Abstract

Most prior work that deals with serendipity in a computing context only considers the role it plays in “discovery”, but we argue that serendipity also includes an important “invention” aspect. We survey literature describing serendipitous discovery+invention in science and technology. We then develop several case studies (some historical and some imagined) showing how serendipitous discovery+invention can work in a computational setting. From this, we extract recommendations for practitioners in computational creativity, and outline our own plan of work.

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1 Introduction

Although computational creativity is well studied in both theory and practice, the role of *serendipity* has often not been discussed in this field – even though serendipity has played a well-documented role in historical instances of scientific and technical creativity. One reason for this omission may be that the field of computational creativity has tended to focus on artistic creativity. But serendipity is increasingly seen as relevant within the arts (McKay, 2012) and other creative enterprises (Kakko & Inkinen, 2009; Lindsay, 2013): it is managed and encouraged with methods ranging from architecture to data science. An interdisciplinary perspective on the phenomenon of serendipity promises further illumination. Here, we consider the potential for formalising this concept and investigate its utility as a new framework for computational creativity.

Serendipity centres on reassessment. For example, a non-sticky "superglue" that no one was quite sure how to use turned out to be just the right ingredient for 3M's Post-it$^{\mathrm{TM}}$ notes. Serendipity is related, firstly, to deviations from expected or familiar patterns, and secondly, to new insight. When we consider the practical uses for weak glue, the possibility that a life-saving antibiotic might be found growing on contaminated petri dishes, and or the idea that cockle-burs could be anything but annoying, we encounter radical changes in the evaluation of what's interesting. In the *dénouement*, what was initially unexpected is found to be both explicable and useful.

Van Andel (1994) – echoing Poincaré's (1910) (negative) reflections on the potential for a purely computational approach to mathematics – claimed that:

> "*Like all intuitive operating, pure serendipity is not amenable to generation by a computer. The very moment I can plan or programme 'serendipity' it cannot be called serendipity anymore.*" (Van Andel, 1994)

We believe that serendipity is not so mystical as such statements might seem to imply, and in Section 5 we indicate van Andel's "patterns of serendipity" are likely to be highly applicable in computational settings.

First, in Section 2.1, we survey the broad literature on serendipity. Then in Section 3 we present our formal definition of serendipity, and examine related work that has applied the concept of serendipity in a computational context. Section 2.2 makes connections from historical examples of serendipitous discovery and invention to our formal model. Section 4 then presents case studies and thought experiments in terms of this model. Section 5 offers recommendations for researchers working in computational creativity (a key research area concerned with the computational modelling of serendipity), and describes our own plans for future work. Section 6 reviews the argument and summarises the limitations of our analysis.

2 Literature review

2.1 Etymology and selected definitions

The English term "serendipity" derives from the 1302 long poem *Eight Paradises*, written in Persian by the Sufi poet Amīr Khusrow in Uttar Pradesh.[1] In the English-speaking world, its first chapter became known as "The Three Princes of Serendip", where "Serendip" represents the Old Tamil-Malayalam word for Sri Lanka (*Cerantivu*), "island of the Ceran kings."

The term "serendipity" is first found in a 1757 letter by Horace Walpole to Horace Mann:

> *"This discovery is almost of that kind which I call serendipity, a very expressive word* [...] *You will understand it better by the derivation than by the definition. I once read a silly fairy tale, called The Three Princes of Serendip: as their Highness travelled, they were always making discoveries, by accidents & sagacity, of things which they were not in quest of* [.]" (Van Andel, 1994, p. 633)

The term became more widely known in the 1940s through studies of serendipity as a factor in scientific discovery, surveyed by Robert Merton and Elinor Barber (2004) in "The Travels and Adventures of Serendipity, A Study in Historical Semantics and the Sociology of Sciences". Merton (1948) (cited in Merton & Barber, 2004, pp. 195–196) describes a generalised "serendipity pattern" and its constituent parts:

> "*The serendipity pattern refers to the fairly common experience of observing an* unanticipated*,* anomalous and strategic *datum which becomes the occasion for developing a new theory or for extending an existing theory.*" (Merton, 1948, p. 506) (original emphasis)

In 1986, Philippe Quéau described serendipity as "the art of finding what we are not looking for by looking for what we are not finding" (Quéau, 1986, as quoted in Campos & Figueiredo, 2002, p. 121). Pek van Andel (1994, p. 631) describes it simply as "the art of making an unsought finding".

