On Birthing Dancing Stars: The Need for Bounded Chaos in Information Interaction

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ABSTRACT

While computers causing chaos is a common social trope, nearly the entirety of the history of computing is dedicated to generating order. Typical interactive information retrieval tasks ask computers to support the traversal and exploration of large, complex information spaces. The implicit assumption is that they are to support users in simplifying the complexity (i.e. in creating order from chaos). But for some types of task, particularly those that involve the creative application or synthesis of knowledge or the creation of new knowledge, this assumption may be incorrect. It is increasingly evident that perfect order—and the systems we create with it—support highly-structured information tasks well, but provide poor support for less-structured tasks. We need digital information environments that help create a little more chaos from order to spark creative thinking and knowledge creation. This paper argues for the need for information systems that offer what we term 'bounded chaos', and offers research directions that may support the creation of such interfaces

CCS CONCEPTS

• Human-centered computing~Empirical studies in interaction design • Human-centered computing~Interaction design theory, concepts and paradigms; • Information systems~Task models

KEYWORDS

Information interaction, chaos, exploration, information-seeking, serendipity, browsing, information encountering, creativity.

1 Introduction

There is an old joke about computing and chaos, and while we might not have the details exactly right, it goes something like this: A physicist, a biologist, a librarian and a computer scientist are talking about the beginning of time. The biologist said 'God made the animal kingdom and all the creatures in it; biology came first and God is clearly a biologist'. The physicist responded that 'God had first said "let there be light", so God was definitely a physicist". The librarian comments that before God created light, order was created from the chaos, so God is definitely a librarian. The computer scientist, grins, taps their fingers together, and asks *'who do you think created the chaos?'*

Computers generating chaos is a common theme in popular culture—consider the movies *War Games* or *Space Odyssey 2001* for example. Even the more recent moral panics about teens, bullying, and social media [15; 18] have an element of this; it is often the computers that are blamed for causing chaos for the teens and those around them, rather than the bullying itself. Similarly discussions of the dangers of filter bubbles (arguably a reducer of chaos) focus on the chaotic disruption caused by the polarization they engender [16; 37; 81]. The common themes in these associations of computers and chaos are threefold: The computers in these cases are actually doing exactly what they have been programmed to do; the chaos is at the nexus of computing and human experience, and the outcome of the computer doing what it is programmed to do is negative for the humans involved. We thus have a chaos paradox: the computer is behaving in a manner that is precisely the opposite of chaotic, yet the human experience is of a chaotic situation. Chaos does not have to be experienced as negative, however. Too much chaos is overwhelming and disturbing, but just the right amount is exciting and full of possibility.

This paper is about how to use computing technology for the good kind of chaos; the kind that inspires and delights. We examine the history of information retrieval and interaction work to argue for a new way of interacting with information, one that prioritises breadth, serendipity, creativity and playfulness rather than precision, speed, and single answers.

Despite their function as chaos engines, computers are ultimately finite state machines: inside a computer everything is a '1' or a '0', true or false, yes or no. Even when we program computers to generate random numbers, the numbers are algorithmically generated and not truly random. Given their precision, the strength of computers lies in precise tasks, such as sorting or accurate repetition [22]. It is perhaps this approach that has influenced our approach to information interfaces: decades of human effort have been dedicated to finding the 'perfect' way to rank by relevance so that the right answer always comes at the top of a list of search results, for example [3]. This is at odds with human nature, though: we are not automata, and the right search result for us on any given day will vary according to our context, including the time we have to investigate a problem, and how deep our interest and expertise is in the topic domain [46]. Sometimes the right answer is not a search result at all: search is designed for machines to retrieve objects, and the human experience of generating the right description of those things for the machine to find them (in the form of query terms) is often poor

[12]. Furthermore, not every information experience is driven by explicit foreground needs: experiences of serendipity, for example, are driven by chance and openness to experience, but occur frequently in information-rich environments [60]. Even more challenging is dormant information—those where a need exists, but the person with the need is unaware of it [1].

This paper is a perspectives paper. Rather than presenting new research, it makes an argument for understanding certain types of information experience as 'bounded chaos'. It illustrates the need for a new kind of information interface, focused on playfulness, connection and curiosity, rather than on presenting the perfect narrow set of search results. We call this 'bounded chaos' and define it in the next section.

2 Defining Bounded Chaos

Information moving online creates a pressing demand for exploratory, playful interfaces to replace information experiences that are being lost. We will extend our argument for these interfaces in later sections, but first we must define them. We describe these interfaces as having the property of **bounded chaos**. Both elements of the definition are important: chaos on its own is overwhelming, destructive, and frightening. Just the right amount of chaos, though, can be experienced as full of potential, exciting, and creative, even numinous. In a bounded chaos information interface, a user can experience a state of flow, generating ideas and leads seemingly effortlessly, never finding themselves at an impasse of too much or too little information.

If, for the sake of mathematical precision, we were to attempt to describe bounded chaos algorithmically, we would describe it as information interfaces presenting a non-deterministic sample of an underlying collection to a user, where there is no clear principle by which the sample can be selected. To focus on the mathematics, though, is to miss the point—it is the user experience of these interfaces that is their key defining feature.

