1. Introduction

Margaret Boden's *The Creative Mind: Myths and Mechanisms* offers the same co-illumination of AI and philosophy which she managed so well in her classic *Artificial Intelligence and Natural Man*. The justification of the book is that the theory and practices of AI have light to shine on age-old questions of creativity and that the shape of these age-old questions and their half-answers have light to shine on AI. The book combines discussion of basic issues in human creativity, detailed discussions of particular creative programs, and good introductions to AI's foundational ideas.

This review begins with a brief discussion of the book and its intended audience but focuses primarily on two particular issues raised by Boden: her distinction between historical and psychological creativity and her connection of creativity with the transformation of representations. Both of these issues are central to the artificial intelligence side of the AI and creativity discussion: the first highlights the social embeddedness of creativity and affects how we judge the success of putatively "creative" programs in artificial intelligence; the second highlights the degree to which any AI program's successes are dependent on its programmer's creativity in determining its representation and how the development of truly autonomous systems must bring representational creativity to central stage. Finally, both of these issues reveal the inadequacy of a single distinction—creative versus non-creative—for describing a phenomenon as contextual as creativity.

2. The book and its intended audience

The topic of human and machine creativity is a compelling one. The very idea...
of machine creativity or non-creativity baits humanist and mechanist alike. But Boden largely avoids this controversy by using each side to illuminate (rather than diminish) the other. From AI she takes the precise language of processes and structures, searches and spaces, and applies it to understanding and clarifying what we call creativity. From philosophical and psychological studies of creativity, she pulls examples and distinctions which AI must make clear in its assertions of adequacy or coverage.

Beyond its contribution to debate and discussion about AI and creativity, I think the book makes a wonderful introduction to AI for non-programmers. It has the character which often distinguishes good textbooks from merely adequate ones: it addresses problems and along the journey stops by many of the field’s central elements. Her descriptions of these ideas are always accessible and sometimes enchanting; and, while I sometimes balked at “sitting through” her metaphors for mechanisms which I understood directly (e.g. her discussion of backpropagation as message passing among a classroom of not-too-bright students), such examples are a virtue in giving non-programmers access to the ideas.

For the remainder of this review I turn from the general character of the book to its particular issues and proposals. In particular, I focus on three of the most interesting elements: the distinction between creativity defined historically and psychologically and her focus on the latter; the importance assigned to social and historical context in understanding creativity; and her central thesis that creativity is fundamentally the exploration and invention of representational spaces.

3. Historical and psychological creativity

Early in the book, Boden introduces a distinction between historically and psychologically creative ideas (p. 32):

...we must note two different senses of “creative”. Both are common in conversations and writings about creativity and (although the context often supports one or the other) they are sometimes confused. One sense is psychological (I call it P-creative, for short), the other historical (H-creative). Both are initially defined with respect to ideas, either concepts or styles of thinking. But they are then used to define corresponding senses of “creative” (and “creativity”) which describe people.

The psychological sense concerns ideas (whether in science, needlework, music, painting, literature ...) that are fundamentally novel with respect to the individual mind which had the idea. If Mary Smith has an idea which she could not have had before, her idea is P-creative—no matter how many people may have had the same idea already. The historical sense applies to ideas that are fundamentally novel with respect to the whole of human history. Mary Smith’s surprising idea is H-creative only if no one has ever had that idea before her.

This distinction is not itself “H-novel” and is included in the introduction to most
works on machine discovery, usually with some assertion that the "real" test for such programs is historical creativity. But in Boden's discussion, exactly the opposite conclusion is drawn (again, p. 32):

Although H-creativity is the more glamorous notion, and is what people usually have in mind when they speak of "real" creativity, P-creativity is more important for our purposes.

H-creativity, she argues, is based on an accident of history and can tell us little but the internal processes underlying it (pp. 33–34):

In principle, however, ideas can be classed as H-creative only provisionally, according to the historical evidence currently available.

