Computing and chance

Designing for (un)serendipity

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The tale of a lame, one-eyed, toothless camel [1] may not, at first glance, seem an auspicious start for ground-breaking discoveries of penicillin, X-rays and chocolate chip cookies. However, when Horace Walpole coined the word *serendipity* in 1754, based on the tale of 'The Three Princes of Serendip' and the aforementioned camel, he was giving name to the *accidental sagacity* (i.e. accidental wisdom) involved in many scientific discoveries and inventions, where there is "*no* discovery of a thing you *are* looking for"[1].

Penicillin, for example, was discovered when Alexander Fleming failed to disinfect cultures of bacteria before leaving for his vacation. Upon his return, he found them contaminated with *Penicillium* moulds which had killed the bacteria. Although this was a successful example of linking together a chance occurrence to arrive at a valuable insight, there have also been many reports of missed opportunities[2]. What we think of as serendipity then really has two key aspects: the first of which is its accidental nature – the delight and surprise of something unexpected, and the second is the breakthrough or discovery made by drawing an unexpected connection – Walpole's 'sagacity'.

The term serendipity in common usage, the popular press and even academia generally relates to the first aspect, the chance encounter, while ignoring the second part, making use of those encounters in a productive way. We propose, as computer scientists designing systems to support creativity, innovation and discovery in science, that reconsidering serendipity may help refine new opportunities to generate not serendipity exactly, but effect the desired results of serendipitous revelation.

Value and study of serendipity

The effect and importance of serendipity has been reported and studied in many different domains. Although popular tales focus on scientific and medical discoveries (e.g. X-rays, Post-It Notes, Viagra), the concept is linked especially to creativity and insight. Picasso's Blue Period has even been attributed[1] to one day finding he had blue and no other colour, inspiring him to use only blue and being intrigued with the effect.

There have been many attempts to examine, induce and design for serendipity, the latter mostly within computer science research[3]. Observing or artificially facilitating something so inherently rare has proved problematic, with past studies largely focusing on attributes such as the *where*, *when* and *who* of chance encounters. Other systems have focused on supporting the fortunate finding of information, such as visualizing a search for data using a genetic algorithm aimed to support the serendipitous discovery of related material, computer agents that email Web search results based on randomly combining keywords from a user's domains of interest and websites, or collaborative filtering mechanisms that, for instance, recommend films that will be more preferred by a user than the population as a whole, helping users uncover less popular films they may like.

Such systems play a relatively passive or background role in finding something unexpected but delightful. However, the real value of serendipity is in the sagacity, connecting something unexpected to form an insight.

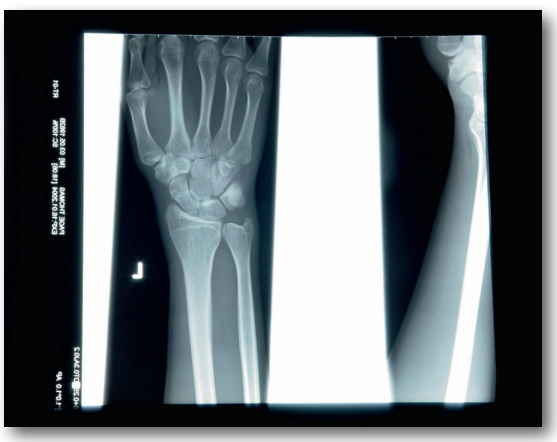

Figure 1. Investigating cathode rays in 1895, William Röntgen discovered that 'invisible waves' (named X to indicate an unknown radiation) emanating from a Crookes tube could pass through cardboard and cause a fluorescent screen to glow. The radiation is still referred to as Röntgen rays in many languages, including German. Credit: tompagenet at flickr

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Figure 2. Viagra was initially studied for use in chest pain, or angina. Researchers were intrigued that, although the drug had little effect on angina, participants still continued to take it. Credit: loauc at flickr

Deconstructing an insight

Far from being a chance occurrence, it seems researchers from various domains agree on a number of attributes to encourage serendipity and the realization of an insight. Louis Pasteur's quote "chance favours the prepared mind"[4] is not just pithy wisdom, but contains the root of a number of subsequent findings relating to insight. Not only is an opening and questioning mind acknowledged as critical [5], but also essential are prior knowledge about the encountered resource and knowledge about the task the person is engaged in[6]. In renowned creativity expert Mihaly Csikszentmihalyi's model of creative insight[7], the preparation stage involves hard work and research to accumulate raw information, before periods of incubation and insight, with domain expertise vital in creative insight[8].

