Computational Creativity - an introduction

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• Some Big Questions
  ▸ What is Creativity?
  ▸ How can we study Creativity?
  ▸ What is Computational Creativity?
• **Some Big Questions**
  ‣ What is Creativity?
  ‣ How can we study Creativity?
  ‣ What is Computational Creativity?

• **Some Small Answers**
  ‣ way of studying creative systems
• Creativity is one of the things that makes humans human
• Creativity is one of the things that makes humans human

• If we are to understand ourselves, we need to understand creativity, both as a cognitive and a social phenomenon
• Creativity is one of the things that makes humans human

• If we are to understand ourselves, we need to understand creativity, both as a cognitive and a social phenomenon

• Enabling computers to create will
  ‣ make them more useful
  ‣ help us to understand ourselves
So what are we doing?
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• My preferred definition of our field is (Wiggins, 2006):
  ▸ “The support, study and simulation, by computational means, of behaviours which would be deemed creative if exhibited by a human”
  ◦ NB this does not imply that creativity is limited to things that can be done by a human!
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• Updated by Colton and Wiggins (2012):
  ‣ “The philosophy, science and engineering of computational systems which, by taking on particular responsibilities, exhibit behaviours that unbiased observers would deem to be creative.”
What is Creativity?
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• Many people think of creativity as the thing that happens when an artist makes a work of art
  ‣ a symphony
  ‣ a painting
  ‣ a sculpture
  ‣ a play
  ‣ etc.
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• Most researchers agree that to study things effectively we need to consider creativity as a process
What is Creativity?
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What is Creativity?

• In the Romantic period of Western culture, “great creators” accrued huge amounts of social capital.

• Even in the post-modern era (now) we still “worship” great artists:
  - Pablo Picasso
  - Wolfgang Amadeus Mozart
  - Charles Dickens
  - Justin Bieber
What is Creativity?
What is Creativity?

- Most people would say that most “ordinary” people are not creative
  - or at least not very creative
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  ‣ or at least not very creative

• We need to deconstruct the Romantic concept if we are to study creativity effectively
Where is Creativity?
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- Creativity (of the kind exhibited by artists) seems to be exhibited only by humans.
- Creativity (of the kind exhibited by humans solving practical problems) seems to be exhibited by many mammalian and some bird species.
  - New Caledonia Crows use Archimedes’ Principle to reach food.
  - Chimpanzees build towers to reach food.
  - Both these tasks can be done without prior observation, in novel circumstances, so they are probably not innate.
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  - Chimpanzees build towers to reach food.
  - Both these tasks can be done without prior observation, in novel circumstances, so they are probably not innate.
- In each case, creativity seems to be a property of a well-developed, embodied mind.
What about evolution?
What about evolution?

- Is evolution creative?
What about evolution?

• Is evolution creative?

• Evolution certainly creates things
What about evolution?

• Is evolution creative?

• Evolution certainly creates things

• But it has no intent and no goal
  ◎ (unless we appeal to mysticism)
  ▶ which makes it different from human creators
An approach
An approach

• Can we apply reductionist science to creativity, as a phenomenon, and thereby understand it better?
  ‣ (yes)
An approach

• Can we apply reductionist science to creativity, as a phenomenon, and thereby understand it better?
  ‣ (yes)

• Attempt to divide the phenomenon up into different parts and see how they work separately
  ‣ then put them back together
Early attempts
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- Wallas (1926), Koestlter (1964), Guilford (1967), Csikszentmihalyi (1976) all propose “theories of (human) creativity” which attempt to break down a creative process into smaller blocks.
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- They are very much behavioural descriptions:
  - theories do not really make predictions
  - Koestler’s at least proposes a cognitive mechanism (“bisociation”) which allows creativity to take place

  *this was reinvented and developed into conceptual blending (Turner & Fauconnier, 1995)*
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- However, there is nothing in any of the early creativity theories that allows us to test them empirically.
Boden: The Creative Mind (1990)
• From the perspective of the embodied mind, an important starting point for many in computational creativity is the work of Margaret Boden
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• The only (?) effective attempt to apply reduction to creativity
  ‣ a conceptual space of created artefacts
  ‣ evaluation
  ‣ novelty
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- Apparently similar to AI search - but NOT THE SAME THING
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The only (?) effective attempt to apply reduction to creativity:
- a conceptual space of created artefacts
- evaluation
- novelty

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Key idea: separate out the production of the artefact from its novelty and value.
Novelty and Value
Both value and novelty are relative concepts, to