Because H-creativity is a historical category (many of whose instances are unknown), there can be no psychological explanation of H-creativity as such. Indeed, there can be no systematic explanation of it at all.

Boden's point is an important one because it moves us from the glamour of historical creativity to the place where the process is actually happening: within and among individuals in communities. To her credit, Boden's descriptions of creative moments consistently refer to the social and intellectual context of the creation; the attraction of historical creativity is that it seems that this contextuality is clear and explicit while in fact it is anything but. Wisely, Boden points this out and turns from the illusory simplicity of labelling historical creativity to the more difficult but fruitful project of examining creativity in its psychological manifestation. But this requires a careful study of context, an issue to which I will return below.

But it also seems to me that her dichotomy between psychological and historical creativity might be profitably replaced by a series of distinctions varying with the size of the community over which novelty is defined. The cases of the community of one individual and the community of recognized history are just two points along this continuum (albeit near extreme ones from the point of view of our scientific community, which resides somewhere between them). As the size of the community grows, novelty becomes rarer. Each community is embedded in some context where some of its novelties are either literally or figuratively passé: they have either already been generated or might as well have been.

As a case in point, when I was working on my rational reconstruction of the mathematical discovery program AM [5], Doug Lenat (the developer of AM and one of my readers) began our occasional meetings with the question "How has your program surprised you recently?" as a way of probing the novelties that had emerged from the system consisting of myself and my program. Likewise, once he'd been similarly surprised by my accounts, we'd expanded the community yet again to include him. This was the spirit of assessment in which Lenat sent English versions of AM's heuristics to mathematicians, asking if they could find "arithmetic" or "primality" hidden in them (none could).

My own subsequent reconstruction of AM generated numerous ideas [1, 2] which were novel to it (not a hard task given its tabula rasa beginnings). Most
were clearly within my own model of its search space and thus not surprising to me. Some, to my satisfaction, were surprising to me and thus novel to the system consisting of the program and myself. In turn, many of these were also novel in the “Lenat/Haase/program” system and most of these percolated out to the contexts in which that system was embedded, where the rest of my committee and subsequent readers of my thesis were likewise surprised.

Boden adopts exactly this sort of “systems” perspective in discussing whether Harold Cohen’s AARON programs—each of which produces an endless series of novel drawings in a particular style—are genuinely creative (p. 151, emphasis in the original):

...only if we think of the various versions of AARON as a single computational system do its drawings count as H-novel (or even as P-novel) in the strong sense defined in Chapter 3. With reference to abstract-AARON’s abilities, the drawings of acrobat-AARON could not have happened before; likewise, acrobat-AARON could not have drawn the jungle scene...

If we consider only a particular version of the program, however, the matter lies differently: each drawing could have been generated (by that version) before. Moreover, the progression from abstract-AARON to acrobat-AARON, and thence to jungle-AARON, is due directly to Cohen, not to any autonomous self-modification by the program.

She suggests that while any particular version of AARON is not creative in a radical representation-breaking sense, the Cohen/AARON system (so to speak) clearly demonstrates substantial creativity embodied in the series of programs implemented by Cohen.

Boden does not return to the question of psychological and historical creativity with this “systems” perspective. If she had, she might have seen that many interesting things can be said at the boundaries of these contexts where the novelty of an idea or invention survives the transition from one system to the system in which it is embedded. In particular, two issues become clearer from this perspective: the embedding of creativity in a social context and the need for more words than “creative” or “novel” to describe innovations in such a complex space.

4. Social embedding of creativity

One of Boden’s earliest points is that novelty does not necessarily imply creativity (p. 3):

People can have ideas which, so far as is known, no person has ever had before. So if I remark (what no one else has ever been daft enough to say) that there are thirty-three blind purple-spotted giant hedgehogs living in the Tower of London, does that make me creative?
and likewise that creativity does not necessarily require novelty (again, p. 3):

Suppose a chemist or mathematician has an idea that wins a coveted international award, and it later turns out that a self-educated crossing sweep had it first. Is this even possible, and if so does it destroy the prize-winner’s creativity?