Caution must be taken when trying to describe these interfaces as algorithms, or as a set of guidelines. Treating serendipity, creativity or even browsing as the output of a checklist seems at best ill-advised, and at worst destructive of something delightful and almost mystical. To say that bounded chaos exists but not to describe it meaningfully is to say nothing useful at all. The principles of bounded chaos given below are descriptive, rather than prescriptive, and should be taken as an inspirational starting point when developing or evaluating information interfaces, rather than as a shortcut to creativity. In this section we describe the necessary elements of both chaos and bounding for information interaction.

2.1 Chaos

The paradox of chaos, as noted in 'The Gap Into Madness' (aptly subtitled *Chaos and Order*), it that it is defined by its limits [31]. Computers limit things further, being precise and fixed, rather than chaotic and uncertain. Even so, the means by which information systems can seem usefully chaotic are described here.

Search, is antithetical to a chaotic experience. It imposes a high burden on information seekers to know what they want, and the historical emphasis is on narrowing results and presenting a small set of (possibly diversified) but highly related items. Ironically, relevance ranking has improved greatly over the years, and better search engines create a worse experience of information richness, chaos and possibility. While Google is wonderful at answering specific questions and finding highly defined information, it rarely generates an experience of chaos or delight, however lucky one might be feeling. Bounded chaotic interfaces may include search, but it cannot be the dominant—or, worse, only—interactive paradigm; **search-free interaction** must be not just possible, but straightforward.

Not only is search the wrong interactive paradigm for chaos, but the search results page is a prime example of an impoverished information interface that cannot meet chaos' need for information surfeit. Too much information, or too much unstructured information can lead to information overload [8; 9]. Too little information, though, is aptly described by Whitelaw in his treatise on generous information interfaces as like being outside a museum while the artefacts are wheeled out ten by ten into a room devoid of interest [108]. Chaos is greedy, it relies on the presentation of a large number of information objects—and an unpredictable selection of these, if presenting only a subset. Seeing the same small set of items upon each search, or seeing only enough objects that one can cognitively conceive of all possible arrangements, is not chaotic or exciting, it is dull and uninspiring. Conversely information tasks that rely on inspiration and excitement rely on **large numbers of objects**: browsers in a library examine surprisingly vast numbers of books [74], and creative professionals deliberately expose themselves to as many triggers for serendipity as possible [60].

Having many objects that all look (or sound) the same is equally a poor approach to chaos. While similarly bound books that are the same height and stood perfectly vertical look lovely on a shelf, they do not invite exploration or discovery. Books with a range of spines, heights, and angles, though, present a perceptually heterogeneous—or 'interesting' [7] scene, and support chaos, curiosity and discovery. This **perceptual heterogeneity** does not necessarily need to be visual; early work on playlist shuffle suggests that multi-artist playlists generate more insight and excitement than shuffling a single album [27].

Alongside perceptual heterogeneity, **topical heterogeneity** is a necessity for the experience of chaos. A collection of items that is too closely related, or where it is difficult to access orthogonally related but not topically identical material will bore information seekers and deepen focus, rather than opening their minds and sparking new ideas. We have seen this need in the work on browsing, on serendipity, and on creativity. Browsing the library shelves allows ready access to a wide range of topics, and supports all three information experiences [54; 59; 74].

Finally, and related to topical heterogeneity, is the capacity to experience information objects next to each other in new ways—e.g. songs next to each other that haven't been listened to in that sequence before in a shuffled playlist. Information experienced in the same order every time—as, for example, with an album on tape—may be familiar and comforting, or it may result in information that could be quite useful becoming merely

background noise to be ignored. **Novel adjacencies**, however (as we term this capacity for things next to each other in new ways) may be jarring; it is entirely possible for things to be 'wrong' together (pickles and ice-cream, anyone?). Novel adjacencies can—and do—though, spark new insight, generate new ideas, and create new ways of solving problems. We know that creative professionals actively seek out novel adjacencies in the hope of generating serendipity [60]; these adjacencies are also likely to support creative problem solving [54].

2.2 Bounding

Having defined chaos for our purposes, we turn to bounding. A participant in [60] noted that *'people think there's patterns in the world—there isn't, there's just chaos. But what we're put here to do, is look for patterns; that's our purpose*'. Bounding strategies support information users in creating 'just enough' patterns or connections for chaos to be inspirational, rather than overwhelming. Bounded chaos may use any or all of these approaches in concert.

One means of bounding is **structuring information**. Consider, for example, a second-hand bookshop where the books are shelved in the order in which they are acquired. Most browsers would find this an untenable organization, so would likely give up and buy nothing in frustration. There is evidence that this happens in practice, when information seekers find an organization scheme baffling [84]. Imposing some slight measure of structure, makes bookshops, libraries and music stores exciting and full of possibility. Structure is a double-edged sword, though—too little structure is just chaos without the bounding; too much removes any hope of novel adjacencies. Tightly structured interfaces may well inform, but they are unlikely to inspire.

