7 Metaverse in Fetal Medicine

The term "Metaverse" was created in 1992 by Neal Stephenson for his science fiction novel *Snow Crash* [1] to designate a three-dimensional virtual space in parallel to the real world. It was a "meta-universe," imagined as the virtual reality successor of the internet.

Since its inception the Metaverse has been associated with applications using virtual and augmented reality technologies, as well as virtual worlds social platforms like *Second Life* [2]. Consequently, these initiatives motivated a general perception of a trend toward an integration between virtual and physical spaces with virtual economies that ultimately would involve the entire industry.

The scenario described above, accelerated by global transformations due to the COVID-19 pandemic, influenced the five major Web companies: Google, Apple, Facebook, Amazon, and Microsoft, to proactively promote the Metaverse as their "vision of the future." For example, in 2021 Facebook changed the company name to Meta.

Given these facts, it is reasonable to imagine that the "metaverse wave" will gradually reach all sectors of modern society, including fetal medicine.

This chapter gives an account of the conceptual and technological aspects of the Metaverse that informs a prospective view of the influence of gradual development of these innovations in the future of medicine.

Here we consider Metaverse in a very broad sense, encompassing all innovations and technologies related to new media, communications, and computing, such as IoT (internet of things), 5G, cryptocurrencies, and machine learning.

In fact, we will not attempt to arrive at a precise definition of Metaverse since we believe it would be misleading given the diversity of points of view of such a phenomenon "in-process."

Nonetheless, it is enlightening to contrast virtual and augmented reality with the notion of Metaverse. While the former (VR/AR) can be considered enabling media technologies, the latter (Metaverse) is a general application context in which they operate, together with many other technological innovations.

7.1 From Virtuality Continuum to Internet 4.0

As discussed above, we can think of the Metaverse as a network of 3D virtual worlds focused on social connection, which is related to the real economy and physical spaces. In that sense, the concept of "virtuality continuum" is instrumental.

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Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/978-3-031-14855-2_7.

H. Werner et al., *3D Physical and Virtual Models in Fetal Medicine*,
https://doi.org/10.1007/978-3-031-14855-2_7

The virtuality continuum is a continuous scale ranging between the completely virtual (i.e., virtuality) and the completely real (i.e., reality). It was first introduced by Paul Milgram [3] and opens possibilities for variations and compositions of real and virtual objects (Fig. 7.1).

The area between the two extremes, where both the real and the virtual are mixed, is called mixed reality. This in turn is said to consist of both augmented reality, where the virtual augments the real, and augmented virtuality, where the real augments the virtual.

The concept has been described in the context of new media and computer science, but in fact it could also be considered a matter of anthropology in the Metaverse scenario.

Besides the virtuality continuum it is enlightening to take into account two other associated continua that also play a role in the unfolding of the Metaverse: the spectrum of technologies ranging from *augmentation* to *simulation* and the spectrum of applications ranging from *personal* to *social*. The interplay of these two axes is depicted in Fig. 7.2.

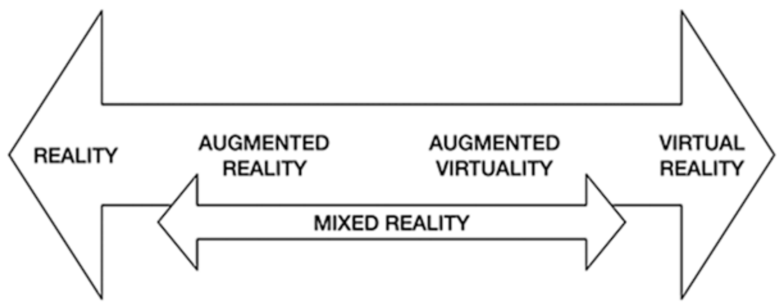

Fig. 7.1 The virtuality continuum. (From [3])

