Towards defining a CAVE like system performance evaluation

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Abstract. One of the main goals of Virtual Reality is to provide immersive environments that take participants away from the real life into a virtual one, this is how *Cave Automated Virtual Environment (CAVE)* came about many years ago. Nowadays there are many of this kind of room-sized systems providing a superior Virtual Reality experience and are used for research into a wide range of disciplines including archaeology, architecture, art, biology, engineering, geometry, geology, medicine and healthcare, meteorology and physics. Nevertheless, for a good Virtual Reality user experience, it is necessary to have a processing system optimized for visual computing (based on CAVE-related features, Interaction, Application, etc.). In this work we propose an evaluation methodology for our Cave-like multi-VRmedia System. The proposal is based on three generic criteria: *Performance*, *Usability* and *Relevance*. The strategy tries to prove how assertive a system is when it comes to solving a problem.

Key words: Virtual Reality, CAVE system, Computer Graphics, System Analysis, CAVE like Evaluation, Multidimensional Evaluation

1 Introduction

Virtual Reality (VR) started about 60 years ago in a form that would be recognized as today such as head-mounted display (HMD), head tracking, computer graphics generated images, among others, although the hardware was completely different. Over the last decade a huge amount of research has nevertheless been carried out across a vast range of applications – from medicine to business, from psychotherapy to industry, from sports to travel.

On the other hand, scientists, engineers, and people working in industry carried on with their research and applications using and exploring different forms of VR, and in turn developing VR systems or creating laboratories. In relation to VR systems, there are two main groups – head-mounted devices and CAVE-type installations, an advanced VR solutions based on specially configured set of projection screens.

Particularly, the *Cave Automatic Virtual Environment* is a room-sized, immersive virtual reality system developed in the early 1990s, which continues to provide a superior VR experience to those offered by other VR systems, such as HMDs. In spite of its sizable volume and cost, the popularity of the CAVE system as a research tool for science has not declined over time. The CAVE was envisioned from the outset as a device to enable distance collaboration among viewers immersed in shared computer-generated scenes – a kind of 3D telephone booth, a technique called tele-immersion [1].

There are several types of CAVE installations in the world, each of them differ in dimensions or number of screens on which images are projected, supporting architectural technology and technical installations. All of them, are improvements to the classic CAVE, mainly as a result of commercialization.

Software for CAVEs, or more generally, for large display systems, has also evolved hand-in-hand with developments in hardware. A common feature of most CAVE-type systems is that a highly immersive experience is afforded to users by surrounding them with large screens on which stereoscopic images are projected. All participants wear active stereo glasses to see and interact with complex 3D objects. One participant wears a six degree-of-freedom location and orientation sensor called a tracker so that when user moves within the CAVE, the perspective of the images is automatically adjusted to a viewer's eyes by the tracking system. The user in a CAVE room interacts with VR objects through a portable controller, which is sometimes called a *wand*.

In particular, the *Laboratorio de Computación Gráfica* (LCG) [2] has so far focused on the development of immersive environments that support multimodal and especially gestural interaction. The result of our efforts has been *IVI CAVE* (Immersive Virtual Innovation CAVE), a low-cost and powerful engine to manage real-time interaction within an immersive environment [3].

IVI CAVE has been used to give solutions to real problems of the society like: traffic accidents [4], car driving [5], civic rules teaching [6], stroke rehabilitation [7], multiple sclerosis rehabilitation [8], among others. Now, the aim is to validate the immersive environment achieved through years of hard work. The analysis would allow to determine if the solutions obtained to address real problems are improved by using the platform. Additionally, determining if our environment follows conventional cave standards and identifying any improvements is desired.

Our research questions are related to the added value of any system in the context of a CAVE-type system:

- To which extent the system brings a better sense of experience in virtual immersion?
- What is the precision of a CAVE like system versus others inmersive system?

The following sections attempt to show some aspects to take into account when defining a systematic method of analysis of a CAVE like system. Section 2 names the existing basic criteria for any generic system. Section 3 attempts to define a test set for any CAVE like system according to the basic criteria of section 2. Section 4 provides a small discussion and future guidelines.