A further means of bounding is **curation**. Every meme on the internet all at once is not a tractable collection to manage, however a Facebook feed full of posts from one's friends is more accessible. Many information sources are curated—the books in a library or bookshop, for example, are selected by the librarian or proprietor. While these examples are ones where there is a clear curator, other information sources are self-curated—for example one's Facebook friends feed, or the playlists one creates. Limiting the information coming in to a chaotic situation—which is essentially what curation does—can, just as structure does, bring the chaos down to a manageable level.

One final way of limiting the experience of chaos is to **slow the speed** at which information is accessed. Consider Wilson's Tetris model of information-seeking: the Tetris game represents an information user's context, and the falling pieces are new information [109]. This information can be sought or acquired information (or Tetris blocks) appearing too slowly is boring and allows for distraction. Conversely information (or Tetris blocks) appearing too quickly is overwhelming and does not allow the player the perceptual time necessary to make the blocks fit in the right place. There is a sweet spot, though, where the game—and any information flow—is fast enough to entertain and allow a sense of mastery, without overwhelming. Allowing information users to manage the speed at which information appears—by swiping right, for example—will ensure that they find their own sweet spot, neither so fast they are overwhelmed nor so slow they are bored. Where speed cannot be in the user's control, however, we should resist the urge to throw information at them as fast as possible, instead allowing time for perception and evaluation.

Having defined bounded chaos, we will now describe why a new way of looking at information interaction is needed. We will begin by outlining the history of digital information, showing why the focus has been on narrowing the range of information. We will then turn to our knowledge of human information behaviour, noting in particular the gaps between behaviour and technology. We follow this with a detailed examination of three information activities that are poorly supported online, then look at three information interfaces that are supportive of bounded chaos. We address the risks of bounded chaos and outline a research agenda before summarizing our contribution.

3 Computers and Information: A Brief History

The challenge of using computers in information work is perhaps exemplified by the issue of library book classification: we have not been able to use computers to generate reliable classifications; this requires human judgement [14]. Once books are classified, though, computers are at an advantage—they can sort the books faster and more accurately than people [14], and even present them in more than a single location at once [63]. To understand the underpinning challenges of computing in information, we look to the history of computer systems and information retrieval.

Early computers had little storage; their memory being mainly used for number-crunching, hence the name 'computer'. While we do not subscribe to the Sapir-Whorf hypothesis (which posits that we can only think about concepts that we have language for [48]), computers were named after the tasks they did initially; and this may have shaped our attitude to how they should be used.

By the late 1960s, computers were storing and accessing large volumes of information. This prompted a series of experiments known as the Cranfield experiments—designed to evaluate the performance of different indexing methods—that formed the basis for the modern discipline of information retrieval [89]. Thus, even relatively early in the history of computers and information, the primary research focus has been on how to narrow the amount of information users see and sort it so that users engage with the smallest possible useful portion of a collection. This approach, though, was designed on the premise that all users had information needs that would ideally be met by a single document [95], and that if we could just provide them with the right document all would be well. Later evaluations of information-seeking showed that users sometimes searched to find a small number of documents [10; 17; 45], or to find an access point for a larger volume of information [63], but information retrieval research has focused on the idea that there is too much information, and we must narrow the field for users. Decades of human effort have been dedicated to relevance ranking algorithms and designing systems and interfaces that get users to the one thing they want quickly and with a minimum of fuss [3].

One exception to this approach has been the investigation of exploratory search, described as searching to learn or understand [64; 106]. Even this paradigm, though, has still focused primarily

on search, rather than exploration or discovery. Research in this area has mostly focused on the presentation of search results in a way that supports users engaged in this type of search task. Further, exploratory search still relies on information seekers to create search terms (difficult for amorphous or unclear [12] needs), and still imposes an often-linear result structure on users.

The advent of the web made the need to narrow choices even more pressing; the internet is a wild west of information—uncultivated, unclassified and unstructured. In this context, Google's original mission statement—'to organize the world's information and make it universally accessible and useful' [103] makes a lot of sense. Google does seem to make sense of the morass of (mis-)information that is the web for many users: a study of students evaluating library systems [51] showed that many of them found that these systems presented 'too many' search results in comparison with to Google. This is in stark contrast to the objective number of search results; arguably Google presents more search results per query than most libraries have in holdings, but because these are well ranked, they are not overwhelming to searchers [96].

Libraries were an early adopter of technology information: OPACs (Online Public Access Catalogues) existed as early as the 1980s [42]. Again, though, these systems were designed (and used) for focused retrieval, Users who had more complex questions than could be typed into a search box were urged to talk to a librarian [26], and users who wanted a less directed information experience could (and did) browse the shelves [42].

Traditional library systems were superseded in the mid-2000s by a new breed of information system; web scale search [94]. These systems were designed to be more user-friendly than traditional OPACs, including exploratory search features such as facets and straightforward help such as spelling correction. They were also designed to bring together information that had previously been siloed in separate search interfaces, such as ebooks, print books, journal articles and digital media. These silos were some of the highest perceived barriers to library information [86]. Presenting this plethora of information together for the first time meant that the interfaces were still predominantly designed to help users narrow the search space, rather than expanding it.

