International Journal of Interactive Communication Systems and Technologies
Volume 12 • Issue 1

Review of User Interface-Facilitated Serendipity in Recommender Systems

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ABSTRACT

Serendipity has become a desirable quality in designing recommender systems and user interfaces, hence offering a new measurement for system quality. At the same time, recognizing serendipitous experiences and determining their value is difficult due to their subjective nature. This review builds on 10 studies of user interfaces facilitating serendipity studies and attempts to understand the patterns that guide relevant user interface designs in recent recommender systems. This study furthers our understanding of turning the elusive experience of serendipity into more actionable user interface designs and patterns. The key findings are as follows. First, user controls and visualizations have facilitated serendipity, but studies of recommender systems have not gained considerable attention. Second, frameworks instrumental for user-interface-facilitated serendipity have not gained the researcher's worthy attention. Third, developing countries need to explore serendipity-facilitating recommender systems with more diverse users and more prominent test cases.

KEYWORDS

Information Systems, Innovation, Interactivity, Recommender Systems, Research, Serendipity, User Interface

INTRODUCTION

The research process not necessarily being linear, changing directions mid-course once you learn something new or look at a problem in a new way due to accidental discovery or a surpriseful way. Useful surprises, sometimes characterized as serendipitous, have gained researchers' interest over the years (Pirkkalainen, Olshannikova, Olsson, & Huhtamäki, 2021). Serendipity facilitation has also been studied in information systems, especially recommender systems. Recommender systems are software applications that predict users' choices based on their preferences or past historical application usage data. A recommender system with user interfaces is also called an interactive recommender system. This review aims at serendipity-facilitating information systems, specifically recommender systems with user interface designs.

DOI: 10.4018/IJICST.320180
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This research article discusses several aspects contributing to interactive recommender systems that facilitate serendipitous encounters. This article reports on critical developments in software applications that flourished due to novel user interface technologies, dashboard engineering techniques, and tested or deployed systems. Initially, this research discusses recommender system applications and the critical designs on which they are based. Further, it discusses user interface design charts and visualizations, user controls, and event-driven actions taken by recommender systems. The article briefly discusses the experiences users have, such as serendipity, transparency, control, and contextual operations by the recommender system. It includes a brief discussion on the cognitive workload experienced by users when serendipity and interactivity are sought out by the users (students).

This paper is intended to be helpful to user interface designers, recommender system researchers, and the general audience looking for human-centric designs of information systems, specifically interactive recommender systems. This article contributes to understanding the emergence of user-interface-facilitated serendipity and the understanding of serendipity facilitation.

BACKGROUND

This section provides a background to contextualize the review. This section explains vital attributes of the recommender systems, followed by an overview of the research landscape, which encompasses journals, books, and publications. User-interface-facilitated serendipity is a process used to facilitate serendipity via user controls and visualizations. A recommender system facilitates serendipity when the user stumbles upon a surprising and useful recommendation. This potential feature of recommending systems opens new avenues for finding solutions to problems through unknown and unanticipated routes. It can be helpful as a solution in situations where researchers intentionally seek serendipitous results but can also be found spontaneously.

Further, it can be helpful to find something beneficial in the future and even build up a stack of solutions that could be useful later. Before discussing serendipity and recommender systems in detail, we briefly discuss the terms used throughout the article. The terms are described as follows.

Recommender System

Recommender systems are machine-learning-based information systems that suggest information to users relevant to their preferences (Bobadilla, Ortega, Hernando, & Gutiérrez, 2013).

User Control

User control is a user's ability to manipulate the recommender system's functioning. The user can implement control through various input methods, manipulating the functions and the recommendations themselves (He, Parra, & Verbert, 2016). Furthermore, multiple techniques such as buttons, re-ranking recommendation lists, sliders, interactive charts, and randomization allow for greater user control. The literature on recommender systems also suggests that users control and manipulate the recommendations in pre- and post-recommendation methods.

User Interface

The user interface is one of the principal components of information systems (recommender systems). Its primary role is to get and return information to the user, establishing interaction with the user.

Transparency

When a recommender system is transparent, it can communicate to the users about the internal working of the system (Sinha & Swearingen, 2002). It is also essential to understand that this function (transparency) is beneficial in establishing trust among users. Establishing trust is crucial when recommenders are deployed in activities (learning /education/research) in which there is an extremely

high degree of uncertainty among users. Therefore, it is essential to develop the recommender system's ability to communicate its decisions and integral functions to users.

Context

Context is a term used to describe current situations that users can exploit to adapt the application behavior or benefit the users. Recommender systems have widely used context awareness to improve human-recommender interaction in the past (Haruna et al., 2017).

Serendipity Trigger

A trigger is an event-driven action performed by a stimulus. In this article, triggers are understood more precisely as serendipity triggers, the stimulus that triggers serendipitous information/recommendations to the user (McCay-Peet & Toms, 2015). Research on user interface design, information, visualization, and dashboard engineering considers developing triggers for users who start a process in serendipitous recommendations.

Connection-Making for Serendipity

Connection-making is an essential aspect of the serendipitous experience. It focuses on bridging one idea to another due to triggering (McCay-Peet, Toms, & Kelloway, 2015).

Visualizations

Visualizations include color, charts, and other output techniques that present recommendations to users in meaningful ways (He et al., 2016). Visualizations are used to present recommendations to users to create a more significant impact and greater desired value. Further, it can be challenging when both serendipity facilitating- and accuracy-oriented recommendations are presented to the users.