Roberts (1989, pp. 246–249) records 30 entries for the term "serendipity" from English language dictionaries dating from 1909 to 1989. Classic definitions require the investigator not to be aware of the problem they serendipitously solve, but this criterion has largely dropped from dictionary definitions. Only 5 of Roberts' collected definitions explicitly say "not sought for." Roberts characterises "sought findings" in which an accident leads to a discovery with the term *pseudoserendipity* (Díaz de Chumaceiro, 1995). While Walpole initially described serendipity as an event (i.e., a kind of discovery), it has since been reconceptualised as a psychological attribute, a matter of sagacity on the part of the discoverer: a "gift" or "faculty" more than a "state of mind." Only one

[1] http://en.wikipedia.org/wiki/Hasht-Bihisht

of the collected definitions, from 1952, defined it solely as an event, while five define it as both event and attribute.

An active research community investigating computational models of serendipity can be found in information retrieval (Toms, 2000) and more specifically, in recommender systems. In the latter domain, Herlocker et al. (Herlocker, Konstan, Terveen, & Riedl, 2004) and especially McNee et al. (McNee, Riedl, & Konstan, 2006) promoted serendipity as an important factor for user satisfaction, next to accuracy and diversity. There are several definitions of serendipity in this domain (Lu, Chen, Zhang, Yang, & Yu, 2012), which all require the system to recommend an unexpected and useful (Lu et al., 2012), interesting (Herlocker et al., 2004), attractive or relevant (Ge, Delgado-Battenfeld, & Jannach, 2010) item. In terms of the prior definitions, the problem can be framed as the user's difficulty in finding items that meet his or her interests within a large and potentially unobservable search space. This problem can also be passive, and items are suggested to support other stakeholder's goals, e.g. to increase sells. Definitions differ in the requirement for novelty, and some researchers (Adamopoulos & Tuzhilin, 2013) develop systems for suggesting items that might already be known, but are still unexpected in the current context.

There are numerous examples that exhibit features of serendipity which develop on a social scale rather than an individual scale. For instance, between Spencer Silver's creation of high-tack, low-adhesion glue in 1968, the invention of a sticky bookmark in 1973, and the eventual launch of the distinctive canary yellow re-stickable notes in 1980, there were many opportunities for Post-it™ Notes *not* to have come to be (Flavell-While, 2012). Merton and Barber argue that the psychological perspective needs to be integrated with a *sociological* one.[2] Large-scale scientific and technical projects generally rely on the "convergence of interests of several key actors" (Cams, 2014), along with other supporting cultural factors. For example, Umberto Eco (2013) focuses on the historical role of serendipitous mistakes and falsehoods in the production of knowledge.

It is important to note that serendipity is usually discussed within the context of *discovery*, rather than *creativity*, although in typical parlance these terms are closely related (Jordanous & Keller, 2012). In our definition of serendipity, we have made use of Henri Bergson's distinction:

> "*Discovery, or uncovering, has to do with what already exists, actually or virtually; it was therefore certain to happen sooner or later. Invention gives being to what did not exist; it might never have happened.*" (Bergson, 1946 [1941])

As we have indicated, serendipity would seem to require features of both; that is, the discovery of something unexpected and the invention of an application for the same. We must complement *analysis* with *synthesis* (Delanda, 1993). The balance between these two features will differ from case to case.

[2] "For if chance favours prepared minds, it particularly favours those at work in microenvironments that make for unanticipated sociocognitive interactions between those prepared minds. These may be described as serendipitous sociocognitive microenvironments" (Merton & Barber, 2004, p. 259–260).

Bronson and Merryman (2010) write that: “To be creative requires divergent thinking (generating many unique ideas) and then convergent thinking (combining those ideas into the best result).” This is exemplified by Voltaire’s (1749 [1748]) character Zadig (a figure inspired in part by the “The Three Princes of Serendip”) who “was capable of discerning a Thousand Variations in visible Objects, that others, less curious, imagin’d were all alike” – and in addition had the “peculiar Talent to render Truth as obvious as possible: Whereas most Men study to render it intricate and obscure.”

2.2 Serendipity by example

In this section, we illustrate the key condition, components, dimensions, and environmental factors that support serendipity, using historical examples. The structure of this section follows and updates an earlier survey from Pease, Colton, Ramezani, Charnley, and Reed (2013), and prepares the way for our model.