Early studies of web scale search interfaces show that users were—once again—overwhelmed, and struggled to identify the resources they needed [105]. Later studies showed that they adapted their search strategies relatively quickly, and took advantage of the new flexibility such systems offered [70].

Ultimately, though, for as long as we have been storing information in computers, research and practice has predominantly focused on how to find and present the smallest and most accurate set of information to users, precision over recall, specification over exploration [36].

This focus is not without exception; Borgman trialled a shelf-like interface for pre-literate and early-literate children in the 90s [13], and Kerne used collages of images to represent search results in an interesting way in the early 2000s [50]. Recent years have seen a flurry of interest in generating playful, curiosity-driven interfaces that support exploration. These are predominantly for library books, for example Bookfish; designed for exploration [82]; and the Bohemian Bookshelf, designed for serendipity [102]. Outside the library domain, presentations such as *MusicMap*[1] and *Every Noise At Once*[2] offer exploratory views of music and *Yossarian*[3] supports creative and exploratory image search. These systems are compelling, one description of MusicMap described it as 'the place that will take up the rest of your day' [11]. Even so, they are experimental and not in regular use. A key challenge for bringing this type of information interface into the mainstream is to understand how best to help information seekers make meaningful connections within the space when the precise nature of these connections remains uncertain (at least until after an 'aha' moment, when users may have the opportunity to provide feedback to the system).

The need for focussed information retrieval continues, and has understandable research appeal: there are standard measures of how successful algorithms are (e.g. precision and recall) [3], gains can be demonstrated numerically (however little these gains mean to actual users [95]). We are not arguing for the abandonment of search as a paradigm, or against precision and recall as measures. Rather, we argue for information acquisition to be recognised as a broad set of activities, incorporating for example active search and browsing and passive (serendipitous) information encountering. Measuring precision and recall can measure search, but not understanding; search can respond to a query, but not to wordless confusion or ignorance. Systems and metrics should reflect the plurality of information experience. There are no metrics even for the systems described in this paper, which are usually evaluated (if at all) in terms of user satisfaction. In a discipline where order and certainty has been the guiding principle, such soft concepts as user satisfaction must seem like anathema. Perhaps new evaluation approaches are needed—where greater value is placed on the usefulness of insight gained, and less on user satisfaction with the broader experience.

4 A New Information Order

Computers focusing on retrieval has been appropriate in an age where other avenues for discovery existed. While we searched for books in an OPAC we still could (and did, and do) browse the library shelves [42; 44; 74]; we still went to record stores to discover new music [28], and video stores for new movies [43].

In the early 2000s, though, a revolution began. First, journal articles began moving online and into searchable databases. With the advent of the iPod and the iStore, music did the same thing. The Amazon Kindle did the same to recreational reading, and academic libraries began to move in the same direction with their books, so that in 2014 95% of the collection of an average Australian academic library is online[4]. Digital cameras took over

[1] http://www.musicmap.info/
[2] http://everynoise.com/engenremap.html
[3] Yossarian.co
[4] http://www.caul.edu.au/caul-programs/caul-statistics/statistics-summary-current

photography, and in 2002 were added to our mobile phones. Finally, Netflix moved movies and television online.

The advantages of digitization are manifold: it provides access to materials that would have been difficult, time consuming or impossible to access in the past. Search makes it possible to find resources we would have not have known existed, a change that has dramatically increased the amount academics read [101]. It has allowed consumers to be selective, for example music can now be bought by the song (instead of in whole albums) or even rented. Digitization has also given rise to new information tasks; where a search for images of cats in the 1980s would have been a specialist research project, these days it is recreational.

Ultimately, information work has shifted from specialist librarian interactions and esoteric archives to the online world, bringing many new possibilities and advantages. This is not an unmitigated good, however; library professionals and users alike claim this move to online information has robbed them of the opportunity of discovery. It would be rare now to hold up a CD case and wonder *'what do you think music that looks like this sounds like?'* [28]. Users bemoan the lack of browsing opportunities for ebooks in academic libraries, some even refuse to use them [59; 69]. We could regard these users as retrograde luddites, but information scholars have voiced similar concerns, lamenting the loss of serendipity in digital environments [65; 85].

One response to information moving online and potentially overwhelming information seekers is the growth in personalization as a means to reduce the unbounded chaos. The library shelves do not present a view of information that hides from a reader everything they might find offensive, or promotes content similar to what they and their friends have read before. If they did, this might offer a better experience for some readers [93], but it would overall lead to more homogeneous reading, and less informed readers. This is the problem of echo chambers and filter bubbles [81; 97], where there is some evidence that the information and ideas we are exposed to are limited and warped by our search history and that of our social networks. This is one way of limiting chaos, but in so doing we potentially limit the analogous thinking needed for creative problem solving, arguably create a more polarised and less informed populace, and reduce opportunities for serendipitous discovery [24; 37; 41; 57; 88].

Whether the lack of interfaces to facilitate less-directed information-seeking, and the growth of hyper-personalisation is a teething problem or represents a new world order is up to us as information interaction specialists. Research and technology has thus far has been focused on search and retrieval tasks but the future offers opportunities to do a different kind of work; it is the argument of this paper's authors that we can and should seize these opportunities. We now examine current limitations before showing existing interfaces that support less-directed seeking.