2 Typical Systems' Evaluation Criteria

Visual computing includes the traditional types of graphics applications plus many new applications. For a good virtual reality user experience, it is necessary to have a processing system optimized for visual computing. When talking about a CAVE system, components, machines and systems must be analyzed and optimized in order to give a better user experience, while at the same time depicted scenarios are simulated and processed at a very short time, and interactions are resolved quickly and easily. In brief, a CAVE like system features can be summarized as follows:

- A CAVE is used to visualize 3D data, transporting viewers directly into the system or machine environment.
- Implementing a system based on CAVE technology requires in-depth knowledge in many different disciplines, such as sensing and tracking technologies, stereoscopic displays, multimodal interaction and processing, computer graphics and geometric modeling, dynamics and physical simulation, performance tuning, etc.
- Input/output, screening and full recognition of the viewer's being and actions (speech, non-verbal utterances, and gestures) must be provided in real time with no great user encumbrances (special glasses, headphones, head tracking, among others).

All these features must be linked together giving a supporting structure to any application system suited for use in CAVEs with near-zero latency and no noticeable artifacts.

The construction of a CAVE like system is an ambitious, complex, and essentially interdisciplinary process. This is inevitable given the depth, sophistication, and many modalities of the products we seek to create. More over, when trying to analyze a CAVE like system, we dealt with different scientific difficulties:

- *CAVE-related questions*, like intrusiveness, visuo-haptic synchronization, and space perception. CAVEs cause specific issues that HMDs do not. Objects cannot be visually intrusive, physical and virtual parts are mixed within the environment (especially the body of the subject), space perception can be biased, anthropological parameters have an influence, etc. All of them can be synthesised in the pair hardware and software relationship.
- *Interaction system related questions*, specific to the modality (kinesthesia, cutaneous, sensory substitution, etc.) or any device implemented.
- *Application system related questions*, specific to the addressed problem.

There are different strategies in the literature to evaluate how assertive a system is when it comes to solving a problem. Generally speaking, systems are usually evaluated in accordance with 3 criteria.

- *Performance*. It should be sufficient to allow effective interactions and feelings of confidence.
- *Usability*. Industrial usage requires the system in study can be measured by taking into account the context of use of the system in order to be accessible to a large spectrum of users, and compatible with a large spectrum of use-cases.

– *Relevance.* Each system modality can respond to additional use-cases which must fit the context.

The following sections develop these concepts in detail for a CAVE like system.

2.1 System Performance

When designing a VR system, the ultimate hardware design goals are: *scalability*, *usability*, *potential to hold several users and/or be network connected*, *extended service intervals and easy access for maintenance*, *power-efficient*, *low cost*, among others.

On the other hand, desirable features include [9][10]:

– *High resolution*, so virtual images are seen as sharply and in as much detail as in reality.
– *High brightness and contrast*, so colors are vibrant and not washed out or dim.
– *3D realism*, production of computer graphics and the display of captured imagery in a way equivalent to or exceeding human visual acuity, in 3D with the correct viewer-centric perspective rendering for every viewer.
– *Whole interaction*, Extended input and full recognition of the viewer's or viewers' being and actions, including speech, non-verbal utterances/noise making, and gestures.

In addition, and if it is useful to the task, the following features are desired:

– *Audio* (sonification) at or exceeding human aural acuity, fully surround, listener centered and focused.
– *Touch* (tactile) input from the user and touch output from the VR system, allowing haptic input and feedback, for all users [9].
– *Olfactory* (smell) output delivered to each user, and input recognition as well.
– *Taste* output and input recognition.

Both design goals and desirable features involve hardware and software aspects. As currently there are a wide assortment of hardware and software configurations assembling a CAVE like system, a comprehensive analysis of their components must be done.

2.2 System Usability

This section address methods for evaluating it as artefacts according to their usability, in an attempt to analyse the quality of the system.

Usability is a quality attribute that assesses how easy user interfaces are to use. The word "usability" also refers to methods for improving ease-of-use during the design process. Usability is an empirical concept, which means that it can be measured and evaluated. In fact, usability is a quality attribute whose formal definition is the result of listing the different components or variables through which it can be measured. Usability is defined by 5 quality components: *Learnability, Efficiency, Memorability, Errors, Satisfaction* [11].

One of the best ways to evaluate the usability of a product or application is to test it with real users, a method known as **user testing**. By observing how users are confronted with interactive tasks, we can objectively quantify design usability by counting the number of errors they make (*effectiveness*) or by measuring the time it takes them to complete them (*efficiency*). In addition, by asking users once they have completed their tasks, we can measure subjective or perceived usability, that is, how users rate the design or what their level of satisfaction is.