Key condition for serendipity

- **Focus shift**: “*After removing several of the burdock burrs (seeds) that kept sticking to his clothes and his dog’s fur,* [de Mestral] *became curious as to how it worked. He examined them under a microscope, and noted hundreds of ‘hooks’ that caught on anything with a loop, such as clothing, animal fur, or hair. He saw the possibility of binding two materials reversibly in a simple fashion, if he could figure out how to duplicate the hooks and loops.*” (Wikipedia, 2014b)

Components of serendipity

- **Prepared mind**: Fleming’s “prepared mind” included his focus on carrying out experiments to investigate influenza as well as his previous experience that foreign substances in petri dishes can kill bacteria. He was concerned above all with the question “Is there a substance which is harmful to harmful bacteria but harmless to human tissue?” (Roberts, 1989, p. 161).

- **Serendipity trigger**: The trigger does not directly cause the outcome, but rather, inspires a new insight. It was long known by Quechua medics that cinchona bark stops shivering. In particular, it worked well to stop shivering in malaria patients, as was observed when malarial Europeans first arrived in Peru. The joint appearance of shivering Europeans and a South American remedy was the trigger. That an extract from cinchona bark can cure and can even prevent malaria was subsequently revealed.

- **Bridge**: These include reasoning techniques, such as abductive inference (what might cause a clear patch in a petri dish?); analogical reasoning (de Mestral constructed a target domain from the source domain of burs hooked onto fabric); and conceptual blending (Kekulé blended his knowledge of molecule structure with his vision of a snake biting its tail). The bridge may also rely on new social arrangements, such as the formation of cross-cultural research networks.

- **Result**: This may be a new product, artefact, process, hypothesis, a new use for a material substance, and so on. The outcome may contribute evidence in support of a known hypothesis, or a solution to a known problem. Alternatively, the result may itself be a *new* hypothesis or problem. The result may be a "pseudoserendipitous" in the sense that it was *sought*, while nevertheless arising from an unknown, unlikely, coincidental or unexpected source. More classically, it is an *unsought* finding, such as the discovery of the Rosetta stone.

Dimensions of serendipity

- **Chance**: Fleming (1964) noted: "There are thousands of different moulds" – and "that chance put the mould in the right spot at the right time was like winning the Irish sweep."

- **Curiosity**: Venkatesh Rao (2011) refers to a *cheap trick* that takes place early on in a narrative in order to establish the preliminary conditions of order. Curiosity with can play this role, and can dispose a creative person to begin, or to continue, a search into unfamiliar territory.

- **Sagacity**: This old-fashioned word is related to "wisdom," "insight," and especially to "taste" – and describes the attributes, or skill, of the discoverer that contribute to forming the bridge between the trigger and the result. In many cases, such as an entanglement with cockle-burs, many others will have already been in a similar position and not obtained an interesting result. Once a phenomenon has been identified as interesting, the disposition of the investigator may lead to a dogged pursuit of a useful application or improvement.

- **Value**: Note that the chance "discovery" of, say, a £10 note may be seen as happy by the person who finds it, whereas the loss of the same note would generally be regarded as unhappy. Positive judgements of serendipity by a third party would be less likely in scenarios in which "One man's loss is another man's gain" than in scenarios where "One man's trash is another man's treasure." If possible we prefer this sort of independent judgement (Jordanous, 2012).

Environmental factors

- **Dynamic world**: Information about the world develops over time, and is not presented as a complete, consistent whole. In particular, value may come later. Van Andel (1994, p. 643) estimates that in twenty percent of innovations "something was discovered before there was a demand for it."

- **Multiple contexts**: One of the dynamical aspects at play may be the discoverer going back and forth between different contexts, with different stimuli. 3M employee Arthur Fry sang in a church choir and needed a good way to mark pages in his hymn book; he happened to have been attending seminars offered by his colleague Silver about restickable glue.

- **Multiple tasks**: Even within what would typically be seen as a single context, a discoverer may take on multiple tasks that segment the context into sub-contexts, or that cause the investigator to look in more than one direction. The tasks may have an interesting *overlap*, or they may point to a *gap* in knowledge. As an example of the latter, Penzias and Wilson used a large antenna to detect radio waves that were relayed by bouncing off of satellites. After they had removed interference effects due to radar, radio, and heat, they found residual ambient noise that couldn't be eliminated (Wikipedia, 2014a).

