Chapter 6
N-SAFE:
A Neuro-Secure Framework for Metaverse and Future Intelligent Environments

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ABSTRACT

This chapter examines these implications and highlights the need for secure neuro-consent interfaces, the protective function of cognitive liberty guardians, and comprehensive legislative frameworks designed to safeguard individual autonomy and mental integrity. Building on these elements, the chapter introduces N-SAFE, a neuro-secure framework for metaverse and future intelligent environments, which

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provides a unified structure for addressing ethical, technological, and security requirements. In addition, the chapter develops a hybrid taxonomy of neuro-secure metaverse components and outlines a research agenda for advancing neuro-rights protection, cognitive safety, and secure neuro-digital interaction. As neurotechnology becomes increasingly embedded in immersive virtual ecosystems, ensuring the protection of neuro-rights is essential to prevent misuse, strengthen security, and uphold cognitive freedom.

INTRODUCTION

The metaverse was established in 1992 by science fiction author Neal Stephenson in his novel Snow Crash, where characters use avatars to navigate a virtual world (Kim, 2021). It is widely recognized that the metaverse is a virtual shared, persistent environment with a high level of immersion that combines elements of the real world and digital space, allowing users to interact and experience the virtual world through avatars (Stephenson, 1992). The metaverse isn't just one space, but many interconnected virtual worlds, from which a larger universe could also develop. According to Dionisio et al. (2013), it is a combination of two elements, meta (beyond) and verse (universe). But there is no agreement on any single conceptual definition. Dionisio et al. (2013) go on to say that Stephenson envisioned the metaverse as a collection of three-dimensional, immersive environments that would be infinite, self-contained, interoperable, decentralized, persistent, and interactive.

The advent of the metaverse has been linked to a lot of changes in how people interact with and think of three-dimensional digital objects. The metaverse is the next big technological revolution, as per Harley (2024), which could be as significant as the arrival of the Internet. Riva & Wiederhold (2022) noted that technology firms are lavishing significant resources on the creation of metaverse platforms that combine physical and virtual reality, predicting a market worth more than a trillion dollars (Muhajjar & Shihabe, 2024). Initially, technological challenges and the expense of developing and sustaining metaverse systems kept its applications to professional simulation fields such as medicine, aviation, and military settings. More recent developments around accessibility have allowed for wider engagement (Huggett, 2020) and are helping to bring new phenomena and research fields to the fore, which are relevant for academic research.

Although the research on the metaverse has largely focused on the technological aspects, it is now becoming a greater focus on the social aspects, and specifically on the individual and the consumer (Park & Kim, 2022). This is a change that incorporates aspects from the social sciences (marketing, user behaviour, social needs in virtual environments) and the neurosciences. Neuroscience is seen to play