5 Information Behaviour and the Limitations of Order and Technology

While information having moved online is convenient and possibly cost-effective, there are a range of ways in which online systems frustrate human information behaviour: only some elements of behaviour are supported online. Marchionini [63] and Kuhlthau [53] are two of the most highly-cited models of information-seeking. Both models have cyclical portions and incorporate query-and-retrieval as a significant element. Even these models, though, have stages encompassing collection understanding, recalibration of information needs, and browsing—all of which are poorly supported by current online information systems. Browsing, in particular, seems to be treated by these models as something of a black box: people do it, but we have little detail about what it actually is or means to browsers. Other work has addressed browsing in more depth, e.g. Bates' early work, e.g. [4-6], and McKay's more recent work [21; 71; 73; 74], but browsing is acknowledged to be under-theorised [63]. These models were created at a time where little attention had been paid to information behaviour other than that involved in active information *seeking*. However, this is not the only way in which information is *found*.

There are models of information behaviour that go beyond information-seeking: Foster and Ford describe being open to information and the impact that may have on information experiences [38]. One notable feature of this work is the impact of classification schemes on the experience of serendipity: they support it by bounding the information space in which information users are working. McKenzie describes a similar approach to information but in a social context: actively leveraging connections and passively being aware of information are important dimensions in her model [78].

Technological support for query-response information-seeking is strong. As we move further from this behaviour, however, support degrades. If an information user can identify a single useful object, computer encoded classification schemes can potentially support some information behaviours. Similarly, the identification of a single useful object allows recommender systems to provide avenues for discovery. Information seekers engaging in semi-directed seeking can get some support from systems designed for exploration or serendipity, e.g. [82; 102]. Social information services (one of the most commonly mentioned is the Facebook feed), browser tabs and bookmarks weakly support information encountering and serendipitous experiences but our tools could be significantly better here [61]. If users cannot describe their needs at all, though, or give an example, of a useful resource, current information interfaces will not support them.

We are not to the first to note that search is not a panacea for information needs. Marcia Bates' criticism of the 30-item search dates from 1984 [4]. She noted search was prone to arriving at a set of documents that was too narrow, lacked topical diversity, or was 'unrepresentative' of the available material. She noted the likely threats of sacrificing a great deal of potentially valuable recall for modest gains in precision. Four years later, Swanson [100] more fully outlined a range of issues that limit the utility of search. He noted nine limitations to the capabilities of search, including the impossibility of detaching any query from a hidden and complex context. He also noted untapped opportunities, such as revealing undiscovered links between different areas of science. Critically, he observed that the perfect search engine is an unobtainable goal [100]. While these authors critiqued search,

they did not offer an alternative framing; it is this framing—that of bounded chaos—that we offer.

Bounded chaos is not just about an interface, it also addresses a wide swathe of information experiences and behaviours where connection building and sensemaking take priority over directedness and narrowing. We address three of these—serendipity, creativity, and browsing—in the next section.

6 Chaos: The Mother of Invention?

The gradual expansion of scope in human information behaviour research has begun to point to the need for a new way of talking about information acquisition and the interfaces that support it. In this section we address the literature on serendipity, creative problem solving, and browsing, and draw it together to show the need for what we are terming 'bounded chaos'.

6.1 Serendipitous Information Encounters

Encountering information that was not directly sought is an important form of information acquisition, first examined in detail by Erdelez [34]. It involves finding useful information unexpectedly when looking for information on a different (perhaps somehow related) topic, when not looking for any information in particular (e.g. when searching or browsing with a vague aim or no aim) or when not looking for information at all (e.g. when talking to a friend or walking down the street). Sought information can also be encountered in unexpected information sources [38; 67].

It has been argued that current digital information environments can both create opportunities for serendipitous information encounters [60] and potentially inhibit them; Erdelez suggests encountering can be inhibited *'if the interface of some information system is constrained only to a focused information search environment'* [33]. The potential for encountering is limited in current online systems, primarily because most mainstream information tools focus heavily on supporting search and relatively little on supporting browsing (particularly unfocused browsing, where the user may not have a clear idea of what they are looking for). There is much potential for the next generation of tools to support the dynamic and smooth transition between search and browse and between focused and unfocused information acquisition.

The concepts of order and chaos are particularly important for information encountering; serendipity, by definition, involves a degree of accident, surprise or unexpectedness. A degree of chaos is inherent, but it is not complete chaos. Serendipitous information discoveries are not merely 'chance' encounters. Serendipity involves some chance, but also sagacity; an open and prepared mind to notice encounters and the opportunities they may present and the willingness and ability to seize these opportunities. As McBirnie [66] puts it: *'while seeking serendipity seems improbable, paradoxically, some degree of control may be possible'* (p. 601). The excitement from an encounter can come from creating a personal sense of order from the chaos; making meaning from the encounter by relating the new information discovered to existing information already known. Some might argue that the holy grail of serendipity research is to build algorithms sophisticated enough to relate incoming information to users' existing knowledge and interests. We argue instead that the real value of future technology may be in finding more useful ways of supporting users to make their own connections between information rather than trying to generate the 'spark' algorithmically. This approach requires presentation of a wide range of objects and ideas, space for the encounterer to have an open mind, and time to consider each item [60]. System support for such activities may truly support information encountering.