- **Multiple influences**: The "bridge" from trigger to result is often found through a social network, thus, for instance Penzias and Wilson only understood the significance of their work after reading a preprint by Jim Peebles that hypothesised the possibility of measuring radiation released by the big bang (Wikipedia, 2014a).

2.3 Related work

Paul André et al. (2009) look at serendipity from a design perspective. These authors also propose a two-part model, in which what we have called *discovery* above exposes the unexpected, while *invention* is the responsibility another subsystem that finds applications. According to André et al., the first phase is the one that has most frequently been automated, but they suggest that computational systems should be developed that support both aspects. Their specific suggestions focus on representational features: *domain expertise* and a *common language model*.

Although tremendously useful when they are available, these features are not always enough to account for serendipitious events. Using the terminology we introduced above, these features seem to exemplify aspects of the *prepared mind*. However, as we mentioned above, the *bridge* is a distinct process that mental preparation can support, but not always fully determine. For example, participants in a Writers Workshop may a possess a very limited understanding of each other's aims or of the work they are critiquing, and may as a consequence talk past one another to a greater or lesser degree – while nevertheless finding the overall process of participating in the workshop itself illuminating and rewarding (often precisely because such misunderstandings elucidate poor communication choices!). Various social strategies, ranging from Writers Workshops to open source software, pair programming, and design charettes (Gabriel, 2002, p. 11) have been developed to exploit similar emergent effects to develop new insights, and to develop *new* shared language. In (Corneli et al., 2015), we investigate the feasibility of using designs of this sort in multi-agent systems that learn by sharing and discussing partial understandings. This earlier paper remains broadly indicative, however, and the ideas it describes can see considerable benefit from the more formal thinking we develop in the current work.

The issue of designing for serendipity has also been taken up recently by Deborah Maxwell et al. (2012), in their description of a prototype of the SerenA system. This system is designed to support serendipitous discovery for its (human) users (Forth et al., 2013). The authors rely on a process-based model of serendipity (Makri & Blandford, 2012a, 2012b) that is derived from user studies, including interviews with 28 researchers, looking for instances of serendipity from both their personal and professional lives. This material was coded along three dimensions: *unexpectedness*, *insightfulness*, and *value*. This research aims to support the process of forming bridging connections from unexpected encounter to a previously unanticipated but valuable outcome. They particularly focus on the acts of *reflection* that foment both the creation of a bridge and estimates of the potential value of the result.

Although this touches on all of the features of our model, SerenA nevertheless matches the description offered by André et al. (2009) of discovery-focused systems: the user is the primary agent with a prepared mind. Accordingly it is the user that undergoes an "aha" moment and takes the creative steps to realise the result; the computer is mainly used to facilitate this. The primary computational method is to search outside of the normal search parameters in order to engineer potentially serendipitous (or at least pseudo-serendipitous) encounters. Another earlier related example of this sort of system is Max, created by Figueiredo and Campos (2002). The user emailed Max with a list of interests and Max would find a webpage that may be of interest to the user. Similar systems with support for serendipitous discovery involve searching for analogies (Donoghue & Crean, July, 2002; Donoghue & Keane, 2012)) and content (Iaquinta et al., 2008).

In earlier joint work (Colton, Pease, Corneli, Cook, & Llano, 2014), we presented a diagrammatic formalism for evaluating progress in computational creativity. It is useful to ask what serendipity would add to this formalism, and how the result compares with other attempts to formalise serendipity, notably Figueiredo and Campos's (2001) 'Serendipity Equations'. In this work, Figueiredo and Campos describe serendipitous "moves" from one problem to another, which transform a problem that cannot be solved into one that can. In our diagrammatic formalism, we spoke about progress with *systems* rather than with *problems*. It would be a useful generalisation of the formalism – and not just a simple relabelling – for it to be able to tackle problems as well. However, progress with problems does not always mean transforming a problem that cannot be solved into one that can. Progress may also apply to growth in the ability to *posit* problems. In keeping track of progress, it would be useful for system designers to record (or get their systems to record) what problem a given system solves, and the degree to which the computer was responsible for coming up with this problem. The relationship between serendipity and novel problems receives considerable attention here, since we want to increasingly turn over responsibility for creating and maintaining a prepared mind to the machine.

