Boden and Beyond: *The Creative Mind* and its Reception in the Academic Community.

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1 Introduction

This review consists of a set of notes on the account of creativity presented in *The Creative Mind* (henceforth TCM) by Margaret Boden[1] and responses to it in the academic community. Thus Section 2 presents a brief summary of some key concepts and issues raised in TCM. Sections 3 and 4 present, respectively, summaries of open peer commentaries from *BBS* 17:3 (1994) and book reviews from *Artificial Intelligence* 79 (1995) including Boden's responses to these. Finally, Section 5 outlines some of the key extensions and modifications to her position in the years since TCM was published.

I have attempted to remain true to the words of the various authors in these summaries including any personal thoughts as footnotes. Also I have concentrated on theory trying to include discussion of actual systems only when they are relevant to theoretical concerns. Unless explicitly stated otherwise, all references in Section 2 are to Boden (1990) and to the authors of the relevant book reviews, commentaries and responses in Sections 3 and 4.

2 Overview of TCM

2.1 Aims

Boden states that "the central theme of this book is that [creative thought] can be better understood with the help of ideas from artificial intelligence." Her aims are twofold:

- To address conceptual problems with the definition of creativity and remove the mystery associated with it so that it may be viewed as a mental capacity and understood in psychological terms.
- To outline the sorts of thought-processes and mental structures in which creativity is grounded.

With these goals in mind, Boden outlines four questions which we can ask about the relationship between computers and creativity:

1. Can computers help us understand how *human* creativity is possible?
2. Could computers ever do things which *appear* to be creative?
3. Could computers *recognise* creativity?
4. Could computers ever *actually be* creative?

Boden is primarily interested in the first question and only in the others to the degree that they shed light on the first.

2.2 Thinking the Impossible

Boden discusses the features used by "combination-theories" to identify creative ideas:

- novelty
- unusual
- surprising

She criticises this definition of creativity on two grounds:

1. "The concept of creativity is value-laden. A creative idea must be useful, illuminating or challenging in some way."
2. This definition/explanation fails "to capture the *fundamental* novelty that is characteristic of creative thought."

Boden expands on her notion of fundamental novelty as follows:

> "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, ideas is one which cannot."

Boden likens this to the use of a map to navigate a conceptual space. The map is used to search the space (exploration) but she argues that the more creative process is the map-generation itself (transformation). She notes that this transformational creativity may involve changing the map (e.g., dropping constraints) or using new search heuristics (e.g., considering the negative). Furthermore, this process of map-tweaking suggests that a prior map is required if a new map which generates ideas which *could not have*

[1] Boden (1990).

been thought of before is to be generated. Furthermore, this implies that the evaluation of creativity will always occur in the context of the previously existing map(s) (i.e., the existing theoretical framework).

Boden invokes the notion of representational redescription (Karmiloff-Smith, 1993) of implicit knowledge on increasingly higher (and more abstract) levels to explain the acquisition of a knowledge framework in which maps can be tweaked and transformational creativity can be possible.

2.3 P-creativity vs. H-creativity

These types are based on the type of novelty possessed by the product of the creative process:

- P-novelty: the product is fundamentally novel "with respect to the individual mind which had the idea."
- H-novelty: the product is fundamentally novel "with respect to the whole of human history."

Boden notes that an alternative definition of creativity might further require that the value of the significance of the idea be recognised but does not state her position on this issue. She goes on to note that:

- "H-creativity is a historical category ... [depending on] shared knowledge and shifting intellectual fashions, ... loyalties and jealousies, finances and health religion and politics, communications and information storage, trade and technology, ... [and] even storm, fire and flood."
- Therefore, "there can be no psychological explanation of H-creativity *as such*. Indeed, there can be no systematic explanation of it at all."
- " ... in understanding *how originality is possible*, P-creativity is our main concern."

2.4 Chance, Chaos, Randomness and Unpredictability

In Chapter 9 Boden confronts the problem of reconciling notions of unpredictability and uncertainty with her account of creativity as the selective use of constraints.

Chance Boden notes that chance can mean different things:

- Randomness: see below.
- Serendipity: finding something valuable without its having been specifically sought.
- Coincidence: co-occurrence of events having independent causal histories.

While noting that serendipity and coincidence are unpredictable and may have a role in the creative process (e.g., Pasteur) she argues that they may also damage the creative process as well. In those cases where they have played a favourable role the creative act has also depended on structural constraints and specialist knowledge and, crucially, the appreciation and interpretation of the chance events.

Chaos While chaos may be taken to mean confusion or disorder (the opposite of creativity) it can also mean the "shape of matter before it was reduced to order." In this sense the creative act requires judgement in order to transform the initial chaos into order.

Randomness Boden separates out three types of randomness:

1. A-randomness: absence of any order or structure.
2. E-randomness: lack, in principle, of any explanation or cause (implied by 1. above).
3. R-randomness: lack of any order *relative* to some specific consideration which does not imply indeterminism (e.g., genetic mutation is R-random wrt survival value).

Unpredictability This is an important concept since surprise is central to creativity and yet predictability is central to science. Again Boden separates out two different types:

1. A-unpredictability: unforeseeable in principle.
2. R-unpredictability: unforeseeable by a finite system (e.g., a human) that is – unpredictable relative to a particular predictor.

Events may be R-unpredictable for three reasons: they are A-unpredictable, the predictor's ignorance, the complexity of the factors influencing the event. Creative events may be R-unpredictable due to our ignorance of the structural constraints involved, the creative transformations and heuristics used, and the initial conditions or due the sheer complexity of the mind/brain.

Boden notes that the prediction of R-unpredictable creative ideas would remove the H-creativity but not the P-creativity from the human who had the creative idea. Furthermore, she notes that the notion of unpredictability does not go in the face of science which is concerned with structured possibilities which address how it is possible for things to happen as they do. Which is to say that the central concern of science is explanation not prediction

2.5 Elite or Everyman?

Boden argues that creative thought, rather than being fundamentally different from everyday thought, depends on our ordinary mental abilities such as perception, memory and so on. Creative individuals are distinguished from the layman not by some magic power but by such factors as: knowledge, commitment, self-confidence, motivation and so on.

2.6 Of Humans and Hoverflies

In the final chapter of TCM Boden addresses the final Lovelace question: can computers actually be creative? She addresses four common arguments against this thesis.

Biological Chauvinism: is countered by using the standard argument that it is the computational description of mind that is important not a description on the hardware level but admits that the argument is "inconclusive."

Chinese Room Argument: is countered by arguing that programs written for a particular computer embody sets of principles whose semantics consist in what each instruction does on the suitable hardware. Each element in the language has a referent which is what the hardware is to do. Extrapolating this notion of understanding as causal relationships between the elements of a language and their referents Boden argues that programs such as BORIS have the elementary beginnings of what it means to compare two symbols. It is suggested that "the important question is not 'Which machines can understand and which cannot?' but 'What things does a machine - whether biological or not - need to be able to do in order to be able to understand?'."

Non-human Argument: the argument here is that computers are not automatic members of the human artistic community and have none of our rights. Boden considers that "inviting" them to join our community would entail giving them artistic and creative rights and the consideration of such issues as their interests, deception and trust and their legal status. She concludes that whether we accept or reject computers will depend on superficial factors concerning the physical similarities between us.

Consciousness Argument: Boden considers that the notion of *self-consciousness* is important in the sense that self-reflective evaluation is crucial to her notion of transformational creativity. Furthermore, she argues that this self-reflection can be modelled in computational terms. On the contrary it is her view that *phenomenal consciousness* is not obviously essential to creativity and furthermore that the state of our understanding of this phenomenon at present prevents us from determining whether anything is or is not conscious.

3 Commentaries from *BBS* 17:3 (1994)

Of the 28 peer commentaries in this issue of *Behavioural and Brain Sciences* I have chosen to include only those which I found to provide enlightening discussion of important issues relating to the study of creativity. Furthermore, I have tried to restrict the summaries to those points on which the authors go beyond the discussion presented in TCM.

3.1 Can AI Explain Age Changes in Literary Creativity?

? picks up on Boden's emphasis of expert knowledge in creativity and argues that this characterisation cannot explain age differences in age peaks for creativity across domains. She argues that while Boden's approach would predict the late age peak in historical fiction (since more types of knowledge need to be manipulated) the emphasis on expert knowledge cannot explain the young age peak in maths and lyric poetry. She suggests that changes in cognitive processes, such as the decline of short-term memory, may be involved in the decline of creativity in such areas. Finally, it is argued that future models must address the role of different cognitive processes in different creative tasks and be able to model inter- and intra-individual differences in creative productivity.