Creating such systems is a difficult but important challenge: designers of digital information environments are faced with the paradox that serendipity might be destroyed by trying to systematise it [7]. Designers of such systems must also consider but that understanding users' background knowledge may be necessary to better support users in making knowledge-enhancing connections between new and existing information.

One approach to managing this is by using user modelling techniques from AI, another is the generation of an implicit user knowledge landscape by capturing the search and browse paths a person follows across many information acquisition sessions. This is not a new approach to determining implicit relevance (see, for example [107]). Nonetheless it is an example of an approach that might allow users to recognise and follow-up on their own connections between information, which might well be more meaningful than those created by algorithm. By allowing users to dynamically and situationally balance the degree and types of order vs. chaos, designers of future serendipity-facilitating environments may free themselves from the paradox of destroying serendipity by creating it algorithmically.

6.2 Creative Problem Solving

Colloquially, 'creative' solutions to problems are hacks, using whatever is to hand—effective, slapdash and fundamentally inelegant. True creative problem solving, though, is a task done by experts—requiring new thinking and new applications of knowledge to create novel methods and solutions to challenging problems. This work is extraordinarily information intensive; experts need to reconsider their existing knowledge while seeking out potential starting points from outside their usual repertoire. Like serendipity, inspiration is more likely to be found in information abundance, rather than narrow focus.

Anecdotal accounts of creative problem solving often ascribe success to 'genius' or 'inspiration', but research has demonstrated that information plays a critical role [63]. The turning point is often finding a relationship between methods used in other domains and the domain of expertise familiar to the problem solver. The role of these discoveries appears to apply equally to making novel ideas that are relatively incremental (sometimes called 'small c' creativity) or dramatic leaps ('big C' creativity) [58]. Given this need for analogous thinking, filter bubbles could be particularly pernicious.

More than serendipity, creativity has been construed as a process that (effective) thinkers deploy more or less consciously. There are numerous approaches to creative problem solving, but a universally acknowledged key element is the need to engage in

divergent thinking [2; 91]. In divergent thinking, users construct or hypothesise new combinations or variants on existing concepts and techniques. To succeed, divergent thinking requires material that brings a diverse range of different approaches and knowledge that might be potentially useful in discovering a novel, creative solution to a problem [29]. Often, it is the thinker's ability to identify new connections between ideas that is the turning-point in problem solving, as noted in [99]. Making these connections relies on (often implicit) strategies such as analogous thinking, or incongruous matching [40; 68]. Knowing this, it is likely that information too remote in topic to the focus of the work, too hard to reinterpret in creative ways, or otherwise a bad fit with creative processes is unlikely to be useful.

There have been some attempts to support creativity digitally. Kules found that exploratory interfaces over collections were a boon for creativity [54]. Kerne's collages [49] place the control in the hands of an algorithm, rather than the user. His montages are intended to provide incidental exploration over time, to increase the likelihood of creative insights. Other researchers have endeavoured to create algorithms that lead to topically diverse sets of results [23]. In all cases, the idea is to provide a rich and changing stream of information to use as a source of inspiration.

Browsing a known collection has been reported as an effective tool for helping creative thinking by scholars [19], but there is no detailed account of why that experience or those collections functioned well. We would argue that it is because such a collection could be rich, but is unlikely to have documents that are too distant from the problem, or too hard to reinterpret. Finding a way to generate such rich and diverse collections that are relatable enough to support creativity is an imperative for the future of knowledge work. Such systems, as with serendipity, will need to offer abundance and diversity, not chaotic fragmentation, to support the moments of inspiration that solve difficult problems.

6.3 Browsing

Few information experiences are described as 'delightful' or 'exciting', but browsing often is [59; 61; 69]. Closely related to serendipity is browsing—particularly collection browsing (e.g. browsing for music or books, as opposed to browsing the internet). Like creative problem solving, browsing is an information interaction strategy that is used when serendipity, inspiration or breadth is sought [38]. It is also used for information needs that are loosely defined, where recognition is a more important tool than specification, or where information seekers are trying to understand what is available [1; 63; 87].

Bates—the foundational author on online browsing—defines it as viewing a large and interesting scene, and sequentially examining objects of interest [7]. It has been suggested that this definition makes library shelves an ideal 'browsing engine', but there is no successful online equivalent [52]. For a scene to be 'interesting' it must contain a large number of objects, but how many objects that is hasn't been defined, though recent empirical work suggests it may be very large indeed [74; 75]. Similarly, we don't know how information seekers choose their objects of interest, but recent work shows that drivers of interest may also be opaque to information themselves [74; 75].

Browsing has clear links to the other human information behaviours in this section: browsing a collection is one means by which information users are known to deliberately 'seek serendipity', for example, and browsing a known collection is shown to support creative problem solving [19].