3 Our computational model of serendipity

Summarising the criteria discussed earlier, we propose the following definition, expressed in two phases: discovery and invention. The definition centres on the four components of serendipity, outlined above, which can subsequently be made sense of and evaluated with reference to the four dimensions of serendipity. These, in turn, are understood to be embedded in an environment exhibiting many, but not necessarily all, of the environmental factors listed above.

(1 - Discovery) *Within a system with a prepared mind, a previously uninteresting serendipity trigger arises due to circumstances that the system does not control, and is classified as interesting by the system; and,*

(2 - Invention) *The system, by subsequently processing this trigger and background information together with relevant reasoning, networking, or experimental techniques, obtains a novel result that is evaluated favourably by the system or by external sources.*

This can be summarised schematically as follows:

The connection to the key condition and components of serendipity introduced in our literature survey are as follows: The **serendipity trigger** is denoted by T. The **focus shift** takes place with the identification of $T^\star$, which is common to both the discovery and the invention phase. If the process operates in an "online" manner, $T^\star$ may be an evolving vector of interesting possibilities. The **prepared mind** corresponds to the prior training p and p' in our diagram. The **bridge** is comprised of the actions based on p' that are taken on $T^\star$ leading to the **result** R, which is ultimately given a positive evaluation.

The features of our model matches and expands upon Merton's (1948) description of the "serendipity pattern." T is an unexpected observation; $T^\star$ highlights its interesting or anomalous features and recasts them as "strategic data"; and, finally, the result R may include updates to p or p' that inform further phases of research.

Although they do not directly figure in our definition, the supportive dimensions and factors can be interpreted using this schematic to flesh out the description of serendipity in working systems.

From the point of view of the system under consideration, T is indeterminate. Furthermore, one must assume that relatively few of triggers $T^\star$ that are identified as interesting actually lead to useful results; in other words, the process is fallible and **chance** is likely to play a role. The prior training p causes interesting features to be extracted, even if they are not necessarily useful; p' asks how these features *might* be useful. These routines suggest the relevance of a computational model of **curiousity**. Rather than a simple look-up rule, p' involves creating new knowledge. A simple example is found in clustering systems, which generate new categories on the fly. A more complicated example, necessary in the case of updating p or p', is automatic programming. There is ample room for **sagacity** in this affair. Judgment of the **value** of the result R may be carried out "locally" (as an embedded part of the process of invention of R) or "globally" (i.e. as an external process).

As noted, T (and $T^\star$) appears within a stream of data with indeterminacy. There is an additional feedback loop, insofar as products R influence the future state and behaviour of the system. Thus, the system exists in a **dynamic world**. Our model separates the "context of discovery", involving prior preparations p, from the "context of invention" involving prior preparations p'. Both of these, and the data they deal with, may be subdivided further into **multiple contexts**. And correspondingly, since both T and $T^\star$ may be complex, they may be processed using multiple sub-processes that deal with **multiple tasks** using different skills sets. The process as a whole may be multiplied out across different communicating investigators, so that the final result bears the mark of **multiple influences**.

3.1 Using SPECS to evaluate computational serendipity

In a 2012 special issue of the journal *Cognitive Computation*, on "Computational Creativity, Intelligence and Autonomy", Jordanous analyses current evaluation procedures used in computational creativity, and provides a much-needed set of customisable evaluation guidelines, the *Standardised Procedure for Evaluating Creative Systems* (SPECS) (Jordanous, 2012). We follow a slightly modified version of her earlier evaluation guidelines, in that rather than attempt a definition and evaluation of *creativity*, we follow the three steps for *serendipity*.

Step 1: A computational definition of serendipity

> *Identify a definition of serendipity that your system should satisfy to be considered serendipitous.*

As above.

Step 2: Evaluation standards for computational serendipity

> *Using Step 1, clearly state what standards you use to evaluate the serendipity of your system.*

With our definition in mind, we propose the following standards for evaluating our definition of serendipity:

Prepared mind *The system can be said to have a prepared mind, consisting of previous experiences, background knowledge, a store of unsolved problems, skills, expectations, and (optionally) a current focus or goal.*

Serendipity trigger *The serendipity trigger is at least partially the result of factors outside the system's control. These may include randomness or simple unexpected events. The trigger should be determined independently from the end result.*

Bridge *The system uses reasoning techniques that support a process of invention – e.g. abduction, analogy, conceptual blending – and/or social or otherwise externally enacted alternatives – to create a bridge from the trigger to a result.*

Result *A novel result is obtained, which is evaluated as useful, by the system and/or by an external source.*

Step 3: Testing our serendipitous system

Test your serendipitous system against the standards stated in Step 2 and report the results.

