Embedding Large Language Models into Extended Reality: Opportunities and Challenges for Inclusion, Engagement, and Privacy

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ABSTRACT

Recent developments in computer graphics, hardware, artificial intelligence (AI), and human-computer interaction likely lead to extended reality (XR) devices and setups being more pervasive. While these devices and setups provide users with interactive, engaging, and immersive experiences with different sensing modalities, such as eye and hand trackers, many non-player characters are utilized in a pre-scripted way or by conventional AI techniques. In this paper, we argue for using large language models (LLMs) in XR by embedding them in virtual avatars or as narratives to facilitate more inclusive experiences through prompt engineering according to user profiles and fine-tuning the LLMs for particular purposes. We argue that such inclusion will facilitate diversity for XR use. In addition, we believe that with the versatile conversational capabilities of LLMs, users will engage more with XR environments, which might help XR be more used in everyday life. Lastly, we speculate that combining the information provided to LLM-powered environments by the users and the biometric data obtained through the sensors might lead to novel privacy invasions. While studying such possible privacy invasions, user privacy concerns and preferences should also be investigated. In summary, despite some challenges, embedding LLMs into XR is a promising and novel research area with several opportunities.

CCS CONCEPTS

• **Computing methodologies** → **Virtual reality**; **Mixed / augmented reality**; **Artificial intelligence**; *Natural language processing*; • **Human-centered computing** → *Human computer interaction (HCI)*.

KEYWORDS

Extended Reality, Large Language Models, Artificial Intelligence, ChatGPT

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1 INTRODUCTION

With research and development in computer graphics, hardware engineering, artificial intelligence (AI), and human-computer interaction areas, virtual, mixed, and augmented reality (VR/MR/AR) setups and head-mounted displays (HMDs) have started to become pervasive in everyday life. Especially also with big tech companies like Apple and Meta bringing their HMDs into the market for vast usage (e.g., Apple Vision Pro, Meta Quest 3), it is likely that such devices will be similar to today's smartphones, smartwatches, or tablets soon. Yet, the major difference is that users often experience highly immersive mixed and virtual spaces through these devices, making interaction and social aspects different from other widely used smart devices.

XR devices and settings, covering the wide spectrum of VR, AR, and MR, have been used for different purposes in various domains, such as education [9, 23, 29], medicine [30, 56, 75], entertainment [4, 32, 36], transportation [7, 14, 42], and business [1, 27, 43]. One of the advantages of XR settings, especially in understanding human behaviors and interactions, is the possibility of obtaining fine-grained motion sensor data, such as eye- and head-tracking [41], possibly with controlled stimuli [6]. This allows a better understanding of how humans behave and perceive in XR spaces and provides an opportunity for real-time and adaptive user support. Combining such real-time and adaptive interaction experiences with high levels of presence, immersion, and sociality might lead to positive user experiences, which can improve users' motivation to use XR and HMDs in everyday setups.

Despite several advantages, such as useful sensors and interaction experiences, one of the issues in terms of sociality with virtual and mixed spaces that include non-player characters (NPCs), even those powered by AI and machine learning, is the limited conversational capabilities of such characters. Oftentimes, these characters are designed as pre-programmed agents [25] or trained for a particular use case with relevant training data [35]. However, these cannot be utilized flexibly for open-ended conversations or open-world settings. In addition, when the audience changes (e.g., adults to children), conversational scripts or trained models must be updated almost from scratch, requiring significant human labor, either for creating scripts or labeling training data.

To this end, embedding large language models (LLMs) as chat agents into XR spaces can significantly solve these issues and help these spaces provide more inclusive and engaging experiences, as LLMs are trained with a good portion of the Internet and are fed with a diverse set of text data, leading them to have conversations about a wide range of topics. In addition, the possibility of fine-tuning such models with use-case-specific small amounts of data and different prompting techniques helps utilize these models for various tasks. Especially with ChatGPT being publicly introduced in 2022 [47], a broader audience has also observed how powerful LLMs are and the human-like text they can generate. In fact, possibilities and related opportunities have been emphasized for different communities, such as education [34] and medicine [62]; however, they have not been addressed and studied in depth in the XR domain yet, except from few works mentioning their potentials as conversation agents in XR [2, 64, 69] or demonstrating their abilities to produce and edit objects, and scenes in MR [65]. One of the reasons might be the uncommon use of textual interaction in XR compared to audial and visual.

Despite the higher likelihood of audial and visual information use in XR rather than text, it is trivial to build automated processing pipelines, including speech-to-text [57], large language [66], and text-to-speech [57] models, to process audio data through LLMs to be used within XR environments. In addition, with the emergence of multimodal LLMs, such as GPT-4 [50] and Gemini [28], the use of LLMs within XR environments to facilitate conversations will be more intuitive than pre-programming the avatars or conventional AI techniques. Therefore, in this position paper, we argue for embedding LLMs in XR as virtual avatars or narratives and state that this process will facilitate more inclusive, diverse, and engaging experiences with three main implications.

