years). The 3 billion mark was reached in 1961. We were 4 billion in 1974, 5 billion in 1987 and 6 billion in 1999 (a doubling time of 38 years). Practically no one believes the population can double again. The food resources required by the human population is currently estimated to be more than half the maximum total world capacity for food production. And the capacity is itself decreasing with time. [Jared Diamond, "Collapse", 2005]

Consider trends in the world's fisheries as a model for trends in world's food production in general.

The population of large predatory fish in the world's oceans have decreased to approximately 10% of their levels in 1952 when large scale commercial fishing (and recordkeeping) began. For example, bluefin tuna populations have dropped by more than 70% in the last 30 years. [Richard Ellis, "The Empty Ocean." 2003] And as we know, the rate that a species will regenerate it's population is proportional to its population. So by consuming at greater than the replacement rate, we are eating future fish. The Atlantic bluefin tuna reach maturity at age 8 and live for about 30 years. If we continue taking bluefin tuna at the current rate, they will become extinct within one tuna lifetime. Largescale conservation efforts could save the tuna, but the human population continues to increase and there are always those who would consume the last of the species rather than go hungry.

The crop growing capacity of the world's arable land is not likely to save us by replacing fish with tofu and bean dip. The latest projections of topsoil loss estimate that we have about 70 years of topsoil left and that we are currently losing topsoil at a rate five times faster than the rate of natural soil regeneration. (Sundquist, B. 2000. 'Topsoil loss - Causes, effects and implications: a global perspective.' The Earth's Carrying Capacity - some literature reviews.) This phenomenon has parallels to the loss of our fisheries. The soil degrades in its ability to produce crop yields as the farmer goes deeper. Lower yields mean more arable land needs to be farmed in order to feed the masses, and that in turn means more degraded soil, and so on until all arable land is being plowed. Unless something changes, we can predict a decreased overall food production in the next half century.

In the simplest and least controversial model, population is limited by the rate of food production (called the carrying capacity). So if food production is decreasing, and our population is near the carrying capacity, then the population will also decrease. Complicating factors are likely to either slow down or speed up the decline. For example, starvation often leads to political unrest which may lead to an additional decrease in the rate of food production, which in turn may lead to more starvation, and so on. On the other hand, humans may evolve rapidly in the face of a crisis and learn ways to halt the environmental degradation of the land and the sea, allowing the carrying capacity and the population to stabilize.

Ready to gauge dissonance? There are 3 options from lowest to highest dissonance.

(1) How many of you believe the population problem can be solved. Hands?
[Note: about 1/3 of the students raised their hands, of ~125 in the audience.]

(2) How many believe the problem cannot be solved but that we should try anyway?
[About 2/3 of the students raised their hands!!]

(3) How many believe I should change the subject?
[2 or 3 students, who had abstained up to this point, cautiously raised their hands.]

Be honest. It's natural to feel a sensation similar to the one you experience when you hear a jackhammer or an accordion when you hear of a problem that is both unsolvable and critical for your survival. It's like staring death in the face. Some people will deny that they are staring at death, saving their tears for the afterlife I suppose [Answer #1]. Others will spend their tears and dissolve into a useless puddle [Answer #3]. Still others will fight back [Answer #2].

I had a dream once that I was facing death in battle and all I had was a violin. I think this dream was telling me that I needed to pick a more appropriate weapon to address the kind of challenges that I would be faced with in life. I sometimes wonder whether we aren't all going to battle armed with violins.

What I told you about the carrying capacity is true to the best of my ability to tell it. You can find many books on the subject, such as "The Empty Ocean" by Richard Ellis and "Collapse" by Jared Diamond. This is the battle we will face in over the next 50 years. But the message has not made it to the mainstream yet, and the reason for that is that it is a very dissonant message. It does not harmonize with our current worldview, it doesn't feel good, and yet the data is undeniable. So the response is to ignore it. But I believe we must really listen to dissonance, and listen hard, because somewhere in there is a way to resolve the problem, but only if we are listening. The secret to victory in boxing and enlightenment in yoga is to move toward the pain, not away from it. Likewise, the secret to success in music and science is to move towards the dissonance. Students in any field can contribute to the solution to the population problem. You have to believe that somewhere in the space of all possible futures is a future that is

minimally painful and reaches at last a long sustained and harmonic existence.

That's basically what this piece is about. Listen for the dissonance and its resolution. And that's it for the long introduction. Let's move on to the music.

You may have noticed that I did in the end choose a more appropriate weapon than a violin to go to battle with. I chose a viola.

[Followed by a 5 minute viola peice called "Art & Science"]