- the creator
- the observer
- the context
Novelty and Value

• Both value and novelty are relative concepts, to
  ‣ the creator
  ‣ the observer
  ‣ the context

• But we may imagine creative processes that are universal in terms of the conceptual space
The conceptual space
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- The conceptual space contains all the possible concepts available to the creative agent.
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![Diagram of the conceptual space](image)
The conceptual space

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- The conceptual space contains all the possible concepts available to the creative agent.
- The space is defined/constrained by rules.
- Exploratory creativity is defined as the action of searching the conceptual space for a new concept.
- This is an abstraction - no strong claim that it works this way in minds/brains.
Transformational creativity
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An alternative kind of Boden creativity is *transformational creativity*. This is where the rules defining the conceptual space are changed so as to create a different (but presumably related) space. Boden suggests that transformational creativity is more significant than exploratory creativity, because it is in a sense “bigger thinking”.
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Boden suggests that transformational creativity is more significant than exploratory creativity, because it is in a sense “bigger thinking”.

Bundy (1998) and Wiggins (2006b) argue against this, as an overly simple definition.
Reasons why not
Reasons why not

“A symbolic system cannot create new concepts”

- weighted semantic networks allow us freely to define new concepts in terms of old ones
- conceptual blending allows us to create new semantic structures directly
- geometrical representations of meaning allow arbitrary interpolation between concepts (e.g., Gärdenfors, 2000)

though we do need to think carefully about what the resulting representations mean!!
Reasons why not
Reasons why not

• “A system which is exploring a search space defined by a representation is not being creative”
  ‣ not necessarily true: it depends on the expressive power of the representation
  ‣ creating an artefact by explicit mechanistic inference doesn’t make doing so any less creative
  ‣ cognitively speaking, creative insight does not “feel” like enumeration
  © but such introspection is almost always misleading
Reasons why not
Reasons why not

• “Non-symbolic systems generalise via a simple mathematical process, which is not creative”
  ‣ There is no evidence that the human mind does not create in this way
  ‣ There are suggestions (e.g., Kanerva’s sparse distributed memory) that this is exactly how the human mind creates
  ‣ Anyway, interpolation and generalisation may be a perfectly good model of creativity
Formalising Boden’s model
Let us represent the conceptual space as a multidimensional (possibly metric) space.
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Formalising Boden’s model

- Let us represent the conceptual space as a multidimensional (possibly metric) space.
- Partial and complete concepts are represented as points in the space.
- Each dimension of the space represents a feature of the domain.
- (So each point denotes a set of property/value pairs.)
Defining a conceptual space
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- Suppose now that we have a set of rules, $R$, which defines a conceptual space, $C$.
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• So $\mathbf{R}$ is a set of rules which picks the elements of $\mathbf{C}$ from $\mathbf{U}$

• $\mathbf{C} \subseteq \mathbf{U}$
Defining a conceptual space
• In order to give our rules, \( R \), we need a language, \( L \), and an interpreter for it
Defining a conceptual space

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- Let $⟦.⟧$ be an interpreter which maps its argument (a set of rules in $L$) to an effective procedure for selecting elements of $U$. 
• In order to give our rules, $\mathbf{R}$, we need a language, $\mathbf{L}$, and an interpreter for it

• Let $⟦.⟧$ be an interpreter which maps its argument (a set of rules in $\mathbf{L}$) to an effective procedure for selecting elements of $\mathbf{U}$

• $\mathbf{C} = [\mathbf{R}](\mathbf{U})$
Defining a conceptual space

• In order to give our rules, $R$, we need a language, $L$, and an interpreter for it

• Let $⟦.⟧$ be an interpreter which maps its argument (a set of rules in $L$) to an effective procedure for selecting elements of $U$

• $C = ⟦R⟧(U)$

• We also need a null concept, $⊤$
Exploring a conceptual space
Let us also allow another set of rules, $T$, describing our creative agent’s method for exploring $\mathcal{C}$.
• Let us also allow another set of rules, \( T \), describing our creative agent’s method for exploring \( C \)

• One more ingredient of Boden’s model remains: it is necessary to be able to choose the better concepts from the less good ones
Exploring a conceptual space