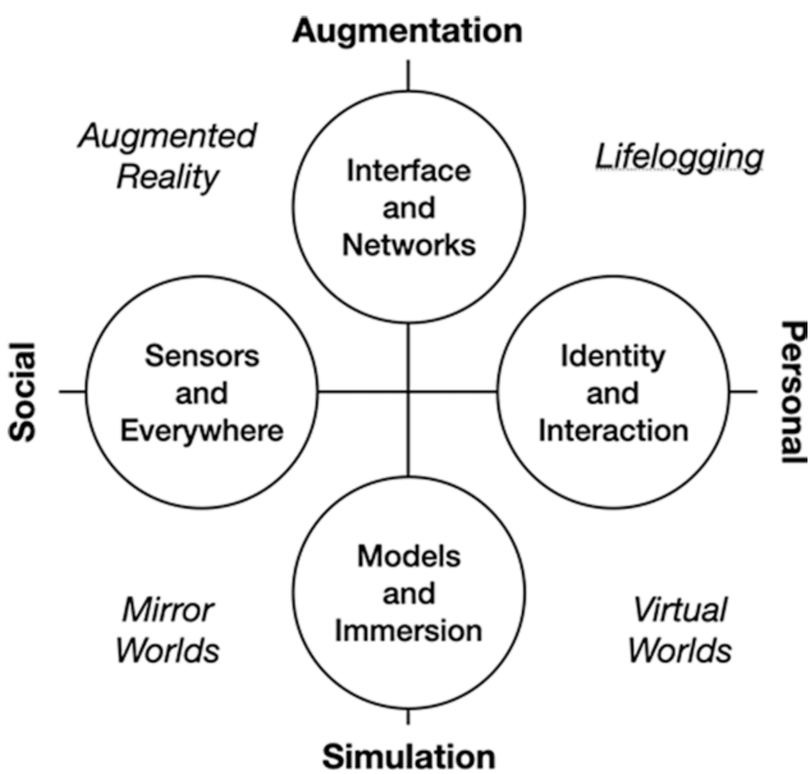

Fig. 7.2 Metaverse scenarios. (Adapted from [4])

The augmentation-simulation axis is akin to AR-VR technologies where augmentation creates a layer onto our perception of the physical environment and simulation models a parallel reality of entire digital environments.

The personal-social axis is linked to a range of applications that focus either on individual users or the world pertaining to a group of users.

The combination of these two axes gives rise to four key components of the Metaverse landscape: Virtual Worlds, Mirror Worlds, Augmented Reality, and Life-logging.

To complete the panorama, there are techniques that enable and link these components, such as: networks and interfaces; modeling and immersion; sensors and IoT; interaction and identity.

This is the scenario proposed by John Smart in the "Metaverse Roadmap: Pathways to the 3D Web" [4].

Finally, to understand the Metaverse as a complete global context for applications is mister to analyze its relationships with the whole society at different levels. Jon Radoff, in "Measuring the Metaverse" [5], proposes a hierarchy of 7 layers where he moves up the value chain from infrastructure at the bottom to experience at the top, stopping at human interface, decentralization, spatial computing, creator economy, and discovery along the way.

Such conceptual framework employs a standard methodology of computer systems that provides a concrete characterization of the Metaverse as part of our culture, society, and information industry.

In summary, as shown in Fig. 7.3, these layers represent:

- Experience—what people engage with, e.g., games, shows, conferences, etc.;
- Discovery—how people find out about an experience;
- Creator Economy—content market for the things in the metaverse;
- Spatial Computing—platforms for 3D environments and interaction;
- Decentralization—democratized distribution ecosystem;
- Human Interface—means of access to the metaverse: mobile, headsets, etc.;
- Infrastructure—cloud computing; telecommunication networks.

In a way, the picture rendered above gives a prospective view the of what the future Web promises with the Internet 4.0.