The example which this brought immediately to my mind was Copernicus’ sun-centered model of the solar system. There were a number of heliocentric cosmologies before Copernicus introduced his own proposal, but nonetheless we credit Copernicus with the great discovery. Why?

Boden addresses this question by considering how much of creativity lies in the flash of insight experienced by a creator or in the ‘spade work’ that precedes and follows it. For example, she cites how Kekule’s proposal of a ring structure for the benzene molecule was based on a dream of a snake biting its tail; she asks if a self-educated street cleaner could have done the same work with the same novel image (Chapter 4, p. 58):

The self-educated crossing-sweeper mentioned in Chapter I might have been seen a tail-biting snake lying on the road, but would probably not have known enough chemistry to make the connection. Even if he did, he might not have noticed—still less solved—the residual problems of the missing valency units. And lacking access to a laboratory, he could not have done any follow-up experiments.

Under this reading, what made Copernicus’ proposal “creative” was that he used it to solve a problem: the diminishing elegance of the Ptolemaic model in the face of empirical data. Copernicus was bothered by the fact that, to deal with new measurements, the Ptolemaic model required positing elliptical epicycles for planetary motion, rather than perfect circles as in the past. By shifting to the heliocentric model, Copernicus was able to get back the simplicity of circular orbits (at least for a while). We remember Copernicus’ postulation as the significant one because it was the one that spread; and it spread (in part) because it solved a problem that everyone at the time recognized as a problem. Such a historical embedding of the discovery should not diminish its significance. Instead, it should point us to its real contribution and to the structure of the “system” out of which its emergence was significant: its problems, values, assumptions, etc.

Boden points out that such social embedding is as important in artistic creativity as in scientific creativity. Here, she cites the example of atonal music as a case where an innovation was creative solely in the context of preceding work (Chapter 4, p. 61):

If, by some miracle, a composer had written atonal music in the sixteenth century, it would not have been recognized as creative. To be appreciated as creative, a work of art or a scientific theory has to be understood in a specific relation to what preceded it. We saw in Chapter 3 that a creative idea is one which surprises us because it could not have happened before. This is a
computational "could", to be interpreted in relation to a particular way of thinking, or generative system.

This contextualization of the creative act is not identical with declaring creativity to be solely "in the eye of the beholder". In response to this quote from Boden, Stephen Smoliar suggested that a modern critic might unearth some Middle Ages atonality and validly declare it "creative" despite the fact that there was no established background of tonality against which it was being judged. But strictly speaking, the creativity of that artist's work was not in its construction of "atonality" against a tonal background but would be in the construction of a twelve-tone row against an even less constrained background. The judgement of creativity still lies in a transition between systems; it is just that the systems are not temporally contiguous, representing what you might call a "tonal detour" taken by the rest of music between that medieval composer and today.

Boden's focus on deeply understanding the social context of creativity is vital to grounding the study of creative process in the phenomena themselves rather than in the gloss with which history paints them. A case in point can be found in Georg Ohm's discovery of a law relating voltage, current, and resistance; Ohm's law (as we call it today) was rejected by his colleagues for many years because it conflated two phenomena—current electricity and static electricity—which were known to be distinct [2,7]. Current electricity (measured by deflection of a magnetic needle) and static electricity (measured by the spreading of an electroscope's leaves) were probably distinct phenomena which Ohm lumped together in proposing his law. Electrical theory of the day proposed that there were two quite distinct "electrical fluids" and Ohm's proposed laws ignored this distinction. They accepted his measurements for the relation of resistivity with current flow, but rejected his central thesis until the availability of an explanation for their experimentally apparent independence.

This contextualization puts the creative nexus of Ohm's discovery in his specification of what the observables really are (his conflation of current and static electricity as a single phenomenon) rather than his positing of the law which connected them. In this sense, when a program like BACON [4] reproduces Ohm's law from particular observables, the creative insight is already encoded in the initial formulation of the problem. When we reproduce creative process in our computer programs, we need to delineate the historical contexts in which a construction was deemed creative; and if our program succeeds too easily, we need to find the hard part of the problem that we are obviously missing.