Browsing is however—by definition—not search. Some information seekers may use search to support their browsing experiences [63; 74], but others abjure search in favour of browsing. [55; 76]. Search interfaces alone cannot support browsing, but what interfaces *do* support browsing remains an open research question, though some guidelines are emerging [73]. We know that library browsers—in addition to using the potentially highly structured environment of the main shelves—deliberately seek out display tables and recently returned piles [80; 92]. These displays generally show a more eclectic mix of materials than the main shelves. We also know that readers approach the shelves expecting to meet unknown content and hoping to find inspiration and ideas [59; 76]. Similarly, music browsers will scan bargain bins, not just for the low prices, but for objects of interest they may not otherwise have found [28].

Again, browsing is an information behaviour where common IR approaches fail users: search does not support the curiosity and openness with which readers approach the library shelves, for example. Equally, though, chaotic shelves would overwhelm. Many commentators have noted that the loss of physical browsing is risky for serendipity, discovery and an overall information experience [25; 62]: what is lacking, we argue, is bounded chaos.

7 How to Harness Bounded Chaos

The obvious question at this point, is what would interfaces that support bounded chaos look like? The answer is that there is no single information presentation that meets these needs, and any attempt to overprescribe them runs the risk of the 'too much structure' problem of traditional IR. While there is no perfect example of bounded chaos, below we present three information interfaces—playlist shuffle, social media feeds, and library shelves—that afford search free interaction, and meet some of the other principles described above.

7.1 Playlist Shuffle

A playlist is a list of songs put together by a listener or listeners, often for a specific purpose. Playlists may have an order to them, but they are mostly played in shuffle mode [27]. The novel adjacencies of music afforded by shuffling a playlist have been noted as valuable and provocative of serendipity, and of insight. That insight can be vast; a participant in [56] noted that shuffling playlists showed them '*connections between the music and the infinite void…[allowing them to]…understand the universe better*'. Playlists are more interesting with a variety of artists than a single artist, meeting the need for topical and perceptual heterogeneity [47]. While playlists may not seem chaotic in general, they are much more chaotic than the highly structured environment of an album ordered by a music producer. The bounding of playlists is perhaps more intuitively obvious: they are naturally speed limited

by the length of the song and bounded by listener curation of the songs within them.

7.2 Social Media Feeds

Social media feeds repeatedly appear as a source in studies of digital serendipity (e.g. [30; 61]). In one study [61], for example, Facebook feeds were mentioned by at least two users (out of 14), even though the study period covered only two weeks and serendipity is considered 'regular but rare' [66]. The examples in [61] tend to be of Facebook sparking a thought or memory, and the participant following up on serendipitous information encounters further. It is easy to see how Facebook meets the need for chaos: the amalgam of cat pictures, advertisements and colourful text that make up the average Facebook feed these days is perceptually heterogeneous enough to make a minimalist cry. The boundedness of social media is perhaps less obvious, though what is presented in a feed is easily speed bound, for example. Social media feeds are also curated—we choose who we follow, limiting what might appear. In Facebook, even within our feeds we can customise who appears first and customise to some degree what post types we see. Obliquely, social media sites themselves are also curating our feeds: the underlying algorithms choose what advertisements to feed us, for example, based on what we will most likely click. While on the surface the interface similarity between social media feeds and playlists is that items appear in a single long sequence, they share some deeper properties—heterogeneity, curation and speed—that support more interesting information experiences than traditional search engines.

7.3 Library Shelves

Our third and final example of a bounded chaos interface is the library shelves. Given the vast volume of information presented at the library shelves, it is notable that they are not commonly associated with information overload. They are, however, associated with serendipity and even creativity [59]. Bounding at the shelves is easy to see—they are both highly structured, and curated [98]. We further know that changing the underpinning structure changes behaviour [93] and that savvy information seekers understand and actively leverage the structure [59; 63; 87].

The highly structured nature of the library shelves may make it hard to anticipate where the chaos lies. Perhaps surprisingly, the shelves meet a number of our criteria for chaos: slight movements in materials at the shelves, for example, can present novel adjacencies even to the most experienced library user. Larger movements in materials demonstrably happen—right up to and including readers secreting items around the library a long way from their natural 'home' [21]; these are one factor in novel adjacencies. Another factor is the irregularity of library use by most readers [77; 90]—the adjacencies they see are novel, simply because they do not know the library well. Indeed many information seekers do not understand the arrangement of shelves, even if they can use it effectively [20; 76]. Even for expert library users, a visit to a new library can elicit novel adjacencies, due to variance in cataloguing practices [14]. Finally, readers actively leverage spaces with a higher chaos spaces (both in terms of novel adjacencies and heterogeneity): e.g. returns trolleys and book displays are favourites of active readers [80; 92].

The perceptual heterogeneity of library shelves is easy to fathom; a range of book spines (unless the books are a specific collection from a single publisher) will be vibrantly heterogeneous. Topical heterogeneity is not immediately obvious—books next to each other are typically on the same topic. However, the library is a three-dimensional space; the books above and below a book are more topically distant from the books beside it, and the books on the shelves behind an information seeker are more distant again, at least with nonfiction shelves. Readers use all of these options, including sitting on the floor or precariously browsing while standing on a stool [44; 72; 74].