3.2 What is the Difference between Real Creativity and Mere Novelty

Bundy (1994) considers Boden's "specific thesis" that what distinguishes while "real creativity" is the "mapping, exploration and transformation of conceptual spaces", "mere novelty" is the generation of a novel object from an existing conceptual space. He considers it paradoxical that the proof of open conjectures by a resolution theorem prover by brute force methods is regarded as an act of mere novelty in Boden's theory while a human who proved the same open conjectures would have been considered creative. Bundy proposes a complexity requirement as a solution to this paradox - generation from an existing conceptual space may be considered creative if the space is large and complex and the generation comes from little explored part of that space. The complexity criterion has a place in transformational creativity as well: simple changes to existing theories are less creative than more radical changes.

Bundy suggests that transformation is a kind of generation - but at the metalevel. "Thus the 'real creativity' of transforming conceptual spaces is just the 'mere novelty' of generating from an existing conceptual space, but at the metalevel. Noting that declarative symbolic representations (as opposed to procedural or subsymbolic ones) can readily be viewed both as a generative procedure and as a data structure, it is suggested that creativity might consist in the "representational redescription" of nondeclarative representations or the invention of transformational metagrammars. However, Bundy warns that it is usually a mistake to view any one aspect of an intellectual process as the key with others playing a supporting role. Creativity is more likely to emerge from the interplay of several relatively mundane processes.

Bundy also adds a self-reflection requirement for the assessment of creativity: "'Mere novelty' may arise as the unreflective generation of new objects from an existing conceptual space. 'Real creativity' may arise when that generation involves some aspect of self-reflection, that is, the simultaneous reasoning about the generation process at the metalevel." Finally, he believes that creativity is not a *natural computational kind*, it corresponds to particular aspects of many different kinds of computational processes, and therefore there can be no general computational explanation.

3.3 Analogy Programs and Creativity

Burns (1994) examines two types of analogy programs discussed by Boden:

1. Those designed to match structures of source and target analogues which are domain general (e.g., ACME, ARCS, SME).
2. COPYCAT: a special purpose program for solving letter string analogy problems which can change the structure of its representation of the problem.

Burns agrees with Boden that the ability to rerepresent the problem during its resolution is an important feature of creative thought. However, he argues that the "slipnet" in COPYCAT (which is initially the same for each problem) is not so different from the initial settings and subsequent changes of the weights in ACME's constraint satisfaction network. Furthermore, he notes that given information equivalent to COPYCAT's slipnet, ACME should be able to solve problems in the domain of letter-string analogies. The extra generative power of COPYCAT is derived from procedures specific to solving letter-analogy problems while ACME is based on the general principles of analogical problem solving. "Flexibity in representation is important but we need to exercise care in characterising the ways in which programs can exhibit such flexibility."

Finally, Burns notes that most of the programs described in TCM deal with generation rather than evaluation. However, realising the importance of an idea is often the key in the creative act since a creative act can rarely be analysed to the final goal state. Therefore, for a computer to be truly creative it will need to recognise creative answers[2].

3.4 Creativity, Combination and Cognition

Defining combination theories as those in which "creativity involves novel combinations of old ideas" Darnall (1994) agrees with Boden that these theories do not tell us which structures in the defined space are novel or valuable or how find such structures. However, he argues that these criticisms apply to Boden's theories of improbabalist (exploratory) and impossiblist (transformational) creativity as well [3].

[2] and promising intermediate steps towards those answers.

[3] In fact, he claims that Boden's theory is a combination theory which I disagree with since neither explorational nor transformational creativity specifically imply the combination of old ideas in new ways.

Dartnall also raises the symbol grounding problem noting that if the generative system is grounded then we have no means of avoiding an infinite regress) while if it is not then infinite regress of meta-structures.

Dartnall considers counter-examples to combinationism in the arts:

> "There is no significant sense ... in which Verdi's Requiem, or *Hamlet*, are combinations of previously existing elements or ideas."

He believes that the reason combination theories are often held to account for such phenomena is due to a confusion with *recombination* theories which say that creativity is the reconfiguring or recombination of whole structures (which he believes is trivially true).

Dartnall concludes by criticising "static, text-based" models of cognition, in which a fixed representational base of ideas is combined according to fixed rules, favouring the dynamic, developmental theory of cognition provided by the RR hypothesis. He argues that this theory is very different from Boden's notion of mapping conceptual spaces in that it describes how the conceptual space itself is generated.

3.5 Goals, Analogy, and the Social Constraints of Scientific Discovery

Dunbar and Baker (1994) consider Boden's theory of creativity within the domain of scientific discovery and discuss four issues.

First, they argue that report that their research shows that distant analogy is used only in the explanation of concepts rather than in their discovery. Rather close analogies from within the same domain are used to suggest new hypotheses and theories.

Second, they have found that subjects often generate new conceptual spaces in situations when they switch goals to focus on surprising and unexpected results. Thus, they argue that current goals place important constraints on the generation and searching of conceptual spaces.

Third, they criticise Boden's use of anecdotal accounts to support her arguments concerning the role of association and connectionism in explaining discovery and insight. They report evidence that subjects can be primed to make a discovery with no awareness of the conditions (the prime) that made that discovery possible. Furthermore, they found that subjects often generated incorrect post hoc hypotheses about how they made the discovery. The same seems to be true of "real" scientists at work[4] and Dunbar and Baker conclude that too much research in creativity is based on introspective evidence.

Finally, Dunbar and Baker bemoan the lack of discussion of the social context of cognition in TCM. They have found that in research groups where different individuals have different types and degrees of knowledge the computations are distributed over a group of individuals. They

[4] although this conclusion is itself supported by anecdotal evidence!

argue that the question of how computers can change their representations can be answered by modelling groups of interacting agents each with different knowledge bases.

3.6 Creative Thinking Presupposes the Capacity for Thought

Fetzer (1994) considers two issues in his commentary. The first, concerns the use of the word "impossiblistic" to describe transformational creativity. That which a sentence describes may be impossible in four different ways:

1. *Logical impossiblity:* because such descriptions are self-contradictory (e.g., a round square).
2. *Nomological impossiblity:* because its occurrence would violate laws of nature (e.g., a causal process faster than the speed of light).
3. *Historical impossiblity:* because it has already been done before (e.g., a novel act which has been done before).
4. *Psychological impossiblity:* because it has been psycholocolgically inconceivable up to now (e.g., the imagination of relative temporal relations would have been impossible before Einstein).

Therefore, Fetzer criticises Boden's use of the term "impossiblistic" as misleading when she only had the final kind of impossibility in mind.

The second issue raised by Fetzer concerns whether creative thinking can be understood as a computational phenomenon. He considers three arguments that it cannot:

1. The ability for creative thought implies the ability to *think*. Fetzer criticises Boden for failing to distinguish the concepts of meaning *for a system* and meaning *for the user of the system*. He argues that nothing in her account establishes that computers are capable of thought (in fact that the issue is not even addressed).
2. Fetzer believes that while it may be possible to model*reasoning* in computational terms this may not be the case for other types of thought (e.g., dreams). He criticises Boden for her use of "subtle equivocation between *reasoning* and *thought*."
3. Fetzer emphasises the distinction between *how-possibly* and *how-actually* which he claims Boden has failed to acknowledge. He argues that this obscures her "excessively expansive conception of computational procedures."

Fetzer concludes that if creative thinking involves thinking psychologically impossible thoughts, then the creative agent must be able to think. Therefore, unless computers are capable of possessing psychological states they cannot possess the capacity for creative thought.

3.7 What about Everyday Creativity?

Noting that everday examples of P-creativity often occur within groups of interacting individuals, Flor (1994) argues that these kinds of creative ideas can only be understood in relation how the resources (knowledge, mechanisms and so on) are distributed and coordinated in the entire multi-agent system. Using the example of two computer programmers working on a problem Flor notes that actor-external influences such as verbal-redirection by other agents and the display of information on the monitor are instrumental in determining the reaching of a solution.

3.8 Creativity, Madness and Extra Strong Mints

Fulford (1994) notes that creativity and delusional perceptions in schizophrenics share a certain phenomenolgical similarity: there is incubation, a trigger and the sudden emergence of a novel organising theory. Furthermore, Fulford characterises delusional thought as H-novel and transformational in Boden's terms.

Of course, there are important differences between the creative insight and the psychiatric delusion but Fulford argues that psychiatry may offer important evidence on the ways in which rational thought may fail. He suggests that the obvious solution in Boden's account is that the delusional individual fails to positively evaluate the delusions is countered by the existence of delusions which actually concord with the facts (e.g., the hypochondriacal delusion of having mental illness[5].

Rather, Fulford characterises delusions as "unfounded", rather than false, beliefs which he notes is consistent with Boden's emphasis on the relativity of creativity to a given set of generative rules. However, since no disturbance of cognitive functioning has yet been found to be specifically associated with the formation of delusional beliefs suggests that the conceptual space within which delusional beliefs work includes motivation and emotion as well as cognition. In particular, he argues that delusional beliefs seem to be a disturbance of *practical reasoning* rather than cognitive function and that accounts of creativity should the consider the conceptual space of practical reasoning as well as that of cognitive functioning.