We will develop several examples of the application of this framework in Section 4.

4 Serendipity in a computational context

The 13 criteria from Section 2.1 specify the conditions and preconditions that are conducive to serendipitous discovery. Here, we revisit each of these criteria and briefly summarise how they can be thought about from a computational point of view, again focusing on examples. We then present a thought experiment that evaluates the ideas described above in the course of developing a new system design.

4.1 Prior partial examples

[Jazz, recommender systems, HR.]

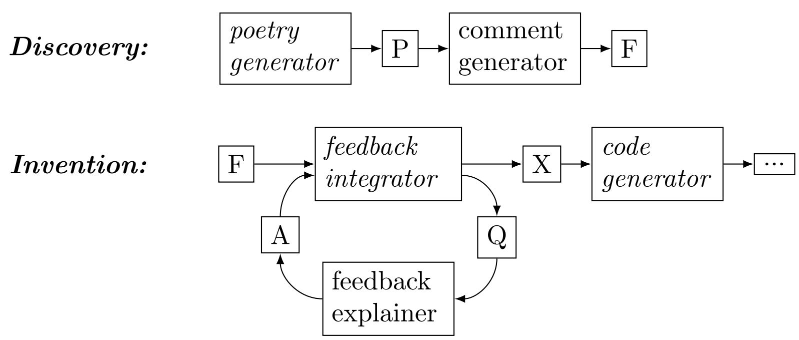
4.2 Thought experiment evaluating our model of serendipity

To evaluate our computational framework in usage, we apply a thought experiment based around a scenario where there is high potential for serendipity. As discussed above, sociological factors can influence serendipitous discoveries on a social scale. The exploitation of social creativity and feedback can create scenarios where serendipity could occur.

In (Corneli et al., 2015), we considered multi-agent systems that learn by sharing work in progress, and discussing partial understandings. The thought experiment we apply here explores serendipity in such scenarios, and is influenced by the ideas of Gabriel (2002) on Writers Workshops.

Following Gabriel (2002) we define a *Workshop* to be an activity for two or more agents consisting of the following steps: `presentation`, `listening`, `feedback`, `questions`, and `reflections`. In general, the first and most important feature of `feedback` is for the listener to say what they heard; in other words, what they find in the presented work. In some settings this is augmented with `suggestions`. After any `questions` from the author, the commentators may make `replies` to offer clarification.[3] This is how these steps map into the diagram we introduced in Section 3:

Italicised elements (*presentation*, *questions*, and *reflections*) are the responsibilities of the presenting author; the other elements (listening, feedback, and answers) are the responsibilities of the attendant critics. The system as a whole can be further decomposed into generative components as follows:



In our thought experiment, we focus on the case of hypothetical discussions and exchange of views between computational poetry systems as our example of a situation where social circumstances could encourage serendipity. We note that similar ideas would apply for prose and, with further adaptation, other arts.

Thought Experiment: Prepared mind. Participating systems need to be able to follow the protocol. This means that participating systems will need components like those listed above. The `listening` and `questions` components of the protocol correspond to p and p' our model of serendipity. The corresponding "comment generator" and "feedback integrator" modules in the architecture represent the primary points of interface to the outside world. In principle these

[3]We return to discuss further work with Writers Workshops and serendipity in Section 5.2.

modules need to be prepared to deal (more or less thoughtfully) with *any* text, and in turn, with *any* comment on that text. Certain limits may be agreed in advance; e.g. as to genre or length in the case of texts, and what constitutes an acceptable comment. The "feedback explainer" is closely connected with the "comment generator" and in an implementation of this model they would presumably share a codebase. The loop for learning by asking questions as they arise is reminiscent of the operating strategy of SHRDLU (Winograd, 1972).

Importantly, one of the most relevant preparations would be prior participation in Workshop dialogues. A system with prior experience in the Workshop may have a catalogue of outstanding unresolved, or partially resolved, problems (denoted "X" in the schematic above). Embodied in code, they may drive comments, questions, and other behaviour – and they may be answered in unexpected ways.