Though Boden mentions the importance of looking at creativity in context, she is not as critical as she might be about the consequences of this stance for programs like BACON. The creative core of past scientific discoveries lies in their invention of the contexts which made laws expressible, not in the laws themselves.

1 Our modern day explanation of the equivalence of the phenomena employs special relativity to explain that the electrical force, under the relativistic transformations induced by motion, is the magnetic force.
Though her central thesis is that creativity lies in the construction and transformation of such contexts, her descriptions of putatively creative programs often fail to reveal how vitally their performance depends on the hand-coded contexts which they are given. It would have been useful to see a description of how these programs' representations “built in” the insights enabling their eventual “discoveries”. I suspect that she would find them wired into the programs’ most basic assumptions about identity, similarity, and reference. Such assumptions, by making certain distinctions impossible or inexpressible, drastically simplify processes of perception, measurement, and search. I will discuss these questions more in the next section.

Historical accounts of ideas emerging into social contexts from individual scientists or communities suggest a way of using the systematic continuum of novelty to characterize creativity: creativity involves the motion of ideas out of embedded social contexts (like the contexts I described above) and requires a combination of circumstances within and without to enable this motion. An apparent problem with this characterization of creativity is that it might mark as uncreative the solitary scientist (like Ohm, Mendel, McClintock, or numerous known and unknown others) unrecognized or not understood by his or her peers but recognized as creative today. This possible injustice resonates powerfully with our own most basic experiences of not being understood. Yet if we understand the equation of motion between contexts with creativity as an ahistorical one, such scientists demonstrate a creativity which skips the social contexts of their day to reach the historical context of ours.

Understanding the social context for significant discoveries allows us to understand both the significance and the foundations of fundamental innovations. But this is just the first step to understanding the processes of creativity themselves; the next step is to understand the intra-psychic structures that enable creativity. In this, Boden takes from AI the notion of representational spaces and frames her central thesis: that creativity involves the exploration and transformation of such representational spaces.

5. Invention and exploration in creativity

Boden’s central thesis is that creativity involves the construction of new mental spaces to be searched for descriptions or solutions; creative insight is typically a change of representation which enables descriptions or solutions which could not be expressed or found in the previous space. Bringing the notion of representational spaces from AI, she illuminates the processes of routine and radical creativity. In this section, I discuss what she means by mental spaces and suggest that while she set the state most excellently, the real work lies in thinking about the boundaries and interactions of these spaces and requires terms more precise (and less loaded) than “creative” or “novel”.

Boden characterizes mental spaces with two central metaphors: the game and the map. Her sense of game focuses on rules specifying allowable and forbidden
combinations of basic elements and the way in which these rules constitute a generative system (p. 45):

The creative mathematician explores a given generative system, or set of rules to see what it can and cannot do. For instance: “Can it do addition?” “Can it do subtraction?” “Can it produce only odd numbers?” “Could it have generated ‘365 + 1 = 366’?”

Her central example of such a system is a game of adding beads to necklaces based on particular rules; it is based on Hofstadter’s pq-system [3] and its extensions, though she goes on to give other examples of such spaces including the topological configurations of molecules (p. 52), the harmonic structure of tonal music (p. 61), or the space of pictures which a child of a particular age generates (p. 64).

Her second metaphor, the map, is introduced to discuss the open-ended character of creativity (p. 47):

... Like much play, creativity is often open-ended, with no particular goal or aim.

Or rather, its goal is a very general one: exploration—where the terrain explored is the mind itself. Some explorers of planet Earth seek something specific: Eldorado, or the source of the Nile. But many simply aim to find out “what’s there”: how far does that plain extend, and what happens to this river when it gets there?; is this an island?; what lies beyond that mountain-range? Likewise, the artist or scientist may explore a certain style of thinking so as to uncover its potential and identify its limits.

