

**Artificial Intelligence and Musical Creativity:
Computing Beethoven's Tenth**

by

Matthew T. Hutson

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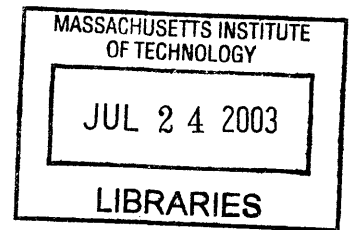
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ABSTRACT

I explore creativity and ask whether computers are capable now, or in the future, of producing creative works. I focus on creativity in musical composition, and within this field I focus on the work of David Cope at UC Santa Cruz. He has developed a program, Experiments in Musical Intelligence (EMI) that can take the works of a given composer and produce new works in that style.

I look at various definitions of creativity and methods people have used to study creativity over the years. Then I go to some composers and see what they think of EMI's music. I take a look at the algorithms under EMI's hood, and look at other algorithms people have used to compose music. I review other fields where algorithms have been applied to creativity, and see if any of these algorithms resemble how humans actually think. Then I test the definition of creativity as unconscious calculation and talk to the chess AI experts behind Deep Blue and other chess software.

Finally, I discuss the importance of embodied cognition and what it means to understand something. I conclude that computers cannot be creative because they don't understand the meaning in what they do.

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Biographical Note

Matthew Hutson received his Sc.B. in Cognitive Neuroscience from Brown University in 2000. He spent two years as Lab Coordinator in MIT's Learning and Memory Laboratory, conducting behavioral and fMRI neuroimaging studies on human volunteers. In 2003 he received his M.S. in Science Writing from MIT.

“If there hadn’t been a crowd around I’m sure he would have punched me. He was about six foot six so he would have done a real good job. Weighed about 100 pounds more than I did too...”

This is David Cope, the designer of a computer program that composes music, describing one German musicologist’s reaction to his program’s very human output. Cope says that among the negative reactions drawn by EMI, his program, this incident at a musicologist conference in Germany was merely the first instance of several threats of physical violence.

“He stuck his finger in my face and pushed me. And said music is dead. And I killed it. He considered that my program was the death of music, because music was magic in his mind. And I was the one explaining the magic. I was explaining how the sword didn’t really go through the lady. It was all an illusion, and he didn’t want to hear that.”

Cope has since stopped playing The Game, a practice where he would play pieces composed by EMI along with pieces composed by actual composers, like Bach and Chopin, and then ask people to guess which was which. The problem is that The Game is too hard. No formal studies have taken place, but most nonmusicians are right about 50% of the time, and most musicians score only marginally better.

EMI offends two strong sensibilities in us: that expressive music is the result of emotional intent, and that creativity is too mysterious to simulate. What does it mean if a computer, with no emotions at all, and simply a list of rules to direct it, generates beautiful music that surprises us and moves us? Is the human soul no different, fundamentally, than a calculator? Is emotion an illusion? Is there an algorithm for creativity?

I don’t read music or play any traditional instruments, but I sometimes wonder if a computer could match my contributions to the musical world: I DJ. The particular types of music I usually play are subsets of electronic music: house music and jungle (aka drum’n’base.) House and jungle DJ’s usually use two turntables with a sound mixer in between. I adjust the speeds of the turntables so that the records match tempo, and use the mixer’s cross-fader to switch from one record to the next, thus producing one continuous

beat that travels throughout a “set.” Towards the end of one record, I switch to the next one. In a sense, I stitch the songs together into one cohesive story.

Some see little room for creativity in DJ’ing—after all, I’m just playing other people’s records—but there are a few areas for expression. There’s record selection, and there’s how you order them. Picking chapters from your favorite books and meshing them together into a complete novel is not a trivial task. There are also many ways to mix them. I can simply slide the cross-fader slowly from one side to the other; I can flick the input switches, rapidly cutting from one record to the other; I can fiddle with bass, midrange, and treble knobs to overlap different layers of the records; or I can do a complex mixture of the above, picking particular elements in different records and playing them off each other. If someone asked me to program my decisions and movements into a computer, I would be at a loss. If someone told me his computer could exactly replicate my style, I would raise an eyebrow.

In exploring these issues we’ll first look at various definitions of creativity and methods people have used to study it over the years. Then we’ll go to some composers and see what they think of EMI’s music. We’ll take a look under EMI’s hood and see how she works, and look at other algorithms people have used to compose music. We’ll look at other fields where algorithms have been applied to creativity, and see if any of these algorithms resemble how humans actually think. Finally we’ll compare creativity to calculation and see if they can shed any light on each other.

A Few Preliminary Ideas about Creativity

The literature on creativity is rich and varied, covering every possible domain. I don’t have the room here to give a full history on the study of creativity and will only brush upon a few topics.

People have approached definitions of creativity from many perspectives. Creativity is closely linked to inspiration, which comes from the Greek word for breath, as in the breath of God. As Beethoven once said, “When I composed that passage, I was conscious of being inspired by God Almighty. Do you think I can consider your puny little fiddle when He speaks to me?” The notion of divine inspiration still reigns popular

today, sometimes implicitly, but we've now tackled the topic with the likes of psychology and neuroscience.

Without implicating spiritual influence, one can still ask: does creative thought differ somehow from rational thought? Over the years people have debated the relationship between creativity and the more general concept of intelligence. In the 1950's the psychologist J.P. Guilford described creativity as a subset of intelligence. His Structure of Intelligence model of human intellectual capacity listed 120 factors, including one directly relevant to creativity: *divergent production*, or what we now call *thinking outside the box*. Guilford devised several creativity tests, many still in use today. His most famous divergent production test is sometimes called Brick Uses; the task is to list as many unusual uses for a brick as possible. More generally, he theorized that creativity depends upon four skills: the ability to produce many ideas (fluency), the ability to alter one's strategies or to consider different ideas simultaneously (flexibility), the ability to produce novel ideas (originality), and the ability to recognize important problems.

By all accounts, a creative act or idea requires two qualities: novelty and quality. At a minimum, it must be different from what has come before, and it must be worth something. (Of course, these "simple" requirements really are not so simple, but we need to start somewhere.)

What has become more apparent over the years is the illusion of the apparent spontaneity in that "eureka!" moment. A lot of work happens behind the scenes before an idea presents itself to consciousness. Many theorists have broken down creativity from an event into a process, describing a multistage development. The first to outline such a process was the British psychologist Graham Wallas, who, in his 1926 book, *The Art of Thought*, named four phases of creativity. This theory became the framework for many subsequent model of creativity. Popular versions have been published by mathematicians and creativity pundits Henri Poincaré and Jacques Hadamard.

The first stage is *Preparation*. You must usually have a good understanding of the background material before offering something new to a domain. Engineers must know their math and physics and must know the requirements of a solution before they can tackle a problem productively. Musicians must have some knowledge of notes and

harmonies, an instrument, a composing technique. The probability of picking up a pen or a guitar without prior training and generating something both new and worthwhile is quite slim.

The second stage, *Incubation*, is the one most often overlooked. Once you have become familiar with a domain, or a problem and previous attempts at solutions, the creative process continues beneath the surface even when conscious thoughts travel elsewhere. When an idea emerges in the third stage of the creative process, the moment of *Illumination*, it appears to come from nowhere, but your mind has in fact been working on the problem continuously up until that moment. Anecdotes of discoveries appearing in a dream or upon awakening illustrate this phenomenon; even when one sleeps, the solution process continues, often in an associative and nonrational way. The work leading up to Illumination may not be visible, but it's there.

By some accounts, the creative process ends there, but *Verification* of the creation must not be ignored. You might sit and generate thousands of haiku or dozens of inventions, but without separating the good ideas from the bad, the mass production as a whole might not qualify as creative. Finally, creative ideas rarely emerge in their final form. Thomas Edison once said, "Genius is one percent inspiration and 99 percent perspiration." Some models of creativity thus contain a fifth stage, *Elaboration*, where good ideas are explored and implemented. Once a good idea has been produced and recognized, it must usually be developed or edited. The details of a new invention, the harmonic component of a musical theme, the exact arrangement of steps in a mathematical proof. Seeds of ideas must be nurtured into full oaks.

A big assumption about creativity is that it flourishes in freedom. Break down the walls, get outside the box, and creative ideas will emerge. A few years ago three scientists published a report in *Science* (one of the world's top two science journals, along with *Nature*) that defies this assumption. Based upon work by psychologists, the researchers showed that applying rules to one particular creative task made people have better ideas. In fact, they showed that computers using these rules could have ideas rated higher creatively than humans not using the rules.