3.9 The Birth of an Idea

Gabora (1994) concerns herself with the comparison in TCM of the generation of novel ideas to the generation of biological novelty. In particular, she notes that both ideas and genomes are patterns which evolve and argues that this analogy might help explain the introspective experience of the sudden emergence of an idea (without any effort on the part of the creator) since the process of replication acquires its own momentum[6]. Furthermore, Gabora

[5] Think about it!

[6] I don't see why the fact that evolutionary processes have their own momentum should have any bearing on the question of whether they are

considers an analogy between the spawning of ecological niches from ones which are already full and generation of new conceptual spaces from old ones to be fruitful. This not only builds a conceptual framework within which the new space makes sense but also creates a need for the new space or "a viable niche for it to be born into."

However, Gabora warns that the evolution of ideas and the evolution of species are not subject to the same constraints and mechanisms. She cites the following arguments in TCM which are based on a failure to appreciate these differences:

- The claim that GAs can help how distant elements can be plausibly combined is misleading since the generation of variation in biological evolution is largely random (its success being due to massive parallelism[7]) while the cultural evolution of ideas is based on the detection and exploitation of regularities.
- The claim that co-adapted genes provide a model of how potentially related ideas are not always located close together in the conceptual space confuses the physical and semantic spaces. Gabora suggests that better analogies would be:
  - between co-adapted genes and the physical distance between parts of the brain encoding different ideas
  - between superficially different ideas and the functionally different tissues which have a common embryological origin.
- While Gabora agrees with Boden that the application of a variation inducing operation does not guarantee success she notes that cultural evolution has the advantage of mental simulation

Finally, Gabora laments the lack of discussion of group creativity in TCM.

3.10 Art for Art's Sake

Contrasting Boden's account with the view that creativity is simply "the minds best work", Garnham (1994) argues that while the theory fares well in the scientific domain it is less appropriate to the arts. His reasons are the following:

- In the arts, the creation of a new style (transformational creativity) is not necessarily expected or valued over creation within an existing genre (exploratory creativity).
- Whereas in science the value of a theory often lies in its promotion of a new way of thinking about a problem (transformational creativity), the value of an artwork is more often related to the aesthetic response it evokes (a work of art does not *have* to introduce a new way of thinking to move us.
- The value of a work of art is partly independent of the artist's psychological processes in producing it (it depends also on the critical interpretation of a particular individual which may bear little relation to the artist's intentions).
- The relation of particular works of art to their "style" is much less important in the arts than in science (to an extent each artwork stands on its own).

Garnham notes that these issues are also pertinent (although to a lesser degree) in scientific creativity.

He proposes that any theory of creativity must account for "how artists create significant works within a style (or 'way of thinking')". Noting that such explanations are inevitable historical he cites Johnson-Laird (1991) as an example of a cognitive scientist who has attempted to define the rules of an artistic genre (jazz improvisation) without considering historical factors. He argues that such cognitive theories can tell us nothing about how new genres (sets of rules) are created, nor why one piece within a genre is "better" than another.

3.11 Creativity Theory: Detail and Testability

Gilhooly (1994) notes that the claim that creativity (as a psychological process) is a cognitive phenomenon which can therefore be understood in computational terms will be uncontroversial for cognitive scientists. The difficult and controversy-provoking issue is the proposal of mechanisms for creative processing and Gilhooly identifies the following issues. Particularly pressing is the problem of defining and describing the domain of creative processes (the type of task) and the scale of the task. Gilhooly suggests using concepts from problem solving such as large vs. small scale, well vs. poorly defined and knowledge rich vs. knowledge lean to structure the task space and identify appropriate mechanisms for searching it.

Gilhooly considers Boden's approach as an advance over combination theories which underemphasise the structured nature of knowledge. He summarises her proposal as having long-term knowledge stored in an associative network which (unconsciously) throws up unusual associations, combinations and analogies (inspiration) and a serial, symbolic system (conscious) which engages in steady searches through the conceptual space (preparation and verification)[8].

Gilhooly criticises Boden for the vagueness of her proposals for a cognitive architecture for creative cognition. Such general proposals are difficult to test and therefore we should develop more specific models for laboratory sized tasks which can then be tested using empirical psychological methodology. He suggests that rarity, slowness, representation and expertise are issues that will constrain such models.

conscious or not.

[7] plus the odd billion years here or there.

[8] I'm not sure that Boden explicitly argues for this kind of architecture.

Regarding expertise, Gilhooly suggests an avenue of research towards finding a mechanism underlying the observation of different productivity peaks in different subjects (better defined domains show earlier peaks than less well defined ones). Networks representing well-defined knowledge might develop strong but sparse connections among the elements relatively quickly while those representing ill-defined knowledge develop weak but more profuse connections and allow unusual associations to be produced for longer.

3.12 The Historical Basis of Scientific Discovery

Grasshoff (1994) argues that Boden's discussion of examples of scientific creativity often commits what he calls the *historical fallacy*. This occurs when the *justification* of a proposition (is conflated with its *genesis*. He notes that the are often very difficult to separate; very soon after a new hypothesis has been generated, the reasons which lead to its formulation may have been forgotten while justifications for a recent discovery are easily quoted as those which lead to discovery.

He provides two examples of the historical fallacy in TCM. First, he criticises Boden's discussion of Pappus's proof of Euclid's proposition 1.5 on the basis that it involves justification not genesis (he also argues that her exposition of Pappus' proof is incorrect and that "having lost the historical foundations of her Pappus argument, [her] objections to the significance of the computer model fail as well"). Second, he argues that the discussion of BACON can only justify Kepler's hypothesis not be a model of its genesis since its knowledge is not a faithful replication of that available to Kepler.

Grasshoff concludes that computer models of scientific discoveries can only provide explanations of cognitive phenomena if they have a firm base of historical evidence concerning the problems, motivations and knowledge which guided the original discovery.

3.13 Conscious Thought Processes and Creativity

Ippolito (1994) disagrees with Boden's criticisms of the unreliability of reports of conscious thought processes and "her corresponding contention that it is probably unconscious thought processes which constitute the lion's share of creative thinking." Her research on introspective reports suggests, on the contrary, that conscious processes (in particular perceptual rehearsal) can help overcome the subconscious biases of our unconscious perceptual processes. She argues that the conscious development of expertise and preparation for a creative act should be fundamental components of our models of the creative process.

Ippolito concludes by arguing that any hybrid computational model of creativity must detail how rules are consciously modified, how these alterations affect automatic unconscious processes and how conscious and unconscious processing interact.

3.14 The Generative-Rules Definition of Creativity

O'Rourke (1994) criticises Boden's definition of P-creativity as the generation of ideas which cannot "be described and/or produced by the same set of rules as are other, familiar ideas" on the following grounds:

- It depends on the generative rules model of mental activity (O'Rourke prefers a connectionist account).
- The distinction between familiar and unfamiliar ideas is unclear.
- The definition of what constitutes a generative rule is unclear.
- Boden is inconsistent: some of her examples of creativity are simply solutions generated from the same conceptual space.

O'Rourke also raises the following points: first, in terms of motivation the ability to rivet attention on a problem is important; and second, "we cannot expect a computer who has not experienced love and grief to create sonnets that touch us as deeply as do Shakespeare's, but we can expect them to exceed our own creativity in domains less dependent on the human experience."

3.15 Computational Creativity: What Place for Literature?

Pind (1994) considers the application of Boden's thesis to the domain of literature. He believes that the notion of exploring conceptual spaces plays a small role in literature. He argues that literature again and again returns to the same themes (rather than trying to transform or solve them). "Each age will return to these themes where facile heuristics('consider the negative') are hardly a spur to creativity[9].

Pind also criticises Boden's discussion of whether H-creativity is predictable *in principle* suggesting that if something has been predicted then it has been created[10].Pind criticises Boden's use of surprising sentences as examples of creativity by presenting results from his research which suggest that very few sentences in actual text are the same. Finally, Pind criticises the loose manner in which Boden uses the word "computational" and her use of qualifications such as "in principle".

[9] Surely the conceptual space in this case is the space of possible ways of expressing these themes and exploring the issues surrounding them rather than the space of possible themes.

[10] I think the point about predictability is that if a system is predictable then it is deterministic and can be modelled in a computer program.

3.16 Imagery and Creativity

Rehkämper (1994) bemoans the Boden's negative treatment of analogical representations and mental imagery. Defining mental imagery as "the mental invention or recreation of an experience that in at least some respect resembles the experience of actually perceiving an object or event either in conjunction with, or in the absence of, direct sensory stimulation", he argues that relatively well understood feature of cognition is an important part of the creative process. Furthermore, he feels that her mathematical problem (the rope tied between two buildings) depends on mathematical knowledge and does not demonstrate that the use of imagery can make it harder to find a solution.

Rehkämper furthermore believes that the use of mental imagery is apparent in Boden's discussions of Pappus and Kekulé. He argues that the use of mental imagery gives us freedom to experiment with constraints.