Thought Experiment: Serendipity triggers. Although the poem is under the control of the initial generative subsystem, it is *not* under control of the listening subsystem. The listening subsystem expects some poem, but it does not know what poem to expect. In this sense, the poem constitutes a serendipity trigger T, not only for the listening subsystem, but for the Workshop system as a whole.

To expand this point, note that there may be several listeners, each sharing their own feedback and listening to the feedback presented by others (which, again, is outside of their direct control). This creates further potential for serendipity, since each listener can learn what others see in the poem. More formally, in this case $T^\star$ may seen as an evolving vector with shared state, but viewed and handled from different perspectives. With multiple agents involved in the discussion, the "comment generator" module would expand to contain its own feedback loops.

Thought Experiment: Bridge. Feedback on portions of the poem may lead the system to identify new problems, indeed, new *types* of problems that it hadn't considered before. The most immediately feasible case is one in which the critic is a programmer who can directly program new concepts into the computer (cf. Winograd, 1972). However, it would be hard to call that "serendipity."

We can also ask whether agents can build new concepts *without* outside intervention, starting with some basic concepts and abilities related to poetry (e.g. definitions of words, valence of sentiments, metre, repetition, density, etc.) and code (e.g. the data, functions, and macros in which the poetic concepts and workshop protocols are embodied). Some notable previous experiments with concept invention have been fraught with questions about autonomy (Ritchie & Hanna, 1984; Lenat & Brown, 1984). **[Some comment about HR here?]** One cognitively inspired hypothesis is that the formation of new concepts is closely related to formation of sensory experiences (Milán et al., 2013). If the workshop participants have the capacity to identify the distinctive features of a given poem, then training via a machine learning or genetic algorithm approach could be used assemble a battery of existing low-level tools that can approximate the effect. Relatedly, a compression process could seek to produce a given complex poetic effect with a maximally-succinct algorithm (cf. Schmidhuber, 2007).

The key point is that feedback on the poem – simply describing what's in the poem from several different points of view – can be used to define new problems for the system to solve. This is not simply a matter of decomposing the poem into pieces, but also of reconstructing the way in which the pieces work together. This is one of the functions of the `questions` step corresponding to p' in our formalism: they offer the poet the opportunity to enquire about how different pieces of feedback fit together, and learn more about where they come from. Although computers are currently nowhere close, the reconstructive process may steadily approach the ideal case – familiar to humans – of relating to the sentiment expressed by the poem as a whole (Bergson, 1911 [1907], p. 209).

Thought Experiment: Result. The final step is to take the problem or problems that were identified, and write new code to solve them. Several strategies for generating a result R, in the form of new code, were described above. Now the system evaluates the new code to see whether it holds promise. In order to do this, it must have a way to carry out an evaluation and judge whether $|R| > 0$. In the most straightforward case, it would simply make changes to the draft poem that seem to improve it in some way. For example, the poet might remove or alter material that elicited a negative response from a critic. The system may proceed to update its modules related to poetry generation. Notably, it may also update its own feedback modules, after reflecting on questions like: "How might the critic have detected that feature in my poem?"

5 Discussion

5.1 Recommendations

Deleuze writes: "True freedom lies in the power to decide, to constitute problems themselves" (Deleuze, 1988 [1966], p. 15); and, elsewhere, rephrasing this sentiment in a social way:

> "*We learn nothing from those who say: 'Do as I do'. Our only teachers are those who tell us to 'do with me', and are able to emit signs to be developed in heterogeneity rather than propose gestures for us to reproduce.*" (Deleuze, 2004 [1968], p. 26)

Dewey emphasised a child's training must deal with objects which "arise out of their interests and their own problems" (Mead, 1935, p. 73). Von Foerster advocated a form of cybernetics in which "the observer who enters the system shall be allowed to stipulate his own purpose" (von Foerster, 2003, p. 286).

The thought experiment presented in Section 4.2 illustrated the relationship between problem creation and serendipity. Looking for the connections that make raw data into "strategic data" is a core pattern of problem creation. This is an appropriate theme for researchers in computational creativity to grapple with.