Dr. Jacob Goldenberg, Dr. David Mazursky, and Dr. Sorin Solomon of Hebrew University in Jerusalem analyzed award-winning advertisements and found that 75% of them adhered to one of six “creativity templates:” *pictorial analogy*, *extreme situation*, *consequences*, *competition*, *interactive*, and *dimensionality alternative*. They then used a computer programmed with the popular *replacement* version of the pictorial analogy template to come up with advertising ideas for different products. Compared to the ideas invented by a group of nonadvertisers who didn’t have any constraints, the computer’s ideas were consistently rated superior by a panel of judges. I’ll give you a couple of examples. To advertise the on-time performance of an airline, the computer suggested a cuckoo in the shape of a jumbo jet popping out of a cuckoo clock. The humans suggested a family running to an airplane while one of the parents screams, “Let’s run, I know this airline’s planes are always right on time.” To advertise the World Cup Tennis Tournament in Jerusalem, the computer suggested the image of a mosque’s dome with a tennis ball texture. The humans suggested the image of a tennis poster on one of Jerusalem’s ancient walls. It must be said, however, that another group of humans given the same template as the computer did the best.

You may not be particularly surprised to learn of the importance of structured thinking (algorithms) in creativity. Anyone who’s ever had writer’s or inventor’s block knows just how paralyzing a perfectly blank piece of paper can be. I think this is why I like DJ’ing; severely restricted by the supply of records in my crates, I never have to begin from scratch. In the same way, I always enjoyed making collages, and creative nonfiction appeals to me more than writing novels, as I’m forced to work with what has actually happened.

Margaret Boden of the University of Sussex has done a lot of research in computational models of creativity and is best known for her 1991 book, *The Creative Mind: Myths and Mechanisms*. She has described three general types of creativity. First, there is Combinational creativity, which involves using particular strategies to combine existing ideas in a given conceptual space. Such is the work of analogies and metaphors. Then there is Exploratory creativity, which involves modifying the strategies used for C-creativity. Finally there is Transformational creativity, in which the conceptual space itself is changed by altering or dropping one of its bounding constraints.

How might these forms of creativity look to a DJ? Juxtaposing interesting records within a genre might constitute C-creativity. Crossing genres (from techno to rock, say) might constitute E-creativity. (For those of you more versed in the subgenres of club music, imagine pulling off a crosscut from tech-step jungle to French hard house.) Inventing scratching, which hip-hop DJ's more frequently do would, I suppose, count as T-creativity. Transforming the turntable from a tool for playing prerecorded songs off records into an instrument in its own right for creating new songs, a practice now called "turntablism," in my mind represents Boden's third category of creativity. (You could, however, go further by, say, banging on the turntable with drumsticks.)

Classifying creativity, as Boden does, breaking down the process into stages, as Wallas and others have, and measuring creative output, as Guilford claims to do, do not fully answer our question of whether creativity is essentially the same as normal thought. Looking at how people describe their subjective experiences of the creative process suggests a distinct difference. Alan Lightman recently published an essay in *New Scientist* on this topic. Lightman, a Cal-Tech-trained-physicist-cum-novelist, perhaps best known for his delightfully imaginative novel *Einstein's Dreams*, has experienced creative moments in both fields, and calls it "one of the deepest and most beautiful of human experiences." The feeling of creative inspiration "isn't an essential part of life, but it's like having kids, or having sex," he tells me. "If you haven't experienced it, you can't imagine what it's like." In the article, Lightman describes staring at a set of equations for months (preparation) before waking from sleep (incubation) one morning to see the problem in a new light (illumination.) Sitting down to his equations, he feels weightless, egoless, a sensation he relates to planing over the water in a sailboat. After nine hours of work he regains his sense of self to find that his problem has been transformed into a solution. Regarding this experience as universal in creative work, Lightman cites an unpublished Einstein essay describing the discovery of one of the implications of relativity: Einstein called it the "happiest thought of my life."

The subjective side of inspiration may be universal, but is it required? Is it possible to enter the creative state and produce creative work without feeling any different?

Meeting Emmy

The first time I heard of David Cope's Experiments in Intelligent Music (EMI, or, more affectionately, Emmy) was in 1999. The cognitive scientist Douglas Hofstadter, author of *Gödel, Escher, Bach*, came to my university to give a lecture on the EMI phenomenon. When Hofstadter first learned of EMI, he visited Cope and soon went on a lecture tour presenting EMI and his interpretations of it. EMI does not just compose music; it can compose music in the style of any given artist. Feed it the scores of Beethoven's first nine symphonies, and it spits out his tenth. (One might argue that composing in an existing style is not creative, but that would mean that Beethoven's symphonies 2-9 weren't creative.) Hofstadter is an amateur composer and a passionate fan of Chopin, and the fact that EMI could produce Chopin-like pieces disturbed him. During the lecture he offered three sources of pessimism, which he later reprinted in *Virtual Music*, a 2001 book by Cope:

- “1. *Chopin* (for example) is a lot shallower than I had ever thought.
2. *Music* is a lot shallower than I had ever thought.
3. The *human soul/mind* is a lot shallower than I had ever thought.”

Faced with these options, one can perhaps empathize with the German musicologist's anger at David Cope.

But generating music with an algorithm is really nothing new. An algorithm is just a series of rules, usually followed in sequential steps; the algorithm for getting dressed might be: put on pants, put on shirt, put on socks, etc. Algorithmic music is much older than computers. In the 17th century, Giovanni Andrea Bontempi designed a wheel with numbers on it assigned to notes, and an accompanying set of rules for using the wheel to compose. The methods appeared in his 1660 work, *New Method of Composing Four Voices, by means of which one thoroughly ignorant of the art of music can begin to compose*. In 1787, Mozart devised a game called *Musikalisches Würfelspiel* that involved arranging precomposed sections of music into a minuet by rolling dice. Mozart and other great composers adhered to a set of rules restricting tonal music given

in 1725 by Johann Joseph Fux in his *The Study of Counterpoint*. Example rule: “From one perfect consonance to another perfect consonance one must proceed in contrary oblique motion.” (A consonance is a combination of notes that sound nice together; its opposite is dissonance. Motion refers to the relative motion between overlapping melodies or voices; oblique means that one voice goes up or down while the other remains steady, and contrary means they move in opposite directions.)

Any kind of constraint or formalism placed upon composition defines an algorithmic process. The haiku is an algorithm; you’re required to write the poem in three lines of five, seven, and five syllables, respectively, and the theme must refer at least indirectly to a season. Many constraints remain invisible, such as the very idea of 12-note tonal music. Constraints also result from the methods of notation, and from how certain instruments can be played. (A chord for a solo piano piece can’t contain three widely spaced notes, as humans usually have only two hands.) Cope argues that all composers are algorithmic and that it would be insulting to argue otherwise, because they’ve spent years learning the techniques and processes of their school and those musicians who came before them.

Playing the Game

I set up an appointment to interview Cope at UC Santa Cruz, where he teaches. But first, I visited some composers at MIT. The first person I talk to is Peter Child, an award-winning composer, music professor at MIT, and former chair of the department. I bring a CD with music composed by EMI.

As Child and I sit in his office and listen to the CD, he bows his head slightly and closes his eyes. Meanwhile I look around the room. There’s a Macintosh with a flat-panel display on his desk, and a musical keyboard nearby facing a window, which looks out onto the alleyways between MIT buildings. On the walls hang three posters for the Santa Fe Chamber Music Festival, each with a large flower on it. Child is bald except for a crown of hair around the back and sides, and sideburns. He wears corduroys, a sweater, and thin-rimmed glasses. He speaks with a British accent.

On the CD, Cope has put three sets of four tracks each. In each set, there are two human compositions and two EMI compositions in the style of the human composers. The first set has relatively obscure composers, the second has Bach, and the third has Chopin. Cope prints the correct track identifications in the back of one of his books. As we sit and listen, Child occasionally laughs (the kind of laugh that consists only of a short burst of air exhaled through the nose.)

We stop the CD after listening to each track. Child has no trouble with the first track, by César Cui. “If that were written by a computer I would be amazed and impressed.” He struggles with the second one, an EMI composition. “That piece is not very good. One of the things that to my mind makes it rather dull and repetitive is it’s so harmonically static. But at the same time there are sort of flashes of inspiration, or rather invention. You know, unexpected harmonic twists. And of course the change of meter and tempo that happens, which seems like a human touch.” In the end, he calls it human. “I’m probably going to say that they’re all human,” he laughs.

Child struggles with the Bachs. Referring to a virtual Bach: “There’s a fluidity to the voice leading that’s very good. In other words the contrapuntal quality of the part writing is good, the harmonic structure of the phrase is extremely well done, the modulation is well done. There’s a use of suspensions, which works really well. I mean it just really works well.” He makes these comments even after I’ve told him that according to the key in Cope’s book, this track is a fake. Then he reflects for a moment. “This is track eight? Let me see that book.”

Next I visit John Harbison, another member of MIT’s music faculty, an internationally known composer, and winner of a Pulitzer Prize for his cantata *The Flight Into Egypt*. He invites me to his home in Cambridge. As I approach through the small but elaborate garden in his fenced yard, I converge with his wife, Rosemary, who has just pulled into the driveway. She invites me in. Harbison is up the spiral staircase meeting with someone in his office, so Rosemary and I drink earl grey tea in their rustic kitchen and talk about their small dogs, Rudy and Scotty. Their kitchen sink is a handsome industrial-sized stone tub pulled from a decrepit building. Finally Harbison comes down with his guest, we exchange greetings and head upstairs.