Maps impose structure on spaces we are exploring and allow us to explore more effectively than we would otherwise (also p. 47):

Using a map, one can return to old places by new paths: unlike Theseus, with a ball of thread to lead him out of the Labyrinth, map-bearers rarely have to retrace their steps exactly. Map-bearers can also roam throughout a circumscribed region knowing that there is something there to find: moving camp three miles to the north is rather like speaking a new sentence, or composing a new melody in a familiar musical style. The map may even indicate how explorers can get to a part of the world they have never visited. Sometimes the map gives them bad news: to get from here to there would require them to cross an impassable mountain-range.

In short, the map is used to generate an indefinite number of very useful “coulds” and “cannots”

Maps are used as heuristics for making one’s way through a formal space defined by a generative system. The absolute locations on the map are points specified by some generative system; the map itself is a sparser, but more reliable, set of paths for getting from result to result (p. 47):

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2 By her use of “the mind itself”, I take Boden to mean the space of ideas as we describe them to ourselves.
Where creativity is concerned, the maps in question are maps of the mind.
These maps of the mind, which are themselves in the mind, are generative
systems that guide thought and action into some paths but not others.
Scientific theories, for instance, define a conceptual domain which can then
be explored. Find a new town, make a new dot: "Another benzene-
derivative analysed!" Follow the river, to see where it goes: "So benzene is a
ring!" What about the other molecules found in living creatures? Identify
the limits: "Is the genetic code (whereby DNA produces proteins) the same
in all living things?".

If I am reading Boden correctly, representational spaces are formal generative
systems (games) which are further organized by other generative systems (maps).
And for Boden, radical creativity lies in the map-making and not in the map-
following. Radical novelty and creativity consist of breaking out of the alter-
 natives specified by any particular generative system (Chapter 3, p. 40):

We can now distinguish first-time novelty from radical originality. A merely
novel idea is one which can be described and/or produced by the same set of
generative rules as are other, familiar ideas. A genuinely original, or
creative, idea is one which cannot.

To justify calling an idea creative, then, one must identify the generative
principles with respect to which it is impossible. The more clearly this can be
done, the better.

For example, she cites the way that atonal music emerged from the generative
framework of tonality (p. 59):

Artists, too, create new conceptual spaces. By dropping the tonal constraints
that had informed all Western music since the Renaissance, composers at the
dawn of the twentieth century passed from one conceptual space to
another—which had not existed previously.

Or rather, it had existed only implicitly, as a potential within tonality itself.
Given the exploratory impulses and rule-changing heuristics available to
musicians (as to the rest of us), the limits of tonal space would inevitably be
respected, tested, modified, and finally abandoned.

She also applies this distinction—in the other direction—in discussing single
versions of Cohen’s AARON program (pp. 151–152, continuing the discussion
quoted above):

In short, AARON’s originality is not truly radical, because its exploration of
its own conceptual space is relatively unadventurous. The creativity of any
given version of AARON is more like that of the child who repeatedly says,
"Let’s make another necklace, with a different number of beads in it," than
the child (perhaps the same one, an hour later) who says, "I’m bored with
addition-by-necklace! Let’s do subtraction now." The program does not seek
to test the limits of its creativity, as the child does...
Though the metaphors of game and map are evocative, the game metaphor breaks down when we need to describe the transformation of games. We do not often think of games as embedded within games or of one game as a “weaker” form of another. But these are precisely the issues we need to address when we look at the transformation of representations involved in creativity.

We can take the descriptive pair of game and map and expand it into a continuum—like the continuum of social contexts described above—where a succession of representational spaces are each embedded in some surrounding space. In this framework, creativity can again be characterized by motion between these embedded contexts. Creative moments occur when the process of map-following creates a change in the context in which the map is embedded. Such changes are usually additive changes which extend the map to cover places originally blank. Occasionally, however, the change is a radical one which throws out the lines and landmarks of the previous map and replaces them with new ones.