Exploration

Exploration is a term used in recommender systems when users, through user control and data visualizations, help search and find diverse recommendations previously unknown. This way, most of the effort is on the users' end. Exploration is not in contrast to the serendipity experience, but exploration does take part when the user seeks a serendipitous experience.

Digital Library

Future technologies aim to reach users with minimum effort, setting the stage for recommender systems. Digital libraries are the driving force of recommender system advancement and offer a high value for return. Serendipitous or non-serendipitous recommenders, for both serendipity- and accuracy-facilitating recommenders, aim to maximize digital library resources, including books, research articles, manuscripts, and other digital resources. Serendipity can, however, go one step ahead of accuracy-facilitating recommender systems by facilitating the discovery (accidental) of digital library resources, which can potentially solve a learning problem from an alternate route.

Serendipity and Scientific Discoveries

A study by (Yaqub, 2018) discusses serendipity and its taxonomy. The author describes serendipity as "the notion of researchers making unexpected and beneficial discoveries," which "has played an important role in debates about the feasibility and desirability of targeting public research and development investments." This article discusses the typology of serendipity in detail. The author explains the mechanisms and types of serendipity experienced until now. Therefore, serendipity was established as a potent scientific paradigm worth investigating and applying in scientific discovery processes. The author presents four types of serendipitous experiences. It involves types such as when

a focused search solves a problem when it is solved via an unexpected route and when immediate and later problems are solved.

A study by (Bawden, 2018) discusses serendipity as a valuable aspect of information retrieval system issues compared to earlier systems. The research routes from an information retrieval perspective to a person's creativity, with serendipity as a goal. The article helps us to understand that there is personality and system leverage when observing serendipity. The system-level setting includes random information presented to the users as an essential strategy to experience serendipity. A study (Martin & Quan-Haase, 2017) discusses the serendipity process. The authors describe the process of controlled serendipity, such as a digitally facilitated process to experience serendipity (a result of facilitation). The article shows that digital systems are at the helm of serendipity; user control is critical in developing such systems.

Serendipity and Technology

Various technologies are also harnessing the potential of serendipity. (Eagle & Pentland, 2005) discuss serendipity in detail, advocating for a technology-driven society. The article advocates for serendipity as a potential technology for driving social interactions. The article indicates that the recommender system is critical to this new social experience. In an article by Maccatrozzo, van Everdingen, Aroyo, and Schreiber (2017), the authors establish that everybody has a varying taste for serendipity. The authors argue that serendipity is critical for advancing recommender system applications in various fields. Their research also establishes that recommender systems are benefiting from serendipity. The authors state that the recommender system will be critical to curious users. The article is focused on the value of serendipity but shows that serendipity depends on the coping capability of users to comprehend added information and their curiosity.

Serendipity and Recommender Systems

The study on interactive recommender systems by He, Parra, and Verbert (2016) discusses serendipity and interactivity dimensions in their designs. Similarly, Parra and Brusilovsky (2015) have extensively studied user control personalization of recommender systems. However, certain aspects of the serendipity-facilitating recommender system are unclear. To understand them, we first must understand the history of research discoveries and serendipity. We will also consider how recent technologies have used serendipity to create a useful user experience. Challenges to serendipity facilitation in recommender systems have been studied (Kotkov, Veijalainen, & Wang, 2016). Some familiar challenges discussed are the definition of serendipity, serendipity understanding and context, serendipity in the cross-domain, emotional dimensions, and evaluation matrices to evaluate such them. However, the article fails to present a holistic approach toward serendipity.

As studied by Race and Makri (2016), Cultivating digital serendipity has been a challenge. The authors discuss various digital platforms that have been instrumental in facilitating serendipity. Recommender systems research has been at the forefront of considering serendipity as valuable for creating a positive user experience. Furthermore, the authors argue that digitally facilitated serendipity results in valuable outcomes when applied to digital libraries' information discovery process.

A study by André and Schraefel (2009) discusses serendipity as a valuable concept in academia and life. The authors recognize the computer technology user's role in facilitating the experience. Their research adds to the argument that more people would like to experience serendipity; therefore, it is imperative to use computer technology to facilitate serendipity. However, the literature fails to clarify and presents more questions, such as what kinds and parts of software and hardware would be critical in achieving serendipity. The authors indicate the value of the network and collective understanding to flourish the concept of serendipity. The authors also emphasize the deconstruction of insight to understand the serendipity process better. Technologies other than recommender systems have also used serendipity as a useful concept and studied serendipity (Olshannikova, Olsson, Huhtamäki, Paasovaara, & Kärkkäinen, 2020). Olshannikova et al. show the value and importance of computational

facilitated serendipity and its applications. The authors believe that serendipity is valuable in concepts such as social technologies and knowledge workers. Andre and Schraefel indicate that serendipity is not only a natural phenomenon but a promising concept that can be applied to software to provide value. Olsson et al. (2020) focus on social technology and the value of serendipity in advancing it.

We conclude that very few studies present the gap in serendipity and interactivity in recommender systems. An interactive recommender system can facilitate serendipity, and users can capitalize on the valuable information it suggests. Specific instances include those in which serendipity was achieved by an interactive system, both recommender and non-recommender systems. A study by Helberger, Karppinen, and D'Acunto (2018) discusses the exposure diversity of users as the route for serendipitous recommendations. The authors advocate for the platform's substantial user control and interactivity, which may facilitate such mechanisms; however, they do not explicitly discuss it from the recommender system's user interface design perspective. The authors believe that the lack of variation in recommender system design is also responsible for the monolithic experience of users.