Harbison is a tall man, with graying brown hair and a mustache. He wears glasses and a serious look. His office is large, with aged brick in the walls, an old wooden floor, wooden beams, Persian rugs, and two skylights. He's got a computer on his cluttered desk, plus a piano, a hi-fi, and racks and racks of tapes, CD's, records, scores, and books.

After listening to the first two computer pieces (tracks two and three out of the four), Harbison says "the second and third piece could be by real composers not working very well...In the second one the tempo changes were kind of awkward...The third piece sounded like kind of a Mahler idiom but without much control over sectional progress." He makes qualifications to his accounts of those two tracks, though. "There are pretty reputable composers who would use the same kind of not terribly expert doublings and part leadings I heard in two...The third piece really sounded like it was in a ramble, just kind of wandering around, [but] good composers do that sometimes."

Of the four Bach tracks, he struggles with the last two, one a Bach and one a fake. The Bach sounds right, except for one chord near the end that "bothers" him. In the fake, "There's nothing wrong with the harmony or phrase structure. There's something fishy about it but it's not impossible...The actual technical workmanship was quite accurate." In the end, he asks which is which without making a final call. "I've heard attempts at chorale harmonization, giving the computer a sort of technical vocabulary, and they weren't nearly that close to a Bach syntax." He says that several years ago he heard something that just sounded like a bad student. "This seems to be getting more help somehow."

Harbison gets the Chopins right without a problem. One of the fakes "had a bunch of fragments in it that were very authentic, but the syntax was screwed up. There were some little chunks that actually sounded like they might have come out of a Chopin piece, but then they didn't string together very well."

I ask Child and Harbison what kinds of clues they looked for to pick out the EMI compositions. Child sums it up best. He explains that he's not just looking for a "quality of competence" but also a "human quality." He would attribute a human quality to an inventiveness that cannot easily be summarized by rules. An example would be "if you hear a segment in one phrase that connects neatly with a segment in another phrase, but in which the melody let's say is being transferred to a different register or to a different

voice in a clever way and then brought back.” In describing creativity, words like “invention” and “cleverness” come up a lot. In some sense this does not help us at all, as they can be considered mere synonyms for creativity. Child pushes a little further into what he means by cleverness; the sort of cleverness he means, the kind that separates humans from machines, “involves sort of a coordination of features that are straightforward in terms of what we hear but quite complex in terms of how they work.” This statement could mean many things. I will interpret it this way: A clever musical invention will involve a complicated coordination of multiple elements on many levels, and yet in the end it will sound natural, it will still “flow.”

Under the Hood

The general principle guiding EMI’s composition is “recombinance.” EMI starts out with a database of source works (all the études of a given composer, say), which it disintegrates and stitches back together into new works. Several factors guide reassembly of the musical scraps on several levels.

EMI uses *voice-hooking*. If it places scrap B after scrap A, it makes sure that B begins with the notes that followed A in A’s original context. The dominant voice of the piece, usually the soprano melody, takes precedence, and if the bass and other voice can match too, so much the better. In this way the fragments hook together naturally.

Another strategy uses grammar. In language, rules of grammar dictate how words may be organized meaningfully into sentences. Cope has applied the methods of natural language processing in EMI using the SPEAC system, which he developed in 1985. Just as words may be identified as nouns or verbs or articles, notes/chords can be identified as Statements, Preparations, Extensions, Antecedents, and Consequents, based upon their tension. (Tension in this case is a well-defined quality based upon the overtones series and relative placement of the note/chord.) Just as one must place nouns and verbs in a particular order, one should obey certain rules in ordering SPEAC objects. For example, you cannot end a sentence whenever you want; it would sound off to say, “I placed a rock on top of.” Similarly, Cope tells me, “If a composer thought he ended a piece on a C

[consequent] but it actually ended on an A [antecedent], I think we'd consider it to be a really strange composition and not to be aesthetically pleasing to us."

Cope's use of musical grammar extends beyond the organization of musical "words" into musical "sentences." In language, organization applies on several size scales. Sentences can act as introductions, developments, or conclusions in a paragraph. A paragraph can act as an introduction or conclusion in a paper. (Remember those five-paragraph essays they taught you in high school?) EMI groups notes into clusters according to their label as a Preparation or Extension or whatever, and then gives each note cluster a label and organizes them into larger clusters. (The tension of a group of notes is calculated as the average tension of its individual notes.) EMI labels and organizes these larger clusters, and so on, all the way up the size scale.

Another particularly important aspect of musical style that EMI tries to capture is the use of what Cope calls signatures. These are groups of four to ten contiguous notes that appear in at least two works of a given composer, and often appear several times in a single piece. The exact instances of a signature may not match exactly, but they are audibly recognizable as similar. For example, Cope describes a particular Mozart signature as "an upward-leading scale passage followed by a downward leap which ultimately resolves by stepwise motion." This signature occurs many times in many forms throughout Mozart's work. Cope's software includes a pattern matcher that is just flexible enough to recognize a signature in different forms, but not so flexible that it finds false examples. To hone the pattern matcher's specificity, it has particular "controllers," or variables that Cope can modify for different artists or compositions. EMI then constructs variations of the signatures it finds and integrates them into the new pieces it composes. To those who are familiar with works in a given style, these signatures create a strong sense of recognition. Cope has implemented a number of other strategies as well.

Other Algorithms

Many other roads have been taken on the way to programming algorithmic music. One of the simplest methods, called *stochastic processing*, uses random or chaotic

mathematical functions. In one form, a number is entered into a function and the result is entered into the equation again, ad infinitum. (For example, $x_{\text{next}} = ax(1-x)$. For certain values of a and starting values of x , x will jump around unpredictably.) Long sequences of x -values produced from iterating mathematical functions have most familiarly been plotted onto a graph and color-coded, generating the psychedelic fractal posters covering many acres of college student dorm room wall space, but they can also be assigned notes and played sequentially. I've heard some of this stuff, and it's interesting. There's enough repetition on various levels that it sounds cohesive, and enough variety that it doesn't sound purely mechanical. I suspect that beyond these surface-level semblances, the output verges sharply away from any music-theoretical rules. Other types of mathematical or geometric patterns, or even natural phenomena, have been translated into musical scores, with their results all over the map. But no one has yet found the likes of Mozart in pi.

Another broad approach is knowledge-based systems (KBS), also called rule-based systems. The programmer uses her knowledge of music composition to program rules that guide the behavior of the program. In 1980 the IBM computer scientist Kemal Ebcioglu designed a system named CHORAL that uses 270 rules to compose the harmonization of chorales in the style of Bach. For example: "If the melody skips, and if the notes within the scope of this skip have not already been sounded, then they must eventually be sounded before the end of the melody." In 1989 William Schottstaedt designed a program based upon the rules for counterpoint set out in 1725 by Fux, whom I mentioned earlier. Schottstaedt assigned point values to each rule, depending on how important they are, and his program tries to collect the fewest points by breaking the fewest rules. If the program collects too many points while composing, it will back up and follow a different path. One problem with knowledge-based systems is that an expert has to program all of the rules, plus all of the exceptions to all of the rules.

The use of grammars, such as Cope's SPEAC system, has also been popular. One weakness is that the use of hierarchical structure contrasts the strong improvisational element of human works.

Genetic Algorithms (GA's) have also been used extensively. Similar to evolution, many solutions to a problem are generated randomly. Then their quality is

rated either interactively by a user or according to a programmed set of standards. The most “fit” solutions combine or are tweaked slightly, while the weaker ones are dismissed or tweaked heavily, and this next “generation” is then rated, and so on. Unfortunately, GA’s are hit-or-miss, so if the search space is large (such as the field of all possible musical works), they will usually do a lot of missing. Evolution, whether real or virtual, is a slow process.

In 1998 George Papadopoulos and Geraint Wiggins of the University of Edinburgh designed a system for generating solo jazz melodies using GA’s. For their system, a “chromosome” is a small chunk of music. The changes used to “mutate” and “cross” the chromosomes include *permute*, *swap*, and *transpose*. The “fitness function” used to judge the quality of the output uses several objective rules similar to those described by Fux and Schottstaedt. They culled these rules from statistical analyses of jazz solos, books and articles describing the mental processes of improvisation, and “some intuitive ideas.” They judge, however, that the program “lacks intention,” and “sheds little or no light on the working of the compositional mind.” In general, they claim that GA’s do not develop large-scale musical structure.

Then there are learning systems. A composer does not work in a vacuum, and most musicians will say that listening closely to music is a prerequisite for composing well. EMI can also be considered a learning system, as it extracts rules and patterns from other works. The most popular variety of learning systems is artificial neural networks (ANN’s), which can take a given set of examples and generalize from them, presenting similar output. Neural nets play a special role in AI, and I will come back to them later.