Considering generic usability evaluations, there is a wide variety of evaluation methods that are classified into four main methods [12].

- Usability Inspection Methods: used by experienced practitioners. While these methods do not involve users directly, they can provide some useful insights. However, the goal is to use them to supplement, not replace, direct user involvement in testing designs and systems; e.g. *Pluralistic Walkthrough*, *Heuristic Evaluation*, *Cognitive Walkthrough*, *Heuristic Walkthrough*, *Metaphors of Human Thinking* (MOT), *Persona Based Inspection*.
- Usability Testing with users: *Usability Testing*, *Benchmark Testing*, *Competitive Usability Testing*, *Summative Usability Testing*, *Remote Evaluation*, *Think Aloud Testing*, *Wizard of Oz*.
- Evaluate Usage of an Existing System: *Critical Incident Technique* (CIT), *User Edit*, *Web Analytics*.
- Questionnaire and Survey Methods: *Rating Scales*, *Satisfaction Questionnaire*, *System Usability Scale* (SUS).

In particular, VR is thus often referred to as immersion technology. VR systems may vary greatly in levels of immersion and user experience they offer based on the system characteristics and context of virtual environments. One of the major evaluation problems is the lack of a suitable criteria for this type of systems. Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences. An environment that produces a greater sense of immersion will produce higher levels of presence. Presence, is the subjective experience of being in one place or environment, even when one is physically situated in another. So *immersion* and *presence* are significant features to be defined as metrics:

- Immersion: measures the degree of visual simulation that a VR interface provides for the viewer - the degree of suspension of disbelief. Factors that affect immersion include *isolation from the physical environment*, *perception of self-inclusion in the virtual environment*, *natural modes of interaction and control*, and *perception of self-movement*. Immersion also refers to a level of sensory fidelity which depends on measurable system attributes such as *Field Of View* (FOV); *display size*; *stereoscopy*; *display resolution*; *head-tracking*; or *input devices*, among others [13, 14]. According to the literature some of the techniques to measure the degree of immersion are: *Immersive Tendencies Questionnaire* (ITQ) [15] and *Biosensors* [16].

- Presence: in [15] the authors state that presence is a normal awareness phenomenon that requires directed attention and is based in the interaction between sensory stimulation, environmental factors that encourage involvement and enable immersion, and internal tendencies to become involved. There are multiple mechanisms that attempt to address the perception of presence: *Presence Questionnaire* (PQ) [15, 17, 18], *Slater-Usoh-Steed questionnaire* (SUS) [19, 20], *Igroup Presence Questionnaire* (IPQ) [21–23], *ITC-Sense of Presence Inventory* [24].

2.3 System Relevance

In [25] Saracevic identified five types of relevance, namely: (1) topical or cognitive relevance; (2) algorithmic relevance; (3) pertinence or intellectual relevance; (4) situational relevance, and (5) motivational or affective relevance. The concept of relevance has long been studied in diverse fields including philosophy, communication, logic, psychology, artificial intelligence, natural language processing, documentation, information science, and information retrieval.

In particular, information science emerged as the third subject, along with logic and philosophy, to deal with relevance - an elusive, human notion. The concern with relevance, as a key notion in information science, is traced to the problems of scientific communication (type 3), due to relevance is considered as a measure of the effectiveness of a contact between a source and a destination in a communication process. Specifically, in information retrieval or data quality, relevance is the ability of an information retrieval system to retrieve material that satisfies the needs of the user. The information retrieval community has emphasized the use of test collections and benchmark tasks to measure topical relevance [26–29].

In contrast to this focus solely on topical relevance, the information science community has emphasized user studies that consider user relevance (type 1 and 5). These studies often focus on aspects of human-computer interaction [30–32]. According to the literature, all existing metrics in the area, so far, have been defined for information sciences and mostly related to information retrieval. This means that the relevance of CAVE systems is a possible gap in existing scientific knowledge.

3 Defining a basic CAVE like system evaluation

In section 2 a group of criteria (*performance*, *usability* and *relevance*) and the corresponding evaluations methods for any kind of system had been mentioned. Nevertheless, a more specific evaluation approach discerning the most relevant aspects of a CAVE like system is desirable. In sections below we will try to define a set of methods that can be used to assist with the analysis process of a CAVE like system following the referred criteria.