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- We introduce a set of rules, $E$, written in $L$, which may be used to accept or reject concepts in terms of their quality
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- We will need a more complex interpreter, $\langle..,..\rangle$, which, given three sets of rules in $L$, will return an effective procedure for computing an ordered set of (partial) concepts, $c_{out}$, from another, $c_{in}$
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$$c_{out} = ⟪R,T,E⟫(c_{in})$$
Exploring a conceptual space
• It will be useful to add the operator $\Diamond$ which will allow us to compute the set defined by repeated applications of a function
Exploring a conceptual space

• It will be useful to add the operator ◊ which will allow us to compute the set defined by repeated applications of a function

\[ F^{\Diamond}(X) = \bigcup_{n=0,\infty} F^n(X) \]
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• We can now define the enumeration of the conceptual space, \( C \), by our creative agent:
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\[ F^{\circ}(X) = \bigcup_{n=0,\infty} F^n(X) \]

• We can now define the enumeration of the conceptual space, \(\mathbf{C}\), by our creative agent:

\[ \mathbf{e}_C = \langle R, T, E \rangle^{\circ}(\{\top\}) \]
Exploring a conceptual space
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• Note that \( \mathbf{e}_C \) may be a subset of \( \mathbf{C} \)
Exploring a conceptual space

- Note that $e_c$ may be a subset of $C$

- This is because a creative agent’s exploratory technique, as captured by $T$, need not be strong enough to discover all the concepts which are actually admissible under $R$
• Note that $e_C$ may be a subset of $C$

• This is because a creative agent’s exploratory technique, as captured by $T$, need not be strong enough to discover all the concepts which are actually admissible under $R$

• Or $e_C$ may intersect $C$, producing some acceptable and some unacceptable concepts
An exploratory creative system

• We are now able to describe an exploratory creative system with the following septuplet:
An exploratory creative system

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\[ \langle \mathbf{U}, \mathbf{L}, [\cdot], \langle\ldots\rangle, \mathbf{R}, \mathbf{T}, \mathbf{E} \rangle \]
• We are now able to describe an exploratory creative system with the following septuplet:

\[ \langle U, L, [.] , \{.,..\}, R, T, E \rangle \]
An exploratory creative system

- We are now able to describe an exploratory creative system with the following septuplet:

\[ \langle U, L, [], \langle.,.,.\rangle, R, T, E \rangle \]

<table>
<thead>
<tr>
<th>U</th>
<th>The universe of all concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>A language for expressing rules and concepts</td>
</tr>
<tr>
<td>[]</td>
<td>A testing interpreter (for R)</td>
</tr>
<tr>
<td>⟨.,.,.⟩</td>
<td>An enumerating interpreter (for R, T and E)</td>
</tr>
<tr>
<td>R</td>
<td>A set of rules defining a conceptual space, C, in U</td>
</tr>
<tr>
<td>T</td>
<td>A set of rules allowing traversal of U (around C)</td>
</tr>
<tr>
<td>E</td>
<td>A set of rules evaluating concepts found using ⟨.,.,.⟩</td>
</tr>
</tbody>
</table>
Boden describes *transformational creativity* as changing the rules, $R$, which define the conceptual space.
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Transforming $R$ is transforming what is allowed as the output of the creativity process.
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In our formulation, there are two sets of rules which can be transformed:

- Transforming $R$ is transforming what is allowed as the output of the creativity process.
- Transforming $T$ is transforming the creative agent’s personal method.
Transformational creativity
• There is a search space of rule sets, which is itself a conceptual space
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• That search space is the power set of the language, \( L : L^* \)
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• So $L^*$ is now the universe in which we are searching
Transformational creativity

- There is a search space of rule sets, which is itself a conceptual space
- That search space is the power set of the language, $\mathbf{L}: \mathbf{L}^*$
- So $\mathbf{L}^*$ is now the universe in which we are searching
- We can describe $\mathbf{L}$ (and $\mathbf{L}^*$) with a metalanguage $\mathbf{L}_*$
Transformational creativity
To capture the exploration of the rule space, we need some constraints on what is syntactically well-formed, $R_L$.
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• We also need to define the search strategy, $T_L$
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• We also need to define the search strategy, $T_L$

• If we use the metalanguage $L_L$ as before for these specifications, we can use the same interpreters as before, $⟦.⟧$ and $⟨.,..⟩$
Transformational creativity
The only thing outstanding is the evaluation of the transformation, which can be done with a set of rules, $E_L$. 
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• We now have another exploratory septuple:
Transformational creativity

- The only thing outstanding is the evaluation of the transformation, which can be done with a set of rules, $E_L$