The way Cope explains EMI to me, it doesn’t fit neatly into any of these strategies. Cope and I are sitting in his office in Santa Cruz on a rainy Monday afternoon in December. Books and boxes clutter his oddly dark office. On his desk sits a Macintosh—EMI’s primary embodiment—and by the door is the special MIDI-controlled player piano that produced much of the work on Cope’s CD’s. Cope is tall, slender, has a closely cropped beard, and eager, deepset eyes. He’s a young 62. In speaking, he occasionally descends into hushed, dramatic tones.

One of its tools is called an “association net,” which Cope says is a hybrid between a neural net and a rule-based system. It uses “inductive association,” which is “the ability to associate things that do not immediately seem associatable.” He says this is how humans compose and how we work creatively. Cope compares it to how he lays awake at night comparing dissimilar ideas out of boredom and insomnia. “That’s how I created EMI, that’s how I do a lot of my work, by shoving things, in particular fields of study that I have no business being in or looking at, together to see what happens.” Usually nothing happens, but once in a while he strikes gold. I asked him if the association net was the best strategy for AI music composition, perhaps an obvious question. “Yeah, or I wouldn’t be doing it. I don’t want to sound arrogant and say mine is better than they are, but for me, yes, without question.”

Other Creative Activities Subjected to Algorithms

Music is not the only field in which people have tackled creativity with algorithms. In the 1980’s psychologist Herbert Simon and collaborators from Carnegie Mellon University began generating a series of programs for scientific discovery, named after scientists who had made significant scientific discoveries: BACON, BLACK, GLAUBER, STAHL, and DALTON. Given a set of data on chemical or physical properties, and a set of heuristics (rules of thumb or general guidelines) for finding patterns in the data, the programs look to establish principles in the style of Boyle’s law or Kepler’s law. For example, GLAUBER “discovered” that every salt comes from a reaction between an alkali and an acid. One of the more successful programs was DENDRAL, which would predict properties of a molecule by looking at a record of the fragments into which it could be broken. This is a classic knowledge-based or rule-based system—it depended completely on a set of chemical laws given to it by the programmers—but its successor, meta-DENDRAL, could actually find new strategies for searching through the data. Here is a jump from Boden’s combinational creativity to explorational creativity. Meta-DENDRAL contributed to discoveries that were not previously known by its users, and was even given something Harold Cohen would never have given it: a byline in a

published scientific paper. For the most part, however, these programs have had more use in history of science than current cutting-edge research

In the late 1970's, computer scientist Doug Lenat developed a program he named AM, Automated Mathematician. Lenat fed the program 115 rules of set theory and 243 heuristics for combining, selecting, and expanding upon the rules. AM rediscovered lots of known material (such as prime numbers as an "interesting" set of numbers.) Lenat then developed EURISKO, a version of AM with metaheuristics, or heuristics for transforming its own heuristics. EURISKO discovered a design for a computer chip that won a patent, but the program had few applications because its domain was so specific.

Kim Binsted, a computer scientist at Sony in Tokyo, developed a program she named JAPE (Joke Analysis and Production Engine) for writing puns. Based upon reactions from 120 children, judged successes include "What do you call a breakfast food murderer? A cereal killer," and failures include "What do you get when you cross a person and a thing? A person thing." (When Binsted retold the latter pun at a conference with co-panelists Marvin Minsky, Douglas Hofstadter, and Steve Martin, Martin immediately quipped, "I think *many* of us have *dated* those people.")

Humor is surprisingly rule-based. In a recent issue of the magazine *Maxim*, the "How To" section includes a lesson on how to "crack wise," in consultation with the comic relic Rodney Dangerfield. Here's an example, offered by Dangerfield: "I went to see my doctor, Dr. Vinnie Boombatz. I told him, 'Doc, I broke my arm in two places.' He told me to keep out of those places." Here's the algorithm that's offered: "Familiar situation + funny-sounding moniker + misdirection that flips audience expectations = hilarity." Makes sense.

By far the most well known application of AI to the visual arts is a program designed by Harold Cohen. Cohen studied painting in London and in 1968 joined the Visual Arts Department of the Slade School of Fine Arts. His work was displayed internationally, and he had regular exhibitions in London and New York. In 1971 he came to the Artificial Intelligence Laboratory at Stanford for two years, and then began work at UC San Diego on his program, AARON. Originally its syntax and vocabulary were slim. It produced interesting but abstract collections of lines and objects. As Cohen extended the algorithms, he instructed AARON on how to draw trees and human figures.

AARON went through a phase of jungle scenes, then acrobats balancing on balls, and now more expressive portraits. It currently incorporates three spatial dimensions into its models of humans, and colors the pictures itself. AARON's works have been put on display around the world, including at the Tate Modern in London. Several years ago Cohen went on tour with Cope, discussing their respective programs. Cohen argues, however, that AARON is not creative, and he signs his own name at the bottom of AARON's works.

According to Cohen, there are at least four criteria for creativity. First, you must have *knowledge*. You cannot create if you have nothing to work with. Second, a creative performance must display *emergence*; something unexpected must come from the performance. The process must be complex enough so that you are surprised by what you produce. Third, to be creative, you must have *awareness* of what has emerged. Emergence of a new idea or property means nothing if you have no awareness of it. (He notes that awareness does not always mean conscious awareness; an artist will sometimes internalize observations without being conscious of them.) Finally, and most importantly, you must be able to *change* your behavior based upon what you learn. You must have a "capacity for continuous self-modification." These four criteria can be compared to the five stages of creativity suggested by Wallas and others. The collection of *knowledge* forms an essential element of *preparation*. *Emergence* designates the transition from *incubation* to *illumination*. *Awareness* suggests the combination of *illumination* and *verification*. And *continuous self-modulation* requires some amount of *elaboration*.

AARON has no problem with the first of Cohen's criteria; Cohen has already filled it with knowledge about drawing, coloring, paint mixing, and the structure of the human body. AARON can also display emergence; Cohen cannot predict what AARON will do with the many rules he has given the program. AARON, however, makes no note of the new things that emerge. (Technically, it could, but only if Cohen programmed it to look for these emergent properties, which would make them not so surprising. He calls this a Catch-22.) And without awareness for emergent properties, AARON has no hope of changing its behavior based upon experience. When AARON gains a new capability or steps up a level in its performance, this is always due to a programming intervention

by Cohen. (Moreover, AARON does not store its works in memory after painting them, and cannot even remember a painting once it is finished.)

In the end, AARON cannot reflect on its past work or develop its skills on its own. Cohen writes that, “as the author of a program capable of generating a quarter-million original, museum quality images every year into perpetuity, I will award myself an A for effort, but no cigar. I don't regard AARON as being creative; and I won't, until I see the program doing things it couldn't have done as a direct result of what I had put into it.”

Neural Networks

None of the systems we've looked at really seems to provide a satisfying model for human creativity. Sure, we use rules sometimes, but usually only as a guideline to narrow our search space. Much of human creativity seems to come from the fuzzy realms constrained within the rules. For example, Dangerfield's algorithm for cracking wise requires thinking of a goofy name, but it says nothing about how to do so, or about how to misdirect the audience's expectations. Similarly, the creativity templates for generating advertisements were fairly successful when used by the computer, but they were even more successful when fleshed out by fuzzy human thinking.

Humans learn from examples and mistakes, not just by extracting abstract rules from them. And when ideas come to us in dreams, they emerge from a sea of seemingly random activity. Surprisingly, many of these aspects of human thought are reproduced in one area of AI: artificial neural networks (ANN's.)

ANN's, as they are described in cognitive science, computer science, and engineering, are not meant to reproduce exactly the messy networks of neurons inside the human head. Also labeled “connectionist models,” artificial neural networks derive their name from the real thing because they share several characteristics, including parallel processing, distributed memory, and emergent behavior, as well as the superficial architecture of “neurons” networked together.

The brain functions as a collection of individual neurons, each neuron acting as a computational device receiving input from hundreds or thousands of other neurons and

then sending output to hundreds or thousands of neurons. Several factors affect the nature and strength of the messages traveling between individual neurons. Over time, the physical structure and chemical behavior of these neurons can evolve, based upon their interactions with other neurons. Learning and memory take their effect through the permanent modification of neurons and the architecture of networks of neurons. No single neuron holds executive control over the others; rather overall behavior emerges from the collective patterns of their individual interactions.

ANN's share this fundamental design. Abstractly, ANN's hold many individual units, or nodes, which take input(s) and send output(s). Connections link these nodes, and each connection holds a certain "weight," usually a number between -1 and 1 , depending on how strongly one node affects another and whether the effect is excitatory or inhibitory. Whereas modern computers act through a series of serial processes one after the other (using sets of rules with logical functions like AND and OR and NOT, or IF and THEN), many neurons can fire at the same time, and information also travels through many connections in a neural net simultaneously.