In (Colton et al., 2015), we outlined a general programme for computational creativity, and examined perceptions of creativity in computational systems found among members of the general public, Computational Creativity researchers, and creative communities – understood as human communities. We should now add a fourth important "stakeholder" group in computational creativity research: computer systems themselves. Creativity may look very different to this fourth stakeholder group than it looks to us. When computers are required to evaluate their own results, we are also implicitly requiring them to evaluate their creative process. We should give them the tools to do that effectively. These ideas set a relatively high bar, if only because computational creativity has often been focused on generative rather than reflective acts. As Campbell (1994) writes: "serendipity presupposes a smart mind." We may be aided in our pursuit by recalling Turing's proposal that computers should "be able to converse with each other to sharpen their wits" (Turing, 1951). Other fields, including computer Chess, Go, and argumentation have achieved such standards, and to good effect.

The Writers Workshop described in Section 4.2 is an example of one such social model, but more fundamentally, it is an example of *learning from feedback*. The Workshop model "personifies" the wider world as one or several critics. It is clearly also possible for a lone creative agent to take its own critical approach in relationship to the world at large, using an experimental approach to generate feedback, and then looking for models to fit this feedback.

5.2 Future Work

Within the context of the ongoing COINVENT project (Schorlemmer et al., 2014), we are interested in using computational theory blending to realise certain aspects of this model in a stand-alone architecture. It will be useful to consider how we can take both the *discovery step*, which combines a serendipity trigger T, and prior preparation p, to produce a classification $T^\star$ – and the *invention step*, which combines the classified trigger $T^\star$, and preparations p', and produces a novel result R – to be *blends* in the sense of Joseph Goguen (1999).

The epistemological framework of discovery gives some important clues about how to compute a common base between T and p, a key step for blending, since these common features will typically be preserved in the blend. Although T was previously uninteresting, it will have attributes or attribute-types that match the patterns recognised by p (e.g. van Andel's (1994) *One surprising observation*). In the invention step, reasoning, experimentation, social interaction strategies rely on p', which might draw on patterns like van Andel's *Successful error* in order to pinpoint the seeds of a useful result within $T^\star$. One important guidepost for implementation is the theory-building orientation that says that outcomes may include new patterns of behaviour that the system can draw on in subsequent interactions.

What is particularly needed is an approach to encoding patterns and methods for pattern discovery in a computationally accessible manner. Here we are drawn to the approach taken by the *design pattern* community (Alexander, 1999), although we recognize that we would be using design patterns in rather nonstandard way:

(1) We want to encode our design patterns directly in runnable programs, not just give them to programmers as heuristic guidance.

(2) We want the (automated) programmer to generate new design patterns, not just apply or adapt old ones.

(3) We want our design patterns to help describe new problems, not just capture the solutions to existing problems.

Meszaros and Doble (1998) describe the typical scenario for design pattern writers: "You are an experienced practitioner in your field. You have noticed that you keep using a certain solution to a commonly occurring problem. You would like to share your experience with others." They also remark that "What sets patterns apart is their ability to explain the rationale for using the solution (the 'why') in addition describing the solution (the 'how')." Regarding the criteria that pattern writers seek to address, they write: "The most appropriate solution to a problem in a context is the one that best resolves the highest priority forces as determined by the particular context." Their article describes a number of criteria relevant at the meta-level of pattern writing, e.g. *Clear target audience*, *Visible forces*, and *Relationship to other patterns*. A good pattern describes the resolution of forces, but it also resolves certain forces itself. In terms of our now-familiar diagram:

This diagram does not suggest that every instance of "a solution to a problem in a context" is serendipity – on the contrary, that is just the discovery step. To van Andel's assertion that "The very moment I can plan or programme 'serendipity' it cannot be called serendipity anymore" – of course, if the context is fully determined in advance, and if the solution is completely replicable, then some of the fundamental conditions for serendipity are not met. However, we can also describe patterns with built-in indeterminacy:

Successful error *Van Andel's example* – Post-it$^{\mathrm{TM}}$ Notes

`context` – You run a creative organisation with several different divisions and many contributors with different expertise. Unexpected discoveries are often made.

`problem` – One of the members of your organisation discovers something with interesting properties, but that no one knows how to turn into a product with industrial or commercial application.

`solution` – You create a space for sharing and discussing interesting ideas on an ongoing basis (perhaps a Writers Workshop).

`rationale` – You suspect it's possible that one of the other members of the firm will come up with an idea about an application; you know that if a potential application is found, it may not be directly marketable, but at least there will be a prototype that can be concretely discussed.

`resolution` – Writing down and promulgating the *Successful error* pattern using this template gives one such prototype.

6 Conclusion

- What answers have we offered?
- Further questions

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