Interactive recommender systems in education and learning primarily focus on academic resource recommendations. The system's weakness includes user information overload and the continuous tendency to loop on a fixed path. These limitations can result in little exploration and a lack of diversity in recommendations. Apart from these challenges, there can be barriers to implementing recommender systems, such as little to no outside knowledge being incorporated into users' tasks, resulting in less user control. An interactive recommender system can further encourage existing learning routes and topics, reinforcing user behavior. The accuracy-oriented recommender system can also lead to more algorithmic and data-centric development of recommender systems because the recommender is less dependent on user control at the interface level. The accuracy-oriented recommender system helps to create more room for hyper-personalization. Further, it can reinforce faster and better in-depth analysis for users/students.

METHODOLOGY

This section presents the research questions and approaches adopted to answer them. The research questions are as follows:

RQ1. What theoretical frameworks facilitate the design of serendipity-facilitating systems?
RQ2. What approaches are employed to develop interactive serendipity-facilitating recommender systems?

The Process:

This rapid review is based on the process presented by (Khangura, Konnyu, Cushman, Grimshaw, & Moher, 2012) and illustrated in Figure 1 below. The review process is discussed by Tricco et al. (2015), Dobbins (2017), and Moons, Goossens, and Thompson (2021). The authors provide a detailed description of the rapid review protocol and describe how rapid reviews can be conducted.

Searching Techniques

The Search strings used to find the articles are described in Table 1.

Scope

The scope focused on discovering novel user interface/interactive techniques for serendipity experience facilitation via the recommender system.

Data Sources

The data selected was formed via leading computer science databases. The chosen data sources include the Association Computing Machinery (ACM) digital library and Google Scholar. These services supply ample information about the scope of crucial recommender system research setup.

Figure 1.
The Rapid Review Process

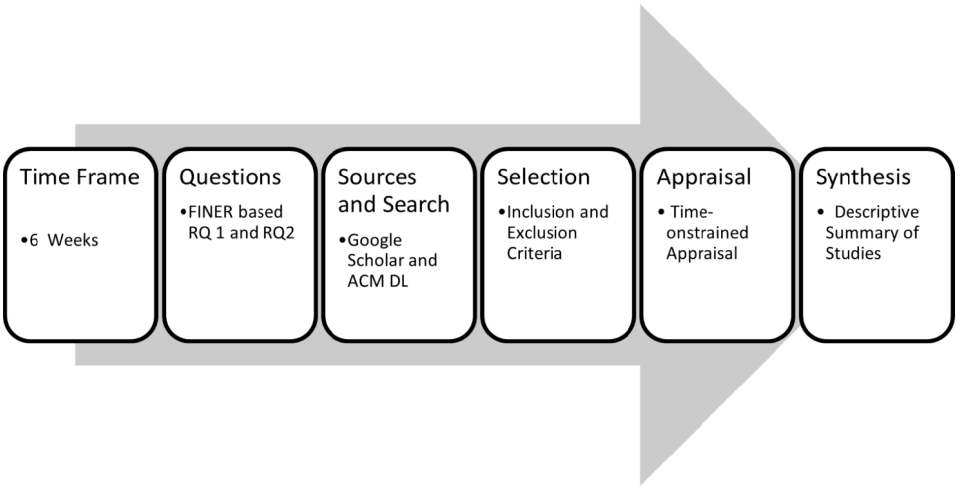


Table 1.
Search Strings

Search String	Keywords
S1	Serendip* Recommend* Interface*
S2	Serendip* Recommend* Control*
S3	Serendip* Recommend* Interact*
S4	Serendip* Recommend* User Interface*
S5	Serendip* Recommend* Visual*
S6	Serendip* Recommend* Article*
S7	S1 AND Novel
S8	S1 AND Control*
S9	S4 AND Article*
S10	S4* AND visual* AND Control* AND Article*
S11	S1 AND GUI
S12	Serendipity AND GUI
S13	“Recommender System” AND “GUI”
S14	“Article” “recommender system”
S15	“Research paper ” “recommender system”
S16	GUI AND recommender AND Serendipity AND Academic

Inclusion and Exclusion Criteria

- The inclusion criteria included articles written in English and published within the last 20 years.
- Most articles were more recent and published within the last five years.
- Journal articles, conference and workshop proceedings, and book chapters were selected.

- The papers included studies on implemented information systems and recommender systems.
- These information and recommender systems presented a novel user interface that facilitated serendipity.
- All research studies were analysed for design attributes, such as user interface level transparency, user interface, context information use, and user controls contributing to the serendipity.

Strength of Evidence, Synthesis, and Process Monitoring (Focus on Repeatability and Completion)

We carefully considered the strength of the evidence and the overall way the research was synthesized. Further, we examined the articles and whether the studies or experiments could be repeated. These processes helped us filter and select the relevant articles for our rapid review. The results from search strings are presented as follows.

STUDY RESULTS

In this section, we answer the research question stated in the previous section. The results of the rapid review are presented as frameworks and serendipity-facilitating user interfaces. The details are presented as follows.

RQ1. What theoretical frameworks facilitate the design of serendipity-facilitating systems?