The relative simplicity of the individual nodes and connections implies that memory is distributed amongst the entire network; because each node or link basically holds a single number, they must cooperate to hold more complex pieces of information. (Actually, real neurons are quite complex, and inter-neural synaptic connections involve many subtle factors, but a single neuron is not complex enough to store, say, the concept of a car.) Neural networks "learn" through the gradual modification of the weights controlling these connections. Input to the network may consist of a set of values given to a set of nodes, each sharing a piece of the input. The nodes modify and output these messages, and once the pieces of information pass through the network, output neurons spit out individual outputs, and these individual outputs will collectively encode an output associated with the network's original input. Thus the memory inside the network directing this output depends subtly upon each of the individual nodes and connection weights. This contrasts the idea of a "grandma cell" model of mental representation, where a single neuron may discretely encode the concept of one's grandmother.

Distributed memory leads to emergence: in a complex system (such as a neural net), one can understand the behavior of each element completely yet have no idea what

the behavior of the overall system will be. With no single element holding executive control over all the others, “intelligent” behavior emerges from the system, usually in an unpredictable manner. The behavior of these association engines resembles the human creative process.

Another aspect of neural nets must be stressed; they can find patterns where even the programmer sees none. In many AI systems, you have to extract patterns and rules and explicitly program them into the machine. For some situations this procedure is not practical. If you want a program that can recognize pictures of familiar faces, you wouldn’t want to have to describe the faces using rules. That’s not how we think. A collection of subtle and correlated features combine and the recognition emerges: That’s Mom! This is how neural nets work. You can simply feed names and faces into the machine, and it will find the patterns for itself.

Although ANN’s can show sophisticated, human-like behavior, they do not approach the complexity of the brain. While a typical ANN may have several or several dozen simple nodes, the brain has about 100 billion complex neurons. While each artificial node may have simple connections to several other nodes, each real neuron connects to ten thousand others via intricate synapses. Many people call the human brain the most complicated known object in the universe. We will never be able to replicate every atom of it using ones and zeroes inside a computer.

Surfing the web looking for creative applications of neural nets, I came across the website for Imagine Engines, a one-man business operated by an engineer named Stephen Thaler. Thaler has designed and patented the Creativity Engine neural network paradigm. He’s purportedly designed the system to resemble human consciousness; there is a stream-of-thought network producing ideas that get filtered by a critic network. He gives a lot of credit to what he calls the “virtual input effect” for generating new responses and not simply ones it has learned. Its trick is that “noise” (random fluctuations in connection weights) is added to the system, the equivalent of internal imagery in humans with their eyes closed. This variation can produce new solutions that are not simply combinations of previously viewed examples. Too little noise in a car design process and you get boring cars, too much and you get “Picasso cars.” Once variations are produced, the filtering layer tuned to his examples of good and bad designs selects the

most promising variations. Thaler's also used it for musical composition. He entered several 10-note chunks from popular songs, and it gave him 11,000 new themes. He went and got them all copyrighted. "That makes me technically the most prolific songwriter of all time." (Almost. Cope estimates that EMI's spit out about 15,000 complete works over the last 20 years.)

Thaler has had some success with industrial applications. By offering a Creativity Engine an assortment of ultrahard materials, it suggested new molecules that had not been tried before. But one is naturally skeptical about Thaler's more grandiose claims about his Engine's potential. In an edition of *Nanomagazine* from 2002, Thaler says, "after showing the net human-originated literature and randomly tickling the net's synapses, it produced new and meaningful literature." On his website he lists things that the CM can do now, such as "generate characters, plots, and themes," and things it will "inevitably" do in the future, such as "autonomously generate full scripts and plays."

Human Creativity

The music EMI composes sounds human, but does it compose the way a human composes? Cope argues that it does. Consider signatures, the SPEAC system, and recombancy. I can imagine a signature sticking in someone's head and emerging occasionally in various forms. The SPEAC grammar system, however, seems a bit formal for a human to use. In composing a piece, do musicians really calculate the tensions of chords, label them Statements or Antecedents, and structure them into a hierarchy? "I think you do it intuitively," Cope tells me. Without knowing any explicit music syntax or having musical training, people can agree on a label. Or if you play a melody and leave off the last note, anyone will know that you didn't end with a Consequent. What about recombancy? People don't chop up other works, their own or anyone else's, and rearrange them, do they? As Hofstadter wrote me in an email, "To be sure, I think EMI has produced some remarkable pieces of music (as well as some incredibly pitiful ones), but I don't think that it constitutes in any sense a model of human creativity. In other words, I don't believe that David Cope is right in claiming that human

composition takes place in somewhat the way that EMI puts pieces together -- i.e., by 'recombination' of older material. That seems to me to be very wrong."

Sitting in Cope's office in Santa Cruz, I relay Hofstadter's argument about recombination. Cope's response?

"I disagree completely. Doug and I disagree on a lot of things. I mean I love Doug, he's the brightest man I know in the world, but there's a number of things we don't agree on." In chapter four of Cope's book-in-progress, he looks at about 50 music phrases from classical music history and shows that they were not original, "how they were piecemeal or recombinancy from other pieces of music." Cope also wrote a piece of software called Sorcerer, a sort of inverse of EMI. With EMI you supply a database of music and it gives you a new piece. You give Sorcerer a database and a target piece, and it will point out the sources in the database of anything the target piece has taken from it.

"It's amazing what it's found. Some of the most impressively supposedly original pieces of music can be easily proven to be parts of various pieces that composer heard, and in some cases explicitly. When *The Right of Spring* hit the stage in Paris the first time it brought a riot it was so different and unusual. It starts with a high bassoon part, which for many years was considered to be *incredibly* original. [Here Cope sings it for me.] It's a Lithuanian folk song. When it was pointed out to Stravinsky that not only was it a Lithuanian folk song, but it was one of the songs in the book that his teacher Nikolay Rimsky-Korsakov gave him, Stravinsky said 'ok ok ok, but it's the only one.'" After more exploration, it was discovered that only a few measures later Stravinsky had repeated another folksong from the same songbook.

"Doug is very romantic when it comes to classical music, and he likes to think of these composers as being original. I like to think of them as being good, but I don't think of them as being original at all. They belong to this vast context, and in fact to me if music has a meaning, it's in allusions to other pieces."

I asked Peter Child and John Harbison to give me some insight into their own compositional processes. Child says that he usually starts with some specific germinal idea. It could be a "music figure or gesture or motif." It could be a harmony, a rhythm.

“Nine times out of ten it’s something specific, it’s all of those things together, a concrete section of music that strikes me as being suggestive or pregnant with possibility.” The idea might be improvised or imagined or even a product of analytic cogitation.

“Subsequent to the idea is a conception of how the idea is placed or literally com-posed.” I ask him if invention requires breaking rules, and how he justifies breaking a rule.

“Composers don’t think of themselves as breaking rules. They think of themselves as inventing rules. I bet that’s true of almost all composers. ... When we’re really writing at our peak and really trying to do something original and fresh and exceptional then I would say all concern for rules goes completely into the background, and we have to kind of jump in the deep end and look for ways to make the connection... The norm for me at the time of composing is that the ideas come spontaneously and in that sense I don’t know where they came from.”

Child and Harbison both point out the importance of improvisation. Harbison tells me, “Improvisation is the testing of certain kinds of ideas. I think it plays a very very important role.” Later: “I get materials and try to find out where they will go. I try to recognize what they might be.”

Because human composers have difficulty understanding how and why they get their ideas, it’s tough to say whether EMI actually resembles the human compositional process. So I decided to visit Jeanne Bamberger, a professor of music theory and music cognition at MIT and author of the recent book *Developing Musical Intuitions*.

Bamberger is familiar with EMI: “I think there probably are composers who compose very much like David Cope’s program. But they aren’t usually the composers who one is moved by or astounded by or impressed with.”

In the 80’s, Bamberger developed music logo, a simple programming language students could use to write compositional procedures. They would analyze Vivaldi and try to encode the melodic and rhythmic structures in sets of logo procedures. One student claimed that he had developed “Vivaldi’s intuitive toolkit.” Bamberger describes some of the procedures that Vivaldi used and demonstrates them on a piano. She plays a note and then a “fill-down,” playing all of the notes in a certain region under that note. She

then repeats this pattern higher and then lower on the keyboard. I ask her if Vivaldi was easy to analyze.

“Yes, because it’s full of these templates. However, there too if you compare some of Vivaldi’s contemporaries with him you discover if you listen carefully and know what you’re listening for that Vivaldi is doing much more than what I just described. The way in which he juxtaposes these pattern areas, the kinds of things that are going on in the juxtaposition is where all the genius comes from. And lesser composers don’t have it.”

In the library I come across a volume titled *Understanding Music with AI*. The introduction consisted of a 1990 interview between Marvin Minsky, the father of modern AI, and Otto Laske, the father of a field he calls cognitive musicology. A computer scientist and composer, Laske now lives outside Boston, so I contact him and set up an interview. The Starbucks where we meet is too crowded so he drives me to his home in Medford. While there, I notice two framed drawings on the wall of his studio that resemble AARON’s early work. The pictures are signed “Harold Cohen 1980.” Though he has never programmed an algorithmic compositional system, Laske uses algorithms for his own work. He doesn’t see the computer moving beyond the role of a sidekick, though.