We suggest that by exploring these opportunities and stories of serendipity, we can better understand the attributes of serendipity in order to design for them deliberately, to reproduce them to both delight and discover. Indeed, we propose that the term serendipity itself may be ironic, more often than not a confluence of specific events, knowledge and attitude is needed to draw insight from chance encounters; in other words, no discovery is truly *by accident* (the *(un)serendipity* of our title). The circumstances may be termed luck, but as Gladwell[9] states, they are generally the particular advantage of experts.

Aiding serendipity

It may be argued that by foregrounding and designing specifically for serendipity, we remove all elements of chance and accidental finding, ending with something barely recognizable as serendipity. As we briefly discussed above, it may be possible for a computer to discover patterns of association or information of related interest that a user would perceive as serendipitous. We propose an automation, acceleration and aid for the first half of serendipity, the discovery of a new piece of information.

It is the second half of serendipity, the sagacity and wisdom needed to make the connection between pieces of information, that we propose has rich potential for intervention. Although still dependent on the human, computer systems may be able to help potential discoverers be as primed as possible to make unexpected connections in such a way that they are able to take advantage of them. Instead of treating serendipity as arcane, mysterious and accidental, we embrace the ability of computers to help us perceive connections and opportunities in various pieces of information.

Regardless of whether or not it is possible to design to generate serendipity, we see several possibilities to design for at least some aspects of serendipity. In the following sections, we propose three areas where we see design opportunities for interdisciplinary collaboration to develop new tools to enhance serendipity as a foreground activity. With these approaches, we believe it is possible to leverage the computer's function to automate processes, accelerate results and improve accuracy.

Support domain expertise

When returning from holiday, Fleming realized the significance of the mould killing the bacteria, but he had already carried out extensive research into antibacterial substances. Although he had the favourable, indeed necessary, trait of having a mindset willing to see new ideas in accidental happenings, he had the background knowledge necessary to identify what was happening in the dish as an antibacterial process rather than just a spoiled sample. As acknowledged discoveries are preceded by preparation and an opening and questioning mind, we see that the enhancement of the inventor's or discoverer's own domain knowledge enhances the likelihood of making a serendipitous connection when one surfaces.

Figure 3. Louis Pasteur highlighted the importance of aspects other than pure luck in serendipity, saying in 1854: "In the fields of observation, chance favours only the prepared mind." Credit: original unknown, this copy vanderkroew at flickr

In order to enhance domain knowledge for this readiness, one opportunity for design is to track *existing* domain knowledge to augment one's current domain knowledge. In a scenario drawing from life logging literature, one might imagine a system that could develop a fairly comprehensive view of a person's current domain knowledge. Such a system integrating heterogeneous sources such as: a (set of) courses in a particular domain, the topics covered, reading list, exam results, confidence ratings, as well as other related resources from one's own writings, publications (and perhaps rejections), would be able to calculate what the current domain knowledge may include. From this, it may be possible to derive gaps around more current literature or programs that may be if not of interest, then relevant.

In the interim of the availability of such a complete domain knowledge appliance, an assessment of one's own work in a domain via various similarity measures may help automate selection of papers from appropriate literature to read. The challenge from a design perspective may not necessarily be discovering domain literature opportunities, but defining mechanisms for presenting these suggestions in ways that are effective for the investigator.

Build a common language model

Another part of serendipitous discovery can be the ability to compare models across domains. Computer science, for the last decade, has deliberately been working with biologists to develop new computing models informed by organic processes. Here, computer scientists have very deliberately been studying biology. There are examples of such cross-domain model inspiration without one domain having to become an expert in the others. In a more accidental pairing, recently, the behaviour of ants as a superorganism[10] has been seen as a potentially valuable new model to understand our brains. This comparison and contrasting of models has sparked new collaborations and much creative thought recently across science domains, via serendipitous discovery by one domain of another's model.