3.17 Creativity: Metarules and Emergent Systems

Rowe (1994) examines three programs which satisfy the criterion of "impossiblist" creativity: EURISKO, COPYCAT and some GAs. Although EURISKO is the only one of these which fits the description with any ease Rowe notes that it failed to go any further than its predecessor AM in the domain of number theory. He suggests that this is because any metarule can be combined with the rules whose application it governs to give more standard rules. For example:

M1: if X then use rule R1
R1: if A then B

can be reduced to:

if X and A then B.

"At best metarules might provide templates for expressing a number of rules in a concise form."

He then discusses COPYCAT and GAs which he notes are decentralised, stochastic and bottom-up. He argues that the generation of structure and regularity as emergent phenomena arising from the interaction of low level structures, without any central control, gives these models a greater degree of flexibility. Furthermore, he notes that these models fit in well with Minsky's model of thinking as arising through the interaction of large numbers of agents.

3.18 Respecting the Phenomenology of Human Creativity

Shames and Kihlstrom (1994) are disappointed with Boden for excluding important aspects of creativity which do not fit a computational account. They take introspective reports as one example of such aspects and criticise Boden for using introspective reports when it suits her (Seurat) and criticising them when it does not (Mozart, Coleridge).

They cite experimental work which shows the involvement of such factors as effortlessness, absorption, imaginative involvement, intuition, incubation and insight in the creative process and note that these all correspond closely to phenomenological reports of creativity. On the basis of these results they suggest that intuition provides the motivation for creative work while insight provides reward. They suggest three possible computational mechanisms for incubation and argue that only empirical data can allow us to decide between them.

In conclusion, Shames and Kihlstrom propose that meaningful theories of creativity should address the phenomena of intuition, incubation and insight and explore the relationships between emotional, motivational and cognitive aspects of the creative process.

3.19 Individual Differences, Developmental Changes and Social Context

Simonton (1994) considers three issues which he feels are neglected in the literature on creativity and yet are of fundamental importance to our understanding of its nature.

1. What enables particular individuals to *consistently* generate creative output or more generally what accounts for the individual differences observed in this respect? Simonton suggests looking at differences in intelligence, motivation, values, cognitive style and genetically-based traits.

2. How does potential and actual creativity change over a lifespan? In particular, what underlies the characteristic inverted U-shaped curve in productivity and why do peaks occur earlier in some domains than others?

3. What is the impact of the cultural, social and political environment on the origination and expression of new ideas?

Simonton is disappointed that cognitive scientists typically ignore these questions and points to two reasons why these issues are important for any cognitive theory of creativity:

1. A fuller appreciation of these phenomena may impose important constraints on the most plausible models of the creative process.

2. By attending to the total complexity of creative behaviour cognitive scientists may become more aware of unnecessary self-imposed constraints which have hitherto "shackled their inquiries." Simonton argues that creativity may sometimes emerge directly from the interaction of individuals (H-creativity may stem from Group-creativity not P-creativity).

3.20 Can Computers be Creative, or even Disappointed?

Sternberg (1994) considers the four lovelace questions in turn. He concludes that: the first "would seem to be answerable in the affirmative by anyone who has even the slightest respect for cognitive science"[11]; the second "also merits an affirmative answer, but so what? . . . Fooling people into believing a computer is creative is possible, but is it interesting?"; and that the third Lovelace question "also deserves a positive answer . . . certainly a computer can be programmed to recognise statistically novel output[12]."

Thus, Sternberg believes the really important issues surround the fourth Lovelace question and he gives three reasons why he doubts that computers could be truly creative:

1. *The creative process:* current programs cannot model the identification of important problems and then defining exactly what these problems are (pattern recognition).
2. *The creative product:* current programs typically recreate old discoveries or otherwise produce good but not outstanding products. Furthermore, the generation of a creative product by a computer would not necessarily imply that it embodied creative processes (it might have found the solution through brute force by virtue of having an extremely fast processor).
3. *The creative individual:* computers don't go through the same kinds of experiences as humans do in forming "purposeful schemes and metaschemes for creative work that unfold over time."

3.21 The Empirical Detection of Creativity

Noting a similarity between Piaget's conception of qualitative change in cognitive development and Boden's theory of creativity as the reorganisation of conceptual spaces, van der Maas and Molenaar (1994) argue that one criticism of Piagetian theory that it lacks empirical criteria for the detection of structural change can also be levelled at Boden's account of creativity. Consequently, they suggest a mathematical analysis of a creative system's architecture and procedural properties in terms of the theory of self-organisation in non-linear dynamical systems.

This in turn would allow a classification of all structural changes in terms of the eight criteria, catastrophe flags, which classify the output of chaotic systems (and require knowledge only of the system's output). These flags are: sudden jump; bimodality; inaccessablity; hysteresis; divergence; anomalous variance; divergence of linear response; and critical slowing down.

As an example of the approach van der Maas and Molenaar describe its application to the acquisition of conservation. In a study of children aged six to ten they found that a quarter of the sample showed clear sudden jumps from non-conservation to conservation. Analysis of the data "showed clear evidence of bimodality and inaccessibility." In the case of computers these techniques could be used to analyse behaviour during training of neural networks to infer structural self-organising changes in its internal representation of the problem.

[11] This answer has no bearing on the important question of whether the methodologies of cognitive science are appropriate for the study of creativity.

[12] But there is much more to creativity than "statistically novel output"!

3.22 The Creative Mind versus the Creative Computer

Weisberg (1994) considers three issues which he believes Boden must address before "she can begin her task in earnest." These concern representation, the first Lovelace question and issues raised in the study of human creativity.

Weisberg feels that Boden has not made it clear "how one determines, in a principled manner, when a product is an exploration of a conceptual space or mere novelty ... Boden has not specified the criteria for differentiating between using some generative system in its ordinary way and going beyond it." Furthermore, he criticises the use of generative rule systems as models of cognition, preferring a connectionist account. Finally, Weisberg considers the notion of positive evaluation. He argues that since value is a socially defined construct subject to change for non-cognitive reasons it should be excluded from the definition of creativity. He prefers the definition of creativity as the production of goal-directed novelty and of *genius* as creativity which is positively evaluated by some social group.

Weisberg also feels that Boden does not take account of issues raised in the psychological study of creativity. Taking analogy as an example, he notes that remote analogies are rarely used in scientific discovery. Furthermore, he argues that computer models take no account of how difficult it is for humans to make remote analogies. Thus he believes computer models must be brought into closer correspondence with the data from studies of human creative thinking.

3.23 Machine Discoverers: Transforming the Spaces they Explore

Żytkow (1994) points out that the distinction between "improbabalist" and "impossiblist" creativity breaks down in the case of computer programs which yield "merely the ideas that belong to their combinatorial closures." Furthermore, he argues that simply enlarging the search space does not make an agent more creative. Rather he suggests a criterion of effectiveness which measures the amount of search it conducts before it makes a discovery. Constraints alone are not sufficient however; a further criterion is the judicious use of operators in selecting next states in the space. This also reduces the amount of computation required to make a discovery and is typically very hard to design.

3.24 Boden's Response: Creativity: A Framework for Research

Boden (1994) divides the points raised in the book reviews into six categories which we consider in turn. I have chosen to focus on those issues raised which prompt Boden to go beyond the material already covered in the TCM or to consolidate that material.

3.24.1 Issues of Definition

A natural kind? Several reviewers point out that creativity is not a natural kind (e.g., Bundy, 1994) which means that no single scientific theory can cover all cases. Boden allows for this in four ways:

1. Positive value is a crucial part of her definition of creativity and is neither definable in scientific terms nor constant across cultures, historical periods, social groups or even individuals.

2. Creativity is the product of many interacting cognitive abilities whose weighting depends on the task domain.

3. She distinguished two types of creativity: combinatorial and exploratory-transformational (impossiblist).

4. There are many different strategies or heuristics for exploring and transforming conceptual spaces. Some of these are domain general while many more are domain specific. "Because of the abundance of exploratory-transformational heuristics ...different instances of creative thought are explicable in different ways."

Exploratory Creativity Boden points out that predictability is a complicated issue - while most cases of creativity will not be predictable in practice they may be in principle (R-unpredictable)[13].

Definition Boden notes that she "should have called the noncombinatorial type of creativity 'exploratory-transformational' rather than 'impossiblist' – truly impossibilist creativity being a special case." This recognises the importance of purely exploratory creativity

Degrees of Creativity Boden agrees with Weisberg (1994) that we cannot always say definitively (in a yes/no manner) whether an idea is creative. She notes that part of the problem is the socially conditioned nature of evaluation but believes (contra Weisberg 1994) that to remove this feature would mean that our definition of creativity would no longer coincide with the "layman's" notion of creativity. In terms of P-creativity we have to consider the relevant psychological context of the generation - "what is 'creative' in light of one of the many structural aspects involved may count as 'unimaginative' in light of the others." This is why "a proof (by person or computer) of theorems ...would be considered less (sic) creative if it involved brute force methods, simple syntactic heuristics and millions of intermediate formulae" (Bundy, 1994). Therefore, rather than think of creativity as varying along a single dimension she prefers to think of it "being located at various points within richly articulated computational structures, allowing for qualitative as well as quantitative variety."