- We now have another exploratory septuple:

\[ \langle L^*, L_L, [], \langle...,\rangle, R_L, T_L, E_L \rangle \]
• The only thing outstanding is the evaluation of the transformation, which can be done with a set of rules, $E_L$

• We now have another exploratory septuple:

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• So transformational creativity is exploratory creativity at the meta-level of conceptual spaces
• The only thing outstanding is the evaluation of the transformation, which can be done with a set of rules, $E_L$

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• So transformational creativity is exploratory creativity at the meta-level of conceptual spaces

• $E_L$ may be characterised in terms of $E$ (see Wiggins, 2006a, for how)
On failing to create...
• We are now in a position to examine the behaviour of creative systems...
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The different components of the descriptions interact, and how they interact can tell us useful information.
On failing to create...

- We are now in a position to examine the behaviour of creative systems.
- The different components of the descriptions interact, and how they interact can tell us useful information.
- Now, we discuss ways in which a system can fail to create.
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The different components of the descriptions interact, and how they interact can tell us useful information.

Now, we discuss ways in which a system can fail to create.

Therefore, a creative system can introspect about how to improve itself.
• *Uninspiration* is the inability to produce valued outputs
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• There are three kinds of uninspiration:
  ‣ Hopeless
  ‣ Conceptual
  ‣ Generative
• *Uninspiration* is the inability to produce valued outputs

• There are three kinds of uninspiration:
  ‣ Hopeless
  ‣ Conceptual
  ‣ Generative

• It is useful to know about uninspiration, because it can act as
  ‣ a “well-formedness” check
  ‣ a trigger to transform a creative system in one way or another
Hopeless Uninspiration
The simplest case of uninspiration is where there are no valued concepts in the universe:

\[ [E](U) = \emptyset \]
Hopeless Uninspiration

- The simplest case of uninspiration is where there are no valued concepts in the universe:

$$\mathcal{E}(U) = \emptyset$$

- This means that no creative agent in this universe can ever produce anything valued
The simplest case of uninspiration is where there are no valued concepts in the universe:

\[ [E](U) = \emptyset \]

This means that no creative agent in this universe can ever produce anything valued

It is a property which we should attempt to disprove of any creative system, *a priori*
• **Conceptual uninspiration** is where there are no valued concepts in a given conceptual space:

\[ [E](C) = [E](R)(U) = \emptyset \]
• Conceptual uninspiration is where there are no valued concepts in a given conceptual space:

\[ \mathbb{E}(C) = \mathbb{E}(\mathbb{R}(U)) = \emptyset \]

• This means that no creative agent exploring this conceptual space can ever produce anything valued.
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• *Conceptual uninspiration* is where there are no valued concepts in a given conceptual space:

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• This means that no creative agent exploring this conceptual space can ever produce anything valued

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• Conceptual uninspiration can be used as a cue to encourage aberrant behaviour
Generative uninspiration is where a creative agent’s technique, $T$, causes it to miss the valued members of the conceptual space:

$$[E](⟨R,T,E⟩ⁿ(\{T\})) = \emptyset$$
Generative Uninspiration

- *Generative uninspiration* is where a creative agent’s technique, $T$, causes it to miss the valued members of the conceptual space:

$$
[E](⟨R,T,E⟩^\diamond (\{T\})) = \emptyset
$$

- This means that the agent will never produce anything valued
Generative uninspiration is where a creative agent’s technique, \( T \), causes it to miss the valued members of the conceptual space:

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Generative uninspiration is where a creative agent’s technique, $T$, causes it to miss the valued members of the conceptual space:

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- This means that the agent will never produce anything valued.
- It is a property which we should attempt to disprove of any exploratory-creative system, a priori.
- It can act as a trigger for transformation of $T$ (or $R$).
Aberration is the production of new concepts which are not in the existing conceptual space (that is, deviation from the expected)
Aberration

- *Aberration* is the production of new concepts which are not in the existing conceptual space (that is, deviation from the expected).

- There are three kinds of aberration:
  - Perfect
  - Productive
  - Pointless
Aberration happens when a creative agent finds concepts which are valued, but which are not in the conceptual space.
Aberration happens when a creative agent finds concepts which are valued, but which are not in the conceptual space.