“What I find intellectually most attractive, most fascinating is the way that a composer works on the basis of reflecting upon previously done work. In other words, there’s a metalevel to composition where we do not just compose by going on from bar to bar or minute to minute or second to second but reflecting about what we have done, either just done or done some time ago, all of that is folded into the process as it continues.” Despite the importance of self-awareness Laske reiterates Cohen’s criticism of algorithmic creativity. “We don’t have good ways of computationally simulating reflection. And reflection, and thus history, of a process is a very very crucial part of any expert composing.”

I suppose to a certain extent we could simulate reflection computationally. If a computer stores previous “experiences” (compositions) in its memory we can program it to sort through this information and draw out new patterns, which is essentially what EMI does, but this type of reflection is superficial. The computer cannot extract any patterns

we have not programmed it to look for. Humans have the flexibility of picking up new ways to see the world as we progress through life. Not only do we think about our experiences, we also think about how we think about our experiences. (We also think about how we think about how we think about...etc. I've heard consciousness defined as a feedback loop.) I take Laske's "reflection" to mean at least a second-order analysis, in which one's pattern-searching techniques are themselves analyzed as the composer progresses through his work. Perhaps this is Boden's "transformational creativity," in which a conceptual space is not simply explored but is actually transformed by altering its defining borders. One can argue what counts as transformation, a conceptual space, a border, etc. but it sounds like Laske is saying that T-creativity requires reflection, and this sets it outside the capabilities of an algorithm.

Composers aren't alone, I find, in their blindness to the intricacies of the creative process. In his *New Scientist* article, Lightman recounts that during his breakthrough he was able to rethink the problem, but he's not sure exactly how. "Like a timid forest animal, [creativity] quickly darts behind a tree when you stare at it."

Calculation

Despite Child's emphasis on spontaneity in the composition process, he says that when he reflects back on his compositional decisions he can always justify them. "When the piece is done we might go back and say 'oh yes I see now that what I was really doing here was, you know I was connecting that A flat in measure 33 on the right hand with this A flat in measure 56 on the left hand, through a pattern of intervals, you know, every other measure.'" Evidently, in the heat of the moment, composers don't think they're following rules, but they may look back and find that they have.

Child's comments, together with Cope's earlier comments, raise the question: Is creativity just another form of calculation, one that happens beneath the surface? I remember a metaphor about a chain where the ends are visible, but the connecting links are submerged under water. I tell Cope about how Child often recognizes logic of inspirations afterwards. But, I argue, if you can find a logical explanation for something

that previously was considered inspiration, I think in most people's minds it would reduce the amount of creativity in that achievement.

In fact, Cope tells me that when he tries to teach certain aspects of music theory to his students, nearly all of them get "very angry." "We're demystifying something that they've always wanted to stay a mystery and something they thought couldn't be that simple and straightforward. And it takes a while to convince them that in the end they'll be rewarded by this knowledge, that they'll actually get more out of the music by having that added information." He notes the rarity of someone not scared to understand the rational nature of creative composition. "People want to get the muse to excite them and to write this thing intuitively down but they don't want to know that there was some logical rationale behind it. Peter Child apparently does and that's great for him. That's good. I respect him for that."

For all of the magic one may feel in the creative process, its product sometimes inspires a feeling one may call paradoxical. Lightman writes that in his most creative moments he experiences "a stunning surprise joined with a feeling of rightness and inevitability." His comment suggests that the particular solution to a problem may be unexpected, but that in retrospect it should have been expected. Though novel, it fits tightly into an existing framework of rules or values.

I asked Child if, once he finds the logical source for an inspiration, he thinks he could write a rule for it and put it into a computer.

He first notes the multiple structures that need to be balanced in music: rhythm, phrasing, harmony, counterpoint. Each is complex on its own, and their interactions make the problem exponentially harder. "That complexity of interrelationship among different kinds of structures is what I think is, A, very hard to articulate in words and therefore, B, would be very hard to program, and I would venture to say probably impossible to program." But the problem is not simply one of calculation. "The human cognitive capacity, at least when it takes the form of musical genius, is capable of producing these immensely complex structures that are both engaging intellectually and satisfying in other ways too, in some human way."

Harbison feels similarly. Suppose a computer is composing a Bach fugue and it comes to a point where it must decide between many harmonic and melodic choices.

“The only good ones to be found are to be found essentially experientially, that is, weighed by some very experienced ear.” Can you simulate experience with statistics? “The choice based on statistics is almost always a bad one.” So when you’re composing and you come to a juncture, knowing which way to go is based on feeling and intuition? Is it ever possible to explain intuition afterwards using logic? “You do have certain procedures which appear logical. But often that logic is there just to reduce the possibilities from the infinite discipline you can manage... Within that smaller group of possibilities, then your ears are trying to work out which is the best one.”

Chess

Is what we call creativity just the complexity of an enormously complex system? Child suggests the need for a “human” quality on top of sophisticated calculation, but that suggestion doesn’t explain much. The issue of creativity and calculation takes an interesting turn in chess. In 1996, the world champion Garry Kasparov defeated IBM’s Deep Blue, six games to two. The next year, Deep Blue beat Kasparov 3.5-2.5. In 2002 the world champion (but rated number two), Vladimir Kramnik, tied the new best computer program, Deep Fritz, four games to four. In February of this year, Kasparov played today’s strongest program, Deep Junior, and split the six games.

One might question whether chess really counts as a creative activity. The patterns of movements are logically constructed. Strategies can be defended. But then maybe the same goes for music. Musical notation can be translated into numbers, so composition is really just organizing patterns of numbers.

I asked one of the designers of Deep Blue, IBM’s Murray Campbell, for his opinion.

“There is no doubt in my mind that chess is an art, although it does of course require a certain level of expertise to appreciate. Some chess games have moves that are described as ‘brilliant’ or ‘beautiful’. There are a number of factors which may contribute to a move being brilliant. For example, a brilliant move should be unexpected. People tend to think alike, and a move that violates these preconceptions is exciting in some sense.”

My interest in music composition reminds him that “composition” also exists in chess, in two flavors: *mate problems* and *endgame studies*. In each, you are given a chessboard with pieces specifically arranged and told to checkmate or draw in N moves. Chess compositions frequently appear next to crossword puzzles in the daily paper.

“For a problem to be considered good, it must have a unique solution that is in some way interesting or beautiful. There are competitions where the composers enter their problems, and prizes are awarded by judges based on how pleasing the problems are... Endgame studies can be remarkably beautiful, and the ‘ah hah’ when you figure it out is a wonderful feeling.”

Apparently a good problem must satisfy both one’s intellect and one’s emotions. “What makes a study beautiful? That is hard to say exactly. Sometimes it is a pleasing geometric pattern, sometimes an amusing move sequence, and sometimes the final position in the study completely violates our preconceptions of what is possible in chess.” He then says something that brings to mind Cohen’s criteria for creativity: *awareness* of the emergent property. “Computers can and have composed some chess problems, but have very limited ability to judge their beauty as far as I know.” It sounds like he’s saying that, while we may consider a chess problem composed by a computer beautiful, our judgment of beauty is apparently different from whatever factors the computer uses to evaluate the problem as “good.”

I contacted Mathias Feist, designer of Deep Fritz. He’s the guy you see sitting across from Kramnik in news photos of their match. He told me that he and his team interviewed a lot of grandmasters in developing their program. They would frequently ask the players how they might evaluate particular complex situations. “Of course, if there’s a position with just calculation, they can explain. But these are the positions computers excel at; we don’t need to ask there. Often the best players know what to do but can’t at all or can’t easily explain their reasons why to do it. This is where knowledge, intuition, creativity, and even mood comes into play... If chess were only about calculation, the contest between humans and computers would have been decided long ago.” The fact that the best computers and the best humans are about equal does not mean that they use similar methods. I’d consider this close competition a historical artifact, merely the crossing point in a wider chart of computer chess ability zooming up

past human chess ability. It's merely a coincidence that at the present moment the rationality of computers closely matches the irrationality of humans.

It appears undeniable that humans use intuition in chess. In the case of chess, however, intuition may not necessarily mean creativity. Intuition may be more similar to estimation, as in "My intuition tells me that this jar has more marbles in it than that jar." You can't calculate all of the possible combinations of moves, just as you can't count all the marbles in the jar from looking at it, so you estimate. Pattern recognition is part of intuition too; players can compare positions to positions they've seen before. To me, these methods don't necessarily qualify as creativity. Quantitative estimations can be accomplished with simple equations (as natural phenomena like tides are predicted by numerical models,) and pattern recognition is simply the objective comparison of current circumstances with those seen before, a task achieved by the simplest artificial neural network.

Monty Newborn, a computer science professor at McGill University, was chairman of the ACM Computer Chess Committee from 1981-1997 and organized the first Kasparov vs. Deep Blue match. I emailed him and told him I was struggling to differentiate intuition from (subconscious) calculation.

"Matt, I can sympathize with you. From all that I have gathered, intuition was one of the greatly overused words to justify why computers couldn't reach the level of the world's best chess players. Intuition, as you say and in my opinion too, is nothing more than unconscious calculation. When selecting a move in chess, the subconscious thought constitutes a major part of the calculation."