The individuation of conceptual spaces Boden considers two issues concerning the identification of conceptual spaces. First, is the problem of how to "count" spaces: "are Baroque and Romantic music distinct spaces, or merely different regions of the one space of tonal music?" The second issue concerns the question of whether domain-specific operators for exploring and transforming a space should be included within it (Bundy, 1994; Rowe, 1994). Boden considers that these questions "can only be answered after we have defined a wide range of putative spaces and heuristic operators and that even then our answers cannot be definitive since "we (and even the experts themselves) often do not know what metarules are being used, nor what conditions make them appropriate." [14].

Measures of complexity Boden agrees with the suggestion of including a measure of complexity in the definition of creativity (Bundy, 1994). She would further include an assessment of the relative depth of change in the conceptual space which is represented by the artefact – a means of distinguishing between a "fundamental transformation" and "superficial tweaking".

3.24.2 Evaluation

Positive evaluation Boden compares AM/EURISKO, which use interestingness criteria to select a subset of generated ideas for further exploration, to AARON which uses procedures to ensure that it never generates an aesthetically unbalanced drawing. Positive value is a fundamental criterion in her definition of creativity and she agrees with Burns (1994) that any computer model of creativity needs its own sophisticated evaluation function. In particular, she notes that since value can change between social groups and over time the evaluation function must be dynamic as well.

Why do we value works of art or science In response to Garnham's question, Boden suggests that while it may be possible to find general psychological mechanisms (symmetry, simplicity and curiosity) many answers to this

[13] It would seem then that predictability is not a useful element in a definition of creativity. This would imply, in turn, that the issues of determinism, free-will, intentional behaviour and consciousness are also best left out of a definition of creativity.

[14] If we cannot, in principle, know what metarules are being used doesn't this undermine Boden's thesis that computer models can help us understand creativity.

question will be domain-specific drawing on detailed and culture-bound knowledge.

Motivation Boden responds to those authors who criticise computer models of creativity on the basis of their lacking an emotional life (Simonton, 1994; Sternberg, 1994).

- The importance of computer models is that they allow us to test our computational theories about motivations and emotions not whether they really have emotions (e.g., Lovelace question 1 not 4).
- Cognitive science is not the study of cognition (as opposed to emotion and motivation). It is the computational study of psychological phenomena (including both cognition and affect).

Creativity and delusions Boden notes that Fulford (1994) also suggests the study of motivation and emotion in creativity from an analogy with research on schizophrenic delusions. She suggests that there are two pertinent questions:

- "Why was X moved to produce novel ideas when Y was content to reproduce the familiar?"
- "Why was X moved to produce these novelties rather than others?"

3.24.3 The Lovelace Questions

Number one Replying to the comment that current computer models of creativity are weak at identifying important or interesting problems (Sternberg, 1994) Boden suggests that a map of the conceptual landscape in which the important dimensions of change and locations are identified. She notes, however, that many H-creators inherit their problems from their peer group. She also agrees with Shames and Kihlstrom (1994) that computer models, like any scientific theory, must be informed by empirical data (although they will always remain underdetermined by the data).

3.24.4 Connectionism

Boden considers arguments that her treatment of conceptual spaces as generative systems is undermined by the development of non-symbolic AI (Weisberg, 1994; O'Rourke, 1994). She argues that classical AI offers the best models of the cognitive regularities in conceptual spaces since neural networks are weak at modelling hierarchy and self-reflection and are also crucially dependent on their representations.

3.24.5 Individual Differences/Testing

Boden agrees with Simonton (1994) that the huge differences in creative output between individuals may be largely due to motivation. Greater motivation may, for example, allow one to withstand the the critical reactions of those with more conventional ideas. Regarding the variation in productivity peaks between domains Boden suggests that it depends on the degree of detailed knowledge (or abstraction) required in a discipline. She ventures no suggestions to account for the age-related decline in creativity.

3.24.6 Miscellaneous Topics

Analogy Boden responds to Burns (1994) that, while she agrees with many of his arguments concerning COPYCAT and ACME, ACME lacks the ability to effect lasting changes in its representations of a problem and COPYCAT can more readily produce answers that violate structural constraints. She also argues (contra Dunbar and Baker (1994) that remote analogies are sometimes used in scientific discovery but suggests that this may be more often the case in scientific revolutions than in normal science. Furthermore, she suggests that, if we accept a group-based account of discovery, then the use of remote analogies to communicate theories to peers is a means by which they enter back into the process of discovery again.

Mental imagery Boden answers Rehkämper (1994) by noting that while mental imagery is often very important to the creative process it can, since it is such a natural means of thinking, block creativity[15].

Literary creativity In reply to Pind (1994) Boden suggests that literature explores many different conceptual spaces (human motivation, betrayal and so on) as well that of literary style.

4 Reviews from *Artificial Intelligence* 79 (1995)

4.1 Too Many Ideas, Just One Word: Haase (1995)

H-creativity vs. P-creativity: replace it with "a series of distinctions varying with the size of the community over which novelty is defined." This systems perspective highlights two issues:

- The social embeddedness of creativity.
- The inadequacy of "creative" and "novel" to describe innovations in this more complex space.

Social/historical context: the creativity of an idea depends crucially on that which has gone before - the culturally defined conceptual space which the creator inherits. This has implications for the hand-coded contexts which

[15] This is just a specific example of the notion that the representation scheme can either hinder or facilitate problem solving.

putatively creative programs are given. In particular, "Understanding the social context for significant discoveries allows us to understand both the significance and the foundations of fundamental innovations."

Invention and exploration: "If I am reading Boden correctly, representational spaces are formal generative systems (games) which are further organised by other generative systems (maps). And for Boden, radical creativity lies in the map map-making and not the map-following." Haase notes that we can view such a system as a continuum where a succession of representational space are embedded within some surrounding context. Creativity is then characterised as the motion between these embedded contexts. With this in mind, Haase highlights two relevant issues:

- If we follow the map, our searches and explorations will be more fruitful than if we play the game without it.
- There are some things in the game which we cannot reach via the map.

The connection of creativity with the transformation of representations (maps) again highlights the dependence of any program on the creativity of the programmer in designing a representation scheme. Representational creativity is a central issue.

Towards a better language "The single distinction *creative* is too coarse to describe the inter-representational relations involved in complex generative systems." Haase suggests the following steps:

- Multiple representations.
- A language for describing whether a representation is good for a particular purpose, tradeoffs between different representations and the relations between different representations.
- Much of the power of a given representation lies in its negative function (what things are not worth considering). How then to redefine those functions?
- Creative insight is the mapping (by loose analogy?) of one set of constraints to another which will allow the problem to be solved. This mapping may not preserve the characteristics of the any features of the solution in the old "map" or even look like a solution to the old problem. However, having solved the new problem "you no longer have a compelling reason for solving [the old one]".

These issues are central to the eventual maturity of AI "since intelligent program depend so vitally on the character of their representational spaces."

4.2 Book Review: Lustig (1995)

An irate attack by a musicologist and historian of music on TCM. Boden's response to this review mirrors my own. "My disappointment at Lustig's review lies in the lost opportunity for constructive discussion and development of the musical examples I presented. ... [his refusal to do so], whether because of an unargued scepticism about computational approaches or because of the musical amateurism of the author reporting them, is unhelpful" (Boden, 1995).

4.3 An Unfair Review from the Perspective of Creative Systems: Perkins (1995)

Perkins reviews the TCM from the viewpoint of "creative systems" which he defines as "any systems that over time yield adaptive novelty, that is, unexpected outcomes that are nonetheless functional in context." He considers four properties of problem spaces which can make resolution difficult and Boden's treatment of them:

- *Rarity:* acceptable (and in particular genuinely innovative) solutions are rare in the possibilities afforded by the space. Perkins considers that Boden addresses this point in her discussion of heuristics but argues that massive search is often used in science and engineering.
- *Isolation:* adaptive solutions are isolated in some way: they are separated from other areas of promise by regions of low value or they require a change of representation to become reachable. Perkins argues that the notion of transformation of conceptual spaces addresses this point but argues that fundamentally creative results may result from uncreative mechanisms (in the rule change sense) and gives biological evolution as an example[16]
- *Oases:* Local maxima/minima - some regions of moderate payoff are hard to leave. Boden does not explicitly address this concern, in Perkins' view.
- *Plateaus:* No indication of promising directions of search. Once again Perkins finds no evidence of this issue in TCM.