An Overview of Frameworks

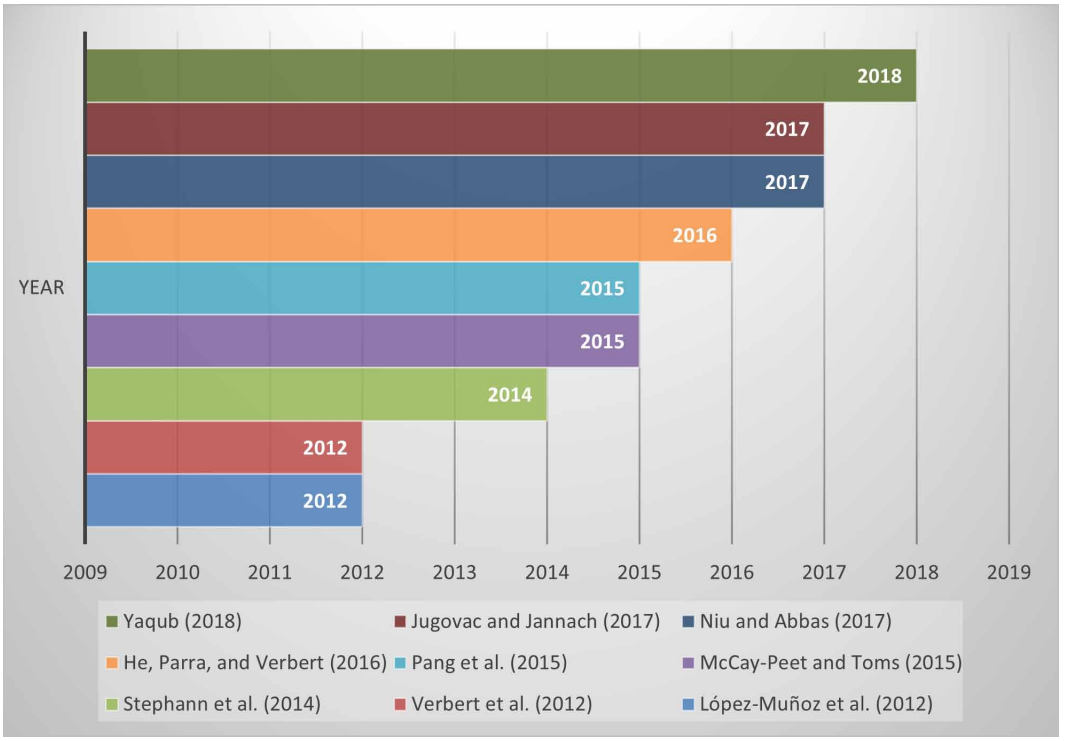
Various frameworks are recommender systems that aim for or can be instrumental in developing a recommender system user interface that can potentially facilitate serendipitous recommendations.

An overview of publications over the years is shown in Figure 2. A study by Stephann et al. (2014) aims to develop a narrative that serendipity cannot be controlled yet has the potential to be influenced and shows that user interfaces that facilitate serendipity can be designed to understand the structure of this phenomenon. The study by McCay-Peet and Toms (2015) describes the development of the taxonomy of the serendipity phenomenon and explains that the components of serendipity can help establish the narrative and structure of recommender systems' user interface. Niu and Abbas (2017) describe in the study how value, surprise, and curiosity models-based recommender system engineering can be done. The work shows the possibility of user interface design that relies on value, surprise, and curiosity-facilitating mechanisms.

A study by He, Parra, and Verbert (2016) shows that user interface development of a serendipity-seeking/facilitating recommender can benefit from the work as it provides the baseline and relationship with serendipity to other attributes of the recommender system. Pang et al. (2015) present design principles that can help the development of exploration-facilitating interfaces. The work shows that serendipity-seeking recommender systems can harness design principles and serendipity as an accidental exploration. A study by Yaqub (2018) describes theoretical work on serendipity as a phenomenon. The work shows that a recommender system can use an interface to create the value of serendipitous recommendations. A study by López-Muñoz et al. (2012) shows how pharmacology advanced due to serendipity, and the study reports the advancement of a study field due to serendipitous information.

Verbert et al. (2012) present a survey of context-aware recommender systems; it defines and explains their configuration, application, and impacts. Furthermore, according to this study, recommender systems designers can exploit context to maximize the value of serendipity in a situation or multiple situations. Furthermore, recommender system designers can benefit from the work by implementing various patterns of serendipity. Jugovac and Jannach (2017) present comprehensive work on user feedback mechanisms and recommender system operations. The work presents

Figure 2. Frameworks and Publications Years



visual approaches, persuasive and proactive user interfaces, explanations, and related issues to the recommender system user interface. The study can be instrumental in designing and developing user control for recommender systems to facilitate serendipity.

Ziarani & Ravanmehr (2021) discuss in details about serendipity facilitation in recommender system.

Similarities and differences among the frameworks: The frameworks presented in this section aim at understanding serendipity-facilitating recommender systems. The frameworks contribute to how serendipity can translate into a recommender systems design goal. The frameworks differ in the three fundamental aspects of critical attributes of recommender systems. They are serendipity, user interface, and recommender system. Further, the frameworks presented differ in their contributions to understanding and developing a serendipity-facilitating recommender system. Some frameworks help to understand the taxonomy of the field; some aim towards evaluating recommender systems and the practical techniques to achieve a system objective.

The divergence of philosophical lines: The studies discussed above broadly contribute to understanding key aspects of serendipity-facilitating user interfaces; however, these frameworks diverge when considering serendipity-facilitating systems and serendipity as an accidental discovery process. However, these frameworks give ample space to understand information systems (recommender systems) boundaries. Serendipity has been facilitated by information systems not designed to facilitate it, but users experienced serendipity.