- We first argue that embedding LLMs into XR spaces either as NPCs or narratives will support designing more inclusive environments and setups with different prompting strategies and fine-tuning of the models. This will also support diversity and equity in XR environments.
- We state that with the multifaceted conversational abilities of LLMs, LLM-powered environments will facilitate more engaging XR experiences for users, which will help XR become more pervasive.
- As more engagement with NPCs and spaces likely means that users will provide more amount of and more fine-grained information about themselves, we state that combining this data with the biometric sensor data will cause novel privacy invasions as well as different user privacy concerns toward such setups, which should be further investigated taking the ethical aspects into account.

2 RELATED WORKS

As we argue for using LLMs in XR by embedding them into NPCs or treating them as narratives to facilitate inclusion, diversity, and engagement by taking ethical aspects, especially privacy, into account, we summarize previous literature in two folds. First, we discuss the recent works in the field of LLMs in Section 2.1. Then, we provide essential previous research on inclusion, diversity, equity, and privacy in XR in Section 2.2.

2.1 Large Language Models

LLMs are specific types of artificial neural networks trained with massive amounts of data by often scrapping a significant portion of the Internet, and they can generate human-like text and conversations [34]. One of the reasons that LLMs are successful in various natural language processing (NLP) tasks is the transformer architecture and the self-attention mechanism [68]. In particular, a transformer is a self-supervised encoder-decoder model, and the self-attention mechanism assumes that some words are more related to each other than others and operates according to this assumption to find the relationships between the words. Due to massive amounts of training data and such an architecture, LLMs can operate in various domains very well, especially for tasks whose related data is widely available online.

Prevalent examples of LLMs are OpenAI's GPT-3 [20], Meta's LLaMa [66], Google's PaLM [3, 12], and more recently multi-modal LLMs such as GPT-4 [50] and DeepMind's Gemini [28]. In addition to these general-purpose pre-trained LLMs, to facilitate chat scenarios, researchers further iterated the LLMs to achieve naturalistic interactions by fine-tuning them to align them in the conversations [67]. Different techniques also exist for facilitating this with other steps, such as aligning language models to follow instructions [52]. Yet, fine-tuning these models with high-quality labels is often necessary to facilitate specific use cases and personalization.

To this end, several works fine-tuned pre-trained LLMs to utilize these models for their specific purposes, including bug fixing in software development [33], dialogue summarization in customer services in the business domain [76], understanding the needs of patients and providing informed advice [39], and legal knowledge understanding [18]. These works showed evidence that fine-tuned models enhance task performance, hinting at better personalization. Apart from fine-tuning, it is also known that different prompting techniques can significantly help in getting more tailored responses from the LLMs, even without fine-tuning [5, 51, 71, 73]. While prompt engineering can be carried out by the users themselves, for the use of LLMs in XR, it is essential to automate this process based on the user characteristics in the backend. Apart from the scientific literature focusing on fine-tuning and different prompting techniques, OpenAI launching a GPT app store [72] and smart NPCs powered by OpenAI or users' own language models being integrated into Unreal Engine [53] are other examples that such custom LLMs can be utilized for various purposes in XR through avatars or as narratives. Yet, along with the opportunities, several challenges to facilitating useful processes exist.

2.2 Insights for Inclusion, Diversity, Equity, and Privacy in Extended Reality

Inclusion essentially means providing equal opportunities to benefits and resources regardless of individual differences such as ethnicity, gender, health-related abilities, or sexual orientation. Facilitating inclusion often promotes diversity and equality, especially as people from different backgrounds are encouraged to engage in particular activities. There have been different focus points regarding inclusion and diversity in XR research. For instance, Peck et al. [55] found that recent research published in IEEE VR includes significantly underrepresented women both as authors and participants in the experiments. In follow-up work, Peck et al. [54] highlighted differences between underrepresented groups compared to commonly studied populations regarding VR usability, and the authors depicted the lack of generalizability of previous VR research. While engaging the underrepresented populations in XR research and conducting studies with representative samples are fundamentally different than supporting various populations according to their individual needs within the XR spaces, the latter is needed in any case, both to personalize the XR experiences and to attract new and underrepresented populations. With this aim, Ajri et al. [2] built a VR-based tool that leverages LLMs for interview preparation for underrepresented individuals in computer sciences. Indeed, with their versatile nature, fine-tuning opportunities with minimal amounts of data, and different prompt engineering strategies, LLMs can provide a good step to achieve this goal.