Perkins finally considers whether creativity amounts to no more than good heuristic problem solving. He notes two arguments against this proposition: first, creative search yields fundamental novelty; and second, the creative process employs heuristics which change the rules defining the conceptual space in order to achieve this novelty. He argues that those attributes of conceptual spaces

[16] This seems to me to be a contradiction in terms: either you consider the process of reproduction and mutation to be an exploration of the space of possible genomes and the result to be or you consider the evolution of new genomes to be a transformation of the space of possibilities. Either way the creativity of the solutions may range from trivial to dramatic. Furthermore, the main problem with attributing creativity to evolution would seem to rest on the fact that it is a non-intentional and non-teleological system.

described above define further what creative problem solving requires:

> "Problems are hard *creatively* when the circumstances mask novel solutions. Search processes are creative when they make the moves they need to make to unmask those solutions."

4.4 Understanding the Creative Mind: Ram et al. (1995)

It is suggested that Boden's is lacking in the following ways:

- There is a paradox in the notion of impossiblistic thought.
- The account is more descriptive than computational.
- What is the overall process? What roles do the suggested mechanisms play? How do they interact? Do they use the same representations? etc.
- What distinguishes creative processes from others both within individual and between individuals?

Transformational creativity: Ram and colleagues highlight a paradox with the idea that fundamental creativity involves changing the conceptual space in order to generate something that couldn't have been generated before. If the structures required to change the space are already present in the creator's mind then this creative thought could have been generated before: "if one comes to a thought, it must have been thinkable". They note that the Boden's conceptual change is as elusive a term as creativity itself and that the possible spaces generated by the application of these meta-operators should be considered part of the thinkable.

Mechanisms: Ram et al. suggest five attributes which define the thinkable. These are based on their CBR model of creative design and are as follows:

1. *Inferential Mechanisms:* such as reinterpretation of as idea in terms of a different but familiar idea; visualisation/mental simulation; constraint relaxation and substitution in problem reformulation; constraint relaxation during memory search; relevance assessment in retrieval and evaluation; and explanation of anomalies in retrieval and evaluation.
2. *Knowledge Sources:* Innovation often arises when ideas from one culture are used in another. In particular, identifying a relevant domain, choosing the appropriate knowledge/strategies for transferral to the new domain and adapting/combining them to solve the new problem can be creative processes. Also knowledge redescription and abstraction may be involved.
3. *Task:* The task at hand greatly influences the the strategic control of the design process: choosing constraints/criteria to add to the design specification and selecting particular elaborations/adaptations of ideas.
4. *Situation:* design specifications and ideas are adapted to fit in with the materials available in the task situation (the physical environment and the context of current ideas).
5. *Strategic Control:* How to choose ideas to elaborate, constraints to relax, what subtasks to prioritise? Methods include: suspending criticism; noticing invariants and anomalies; try quick/easy solutions first; make nonstandard substitutions; applying strategies in non-standard situations; merging parts of solutions in non-standard ways; analogy to other situation; and problem reformulation. These are particularly important when "normal" strategies have failed to provide a solution.

Beyond the Thinkable: Ram et al. define the normal search space as "the space of the normal thoughts one would usually explore in a pragmatic context." They note that this may be different for different individuals tackling a certain task. Also that creativity is not a discrete concept. Finally, they outline three ways (based on the attributes listed above) in which individuals may go beyond this space:

- Transformation of knowledge (conceptual change).
- Application of new inferential methods (e.g., changing heuristics).
- Using different control strategies.

Finally, analysis of the task and situation influences the knowledge, inferential methods and control strategies that are available.

Social/historical context: The importance of the task and situation and the analogical use of ideas from another context points to the importance of social and historical context in creative thought.

4.5 The Engineering of Creativity: Schank and Foster (1995)

Importance: Schank and Foster identify four reasons why it is important to understand and explain creativity:

1. It is a natural phenomenon which deserves explanation. "Neurologists are very unlikely to come up with useful explanations for it. Most psychologists will be similarly ineffectual, wedded as they are to the method of controlled experiment on one side and overly vague psychodynamic theories on the other.

It seems clear that an understanding of human creative thought must come from AI and Cognitive Science[17]."

2. It is a "potentially fruitful research front" in practical engineering terms.
3. "It is closely tied to the problem of learning, which is one of the most serious hurdles for AI[18]."
4. A clear understanding of the creative process will put us in a better position to teach people how to be more creative. It is pointed out that Boden does not address this issue.

Kinds of Creativity: Schank and Turner are disappointed that although Boden considers P-creativity the more important concept most of her examples are, in their opinion, examples of creativity. They believe that a more fruitful approach would be to model normal, everyday P-creative insights. Their work involves the use of *explanation patterns* to associate unexplained events with explanations for previously encountered, similar events. When none of the retrieved patterns fit the new event, new candidate explanation patterns are found and the constraints of a candidate pattern are heuristically altered so that it applies to the current event. The implemented algorithm consists of five stages:

- Anomaly detection.
- Memory search for an explanation pattern.
- Attempt to apply explanation pattern.
- Tweaking of explanation pattern.
- Integration of new explanation pattern into memory.

Induction as Creativity: Boden's argument that since inductive algorithms such as ID3 can generate rules that no human expert had ever formulated before they can be considered to be creative is criticised for the following reasons:

- Phylogenetically primitive animals are capable of inductive learning.
- Inductive learning is a *I*nduction is weak method whereas creativity is "simply impossible without the application of knowledge." They note that the difficult (and creative?) part of the process involves asking the right questions and determining which features to attend to. It is argued that this process of feature selection is generally performed by humans, leaving ID3 to carry out "a simple inductive search." Therefore, induction may play a part in creative systems but cannot be the key mechanism.
- We are not entitled to call ID3 creative simply because successfully performs a socially useful function (it extends the capabilities of humans).

They conclude that "it is important not to confuse computer creativity with tools that aid human creativity or with the creativity of the designers of such tools."

Connectionist Creativity: Boden's discussion of connectionism as a potential mechanism for modelling the creative process. It is argued that:

- The features used as input fields to a neural network are hand selected by humans.
- Neural networks are inadequate wrt higher-order relations and sequential reasoning.
- Unconscious association does not necessarily imply a subsymbolic process.
- No evidence that connectionist models "have been successful at modelling the kinds of associations required for creative insight."
- Although biologically inspired, neural networks are not biological models. "The connectionist neural net is just another metaphor for understanding cognition."

Schank and Foster conclude that "connectionism seems destined in the long run to be relegated mostly to low level perceptual processes and simple pattern recognition tasks, and we consequently feel it is somewhat futile to look to connectionism for useful insights about creative insight."

Degrees of Creativity: Schank and Foster note that creativity is a continuous concept and consider the following issues that this point raises:

- This has important methodological implications (i.e., we can begin to work on moderate creativity rather than jumping into trying to model revolutionary creativity).
- The assessment of the degree of creativity of an insight depends partly on subjective factors such as the evaluator's experience, knowledge and values. Therefore, there can be no single decisive test for creativity.
- "How important is it that the internal processes that produce the output be completely faithful to our intuitions about the way humans produce a similar output?" Schank and Foster argue that humans evaluate creativity on the basis of external behaviour not internal processes[19]

[17] It seems clear to me that a full explanation of human creative thought (and indeed any phenomenon related to the mind/brain) must include explanations on a number of levels of explanation: the physical, cognitive and experiential. Furthermore, cognitive/AI theories of creativity must be informed by, and evaluated against, our understanding of human creative thought gained through controlled empirical experimentation.

[18] However, the importance of understanding learning itself comes under points one, two or four.

[19] However, it is likely that the importance of external behaviour is that it allows us to intuit or infer the internal processes.

- Computer programs may exhibit a degree of creativity even with no *understanding* of what it is they have produced.

Degrees of Value: Schank and Foster agree with Boden that value in the product of the creative process is a necessary but not sufficient criterion for creativity[20]. They go on to discuss the following points:

- By reference to the goals of the process: something is useful or valuable to the degree that it goes towards fulfilling one or more of these goals.
- Therefore, it is important to develop "a rich, detailed theory of the kinds of goals that determine the criteria by which new ideas are judged for usefulness and interestingness."
- We use the output of the program to refine this theory which is used by the program to criticise its own output. Finally, the output may be valued for its own sake "rather than for the sake of the theoretical refinements" that it suggests.

A Scientific Explanation: In conclusion, Schank and Foster agree that a "mechanical and, in fact, a scientific explanation of creativity is possible" and that this would enrich creative achievement not devalue it. They also provide the following suggestions for research:

- Prototyping should use real problems not toy ones.
- Attention must be paid to software engineering issues (e.g., scaling up from toy problems).
- No progress will be made if the focus is on theoretical research (developing "a better set of models for understanding and accounting for mental phenomena")[21].
- Tool building is the single most important activity in AI ("AI is not science: it is engineering")[22].
- Therefore, the question of how creativity is possible can only be answered by the development of programs that:
    - Model ordinary, everyday P-creativity.
    - are primarily based on the application of stored knowledge.
    - scrupulously address scale-up issues.

[20]Furthermore, the products generated should be consistently valuable.

[21]Equally, no progress will be made if we fail to rigorously study the object of our models, human creativity, and build models based on hazy, intuitive notions of what constitutes creativity.