It may be because creativity involves this sort of motion between maps and their contexts that it so often entails involvement with the world: in scientific experimentation or artistic expression, the things we can test, observe, create, or perform are the embedding context for the maps determined by our particular theories or styles. Likewise, it also suggests why the combination of fields or models is so often fruitful with creative ideas. To discuss the boundaries between two different maps, we must step out into the context in which they are both embedded.

But the distinction between maps and games or among the series of embedded spaces in the more continuous scheme raises a logical problem: if our maps are themselves generative systems, what’s the difference between the two? What is it that makes one thing the game and another the map? Is the map reducible to the game? Can we say things in the game which we can’t say in the map? Or vice versa?

It seems clear that there are two differences between the game which serves as the context for the map and the map which guides us through the game:

- if we follow the map, our searches and explorations will be more fruitful than if we “played” the game without it;
- there are some things in the game which we cannot reach via the map.

These dual constraints keep us from labeling any particular construction as “creative” or “non-creative” but force us to look at both the payoffs and limitations of the map-making of our programs and ourselves.

For instance, if a program proves an interesting theorem, we should ask how big the space of theorems it might prove would be (given its representation and its practical execution limits) and how thick with interesting theorems that space was. Paradoxically, if the space is thick with interesting results (where “thick” might be 1%, or 0.1% or 0.01%), it is then the space (the “map”) which is interesting and not the program. The questions which we then need to ask include: Does it stay so thick as we expand its execution limit? Are there relatively simple variations (renaming of symbols, tweaking of preferences) which preserve thickness when
the domain evolves or shifts beyond its initial focus? What do we miss in the embedding context in exchange for the benefit of such thickness? Are there other "maps" for those parts of the embedding context?

6. Towards a better language

In discussing this review with a philosophical colleague (Eileen Sweeney of Boston College, a philosopher of medieval thought and language) we noted that creativity as a human category is a relatively recent invention of Western thought. In the Middle Ages, creativity was largely reserved for God; during the Renaissance and Enlightenment, creativity was taken as more an act of discovering God's creation than inventing anything new. It was only in the romantic period that creativity emerged as a human category, perhaps in response to a Cartesian dualism which limited physical explanation to a narrow set of metaphorical models. We are the inheritors of this "dumbbell theory" [6] which breaks down when we try to understand creativity in precise computational terms.

Boden's important and central point is that creativity has to do with the maps we use to navigate the vast uncharted territories of the systems we inhabit. She brings from AI the notion of representational spaces and uses this to clarify—more precisely than ever before—the conditions of creativity. But such a clarification shows us that the single distinction "creative" is too coarse to describe the inter-representational relations involved in complex generative systems. We need better language and better tools for talking about the relations between representations and the processes which operate over them. It is disappointing that Boden, having ably led us to threshold of such an enterprise, fails to take the first few steps into it. For instance, while the representational inventions and transformations of Lenat's AM qualifies it as the only program whose "creativity" is not eventually dismissed (she describes its status as "unclear" (p. 209)), her discussion of AM ends at this point rather than exploring this one example of possibly "genuine" creativity in greater depth.

If I may be so bold as to suggest what those first steps might be, I believe that any such exploration must begin with a pragmatic representational pluralism. Multiple representations are important because much of the power of representations arises from their negative functions: the things which they make difficult or impossible to express. Good representations are brittle for good reasons arising from choices made about what the representation will be effective at describing. Such choices must be made because a single representation cannot adequately describe effectively describe everything any more than one information-theoretic encoding cannot shorten all the strings of a language.