We are keen to explore how we might reduce the barrier of one field discovering another field's similar and useful model, especially given that each field may have its own very different language for describing what may be very similar concepts.

Physicists, engineers and mathematicians address the cross-domain specificity by using a shared metalanguage: mathematics. But even in this space, there are instances where different terminology for similar concepts means that, for example, robotics researchers miss relevant references in biology, with little chance of ever uncovering the related work.

Extending the idea, could we accelerate the automation of such discovery by developing a shared semantics, a new way to abstract ideas? In the linked data domain, a key rationale for the Semantic Web efforts is to enable ontology mapping between domains, where different terms for shared contexts could be recognized. But encouraging non-ontology experts to create mappings, let alone ontologies, is a significant problem. There is a clear role for interaction design to play in developing useful and usable designs to enable concept mapping for creative, cross-discipline concept discovery.

Networks to help serendipity flourish

For serendipitous discoveries to happen, it is necessary that the person making the connection has the ability to see a connection and the infrastructure available to see that connection flourish.

For example, Ernest Duchesne documented penicillin in 1897, 30 years before Fleming forgetfully went on holiday. But his paper was rejected by the Institut Pasteur because of his youth. As a consequence, humanity would have to wait another

Figure 4. When the first synthesis of copper phthalocyanine was discovered, its relevance was not immediately apparent or considered important enough, and the substance was not pursued for several years. It would later become an important pigment and dye. There are many other examples of potentially serendipitous discovered missed for lack of sagacity[2] Credit: m-louis at flickr

Figure 5. Cross-domain sharing can lead to serendipity and inspiration. In a recent book, Hölldobler and Wilson[10] discuss the behaviour of ants as a superorganism, as a potentially valuable model to understand our brains. Credit: kasimetcalfe at flickr

30 years for the person with the insight to recognize the discovery and the infrastructure to publish the finding to make it available to be mechanized for delivery as a drug.

If there had been a form of network available to share interesting but uninterested-in results for others in the field to attempt a 'Eureka!' moment, the discovery of penicillin or uses for copper phthalocyanine may have happened much earlier. If only Duchesne had had a blog. But a blog is too limited as well: it assumes that someone else will actively read it. More important is the ability to publish a discovery such that those serendipity-hunting agents can find it and connect it with the domain expert who may be able to make something of it, too. Here, of course, the ideal model would enable the idea to be set free for others to use with appropriate acknowledgement or be part of a collaboration, perhaps what Duchesne would have appreciated.

This idea again supposes a form of common language model, a way to express interest or expertise in particular areas, and a way to search for results. In some cases, it may not even be expertise that is required. For Ernest Duchesne, merely asking if someone out there has the right resources, the right connections, or the right marketing department would no doubt have been useful.

We recognize that some organizations are taking the initiative to develop such discovery networks. Eli Lilly, for instance, has collaborative agreements with many universities worldwide to enable them to share their IP (intellectual property) with universities, and have universities work with them. But let us suppose that these networks do work flawlessly to enable discovery of resources across it, it is a closed network. How would we design open automated systems to guide the publication of the *shape* of an idea for the automatic detection and uptake of an idea by an idea-hunting agent on another inventor's behalf?

Future challenges

Considering the history of serendipitous discovery, we see that success of serendipitous discovery is not just the find itself, but being able or willing to do something with it. Our approach has been to consider ways where we can enhance the likelihood and potential for serendipity and insight: for example, through surfacing connections, play, enhancing domain expertise and mechanisms to share discoveries.

Each of these mechanisms, grounded in our formal investigation of serendipity, is challenging but plausible. By taking a broader view of serendipity, we have presented, we think, a more holistic picture of serendipity, and thus perhaps ideas that may improve the creativity, innovation and discovery process. Better applications to support serendipity, especially across disciplines, will have benefits beyond any one community.

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