3.1 Performance

In order to evaluate the performance of the CAVE configuration, and for simplicity, components will be evaluated separately as hardware components and software components.

In the core of a any VR system events are processed and the corresponding images generated, transmitted, and depicted on screens; this is called a *graphic pipeline*. The greatest opportunity for any visual computing system is to "accelerate the graphics pipeline". Among all the hardware components, graphics card is the most important, processing each image and deciding where it is going to be depicted (which screen will show them). However, there is no point in generating high quality images if the used display device does not truly depicts the generated graphic information to users. Moreover, allowing the user to affect or interact with 3d scenes will require space perception and visuo-haptic synchronization. In brief, mostly improvement in features named in subsection 2.1 can be achieved focusing on quality of three specific hardware component:

- *Graphic Cards:* Nowadays, graphic cards are manufactured to work specifically in applications that require processing scenes with millions of polygons with good refresh rates (real time). In addition, they have the power to work with multiple outputs, mostly, with three or more displays. These features enable different architectures of CAVE systems. It makes possible to build systems where the work of generating and distributing each image is done by a single graphic card or even combining several graphic cards, increasing the number of available outputs [33].
- *Display Devices:* Immersion and space perception require that images depicted by a CAVE system show the high quality information generated by graphics cards. Since a CAVE user is so close to screens, the perceived realism is obtained with high image resolutions (2k o more). Nowadays, high-resolution screen walls could be delivered by monitors or multimedia projectors. They differ in brightness, contrast, and covered space. While High Dynamic Range (HDR) monitors emit a high range of colors, they need a complex structure to get the required space. On the other hand, multimedia projectors enable to easily paint complete walls but colors are quickly washed out and dimmed.
- *Interaction:* Ideally, immersion and presence will be more likely obtained depending on how a CAVE system could recognize the user through different communications channels, that is, the use of verbal and non-verbal recognition technology, such as motion sensors, tracking, GPS, pointers, sound/voice recognition, among others.

From a software perspective, graphics libraries have evolved to maximize the power usage of both CPUs and GPUs. Some libraries have gained popularity like *DirectX* but continue to be OS-dependent. Other libraries like *Vulkan* (OpenGL) have little commercial impact but are multi-platform. The optimal coding under these libraries maximizes the use of graphics cards, allowing a reduction in work times and providing real time. The system performance will be affected by the selected graphics library and its compatibility with hardware components. Finally, the whole CAVE like system performance will be the resulting of sum of each component performance.

3.2 Usability

Considering that usability is a quality attribute defined by five components (*Learnability, Efficiency, Memorability, Errors and Satisfaction*), and bearing in mind that a CAVE like system must prioritize *psychological/cognitive intrusiveness, visuo-haptic synchronization, space perception and functionality*, we are interested in evaluating our system from a *user interface point of view* (infrastructure use) and from a *design point of view* (infrastructure design). For both point of view evaluation, the method of *user testing* will be applied. Taken into account the average sample size used for questionnaires in the literature, a group of 30 participants will be design. To ensure heterogeneity in the samples, participants should be selected ensuring both age and gender assortment.

From the user interface point of view, the *perceived* or *subjective usability* of the user (evaluation of the level of satisfaction) will be computed by performing small specific tasks that will test the total architecture of the CAVE. Given the features of our system, the best adapted techniques are: *Critical Incident Technique (CIT), Satisfaction Questionnaire and Think Aloud Testing.*

From the design point of view, the efficiency/effectiveness of the design will be computed. Given the features of our system, the best adapted techniques are: *Rating Scales and System Usability Scale(SUS).*

3.3 Relevance

Relevance has been most fundamentally studied in epistemology (theory of knowledge). Different theories of knowledge have different implications on what is considered relevant and these fundamental views have implications on all other fields as well. This subsection looks into the relevance of a CAVE system in the context of the emerging opportunities brought by the 4th industrial revolution and trying to fill a gap in the study of relevance in CAVE systems.

In a CAVE system the measurement of relevance should enable to determine what is the contribution of the system to the personal experience of the individual (user). The idea is to engage users in a context and not just display them something, for that matter, the most important features ensuring that users are involved in a cave systems are *immersion* and *presence*.