Library shelves appear to share little with a social media feeds (other than a certain visual chaos), and almost nothing with a shuffled playlist. Examining the underlying information structure and interface affordances, though, we discover similarities like curation, novel adjacencies, and heterogeneity—and, notably, an absence of the requirement to search—that constitutes the interaction we are describing as bounded chaos. It is these features that can support non-search interaction patterns, such as serendipity, browsing, and creativity.

8 More (Un)comfortable with Chaos?: The Risks of Chaos

Bounded chaos interfaces are not inevitably positive for users: they have strong potential downsides. It is possible that one of the reasons researchers have been so cautious about introducing breadth, exploration, serendipity and playfulness—all of which might look like chaos in the wrong circumstances—into user interfaces is the spectre of information overload. Information overload occurs when we offer users too many choices about information. These choices may be simply between many pieces of information, or they may be more complex—including information source, search interface and information type. Information overload results in information users accessing less information and making poorer decisions than the presentation of a few simple options (even though they may not be the absolute best options for the specific context of the information user) [8; 9; 39; 83]. Despite Netflix having thousands of hours of content, it is notoriously hard to find anything to watch. This is likely due o information overload and the paradox of too much choice [32].

Given the severe impact and unpredictable precursors of information overload, the caution of researchers developing information interfaces is perhaps understandable. This is especially true given that there has been no particular research imperative to offer anything other than highly focused interfaces until very recently. We argue that this research imperative has arrived, but what should we do about information overload? We might re-conceptualise information overload in chaotic interfaces; the challenge becomes how to ensure users enjoy interacting with (potentially voluminous) and loosely connected information—riding the waves rather than drowning in the ocean.

A further challenge for chaotic interfaces is the information seeking-encountering tension, or 'dark side of serendipity' [104].

This tension appears as the choice between completing a pre-defined, directed information task with reliable, predictable information interfaces and choosing to follow more ephemeral, risky but potentially fruitful information needs, In practice this might look like a student trying to choose between reading the books that help them finish their assignment and browsing an interesting section of the library discovered on the way to fetch the original books. Chaotic interfaces risk exacerbating the seeking-encountering tension as they are designed to tempt and offer serendipitous experiences, so allowing users to limit their exposure seems a key element of a successful chaotic interface.

Both information overload and the seeking encountering tension are highly context dependent: they are affected by the user, their task, the time available to do the task, and a host of other issues such as the user's depth of interest and how directed they were in their original intention. This suggests that chaotic interfaces must be both accessible and optional; we should not be forcing users into playful and wild interfaces any more than we should be restricting them to highly focused and directed systems.

9 The Gap into Chaos: A New Research Agenda

Given the need for a new type of information interface and the risks outlined above, how can we develop effective, user friendly bounded chaos interfaces? Chaos theory argues that chaos and order are not opposites but composites [31], the perfect bounded chaos information interface would reflect this. Chameleon-like, it would appear chaotic to those who need chaos, and structured to those who need structure, and shift with their needs as they moved from browsing and exploration to search and back again.

The interfaces we have that reflect bounded chaos are far from perfect. To advance this field, we advocate for three strands of research: users, metrics, and algorithms.

The strand of research on **users** should identify the contexts in which chaos is most supportive, and how users currently meet their needs for chaos. It should address which features of information interfaces support chaotic, playful exploration, and which overwhelm—and what the needs and tasks are that predict the difference. This research should focus not just on online interfaces, but on all aspects of the information ecology.

There is clear evidence that the **metrics** of precision and recall have driven the development of search systems [35], and made these systems a key focus of information interaction research. Recent developments around novelty and diversity have aimed at supporting more exploratory information systems, but still focus on search results [23]. The development of metrics around chaos, the balance between chaos and order, and the user experience of bounded chaos could drive improvements in these interfaces. How to metricate playfulness, exploration and creativity may be a difficult challenge, but the information interaction community are ideally placed to address it.

Finally, despite our earlier admonition against reducing bounded chaos to **algorithms,** any information interface that supports bounded chaos experiences will need underpinning algorithms to select content for presentation. One approach to this would be a fully random algorithm, another is clearly ranked search results. Other possibilities are infinite, and which ones are best for bounded chaos remains a challenge for future work.

10 Birthing Dancing Stars: The Case for Bounded Chaos

Nietzsche said *'you must have a little chaos inside you to give birth to a dancing star'* [79]; we argue in this paper that the same is true of information interfaces. In contrast to the 'chaos' computers are so often perceived to generate, this kind of chaos is experienced as positive and valuable by users. With so much information moving online, it is more important now than ever before to offer users something other than deterministic, goal-driven information experiences if we are to preserve serendipity, creativity and other valuable information experiences. We advocate adopting a new approach when designing digital information environments that values lack of organization as well as clearly-defined information structures. We are not suggesting abandoning the valuable design principles that have enabled increasingly more efficient and effective information retrieval; to force someone with a highly specified information task to use a chaotic interface would be at best misguided, at worst cruel. Equally though, for less focused tasks we suggest designers consider the value of supporting less structured, curiosity-driven and playful information interactions. Addressing these issues will go some way towards defining a new information interaction paradigm, one in which browse is valued alongside search, connection alongside filtering, discovery alongside retrieval, and chaos alongside order.

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