[22]The motivations in AI vary between cognitive science and engineering

4.6 Book Review: Turner (1995)

Correctness of Definition: It is noted that the definition of creativity as transformation of generative structures does not cover those solutions which "violate our expectations of *where* in the problem space we are likely to find useful solutions."

Plausibility of Definition: Furthermore, he argues that the definition is refuted by experiments against the gestalt concept of perceptual restructuring which suggest that "restructuring knowledge may be easy compared to the task of operationalising the new knowledge."[23]

Consistency of Definition Turner considers that Kekulé (considering him as a whole) *could* have thought of circular structures before but he *didn't*. Thus he proposes that creativity involves the selection of novel and valuable solutions out of a vast number of possible solutions[24]. He also raises the annotation of determinism to argue that a computer could never be truly creative (i.e., do something that was previously impossible) [25] Finally, he bemoans the fact that Boden does not address the final Lovelace question.

Mechanism: Turner's view of the creative process is as follows:

- If problem solving is "the search of an *explicit* knowledge space for *known* solutions" then creative the "search of a a vast, *implicit* knowledge space for *new* solutions.
- "Creativity is distinguished from problem solving not by a single distinguished mechanism (i.e., RR) but by the types of solutions it discovers" which are those not found by ordinary problem solving.
- Challenges include:
    - How creativity is integrated with problem solving.
    - How the creators vast implicit knowledge may be searched for useful knowledge in creating new solutions.
    - How the knowledge found may be applied to the problem with reasonable effort.

Turner's approach is as follows: whenever the problem solver fails, it transforms the problem into a new problem (which it has solved before), solving the new problem and then adapting the solution back to old problem.

[23]However, what holds true for perceptual restructuring may not do so for the restructuring of cognitive concepts. In fact, it may be that in these studies there was perceptual restructuring but no conceptual restructuring which is why the subjects failed the "insight" problems.

[24]exploratory creativity.

[25]But it is an open question whether it would be possible, in principle, to predict everything a human a human could do through an understanding of the neural hardware just as with a computer program it would be possible, in principle (but not necessarily in practice) to determine every concept that it was capable of producing.

Advantages: Turner notes three advantages of this approach:

- The search for new knowledge is based on the original problem specification and localises search to useful areas (assuming that similar problems have similar solutions).
- Specific solution adaptations are bundled with each problem transformation.
- It describes a mechanism for the redescription and transformation of knowledge.

Furthermore, the approach demonstrates that:

- Creativity can be implemented as a search for useful solutions in a vast, implicit knowledge space.
- Boden's model of RR can be incorporated into a model of creativity.
- A model of creativity can be integrated into a model of general problem solving.

4.7 Boden's Response

Boden (1995) divides the points raised in the book reviews into six categories which we consider in turn. I have chosen to focus on those issues raised which prompt Boden to go beyond the material already covered in the TCM.

4.7.1 The Definition of Creativity

Vagueness Boden agree that her definition of creativity was vague and notes that she should have made more explicit the differences between combinatorial, exploratory and transformational creativity. In particular, she notes that exploratory creativity "can offer surprises comparable to the surprises provided by transformational creativity." Furthermore, Boden agrees that her distinction between "a (superficial) tweaking and a (fundamental) transformation ... was intuitive rather than analytic." She suggests that a more precise explication of these concepts will involve both defining the the dimensions of conceptual spaces and individuating them. This latter is hard due to the hierarchically structured nature of many conceptual spaces but is crucial if we are to judge the creativity (novelty, surprise, utility) of artefacts.

Inconsistency In reply to Ram et al. (1995) and Turner (1995) Boden argues that her description of transformational creativity as impossibilistic does not lead to a contradiction. She argues that "to say that someone 'could not' have produced the idea before can be sensibly asserted only by reference to a specific conceptual space." Thus she replies to Perkins (1995) that evolution can be considered to transform its conceptual space if "taxonomic and morphological categories in biology are comparable to conceptual spaces."

Overly Restrictive Boden replies to Turner (1995) that she does not claim that Representational Redescription "is the sole factor underlying creativity, rather that it is a precondition for the construction, exploration and transformation of conceptual spaces." She notes that the complaint of Ram et al. (1995) that her definition presupposes a particular account of mental life is perhaps the result of the lack of emphasis on exploratory or combinatorial creativity in TCM. In reply, she argues that eventually creative programs will not only transform their own representation but also their "forms of inference and control."

Properties of Problem Spaces: Boden welcomes the analysis of problem spaces presented by Perkins (1995) and notes that these may be of help in defining:

1. a measure of likelihood that a system will become stuck or be liberated on certain dimensions or at certain points in the space;
2. heuristics (domain general/specific?) for overcoming Perkins' four problematic attributes of problem spaces.

Miscellaneous Other points addressed by Boden include the following.

- Boden agrees with Haase (1995) and Schank and Foster (1995) that creativity is a matter of degree but prefers a multidimensional perspective rather than a single linear gradient.
- Boden agrees with Perkins (1995) that the notion of value is dependent on context and may shift unpredictably (particularly in the Arts).
- She also welcomes the suggestion by Perkins (1995) that we should focus on "the slow growth of novel ideas as well as sudden insights."
- In response to Turner (1995) Boden states that "conceptual restructuring is not a question of a sudden Gestalt-switch, but a focussed (sometimes conscious) change in one or more dimensions of the pre-existing structure."
- This leads her to respond to Haase (1995) that "some aspects of the previous space need to be retained if we are to orient ourselves intelligibly."

4.7.2 H-creativity vs. P-creativity

H-creativity Boden emphasises that H-creative acts form a subset of P-creative acts. While an H-creative "idea may be dependent in various ways on the closely related ideas of other individuals in his/her reference group ... insofar as our question is the psychological query 'How did the idea arise?', the answer can only be in terms of individual minds." Thus she agrees with Ram et al. (1995) and Schank and Foster (1995) that "the best research strategy in AI-modelling is to focus on the everyday psychological processes underlying P-creativity" but argues that H-creative processes are still relevant since they are also examples of P-creativity. She cites the work of Gardner who found that certain motivational and personality factors are typical of H-creators (e.g., determination, self-confidence and self-directedness).

Social-Historical context Boden emphasises the point that there can be no systematic answers to the historical-sociological question "Why is an idea greatly valued?" for the following reasons:

1. The answer depends on non-psychological factors which are undiscoverable in practice.
2. Since not all of these factors are of the same type there can be no unifying theory.
3. What counts as valuable varies between cultures and may change unpredictably within cultures.

Psychodynamics Boden agrees with the suggestion from Perkins (1995) that the question "What motivated the generation of a creative idea?" is distinct from the question of how it was possible to generate that idea and deserves attention in its own right.

Persistent H-creativity The question of what enables certain people to H-create over and over again (Perkins, 1995) needs to be addressed according to Boden. She notes that the ability to generate P-creative ideas consistently is a good predictor for H-creativity. Furthermore, she takes up the suggestion of Ram et al. (1995) that in these individuals "the search space may be interestingly different or expanded, so enabling creative thought using the very same mechanisms that usually generate more mundane ideas." Boden goes on to suggest that this may be "what is going on when, as we say, the creator is spending years "acquiring domain expertise." She cites psychometric research suggesting that specific ways of using and generalising concepts are characteristic of P-creative individuals but notes that this cannot answer the sociological-historical questions about the value of an idea.

4.7.3 The role of social context

In Generation Boden takes up the point made by Ram et al. (1995) that the social context is important in the generation of creative ideas in the following ways:

- innovation often arises when ideas from one culture are applied in another;
- scientific discovery often takes "years of theoretically informed (and nationistically biased) negotiation within the relevant scientific community";

Boden notes, furthermore, that for the computational modelling of culture to be fruitful, the generative processes available to the model must be powerful enough to deal with the injection of unfamiliar ideas (from different culture).

4.7.4 Evaluation

Socially Determined Boden considers that the crux of the problem of evaluation of creativity, noted by Ram et al. (1995), is the difference between a novel idea and an interestingly novel idea. The question of interestingness is affected by factors such as "nationality, fashion, rivalry and commercialism." Boden argues that one may choose certain criteria oneself while still recognising that creativity is "a socially bestowed honorific"[26].

Degrees of Creativity Another difficulty, noted by Ram et al. (1995), is that if the processes underlying creativity are possessed by us all, how do decide whether a given thought is creative or not? Boden recommends that instead of talking about a degree of creativity we should view it as a multidimensional construct and specify the respect(s) in which an idea is creative.

Terminology Boden agrees with Haase (1995) that the problem of drawing boundaries between conceptual spaces and modelling their interaction requires more precise (and less loaded) terms than "creative" or "novel". However, she emphasises that positive evaluation is a fundamental aspect of our creativity. Therefore, she welcomes the proposal by Schank and Foster (1995) that "we need a richly detailed theory of the kinds of goals and evaluative criteria that may inform this type of creativity". She notes furthermore that the "goal" will typically become better specified as the creative act proceeds.