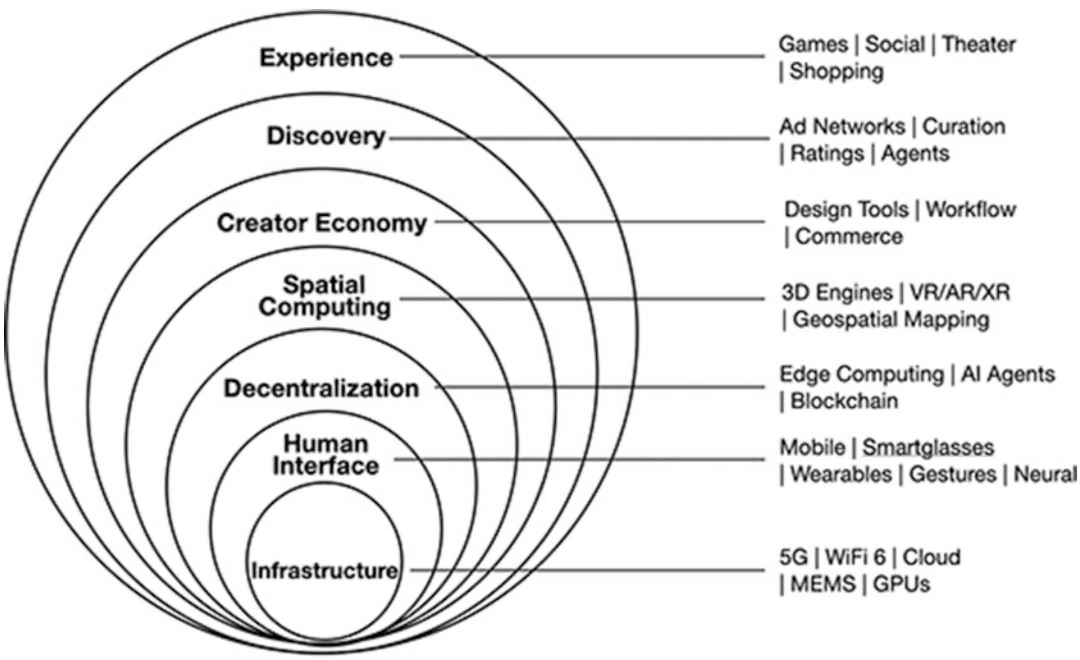

Fig. 7.3 The 7 layers of the metaverse. (From [5])

7.2 Expanded Reality for Mediatic Shared Experiences

As we have seen in the previous section, at the top of the Metaverse pyramid lies "*the experience*." Arguably, from the user's point of view, this is the most important element because it is how people relate to the applications context.

It is important to highlight what is novel and unique about metaverse experiences. They are essentially "Mediatic Shared Experiences" within an "Expanded Reality." This scenario involves: mediation, communication, and intelligence.

In such experiences the users share content and communicate with each other through an intelligent medium. In this setting we have three levels of abstraction: (1) concrete—the metaverse technology; (2) perceptual—the psychophysiological fruition; (3) symbolic—the involvement with content and activity (Fig. 7.4).

The mechanisms behind a metaverse experience belong to the field of study of "Computational Applied Mathematics for Media." This emerging branch of science deals with *mathematical models* that arise from *data sources* and are experienced by *users within an application.* These three entities are mediated by computational processes that enable the fulfillment of the experience.

As can be seen in Fig. 7.5, the users' interface with data though sensing and display processes (note that this involves perceptual aspects, and this same mechanism allows users to interface with each other through data mediation). The data can be processed in different ways as a signal according to application requirements. Further, it can also go through a process of analysis to create a mathematical model that can be used for simulations, as well as in a synthesis process to generate new data [6, 7].

The data/model framework is based on many traditional disciplines of science and engineer-

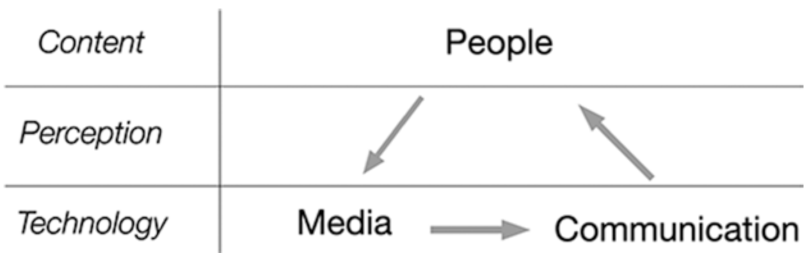

Fig. 7.4 Mediatic shared experience

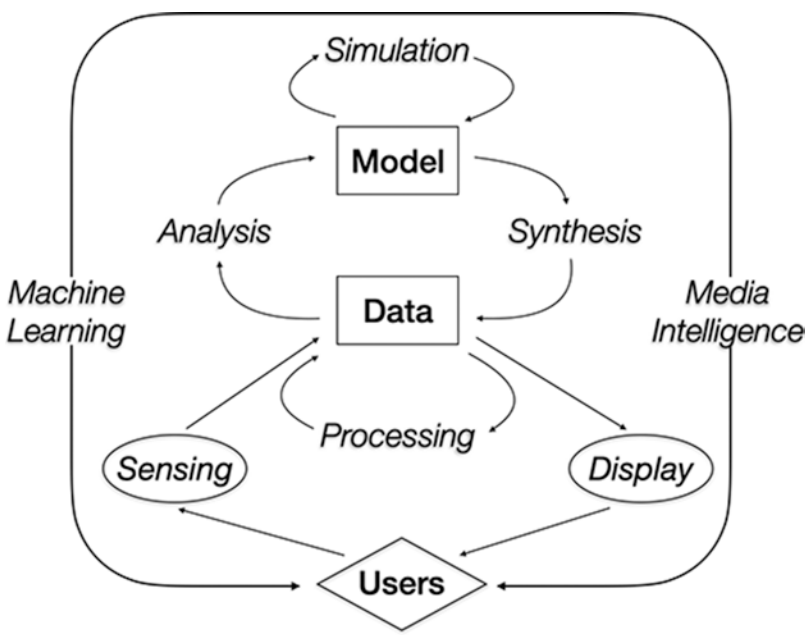

Fig. 7.5 Data/model framework

ing. Recently, it has been enhanced by artificial intelligence and machine learning techniques.