He says that in chess many moves are called creative simply because they are unexpected. Thus, he suggests "brilliant" as a replacement word for "creative." "In my opinion, the better chess players are better because they calculate better as a result of practice and a certain amount in 'natural talent.' Their neural system is somehow better adapted to carrying out calculations. Their moves look creative because they see more than the rest of us."

I got the same reaction from Jonathan Schaeffer, the designer of a very competitive chess program and the world champion checkers program.

“Creativity is a quality that we ascribe to some forms of intelligent behavior, but is something that we perceive, rather than can quantify... Most of chess/checkers creativity is, in my opinion, just the result of a player with a non-standard evaluation function. Because it is different, it gets different results. And if they happen to be good, then they are [called] creative. If they happen to be bad, then they are [called] a weak player :)”

The experts appear to be split, two to two, on whether chess involves creativity. I play chess very infrequently, but I think chess in fact goes beyond calculation. The rules constructing play and defining success may be “hard,” but your opponent’s mind is “soft.” In a game you must consider your opponent’s psychology, and your opponents’ psychology cannot be calculated, so there are no complete objective bases by which to guide your strategy. Even when you play a computer, you cannot calculate the psychologies of the humans who designed the program. This makes chess a very human game.

The more I considered estimation, the more I realized its fuzziness on another level. In estimation, we are reaching into the darkness beyond logic. In reaching, we must design our own tools, our own extensions. Designing the implements for blindly exploring this complex terrain requires ingenuity and invention. Most frequently, I think, it involves analogy. Analogy to games one has seen before, and analogy to real life. In forging our own heuristics for chess, or any other complex cognitive task, we draw upon our own experiences and our own knowledge of the world. There is no discrete chess module in your brain, and integrating the game of chess into the rest of your life requires making new connections.

The Meaning of Meaning

All of these descriptions of computation don’t seem to get to the heart of the mystery of creativity. I have a subjective sense that creativity is special, but proving this mathematically isn’t quite satisfying. Maybe it’s just a special kind of algorithm, but I feel like there’s *something else*, another dimension to consider. This feeling led me to the notion that for someone to be creative, he must *understand the meaning* of what he

creates. By this, I mean he must be able to make an analogy, or a connection, between the created thing and another thing outside its domain. (For example, you could never learn Chinese by reading an unillustrated Chinese dictionary. Every definition of a Chinese word just uses more Chinese words. To get a grounding, to begin to piece together meanings, you would need to start making connections between the words and something outside the domain of the dictionary, such as a picture.) This process gives you two different views of the thing, and in a sense allows you to lift it from its context and look at it from all angles in your head. It becomes three-dimensional.

So AARON can make nice paintings of people, but AARON just sees them as lines and colors; AARON does not see that these pictures represent anything other than what they are. In that sense, AARON does not understand the meaning in the paintings, so I don't consider it creative. EMI can compose music, but only by manipulating patterns of notes using statistics. The melodies do not appeal to EMI's emotions (as it has none.) When I asked Cope what was lacking in EMI's simulation of human composing, he said, "Well, there's one humongous difference. My program doesn't have eyes and ears. It still doesn't know that it's not doing cookbooks. It still doesn't know that it's not making spaghetti when it's composing a new composition."

But how much of real life must the computer understand? Must a thing have emotions to be creative? In the interview with Otto Laske, Marvin Minsky reports: "A machine that was really competent to listen to nineteenth century classical chamber music might well need some knowledge-understanding of human social affairs—about aggression and conciliation, sorrow and joy, and family, friendship and strangership...And clearly, an important aspect of 'understanding' music experience is the listener's experience of apprehensions, gratifications, suspense, tensions, anxieties, and reliefs—feelings very suggestive of pains and joys, insecurities and reassurances, dreads and reveries, and so forth."

In *Gödel, Escher, Bach*, Hofstadter prospected that "a 'program' which could produce music as [Chopin or Bach] did would have to wander around the world on its own, fighting its way through the maze of life and feeling every moment of it. It would have to understand the joy and loneliness of a chilly night wind, the longing for a cherished hand, the inaccessibility of a distant town, the heartbreak and regeneration after

a human death. It would have to have known resignation and world-weariness, grief and despair, determination and victory, piety and awe. In it would have had to commingle such opposites as hope and fear, anguish and jubilation, serenity and suspense. Part and parcel of it would have to be a sense of grace, humor, rhythm, a sense of the unexpected—and of course an exquisite awareness of the magic of fresh creation. Therein, and therein only, lie the sources of meaning in music.”

Cope doesn’t take understanding this far. He says that he loves the work of many composers from many different cultures and time periods. Even if he wanted to understand a composer as well as Hofstadter suggests is necessary, it would take a lifetime. “What’s coming to me is a bunch of translations of black dots on white paper. You mean to understand the way those black dots go together I got to understand what they had for dinner on Sunday? I mean, God [laughs] I don’t think so.” I relay Minsky’s opinion. “Minsky is stating exactly what Doug states, this very romanticized view, that somehow incorporated in that fugue of Bach’s is all his religion and his whatever. And what I think, truthfully, is that that has nothing to do with those black dots. We can never figure out what Bach’s relationship with God or with his religion or with his two wives or his 18 kids and so forth was. We haven’t a prayer.”

A musician named Bernard Greenberg has dedicated his career to the study of Bach—his life, his times, his work. Greenberg writes in a Cope volume that “the unique psychodynamics of the Jesus drama, particularly its characteristic notions of glorious, redemptive suffering and the man/god, have everything to do with the emotional rhetoric and concomitant effect of the flats and sharps and canons of Bach.” Greenberg is perhaps EMI’s top human competitor (and critic) when it comes to aping Bach works, and he feels that to understand Bach’s music fully one must also understand Bach’s theology. This, you might say, gives Greenberg an unfair advantage over the computer. I write to Greenberg and suggest that while feelings of tension and release come across in Bach’s music, I’m skeptical that the more complex messages, like the story of Jesus, are retained. He replies:

“The world view of traditional Christology permeates Bach’s output. We can ‘understand’ to different levels of understanding. We can understand ‘wow, listen to that cool mediant ninth!’ or understand what canvas Bach is trying to paint with...

“The use of music to illustrate and paint emotions and stories is as old as recorded history. Music is not a kind of Unicode equivalent where da-de-dum----dum-de-dum-de-dummm... means ‘I had undercooked ham for dinner on Thursday.’ Or... ‘this riff means “Billy.”’

“But who among the race of humans does not feel sadness from Barber's ‘Adagio,’ exaltation from Handel's ‘Hallelujah’ chorus, and so on? The ability to map human emotions, create progressions of human emotions, and direct screenplays of human emotions is the mark of a great composer.”

For what it’s worth, Greenberg is indeed impressed by EMI. In that Cope volume, he writes that EMI “is the best attempt at credible automatic art I have yet seen.”

The biographical details may not be necessary to understand the meaning of music, but I would suggest that physical experience in the world is required. In the past 20 years a paradigm has emerged in cognitive science called “embodied cognition.” The idea is that all of our thoughts, even our most abstract concepts, are ultimately grounded, through metaphors, in our physical interactions with the world: forces, movement, spatial positions. In a book called *Philosophy in the Flesh*, linguist George Lakoff and philosopher Mark Johnson list many of these “conceptual metaphors” that show up as language metaphors: to understand something is to *grasp* it or *see* it; when two things are similar they are *close* to each other; causes act as *forces*; to change states is to *move* from one *location* to another; difficulties are *burdens*, or they cause *resistance*. These metaphors have become transparent to us because that is actually how we understand the world. I think that describing such an emotional and intellectual art as musical composition using references to *tension* and *release* is more than the employment of *language* metaphors. The physical feelings of tension and release we all experience while listening to music is undeniable.

I asked Bamberger if some of these basic physical meanings came through in music. She walks over to the piano. “Well this has meaning [she plays a high chord] in relation to [she plays a lower chord]. But what kind of meaning is that? Well, you can make analogies, and say it’s like standing on a cliff and then jumping down. Or it’s like throwing a ball up and catching it, or all the things that have to do with tension and

resolution. Closing your hand tight and relaxing it. I think the whole body thing is the closest to [referential meaning.]”

In his classic book, *Emotion and Meaning in Music*, music theorist Leonard Meyer argues for the necessity of physicality in musical meaning. “It is not enough, for example, for the listener to know that in Western music of the past three hundred years a particular sound term, the dominant seventh chord, creates an expectation that another particular sound term, the tonic chord, will be forthcoming. The expectation must have the status of an instinctive mental and motor response, a felt urgency, before its meaning can be truly comprehended.”