The discussion on frameworks in recommender systems is divided into two basic approaches: accuracy-oriented and serendipity-facilitating recommender systems, as discussed in Table 2. The classification distinguishes between algorithmic-based and non-algorithmic performance enhancement, homogenous and hybrid design algorithms, and objective and subjective evaluation methods.

Table 2.
Comparison Between Accuracy-Oriented and Serendipity-Facilitating Recommender Systems

	Recommender System Attribute	Accuracy-Oriented Recommender System	Serendipity-Facilitating Recommender System
1	Usefulness	Most useful in the fixed line of action	Most useful in the exploratory line of action
2	Relevance	Relevant recommendations	It might be less relevant or useful. It might be useful from a new perspective
3	Event-Driven Approach (Contextual Operations)	Event- or situation-based relevance of recommendations	The context might be more necessary on an uncharted path/uncertainty due to surprise
4	User Control	Little user control needed	It might require more user control for pre-and post-recommendation manipulation
5	Visualization	Highlight more relevant and useful recommendations	Highlight recommendations that are unanticipated but not irrelevant
6	Evaluation	Algorithmic and non-algorithmic evaluation	Most evaluation is non-algorithmic subjective
7	Established Effectiveness	Has an established effectiveness	The effectiveness is yet to be established

Various visualizations and user controls have been used to facilitate serendipity, and a significant division of state-of-the-art recommender systems is between search-facilitating and serendipity-led exploration. The glimpse into the exploration-facilitating visualizations for serendipity shows most of the work done in this decade. The aspects discussed in the table show frameworks, research approaches, conflicting issues, and structures used to transform work based on serendipity. The chart supports exploring these frameworks for more user-driven serendipity approaches in recommender systems design.

RQ. 2. What approaches are employed to develop interactive serendipity-facilitating recommender systems?

To answer RQ. 2, we present Tables 3 and 4. These two tables present the comparison and composition of user interface-driven serendipity in recommender and search-facilitating information systems. The tables describe the techniques used to visualize and control software, outcomes, and the impact of the work on understanding user-driven serendipity. A review of interactive information systems and recommender systems is presented in Table 3 and Table 4.

User-interface-facilitated serendipity has the following pros and cons. First, this approach is novel, and few currently support such studies. The work has a high potential for 3D (AR/VR) studies. Only educational recommender systems have been explored in this approach. More domains, however, such as e-commerce, entertainment, industry, and engineering manufacturing, should explore user-interface-facilitated serendipity. Serendipity should not only be synonymous with discovering accidental and useful books, but it should be studied for exploring movies, apps, and user experiences of Internet of things-based setups. With user-interface-facilitated serendipity in query-based information, systems have been observed to have the following outcomes. First, some of the systems have facilitated serendipity, but in most cases, serendipity was not the objective of the system's design. Second, exploration-facilitating search-facilitating serendipitous recommenders have been achieved in augmented reality systems (A.R.), unlike their search-facilitating recommender system counterparts. Table 4 shows that only a few user controls and visualizations were tested and experimented with facilitating serendipity.

Table 3.
Review of Exploration and Serendipity-Facilitating Techniques in Information/Query-Based Systems

Reference	Year	Country	Type of Work	Serendipity Technique	Outcomes	Impact
Bach et al. (2017)	2017	USA, UK	Augmented reality-based work on the exploration of libraries.	None/exploration/ discovery.	Augmented reality can be a less explored option for serendipity-based recommender systems.	AR can be essential in redefining user interface visualization-based serendipity to explore augmented reality.
Bruns et al. (2015).	2015	Germany	Graph-based visualizations and user-controlled recommender behavior.	None/ exploration of relevant recommendations.	User control and visualizations can help reduce the recommender system's efforts to find relevant recommendations.	User control and visualizations-based serendipity is a dimension explored by recommender system designers.
Alexander et al. (2015)	2015	USA	Layer-based information exploration and discovery of large corpus text.	Interactivity and visualizations-based exploration.	Interactivity plays an essential role in exploration-oriented missions that can be embedded in recommender systems.	The exploration of a layer-based user interface or visualization technique can facilitate serendipity.
Rädle et al. (2012)	2012	Germany	Search, and serendipity are supported by information visualization.	Two-dimensional interactive scatter plot used to support serendipity.	Serendipity via interactivity is an essential concept for advancing non-algorithmic serendipity.	Serendipity facilitation by the non-algorithmic technique can even start with a scatter plot.
Calero Valdez et al. (2015)	2015	Germany	Visualization of documents for organizational knowledge and usability.	Graph-based visualizations and document/ author-centric bubble chart visualizations.	The serendipitous discovery was possible with the help of data visualizations.	The study shows how serendipity can be achieved by graph-based recommender visualization.
Kleiner, Rädle, and Reiterer (2013)	2013	Germany	A user interface design that uses real-life reflection/ setting in a user interface to support exploration.	Serendipity support via exploration-centered work	Serendipity can be supported in recommender systems via real-life graphical output and projections in the recommender system.	Recommender systems that facilitate serendipity can benefit from realizing the presentation of items with more understanding of real-life serendipity triggering and ideas that connect thoughts for serendipity.
Dumas et al. (2014)	2014	Belgium	A tangible user interface for the exploration of artwork.	Supports serendipity via a user interface design. It also uses tangible user interfaces.	Serendipity can be facilitated with tangible user interfaces.	The recommender system can benefit from tangible user interfaces for serendipity facilitation.