Representation-breaking creativity is necessary due to this unavoidable connection between effectiveness and brittleness. A discussion of the creative processes by which representations are adopted, abandoned, or transformed requires a language for describing why a particular representation is good for a particular purpose. But what would such a language look like?
As an example, consider three distinct representations for whole numbers: tallies, roman numerals, and our own arabic numerals. Each of these has advantages and disadvantages with respect to different functions: comparison of roman and arabic numerals is much faster than comparison of tallies; but on the other hand, single increments and decrements are much easier with tallies than in either the roman or arabic systems. Calculations like addition or subtraction are much simpler in the arabic system, but roman numerals simplify judgments of variance from standard (prototypical?) values at different orders of magnitude (numbers get longer as their variance gets greater). A good language for talking about representations would make it possible to discuss these tradeoffs and also allow the articulation of how such representations relate to one another.

Because the character of representations in such a language is not founded on description of a common domain but rather on fitness to particular purposes, we cannot compare representations by reference to "meaning in the world" or "translations which preserve x" (where x might be truth, consistency, or your favorite foundational property). I suspect that the relation between representations will be based on a kind of "loose analogy" which maps between the representations without necessarily guaranteeing the preservation of truth, consistency, or any one property in particular. Instead what the mapping guarantees is some loose kind of relevance: "if you're frustrated trying to solve problem x try solving problem F(x) instead". Solutions, advice, warnings, or fine details might not survive the translation and the result of solving F(x) might not even look like a solution to x outside of the fact that when you've solved F(x) you no longer have a compelling reason for solving x.

For example, compare the tasks of doing subtraction with tallies and with arabic numbers. The elements of subtraction among arabic numbers (e.g. borrows) have no clear analogs with subtraction among tallies. However, once the subtraction is done in the arabic representation, it does not need to be done in the tally representation. The tally representation can even check the answer, even if it cannot "check the work". There is a loose analogy between the representations which we (outside of the representations) can see will always allow a problem to be translated and solved. But this "always" is not necessary for the loose analogy to have value.

7. Conclusion

Boden's book describers a large and interesting territory; the creative programs and individuals she describes are fascinating and her insights into the conditions of

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3 This example is driven by a suggestion of Walter Hamscher that it would be nice to have a version of AM which could invent a digital representation for numbers while starting from an analog representation.

4 To be meta-consistent, we must admit that such a language would be "good" for talking about relative tradeoffs and relations but not about the implementation issues of particular representations, their truth semantics, or other aspects.
their creativity are both revealing and incisive. The points I found most evocative (and expanded on above) were:

- her focus on psychological creativity (and its conditions) rather than on the more glamorous but accidental phenomena of historical creativity;
- her attention to the context of creativity as being an essential determinant of how creative behavior is assessed; this includes both creative moments in history and the constructions of our computer programs;
- her central thesis that creativity lies in the extension and reformulation of representational spaces.

This final element points to an important direction for future work in AI in general, since intelligent programs depend so vitally on the character of their representational spaces. I hope that Boden's book opens a broader discussion on the ways in which our programs can be "stuck in" or "liberated from" the confines of the initial representations we give them.

Such creative innovation is not just an interesting sidelight or subfield of artificial intelligence, but is central to its eventual maturity. When the first attempts at computer intelligence found themselves cast about in vast combinatorial spaces, better languages and architectures for search control seemed the obvious solution. When such mechanisms evolved and stabilized (as much as any under-constrained system can stabilize), it became clear that the source of search control expertise lay mostly in domain knowledge ("in the knowledge lies the power"). The problem then became one of knowledge acquisition: the search for useful descriptions in given representations. But the ultimate limit to such efforts lies in the fact that much of the power of any given representations is negative: it tells us which things aren't worth considering. When such negative prescriptions are in error, programs become more struck than any human being could possibly be. At this point, creative insight (on the part of the program) is required to redefine those negative functions out from underneath the very systems using them; to change the representation that gave the program its power in the first place.

As I mentioned above, Boden's book takes us to the threshold of examining these processes but does not take the first steps in such an examination. This path of exploring and explaining creativity is central to artificial intelligence because it is in creative response to changed circumstances or inadequate preparation that the flexibility and ability of the human mind is so far unparalleled. If the programs we build are to ever surprise us or survive surprise themselves, we must understand how to give them the same ability to change, abandon, and transform the maps with which they begin.

References