This is why value (E) needs to be represented distinctly from acceptability (R).
• Aberration happens when a creative agent finds concepts which are valued, but which are not in the conceptual space

• This is why value (E) needs to be represented distinctly from acceptability (R)

• In the CSF, this means that

$$\langle R, T, E \rangle^{\diamond} \cap \{T\} \setminus \llbracket R \rrbracket(U) \neq \emptyset$$
Perfect Aberration

- Perfect aberration is the case where

\[
\langle R, T, E \rangle^\diamondsuit(\{T\}) \setminus [R](U) = [E](\langle R, T, E \rangle^\diamondsuit(\{T\}) \setminus [R](U))
\]

that is, where all the aberrant concepts are valued
Perfect Aberration

- Perfect aberration is the case where

\[
\begin{align*}
\langle R, T, E \rangle^\circ (\{T\}) \setminus \llbracket R \rrbracket (U) &= \llbracket E \rrbracket (\langle R, T, E \rangle^\circ (\{T\}) \setminus \llbracket R \rrbracket (U))
\end{align*}
\]

that is, where all the aberrant concepts are valued

- This, in most cases, will be a cue to transform \( R \) so that it includes the new concepts
Productive Aberration
Productive Aberration

- Productive aberration is the case when

\[
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\]

that is, where some aberrant concepts are valued
Productive Aberration

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\[ [E](\langle R, T, E \rangle \diamond \{T\} \setminus [R](U)) \neq \emptyset \]

that is, where some aberrant concepts are valued

- This, in many cases, may be a cue to transform \( R \) or \( T \) or both
• Pointless aberration is characterised by

$$[E](\langle R, T, E \rangle \circ \{T\} \setminus [R](U)) = \emptyset$$

that is, where no aberrant concepts are valued
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$$\llbracket E \rrbracket(\langle R, T, E \rangle ^\circ (\{ T \}) \setminus \llbracket R \rrbracket(U)) = \emptyset$$

that is, where no aberrant concepts are valued

• This is a cue to transform $T$ but not $R$
Reflection and transformational creativity
These ideas pave the way towards creative agents which can reason about their own performance, in terms of both value and productivity.
Reflection and transformational creativity

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Just because we can use the CSF to model creative systems, it doesn’t mean that all creative systems have to work by search.

We can usefully conceptualise/model a process as a search mechanism in the abstract even if that is not how it actually works.
An important question
• What is the difference between Good Old-Fashioned AI Search and Computational Creativity based on the Boden/Wiggins model?
Given an agenda $S$ (a sequence of states):

1. If $\text{head}(S)$ is a solution, stop.
2. Remove $\text{head}(S)$ from $S$ giving remainder $S'$
3. $\text{expand}(\text{head}(S))$ giving $S''$
4. $\text{merge}(S'', S')$ giving (new) $S$
5. Repeat from 1
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- For Breadth-First Search, $\text{merge} = \text{append}$
- For Best-First Search, Hill-climbing, A, A*, $\text{merge} = \text{append+sort}$
GOFAI Search

Key Features:

- Representation: can represent all and only output configurations of problem (closed world)
- Solution detector: Boolean test for (a representation of) a solution
- Heuristics allow control of search for best one(s)
  - calculate “quality” of solutions
  - calculate “distance” from nearest solution
  - combination of these
• GOFAI search vs. CSF
  ‣ Representation syntax ≈ Rules of \( R \)
  ‣ Search space ≈ Conceptual space
  ‣ Algorithmic framework ≈ Algorithmic framework
  ‣ Heuristics ≈ Traversal (\( T \)) and/or Value (\( E \)) Rules
  ‣ Agenda (\( S \)) ≈ Current expansion of space (\( c_{in} \))
Differences

• Representation: closed vs. open world (C vs U)
  ‣ admits “discovery” of solutions not envisaged by system designer
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  ‣ admits “discovery” of solutions not envisaged by system designer

• Algorithmic framework: single vs. multiple operands
  ‣ admits more complex (powerful?) search algorithms, e.g., GA, blending
• GOFAI search can be implemented in the CSF
CSF > GOFAI Search

- GOFAI search can be implemented in the CSF
- The CSF cannot be implemented as GOFAI search
  - (unless, in both cases, we disingenuously jump to a meta-level)
  - The CSF is therefore more expressive than the GOFAI search framework
  - So Boden’s notion of creativity is not “just AI search”
Summary

- Introduced Creative Systems Framework
  - Conceptual Space and Rule Set $R$
  - Traversal of Space to find Concepts and Rule Set $T$
  - Evaluation and Rule Set $E$
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• Transformational Creativity is Exploratory Creativity at the meta-level

• The CSF is more expressive than the standard search framework of AI

• We can use the CSF to help conceptualise creative systems