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Table 3.
Continued

Reference	Year	Country	Type of Work	Serendipity Technique	Outcomes	Impact
Cleverley and Burnett (2015)	2015	UK	Set of visualizations that document keywords-based and graph-based visualization.	Supports serendipity via a user interface.	Serendipity can be facilitated via user-interactive design.	Graph-based visualizations for serendipity should be explored and can be powerful.
Thudt, Hinrichs, and Carpendale (2012)	2012	UK	Exploration of books through interlinked visualizations, facilitating serendipitous encounters.	The visualizations have the following: -keywords chains -hover circle visualization -author lists -content timeline graph -pages of block visualization.	Although it is a search-based serendipity feature, it provides immense value for recommender system adaption.	Novel visualization concepts have been applied to book discovery and exploration, supporting serendipity.
Kleiner et al. (2013)	2013	Germany and Denmark	The work presented book exploration visualizations that are presented on real-life bookshelf presentations.	Interactive 3D item presentations that enable users to explore the books.	Serendipity-facilitating recommender systems must explore the real-life models and projection to visualization results.	The subjective evaluation should be incorporated and cross-examined with exploration-oriented search-based interfaces.

However, the systems that have proved useful have not been fully exploited for facilitating serendipity. The work discussed in the tables spans from 2012 to 2017, further works from 2018 to 2021 have also been discussed . From the above analysis, we conclude that even serendipity was experienced because, in specific experiments, it was surprising to discover the serendipitous impact of visualization and user control. Furthermore, studies on user control and visualization have been explored for serendipity facilitation in recent years by Afridi (2018b, 2018a, 2018c, 2019b, 2019a). These studies involve examples, user control, data visualization, and developing serendipity-based information and recommendations. Therefore, we can conclude that user interface components, such as recommendations, Top-N list re-rank, and visualization, significantly facilitate serendipity in information and recommender systems. For user interface designers, it is essential to understand the impact.

Most recommender systems evaluation techniques have been established because of algorithmic advancement (Beel et al., 2013). In Table 4, the analysis of the interactive recommender system allows us to investigate experimental objectives and experimental setups of user studies and provide us with information on how and what kinds of evaluations have been carried out concerning interactive recommender systems. The literature on recommender system evaluation lays down the following criteria. First, the sample size and this table results show that the evaluation may be carried out with as few as thirty and more than 100 users. Further, most of the recommender systems tested are on either web-based implementations or mobile app platforms or, in some instances, both. The evaluation methods applied to the user interfaces of recommender systems are subjective (user studies), but some are subjective and objective (algorithmic evaluation). Statistical methods have been used to

Table 4.
Interactive Recommender Systems and Experimental Setups

Reference	Year	Country	Study Theme	User Controls and Visualization Used in Interface	Experimental Setup	Impact
Parra and Brusilovsky (2013)	2013	USA	A conference talk recommender based on Venn diagram-based recommendations helps conference participants to attend a talk.	Visualization of recommendation through Venn diagram	One hundred sixty-eight participants used the system. The system supports the exploration of recommenders. Subjective evaluation through the survey was performed. objective and subjective evaluation was performed to analyze the usefulness of the software	Recommender system study that encourages serendipity facilitation
Loepp, Hussein, and Ziegler (2014)	2014	Germany	This study was conducted to look at user-controlled recommenders with algorithmic development. The study provides a case to study the trade-offs between user control and automatic function in recommender systems.	Set of two recommendations sets for preference selection. The display sets are in a Grid formation.	The work uses both subjective and objective evolution mechanisms.	The study points towards a study between algorithmic serendipity and serendipity achieved via a user interface
Loepp, Herrmanny, and Ziegler (2015)	2015	Germany	The studies blended recommendation mechanisms with a focus on user-controlled filtering. The work uses subjective and objective (user interaction data) evaluation for user interface evolution.	The user interfaces feature slider user controls for preferences input and grid-based output of recommendations results	The work was evaluated using a subjective evaluation mechanism	User-controlled recommender system for serendipity can explore item level filtering via user control and study the degree of serendipity in user-based subjective evaluations
Knijnenbur, Reijmer, and Willemsen (2011)	2011	Netherlands	The work presents a study on user control of the recommender system with user-centered subjective evaluation.	Buttons controls and slider controls for user input, visualizations for explicit input, list-based output for output	The study was conducted for the study of five interaction methods. The user interface was evaluated among 147 participants.	Since serendipity is subjective, the user interface evaluation should be carried out with an extensive user-centered approach with changing user controls
Bostandjiev, Donovan, and Höllerer (2012)	2012	USA	The work presents a recommender called Taste Widget. It uses a root-leaf approach-based visualization for a recommender system.	A visualization based on roots-leaf connected graphs	In a controlled study on thirty-two users, the study performed subjective evaluation (question-based) of users of the recommender system.	The work is one of the pioneering studies of the user interface for the recommender system, and the work can benefit serendipity-oriented user interfaces under various contexts
Bruns et al. (2015)	2015	Germany	The work presents a recommender system that uses responsive graph visualization. It supports exploration.	Connected graph-based visualization	User study based on sixteen users. The evaluation was done using	Responsive graph-based serendipity should be explored for serendipitous experiences for recommendations.