It seems to me that embodied cognition should lead to particular universals in music. While we each may have different musical and cultural and biographic influences, we all have pretty much the same body, and we exist with the same physical laws. This theory has, in fact, been tested. Music theorist Steve Larson of the University of Oregon, building off the work of Johnson, describes three “musical forces,” or metaphors from physics that we instinctively apply to music. There is gravity: “The *rising* melodic line climbed *higher*.” And magnetism: “The music is *drawn to* this stable note.” And inertia: “The accompanimental figure, *once set in motion*,...” Larson then lists certain patterns of notes that obey these laws and predicts that the patterns should appear frequently in tonal works. He does an extensive literature search on hidden tonal patterns and finds this to be the case, supporting the idea that musical meaning relies on physical metaphor.

This conclusion has two implications. One is that because musical meaning is indeed based upon physical experience, computer composers suffer a fundamental disadvantage. They can never understand music in the way a human does. The other is that we may be able to simulate understanding in a powerful new way by integrating mathematical approximations of these musical forces into compositional algorithms. These will always remain approximations, though. The musical forces and patterns described by Larson only scratch the surface of human experience. We may find more sophisticated ways to model our experience, but our physical interactions with the world are too rich and complex for us ever to completely describe them to a computer.

The Algorithmic Self

In the end, perhaps the algorithm is just an extension of the self. Laske claims this view. Almost all of Laske's music is written on the basis of scores synthesized on the computer. "The algorithm is just a pencil. It's just a tool. That's what people don't understand." He says computers act as "alter-egos" that "can put me in new situations that I myself could not always envision. The challenge of computers for me was not so much in what they produced but in the interaction they made possible between me and some musical grammar that they embodied. So my interest in AI was always not making musical products any quicker, or any better, but to challenge the composer to reflect on his own process. This interactivity is what I cherished and even cherish today... [computers are] intellectual stimulants for me, they are for occasions that help me pose musical problems in a way that I wouldn't ordinarily have thought of."

Even though the computer stands apart from the programmer, it still manifests her own thinking. And algorithms should not seem so foreign to human thinking in the first place. Laske tells me that people "don't consider the history in which a person absorbs computation as a manifestation of their own personal thinking." He says he's produced 90% of his music using algorithms. I ask him to clarify whether he means computer or mental algorithms. He says both, but he started writing algorithmic pieces in the 60's, even before he used computers. "But the two things really can't be separated because I have absorbed the programs and so now *my* thinking is like *them*, but it's *my* thinking."

I mention that people really don't like seeing the man behind the curtain, realizing that much of creativity is algorithmic. Laske concurs. "They don't realize that the man behind the curtain is still a mystery. That you have just taken away one layer, one curtain, but then there are ten others behind the curtain." He feels that no matter how much of creativity we explain, there will always be more that we cannot understand.

Laske also says that explaining some piece of creativity with an algorithm does not squash creativity; it merely lets us build upon this algorithm and push creativity into new realms.

"I think creativity and calculation or computation are intertwined historically. What at one point was intuitive, not understood, not proceduralized then becomes

technique, and then we are at a different level. So the distinction between creativity and technique is relative to what we know, so it's historically changeable. It's not that we don't need insight anymore because we have technique. The level at which we now work requires insight that before we couldn't even think of. That's the historical process. So I think in that sense AI and music is open to the future."

Cope expressed similar sentiments. "A lot of cases where people become defensive ... [are] based on a very false premise ... that machines are somehow separate from us, which is absurd. The machines are in a sense *us*. I make a statement in my book where I say that most people think that somehow not being able in 1000 years to create a computer program that would somehow fool us makes humans somehow superior. It makes humans *incredibly inferior*, that we're not smart enough to do that. It seems to me that we are the ones making the programs, it's not the programs making us, for heaven sakes.

"It's exactly like [my] argument for Deep Blue. And it's precisely why I was so happy [when Deep Blue beat Kasparov], and why my wife was so confused until I explained it to her. It was a great day for human beings, not a sad day. We made the programs. They are us, we are them."

The Future of Music

Cope has designed an algorithmic composing environment that lets composers collaborate with the computer called Algorithmically Integrated Composing Environment (ALICE.) While writing a piece, you can ask ALICE to fill in a section or extend a theme, from one note to the whole thing, based upon what's written so far. He has also included a version of this software on CD with his books. Cope wrote in one of his books that he will work with ALICE for the rest of his life. ALICE in fact carries out one of the original tasks he assigned EMI. He began to write EMI back in 1982 not to ape the styles of famous composers but to solve his own case of composer's block. Cope hasn't used ALICE in a year because of some technical bugs, but he hopes to get back to it eventually. I ask him if there's a split between composers who use algorithmic aids and those who don't.

“Do I see a split? Yes. Do I see that changing? Yes... We’ve already got some algorithmic tools in Finale.” Finale is the standard computer application for musical notation. He launches it on his computer, then shows me a menu titled *composer’s assistant*. “These are all algorithmic things that are in the best, most known commercial application for music. It’s just a start... I know that people are starting to look at them, and it’s just edging along, and the next edition of this program, which has almost nowhere else to go, [will extend these options] until they start asking ‘do you want to see what this program would do with the next measure, the next two measures, the next four measures?’ There’s just no question it’s going to happen.”

How will these tools change music? Cope says that composers will shift attention to different musical elements.

“Architects don’t pound nails. They don’t lay concrete in the foundations and they don’t put tiles on roofs. They *design* houses, and I think composers will *design* pieces. And they won’t be put in a position where they have to put all the dots on the quarter notes and all those things. They’ll be more architect-like. And I like that, that vision.”

Final Exam

The ultimate test for any computer trying to replace a human is the Turing Test. In 1950 the British mathematician Alan Turing described a test where a human judge had a conversation with a computer and a human, through typed communication, and would decide which was the human. Turing thought that the key to judging intelligence was conversation, but the same idea can be applied to other fields of activity. Cope’s Game, in fact, is a type of Turing Test. Computers may get better and better at playing these games, so that a program can pass the Turing Test after a five-minute conversation, or a ten minute conversation, but eventually, I believe, we will catch on. After listening to enough of EMI’s music, a musician will probably be able to tell it apart from human composition. Will computers ever be able to play this game indefinitely, without losing? What happens if they do? Do we congratulate them and invite them to join the human race?

Currently, computers simulate human behavior using shortcuts. They may appear human on the outside (writing jokes, fugues, or poems) but they work differently under the hood. The facades are props, not backed up by real understanding. They use patterns of arrangements of words and notes and lines. But they find these patterns using statistics and cannot explain why they are there. There are three main reasons for this. First, computers work with different hardware than the human brain. Mushy brains full of neurons and flat silicon wafers packed with transistors will never behave the same and can never run the same software. Second, we humans don't understand ourselves well enough to translate our software to another piece of hardware. Third, computers are disembodied, and understanding requires living physically in the world. The meaning in music eludes computers. Perhaps robots will someday approximate embodied cognition, but they would, again, be working with very different hardware.

When I was with Cope in his office, I suggested that perhaps a computer will never win the unconstrained Turing Test. He replied:

"I'm sad if you're right and we can't ever build a machine that could fool us. That saddens me a great deal, and it means that maybe someday human beings will reach a dead end where we can't go any further. Our minds just aren't big enough to go there. And I just, I just don't believe that and that's why I keep working, because [and here, Cope's voice descends into that dramatic, hushed tone] I believe we can do anything we set our minds to."

Cope is what those in the AI literature call a *hard AI* proponent, someone who believes we can simulate human intelligence completely. He's in good company, joined by such AI innovators as Marvin Minsky and Ray Kurzweil. Kurzweil, author of *The Age of Intelligent Machines* and *The Age of Spiritual Machines*, argues that Moore's Law dictates the surpassing of human capabilities by computers around the year 2030. I, however, am a *soft AI* proponent. I think particular qualities of human intelligence result directly from the particular physical structure of our brains and bodies. We live in an analog (continuous, infinitely detailed) reality, but computers use digital information made up of finite numbers of ones and zeroes. Imagine building a sphere out of Lego. From a distance, it will look round, but up-close the effect disappears and the chunky

edges make a difference. I suspect that the analog-digital divide is a fundamental problem we cannot avoid.

When I'm mixing records, all of my life experience comes to bear. At a party, I usually don't plan my set beforehand; I don't know more than one or two records ahead of time what I'm going to play. The atmosphere, the reactions from the crowd, and my own mood play parts. Each record has a different effect, and it's not always clear what that effect will be in a given situation. The mixing process is also mostly improvised. I know my records well enough to have some idea of how they will fit together, but frequently I'll put together two records I've never mixed before. Then the crossfading and cutting and flipping of switches come down to rapid decisions. I have no calculus for the process; this stage is where emergence really comes into play. I've also planned out sets in my apartment, preparing to record them for mix CD's. Here the decision-making more closely resembles classical composition. It's more methodical, takes different musical factors into account. How does this bassline overlap with that melody? Do the drums here work well with the chorus there? I don't have to read the crowd, but I still have to read the records, and I have to read my own emotions and my own motivations. This is telling a story. And there's room for cleverness on several more scales. On my first mix CD, mostly house and trance, I end the set with a surprise: Michael Jackson's "Beat It." Somehow it fits in musically. It's not that you couldn't program a computer to think of this. It's that a computer could never even understand how cool "Beat It" is.

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