In addition to including different populations in the XR research and development, to support diverse user populations, it is essential to understand the differences between different user groups in XR, especially in how they perceive stimuli and behave in XR spaces. To this end, researchers analyzed different user characteristics such as gender [26, 60], health [16, 59], expertise [24, 31], sexual orientation [21, 58], and race [17, 61]. For instance, Gao et al. [26] found with explainable machine learning models that girls and boys visually behave differently when they attend a lesson in VR. In another work, Hosp et al. [31] were able to distinguish three levels of expertise levels of goalkeepers in the VR context using their eye movement data and stated that their work paves the way for future training systems.

Regarding health-related scenarios, the usability and acceptability of smartglasses have been assessed with children with autism spectrum disorder (ASD) and their caregivers [59]. While the authors found that their audience found the smartglasses acceptable and usable, the reason the study was conducted in the first place is that people with ASD often have issues with social communication and interaction, leading to different ways of learning, moving, or paying attention [11]. Similar trends in different populations have been found in race and sex research as well, with humans remembering faces of their own race better than the other faces [17], and visual behaviors being representative of sexual preferences [21]. While sensor data revealing different user characteristics are not only limited to XR [17, 21] and aforementioned user attributes [37, 40], these previous works indicate that there is no one-size-fits-all approach for personalizing the 3D user interfaces and creating adaptive support for the users considering the distinct behaviors of different populations. In this regard, customizing LLMs with fine-tuning and applying prompt engineering techniques can facilitate supporting different user populations and profiles efficiently.

Studying different populations with distinct behavioral patterns and attempts to further provide personalized experiences to such populations might lead to accurate identification of user groups and individuals, especially with machine learning techniques. On the one hand, this identification is convenient in supporting the utility of adaptive interfaces; on the other hand, it can be considered a privacy invasion. To address this ethics-related issue, a good chunk of research has focused on providing privacy-preserving technical solutions in XR especially considering biometric data obtained from different sensors such as eye tracking [6, 10], by particularly focusing on statistical notations such as differential privacy [8] and practical ways of streaming such data in a privacy-preserving way [13]. Similar to these, other research investigated going incognito in VR by leveraging differential privacy [46] and deep motion masking facilitating real-time anonymization [45] and showed that practical privacy-utility trade-offs are possible in VR.

While the technical approaches that focus on the conundrum between privacy and utility are essential for anonymization in XR, it is equally vital to understand the privacy behaviors of users by focusing on their privacy concerns and preferences so that more human-centered solutions can be designed. To this end, Gallardo et al. [22] focused on the speculative privacy concerns in AR data collection through a set of data types and data uses and found that participant privacy attitudes and reservations are context-dependent. In another study, Denning et al. [15] focused on user privacy perspectives for using AR glasses and found participants' requests to be asked before being recorded. Lebeck et al. [38] showed that bystander privacy is an important concern in a multi-user AR setting. Along the same lines, in a more recent study, O'Hagan et al. [49] indicated the importance of user activity and its relation with bystanders in everyday AR. Considering all of the research on the technical solutions to preserve the privacy and usable privacy in XR focuses on existing or speculative cases, especially about different data types and use cases, it is an open question whether integrating and utilizing LLMs along with user sensor data will lead to novel privacy leaks in XR and how users' privacy attitudes will be in such situations.

3 OPPORTUNITIES, RESEARCH DIRECTIONS, AND CHALLENGES

As the previous research implies, LLMs, especially with their versatile conversation capabilities, fine-tuning possibilities, and prompt engineering techniques, hold an immense upside for XR environments, particularly if such models are embedded in the XR spaces as NPCs or narratives. However, until now, not much research has been conducted in this direction. In the very naive scenario, to integrate LLMs in XR, it is essential to utilize speech-to-text and text-to-speech models [57] to enable information transition from the user to LLM-powered NPCs and vice versa in an audial way, which is depicted in Figure 1. While there might be some drawbacks to such a pipeline, such as latency issues between components or sophisticated LLMs requiring a lot of storage as they can easily occupy several hundreds of gigabytes, these issues can be solved by good engineering practices and deploying customized models on a shared place communicated via web services. In addition, future versions of multimodal LLMs [28, 50] might utilize this pipeline in an end-to-end fashion, mitigating issues like latency. Therefore, as these issues can be handled commendably, we argue for using LLMs to facilitate inclusion in XR and create more diverse, equal, and

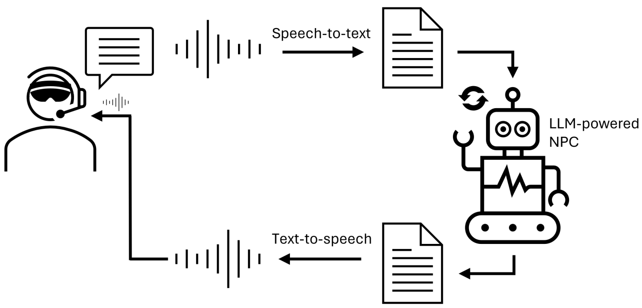

Figure 1: Technical workflow.

engaging XR spaces. However, we also state that having more inclusive and engaging environments will lead users to spend more time in these spaces by interacting more with the personalized LLMs. As a result, more data and likely more sensitive information will be available during the interaction experience. While it is unknown, we foresee that such an amount of data combined with the already available sensory data from XR (e.g., eye- and hand-tracking data) will lead to novel privacy invasions, with different user privacy attitudes compared to today's XR devices. Therefore, considering all of these, we provide three sets of opportunities and challenges, each including research opportunities discussed in the following.