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Table 4.
Continued

Forsblom et al. (2012)	2015	Finland	The work presents the use of location technology for serendipitous event recommendations. The location, which is a type of context, indicates contextual information for serendipitous recommendations.	A geographical map with a list of outputs	The work was evaluated in a field study by fifteen participants	Visualization used in context-aware computing and serendipitous recommendations can be used to demonstrate novel visualizations
Millecamp et al. (2018)	2018	Belgium	The work presents user control for exploration and user preferences in Spotify (music recommendations) platform.	Prototype user interfaces use slider-based user controls and radar-based visualizations for preferences	Forty participants evaluated the prototype. The system emphasized user control and transparency of recommendations	Serendipity-facilitating recommender systems should be evaluated for various visualization techniques and user controls on user interfaces for user preface election and representation.
Parra and Brusilovsky (2015)	2015	USA	The work presents a recommender called Set Fusion that studies Venn diagram-based visualization of recommendations.	Slider-based input controls and Venn diagram-based recommendation visualization with details in the list-based output.	Forty participants over different conditions.	The work forms the baseline for various accuracy/ serendipity-oriented dual visualization presentations.

differentiate between user interfaces, comparing a baseline recommender system. Further, a fixed set of visualization objects has been used to test the user experience of serendipitous recommendations. The research gaps are presented in Figure 3 and Table 5, respectively.

He et al. (2016) has established the attributes and variables for the interactive recommender system. The primary purpose of mentioning these attributes is that they have recently been studied for serendipity-facilitating recommender system development (Afridi & Outay, 2020b). Therefore, it is essential to understand these three variables and the work done in interactive recommender system development and establishing user trust. Furthermore, it also indicates the pursuit of the research community for balancing autonomous vs. user control for manipulating recommender systems.

DISCUSSION

Internal and external factors influence their serendipity experience when using recommender systems. The internal factors include user preparedness, trigger elements, and connection-making among those entities, as McCay-Peet, Toms, and Kelloway (2015) described. The external factors include interface design, mobile, and desktop sensors suit feeding contextual information, support of high-end graphics, augmented reality, virtual reality, and finally, the persuasive design of the recommender system. It will offer more options to designers and engineers developing serendipity-facilitating recommender systems.

Since a vast gap of approaches in recommendations exists between user interface-based Serendipity and algorithm-based Serendipity in recommender systems, the user interface can play a role in further manipulating or testing various serendipity-facilitating algorithms and recommendations list manipulation used in multiple scenarios to enhance the user experience for recommendations.

In real life, we often experience serendipity. We find unexpected useful information or objects when we roam around physical spaces. Recommender systems that focus on augmented reality/

Figure 3.
The Interactive Systems, Recommender Systems, and Serendipity Facilitation