7.3 Perspectives for Fetal Medicine and Experiments

Medicine is perhaps a field of human activity that mostly benefits from technological and scientific advances. One example is the area of fetal medical imaging that relies on sophisticated sensing devices, such as computer tomography (CT), magnetic resonance (MRI), and ultrasound for diagnostics of patients, as well as, for procedure support. Another example is the early adoption of artificial intelligence with rule-based expert systems [8].

Overall, we can predict a great impact of the Metaverse in the future of medicine, both in health and wellness [9, 10].

These developments will likely contribute equally to research, practice, and education in fetal medicine.

To demonstrate the potential of Metaverse developments in the area of fetal medicine, we will show examples of some experiments for education in fetal medicine. The experiments have been developed in the Spatial.io platform [11] that offers support for a wide range of VR, AR, and mobile devices.

The first experiment is a remote lecture in which the instructor presents a case to participants joining in VR from different locations. The group is immersed in a virtual classroom and have as study material the digital medical data generated by various processes.

In Fig. 7.6, the participants view the result of fetal MRI that can be manipulated interactively to navigate through the 2D slices of the 3D data.

In Fig. 7.7, the instructor shows a 3D reconstruction of a real fetus to the class. Note that the virtual object can be freely inspected spatially

Fig. 7.6 Fetal magnetic resonance

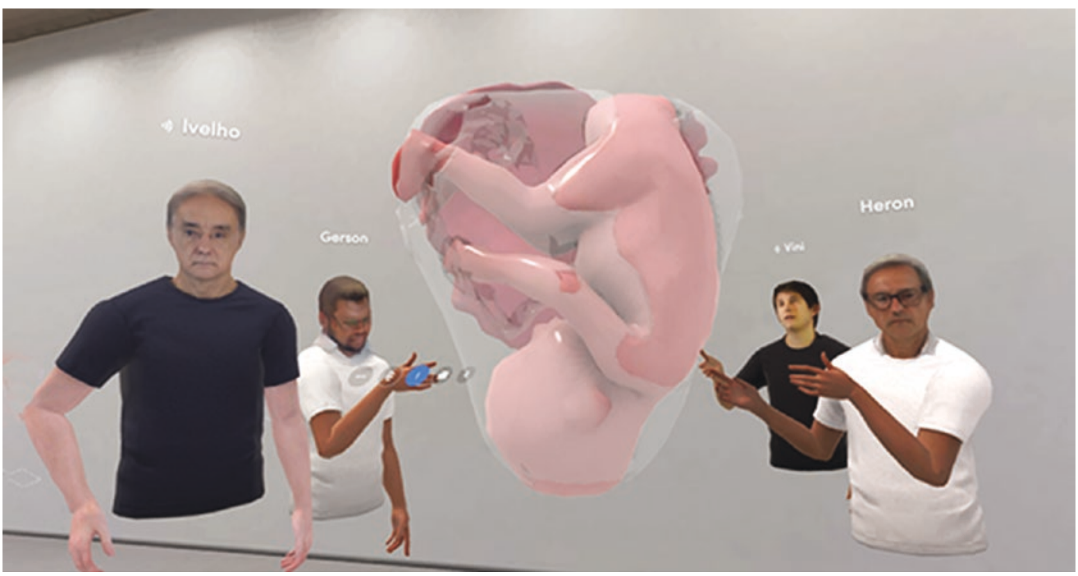

Fig. 7.7 3D reconstruction of a fetus

Fig. 7.8 Segmentation of the fetus organs

Fig. 7.9 3D structure of a fallopian tube

with 6 degrees of freedom (translation and rotation) plus scaling.

In Fig. 7.8, the instructor presents a 3D virtual model with a segmentation of the fetus organs to discuss various anatomical aspects.

The second experiment demonstrates the possibility to have a shared meeting virtually inside the 3D structure of a fallopian tube which was micro-CT scanned in high resolution [12] (Fig. 7.9).

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Part IV

Applicability in Clinical Cases

The objective of this chapter is to describe virtual and physical models of the main fetal anomalies diagnosed by ultrasound (US), magnetic resonance imaging (MRI) and computed tomography (CT). This chapter also describe virtual and physical models assisting fetal surgeries, postnatal surgery, multiple pregnancy and maternal-fetal attachment in cases of blind women.

This chapter intends to show the use of 3D technologies applied on real cases in medicine.