Inclusion, diversity, and equity. We argue that pre-scripted NPCs or conventionally generated AI characters first require a lot of manual labor to serve different user characteristics in XR. For instance, in a skill training scenario, a novice and an expert will have different needs when communicating with an NPC that trains our user in XR. Conventionally, two different scripts or AI agents need to be created to support these two users. Still, such agents might be perceived as shallow regarding their knowledge or the conversation quality due to rule-based conversation generation or agents that are trained with a small amount of data for these particular use cases. In contrast, even the pre-trained LLMs without fine-tuning can provide personalized experiences to users if they are prompted in the backend with specific examples [51], such as "When I ask for help, provide a response considering I am an [expert/novice] in extended reality area." With fine-tuned for specific uses, they can provide even more adaptive responses, and we argue that such LLM-powered environments will be more inclusive by motivating and attracting diverse types of users for XR environments. In addition, since technically, any user characteristics can be supported in a personalized manner with these LLMs and prompt engineering, they will facilitate equal opportunities for users.

Considering the aforementioned opportunity, the major research direction concerns how different user characteristics perceive the LLM-powered XR environments and whether such environments can motivate different user characteristics comparably so that they can facilitate diverse and equal opportunities for all. However, LLMs can have hallucinations [74], and it is a challenge to mitigate the effects of hallucinations to provide equal opportunities for different users.

User engagement. We think that LLM-powered XR environments through NPCs or narratives will engage users more than conventional conversational interactions due to LLMs' abilities to create human-like responses. As a result, the overall immersion and interactivity within the XR environments will be enhanced, and consequently, these enhancements are likely to captivate users' attention and encourage them to spend more time within XR environments. The rich, dynamic narratives and lifelike interactions facilitated by LLMs would not only elevate the entertainment value of XR experiences but also open up new avenues for creative storytelling and interactive content, revolutionizing how users perceive, engage, and interact in XR.

The major research direction concerning user engagement is understanding whether LLM-powered environments can significantly increase user engagement compared to conventional environments. When this is the case, users likely provide more information about themselves during their conversations with the NPCs or narratives of the XR spaces, which might include more sensitive information about themselves, leading to ethical challenges regarding data privacy.

Privacy. From the user engagement point of view, we hypothesize that these environments will engage users more, and the users will provide more information about themselves, including the sensitive ones, due to the increased engagement and interaction time. In addition, we expect that such sensitive information obtained during the user and LLM interaction combined with other sensor data will likely end up with novel privacy invasions about users, which also requires an ethical discussion about how to address these issues. It is already known that LLMs have several privacy issues [48, 63], and such investigation should be more in-depth, as in this sense, XR will combine LLM interaction with multimodal user sensor data. Furthermore, we argue that such privacy invasions should be addressed by also asking users about their privacy concerns and preferences as it has been done in other domains [19, 22, 44] by observing whether or not there is a gap between privacy expectations and behaviors [70] in the long run for XR. All of these aspects form opportunities, especially for privacy and security researchers, to design privacy-aware and user-centric XR environments.

Therefore, the research direction we identified under the privacy and ethics umbrella concerns understanding whether novel privacy invasions and leaks occur in these environments, understanding users' general privacy attitudes, and, later, designing privacy-aware methods when the former is the case. However, since the research in the LLM domain is moving very fast compared to others, some aspects might need to be evaluated in a longitudinal manner, which we identify as a challenge.

4 CONCLUSION

In this paper, considering the developments in generative AI and LLMs, we argued for embedding LLMs as virtual avatars in the form of NPC or narratives in XR. We state that due to the versatile conversational capabilities of LLMs, as they are trained with a massive amount of text data from the Internet, prompt engineering options, and fine-tuning opportunities, such NPCs and narratives will provide significantly improved personalized experiences for users in XR, regardless of different user characteristics, such as expertise or gender. We argue that these will enhance the motivation to use XR more frequently in an engaged way and facilitate the inclusion of different types of users in XR, leading to more diverse populations using XR. Furthermore, as such personalization and adaptivity can support any user type, these environments will also ensure equity in XR. Lastly, we underline the importance of keeping privacy in mind by assessing possible novel privacy invasions and understanding user privacy attitudes in these novel settings.

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