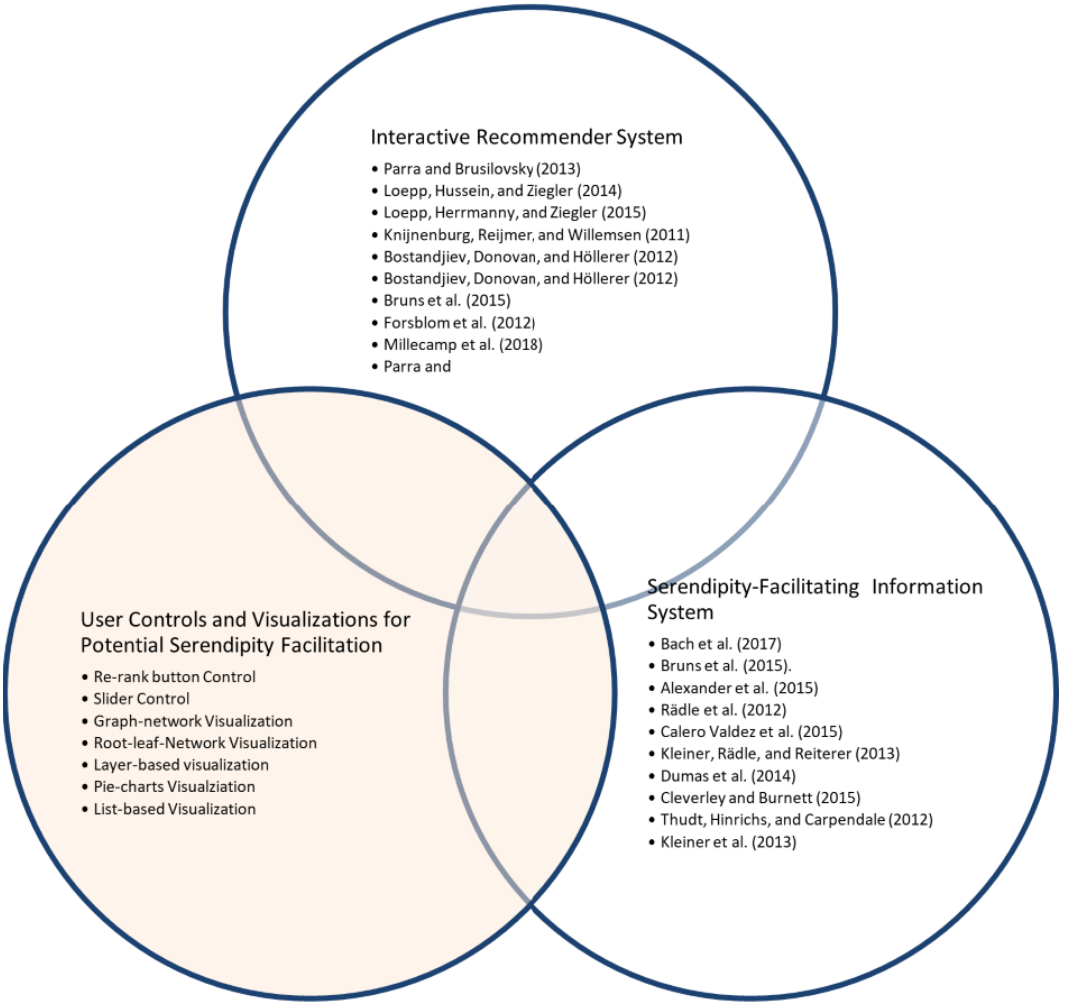

Table 5.
Gaps in Interactive Recommender Systems

Application Area	Gaps in literature
Scientific Discovery	A review of serendipity-based accidental discoveries in the information systems/ recommender systems domain
Developing Countries	Developing country perspective and user experiences
Sample Size	Sample size larger than 30-60 users with more diversity of users.
Open-Source Contribution	Algorithms and user interface designs as opensource projects
Impact of Serendipity on Users	Task load studies with varying user interfaces for recommender systems
Contextual Serendipity	Understanding serendipity using context-aware computing

virtual reality provide an analogous way to explore serendipitous recommendations. User controls and recommendation visualizations will change how we explore information and experience serendipity in the same pattern.

There are numerous opportunities for technology-enhanced learning. The perception of serendipity and value should be explored in detail. The current perception of serendipity in learning is still in its infancy. Some potential scenarios in which recommender systems may benefit students and researchers include suggesting a thesis topic, a class presentation topic, or a group project idea. The user/student of the recommender system might be unfamiliar or unaware of the topic "accidentally" discovered. The literature discussion shows us that user controls and visualization are still not fully explored and applied for multiple types and scenarios involving serendipity. Further, context awareness can aid user controls and interactivity when engaging users to use the user interface when users seek serendipity.

Limitations

There are limitations to this study. Multiple studies show variations in the number of participants involved in evaluating the recommender system. Establishing serendipity, a useful phenomenon in learning and a recommender system feature requires an established large sample size. This point is self-evident in the commercially available recommender systems designs and emerging design of user interfaces for recommender systems. Platforms such as Netflix and Facebook use recommender systems to make recommendations for many users. If such a platform implements serendipity that is user-controlled/driven, it must test a broad range of users. Nevertheless, the industry is not yet convinced of the usefulness of serendipity and its effects.

Methods and frameworks point to the need for a comprehensive evaluation of technologies and detailed user studies to observe the use of serendipity and its impacts. When serendipity progresses towards meaningful and enhanced business value, there will be a demand for taxonomy and frameworks to complement the effort to develop software systems across disciplines. The current frameworks discussed in the literature review offer a platform to start the discourse. Another limitation is that serendipity driven by the user interface can face several challenges across various domains. The challenges in the entertainment industry using the recommender system for serendipity can be different from the academic recommender system, the ownership of results, impact on users, impact on consumption of information, and development of products/ series and artifacts. Therefore, we can conclude that the engineering of serendipity-facilitating products will provide challenges and opportunities for users.

CONCLUSION

This work provides a literature review of serendipity and the interactive recommender system. Frameworks exist for understanding serendipity, identifying it, and using it for recommender systems development. However, new, and better frameworks must be developed for serendipity for the information and recommender systems. We discussed the frameworks that provide a great platform to identify, understand, and serendipity in various forms currently applied to digital technologies. The user interfaces design and development of recommender systems and related work aids in designing serendipity-facilitating recommender systems. This literature review allows users to expand the framework's design and development recommender systems and conduct more case studies about serendipity.

The literature shows that serendipity via the user interface is still in its infancy, with most of the work based on information system user interfaces that are exploration-facilitating. The main reason behind the user interface facilitated approach is that serendipity has limitations concerning the user-controlled process, limited case studies, and platform limitations (software on which such features have been experimented).

The literature shows us the trends and helps designers and engineers to develop novel case studies to explore user control and visualization based on their ability to create serendipitous experiences. Significant contributions to serendipity facilitation were attributed to the user interface designs that were exploration friendly. Various user controls and visualizations that facilitate exploration on the user end can help identify potential user interface design approaches. Further research can be advanced within the following areas of research.

Context Awareness and Serendipity

Developing context-aware serendipity in recommender systems can supply new capabilities and outlooks to enhance the ultramodern context-aware recommender system. The main idea of using context is to guide users toward serendipity, often attributed to uncertain information. Further, context awareness can find relevance and prepare the user's mindset for serendipity and facilitate serendipity triggers and situation-aware connection-making for the serendipitous experience. Location-based serendipity can be considered an offshoot of this idea.

A Unified Framework for Developing Serendipity-Facilitating Systems

Engineering serendipity-facilitating recommender systems rely on the theoretical background and its roots in accuracy-orientated systems. Thus, the evaluation of the serendipity-facilitating recommender system can be tested by novel evaluation technicians designed to test users' attempts for serendipity in recommender sets. Further, user control and autonomous serendipity-seeking behaviors should be explored to understand users' experience needs.

Establishing the Value of Serendipity

The value of serendipity is still an important question for researchers and industries investing efforts in developing such technologies. Therefore, it is vital to conduct novel studies to understand and prove the value of serendipity (specifically, serendipitous recommendations) to the research community.

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