Delayed Recognition Haase (1995) remarked on the question of why ideas often lie unrecognised for many years before being hailed as examples of H-creativity. Boden replies that the answers are partly sociological-historical and partly due to lack of the strong determination that typically drives H-creators.

Reception Boden agrees with Schank and Foster (1995) that evaluation is often made possible since the evaluator has already internalised the conceptual spaces and evaluative criteria of the creator. Therefore, she argues that interpretation and evaluation of creative work also involve complex cognitive skills.

A Scientific Theory Boden believes that a general scientific theory of evaluation is impossible since values change for unpredictable (and perverse) reasons[27]. However, she

[26] This would be equivalent to saying something like 'For a particular social group at a particular point in history, disregarding the issues of rivalry and commercialism this idea would be valued as creative."'

[27] But generative creativity also sometimes does perverse things - isn't this an argument for the study of evaluation as a creative act in itself?

argues that there may exist criteria which are very common or even universal (e.g., simplicity or symmetry in art and science). “Identification of shared evaluative biases however is hampered by the fact that these are only tendencies - which may be swamped by strong cultural influences. ... they should not be included as a matter of course in AI models of human creativity.”

4.7.5 The Lovelace Questions

With respect to the fourth Lovelace question and, in particular, the Chinese Room argument reply, Boden agrees with Schank and Foster (1995) that understanding is not an all-or-none matter and that since people do not always understand each other it would be unreasonable to expect AI-models to. However, she takes issue with Schank’s conclusion that a purely behavioural criterion of understanding is acceptable on the grounds that human subjects may mistakenly attribute capacities to user-friendly system which it does not in fact possess (e.g., in the case of ELIZA). Furthermore, Boden considers the putative response that AI-models of “thinking” need not fit our intuitions about how humans think since: first, our intuitions may be wrong; and, second, there may be more than one way of achieving the same results. She counters this reply by arguing that a study of mechanism can lead us to reject the creativity of a program if it consists in a giant look-up table or the solution is easily found given the representation scheme it has been provided with.

4.7.6 Specific Computational Mechanisms

CBR Boden considers the framework of CBR proposed by Ram et al. (1995), Schank and Foster (1995) and Turner (1995). She praises the fact that these approaches involve multiple processes interacting and the adaptation of old solution to new problems. However, she notes that CBR relies heavily on powerful mechanisms of storage, access, comparison and control and believes that the knowledge bases involved for true spontaneous cross-domain transfer would be impractically large.

Connectionism Boden argues, contra Schank and Foster (1995), that subsymbolic systems are more appropriate for the modelling of combinatorial (associative) creativity than symbolic systems. Given this she concedes that current connectionist models are also dependent on their representation schemes (as are many symbolic systems). Finally, she argues that “we need to understand the interplay between associative and structuring processes in creativity - for example, the imagery and the stanza structure in ‘The Ancient Mariner’. Connectionist models may be more appropriate in task domains which lack a sense of goal-direction[28].

[28] Isn’t this because they tend to be learning algorithms? Symbolic machine learning algorithms like ID3 would also be appropriate to non-goal-directed problems.

Transformation Haase (1995) argued that we need to understand how to liberate our systems from the confines of the initial representations we give them. Boden agrees and identifies two problems to be addressed: how to make (fundamental) transformations; and how to evaluate those transformations. Boden suggests that GAs are more likely to produce fundamental transformations than structure-specific heuristics. However, she recommends that the evaluation is done by the program not a human and the use of plausible-generate-and-test rather than random mutation. How then to decide on what counts as plausible?

4.7.7 AI Models as Aids to Creativity

Boden responds to the criticism of Ram et al. (1995) and Schank and Foster (1995) that little was said about what guidance can be given to make creativity more probable. She suggests that computers could function as creative aids in the following ways:

- They could help humans learn the constraints involved in a particular conceptual space.
- They could suggest and identify differences between familiar ideas and novel ones.
- Together with the human as evaluator (e.g., an IGA) they can create novel structures which the human could not have generated alone.

In such an endeavour, the fact that visualisation sometimes blocks (Perkins, 1995) and sometimes aids (Ram et al., 1995) the path to a solution, suggests ways in which the computer could help a human come to a creative solution. Boden notes concludes that any research on AI-models for educational purposes should work very closely with empirical psychologists for the validation of the pedagogical advantages of such models.

5 Extensions and Modifications

In her writings on creativity since TCM was published Boden has made several changes to her account of creativity presumably (at least in part) on the basis of the reviews and commentaries summarised above. This section contains a brief overview of some of these changes.

5.1 Types of Creativity

In her later writings Boden (1998, 2000) has dropped the terms impossiblistic/improbabalistic and explicitly defined three types of creativity:

1. Combinatorial creativity.
2. Exploratory creativity.
3. Transformational creativity.

She takes pains to emphasise that exploratory and transformational creativity are closely linked (Boden, 1998) and that “exploratory creativity is not to be sneezed at” (Boden, 2000).

Boden’s has also found more recent examples of programs (not mentioned in TCM) which embody these three types of creativity. For example, (Boden, 1998) cites the punning program JAPE (Binsted and Ritchie, 1994) as an example of combinatorial creativity. Her examples of exploratory creativity include EMI (Cope, 1991) and a grammar-based program for the generation of designs for houses (Koning and Eizenberg, 1981). Regarding transformational creativity Boden (1995) states that “it is difficult enough to enable computer programs to change their representations. At present, most cannot do so: they explore, rather than transform, their conceptual spaces.” As examples of programs which can transform their spaces, Boden (1996, 1998, 2000) discusses GAs which allow their representations of problem solutions to be lengthened and made more comples (e.g., Sims, 1991)[29].

5.2 Motivation and Emotion

Boden (1998) emphasises that creativity “involves not only a cognitive dimension (the generation of new ideas) but also motivation and emotion.” She notes, however, that “current AI models focus on the cognitive dimension” and follows suit herself. Boden (2000) she states that motivational and emotional factors are crucial in explaining why “some of us seem more creative than others.” Again, however, she simply points to the work of Aaron Sloman (e.g., Sloman, 2001), and suggests that the integration of this work with computational theories of cognition would prove fruitful in future research.

5.3 Measurement

If creativity can be identified and even explained, Boden (1996) asks whether it can also be measured. Suggesting that creativity typically applies to ideas she considers what it means to say that one idea is “more creative” than another. In keeping with her emphasis on P-creativity she rejects the obvious meaning that an H-creative idea is more creative than a P-creative idea: “the point at issue here is not ‘Who thought of X first?’ but ‘Is X a creative idea?”’ She further dismisses any notion of measurement through the application of a linear numerical scale of “creativity”.

Boden (1996) suggests that a complexity metric would be useful (Bundy, 1994) but also notes that any method of assessment must take into a account the following features:

- Conceptual spaces are multidimensional structures.
- Some features are “deeper” (more influential) than others.
- Creative achievements may involve exploration and “tweaking” as well as radical transformation of a space.

In terms of transformational creativity Boden proposes a measurement which takes into account the depth of change (novelty and value etc.) on all the relevant dimensions of the space. In terms of exploratory creativity she suggests that the larger and more complex a conceptual space the more exploratory creativity will be valued[30]. Finally, Boden (1996) suggests that information about the “depth and mutual influences of different parts or dimensions of the relevant conceptual space” will come from aesthetics, musicology, and the history and philosophy of art and science.

5.4 Evaluation

Boden (1998) suggests that the main reason why most AI models of creativity shy away from transformational creativity is the problem of evaluation: structures generated from a newly transformed space will need different types of evaluation from those generated from the old, familiar space. She notes the following problems with identifying the evaluative criteria used by humans:

- It is difficult to explicitly “express ... what it is we like about a Bach fugue or an impressionist painting ...”.
- “... to say what we like (or even dislike) about a new or previously unfamiliar form of music or painting is even more challenging.”
- Any causal explanation of *why* we rely on these criteria will depend on motivational and emotional factors and will be even harder still to express.
- Human values change across cultures and across time and sometimes in unpredictable and irrational ways.

Boden (2000) argues that current AI models of creativity do without sophisticated evalution functions by “defining a culturally accepted conceptual space so successfully that any structure generated [through exploration of that space] will be valuable.” And she concludes that:

> “The ultimate vindication of AI creativity ... would be a program whose H-novel ideas initially perplexed us, but which could persuade us that they were indeed valuable. This would involve showing us how the new structures were related to previous ones and perhaps showing how values already in the other areas could find analogies in the new one.” (Boden, 2000)

[29] The problem with these GAs is that they typically use a human evaluation function which removes much of their interest as cognitive models. The development of a critic which could provide reliable fitness values for chromosomes of different lengths and with different structural properties would not be a menial task.

[30] In the case of exploratory creativity a measure of those areas of the space which are hard to get to relative to particular search mechanisms could yield an analogue to the notion of depth of change.

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