In [26, 34] authors said that relevance is naturally cognitive (type 1 of subsection 2.3) and the greater the cognitive effects, the greater the relevance, and the smaller the processing efforts to derive these effects, the greater the relevance (*Ease-of-use* and *Learnability*). As a consequence, we propose to evaluate the cognitive relevance of a CAVE system taking into account *immersion, presence, easy of use* and *easy to learn* as the minimum metrics that should be taken. Most of these metrics have been considered in subsection 2.2 (usability criteria), therefore the tests already defined could be considered to evaluate each metric.

In particular, for *immersion experience* and *presence*, the *Immersive Tendencies Questionnaire* (ITQ) and *Presence Questionnaire* (PQ) questionnaires will be used, due to they were defined jointly and are suitable for joint evaluation, allowing that the efforts required for both the respondents and the measurement collection to be reduced.

Ease of use and *learning* are standard metrics of usability, therefore they are covered by proposed tests in the subsection 3.2. Also, the basis established for user testing participants selection are copied from this subsection.

4 Discussion and Future works

Today, providing real-time visual interaction with a unified graphics (computed objects via graphics, images and video) and computing architecture that serves as both a programmable graphics processing and a scalable parallel computing platform combining hardware and software to form heterogeneous systems, is the proposal of any CAVE like system. Nevertheless, even when this is achieved that not means the obtained system is really assertive at the moment of solving a problem. Over time, it has become necessary to generate a methodology to evaluate a complete cave system.

In this paper we have presented a evaluation methodology for CAVEs systems. The criteria analysis and its evaluations produced an evaluation methodology that will be used to analyze, and if necessary modify and improve our CAVE like system. In summary, our research has produced evaluations on three levels:

– *Performance*: Graphic Cards, Display Devices, Interaction, and Graphic Library.
– *Usability*: Critical Incident Technique (CIT), Satisfaction Questionnaire and Think Aloud Testing, and Rating Scales and System Usability Scale (SUS).
– *Relevance*: Immersive Tendencies Questionnaire (ITQ) and Presence Questionnaire (PQ).

The research framework described in this document has been done, so far, only to analyze the characteristics and criteria that enable the evaluation of CAVE like systems. Based on this, our system will be evaluated in a future work. We hope that the methodology outlined in this paper will provide a starting point for techniques that allow immersive VR system developers create immersive environments that are usable, useful, and engaging. Finally, we believe that this type of analysis will allow us to outline new lines of work that will answer some unanswered questions, such as:

– Which is the best conceptual model for a CAVE like system?.
– Which is the best prototype technique?.
– How understand the underlying influence of each device.
– Which are good practices to minimize the lag between input and output devices used in the CAVE?.
– How to minimize the use of I/O devices that constraint the participant?.
– Can we use prop devices to convey real devices?.

References

1. Robert V Kenyon. The cave (tm) automatic virtual environment: characteristics and applications. 1995.
2. Laboratorio de Computación Gráfica. http://www.lcg.unsl.edu.ar/.
3. Yoselie Alvarado, M Moyano, David Quiroga, Jacqueline Fernández, and Roberto A Guerrero. A virtual reality computing platform for real time 3d visualization. In *XVIII Congreso Argentino de Ciencias de la Computación*, 2012.
4. Guerrero R. et al. Uso de la realidad virtual para la prevención de accidentes de tránsito, 2013.
5. Guerrero R. et al. Conduce, 2016.
6. Yoselie Alvarado, Roberto Guerrero, and Francisco Serón. Be civic: An immersive serious game. *EAI Endorsed Transactions on Serious Games*, 4(15), 2018.
7. Nicolás Jofré, Graciela Rodríguez, Yoselie Alvarado, Jacqueline Fernández, and Roberto Guerrero. Natural user interfaces: A physical activity trainer. In *Argentine Congress of Computer Science*, pages 122–131. Springer, 2017.
8. Guerrero R. et al. Esclerogym, 2017.
9. Antoine Lassagne, Andras Kemeny, Javier Posselt, and Frederic Merienne. Performance evaluation of passive haptic feedback for tactile hmi design in caves. *IEEE Transactions on Haptics*, 11(1):119–127, 2017.
10. Thomas A DeFanti, Daniel Acevedo, Richard A Ainsworth, Maxine D Brown, Steven Cutchin, Gregory Dawe, Kai-Uwe Doerr, Andrew Johnson, Chris Knox, Robert Kooima, et al. The future of the cave. *Central European Journal of Engineering*, 1(1):16–37, 2011.
11. Norman Nielsen. Usability 101: Itroduction to usability. urlhttps://www.nngroup.com/articles/usability-101-introduction-to-usability/, 2012.
12. User Experience Professionals' Association. Usability body of knowledge. urlwww.usabilitybok.org, 2012.
13. Mel Slater and Sylvia Wilbur. A framework for immersive virtual environments five: Speculations on the role of presence in virtual environments. *Presence: Teleoper. Virtual Environ.*, 6(6):603–616, December 1997.
14. D. A. Bowman and R. P. McMahan. Virtual reality: How much immersion is enough? *Computer*, 40(7):36–43, 2007.
15. Bob G. Witmer and Michael J. Singer. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoper. Virtual Environ.*, 7(3):225–240, June 1998.
16. Bryn Farnsworth. Measuring the power of virtual reality immersion [a case study], 2019.
17. Rod McCall, Shaleph O'Neil, and Fiona Carroll. Measuring presence in virtual environments. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '04, page 783–784, New York, NY, USA, 2004. Association for Computing Machinery.
18. Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. Using presence questionnaires in virtual reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, page 1–12, New York, NY, USA, 2019. Association for Computing Machinery.
19. Mel Slater and Anthony Steed. A virtual presence counter. *Presence: Teleoper. Virtual Environ.*, 9(5):413–434, October 2000.

20. Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. Using presence questionnaires in reality. *Presence: Teleoper. Virtual Environ.*, 9(5):497–503, October 2000.
21. Holger Regenbrecht and Thomas Schubert. Real and illusory interactions enhance presence in virtual environments. *Presence: Teleoper. Virtual Environ.*, 11(4):425–434, August 2002.
22. Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. The experience of presence: Factor analytic insights. *Presence: Teleoper. Virtual Environ.*, 10(3):266–281, June 2001.
23. Thomas W. Schubert. The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Zeitschrift für Medienpsychologie*, 15(2):69–71, 2003.
24. Jane Lessiter, Jonathan Freeman, Edmund Keogh, and Jules Davidoff. A cross-media presence questionnaire: The itc-sense of presence inventory. *Presence: Teleoper. Virtual Environ.*, 10(3):282–297, June 2001.
25. Tefko Saracevic. Relevance reconsidered. In *Information science: Integration in perspectives.Proceedings of the Second Conference on Conceptions of Library and Information Science, Copenhagen (Denmark)*, 1996.
26. Saman Koswatte, Kevin McDougall, and Xiaoye Liu. Relevance assessment of crowdsourced data (csd) using semantics and geographic information retrieval (gir) techniques. *ISPRS Int. J. Geo-Information*, 7:256, 2018.
27. Hansi Senaratne, Amin Mobasheri, Ahmed Loai Ali, Cristina Capineri, and Mordechai Haklay. A review of volunteered geographic information quality assessment methods. *International Journal of Geographical Information Science*, 31:139 – 167, 2017.
28. J. ODonovan, B. Kang, G. Meyer, T. Höllerer, and S. Adalii. Credibility in context: An analysis of feature distributions in twitter. In *2012 International Conference on Privacy, Security, Risk and Trust and 2012 International Confernece on Social Computing*, pages 293–301, 2012.
29. Saman Koswatte, Kevin McDougall, and Xiaoye Liu. Vgi and crowdsourced data credibility analysis using spam email detection techniques. *International Journal of Digital Earth*, 11:520 – 532, 2018.
30. Yunjie Xu and Hainan Yin. Novelty and topicality in interactive information retrieval. *Journal of the American Society for Information Science and Technology*, 59, 01 2008.
31. Roman Y. Shtykh and Qun Jin. A human-centric integrated approach to web information search and sharing. *Human-centric Computing and Information Sciences*, 1(1):1–37, December 2011.
32. Yunjie Calvin Xu and Zhiwei Chen. Relevance judgment: What do information users consider beyond topicality? *J. Assoc. Inf. Sci. Technol.*, 57:961–973, 2006.
33. Marián Hudák, Štefan Korečko, and Branislav Sobota. On architecture and performance of lirkis cave system. In *2017 8th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, pages 000295–000300. IEEE, 2017.
34. Howard D. White. Relevance theory and citations. *Journal of Pragmatics*, 43(14):3345 – 3361, 2011.