Mixed Reality Applications Powered by IoE and Edge Computing: A Survey



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Abstract IoT field is continuously evolving to cope with the tremendous number of applications that satisfy the user needs. IoT is implemented by physical objects with virtual representations and services. Augmented reality provides the user with a simple interacting interface to applications. The merge between IoT and augmented reality is a realistic consequence of the need to handle the IoT components in non-traditional methods. This merge facilitates the user to interact with the physical components while receiving additional context-aware information about the object. The existing IoT augmented solutions are facing problems in connectivity, security, trustworthiness, latency, throughput, and ultra-reliable, which necessitate using edge computing to assist in solving these problems. In this paper, we shed some light on these topics and the trends of current solutions combining these fields.

Keywords IoT · IoE · Augmented reality · Mixed reality · Edge computing · Cloud computing

1 Introduction

The increasing development of Internet of Things (IoT) technology facilitates connecting various smart devices together in one application. The number of devices belonging to IoT is predicted to grow at an exponential rate predicted to reach around 26 billion devices by the end of the next decade. Internet of

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Everything (IoE) plays an important role in many applications in our lives and offers promising solutions to evolving many industrial systems. IoE connects people, data, processes, and things. Making it easier to construct data flow models between real objects interactions (collected by sensors) and Virtual objects in mixed reality applications (processed by MR devices or any kind of distributed system). Internet of things (IoT), which is a subset of IoE, focuses on the communications between physical objects, managing the devices, and most importantly data gathering. As a result, the market and industry tend to have more focus on building smart devices containing more advanced features (using machine learning algorithms computed on the cloud) to increase the quality of life.

On the other hand, the massive capabilities of hardware used in our daily life like smartphones, tablets and wearable devices, mixed reality applications increase and attract more industries to extended user interface and experience (UI/UX) to new dimensions. Mixed reality aims to create an illusion between the real and digital worlds by creating an entire virtual scene to the user or creating some virtual objects in a real scene. These virtual objects interact in real-time with real objects and user gestures. It's easy now to develop AR and VR applications with free libraries like ARKit [1] and Vuforia [2]. This ease of development leads to the use of mixed reality in more powerful industries and a fast-growing market.

Due to the huge amount of data generated by the exponential increase in the number of IoT devices, the cloud services started to scale much faster in order to manage storing and processing these data. Yet the real challenge here is that the communication is bound by the network itself acting as a bottleneck. In order to solve this issue, fog computing becomes an essential part to decentralize the cloud. As a result, the amount of data sent in the network will be dramatically reduced and the latency of the IoT device's responses will be reduced as well. Fog computing is one of many aspects of edge computing which is the extension of cloud computing where services are brought closer to the end devices. Edge computing is developed to address location awareness, mobility support, and the issues of high latency in delay-sensitive applications.

Edge computing was introduced to improve the performance of latency-sensitive mixed reality applications in some scientific articles. This improvement includes latency reduction and power consumption minimization for MR devices. As a result, MR applications supported by edge computing rely on providing more Quality of Experience (QoE) and supporting more functionalities that need more processing power. There are some solutions introduced to cover a wide area of MR devices using 5G technology. 5G technology offers less latency than 4G and 3G technologies. Edge computers can also improve the rendering scene of MR applications because they have more processing resources than MR devices but need some protocols and standards that control these functions [3–5].

In the past few years, many research efforts have been made on IoE infrastructure, edge computing architecture, and mixed reality. Technology is shaping future smart cities infrastructure and the new generation of applications interacting with the user's environment relying on his activity or his gestures.

This article will survey the recent researches of MR/AR applications with IoE/IoT infrastructure, researches of MR/AR supported by edge computing, and others that mix between these three technologies.

The rest of this paper is organized as follows: Sect. 2 presents the background and current research of IoE, mixed reality, and edge computing. Section 3 provides an in-depth review of the mix between edge computing and IoT introducing how fog computing was deployed to help IoT. Section 4 discusses how mixed reality was used with IoE. Section 5 summarizes how mixed reality benefited from edge computing and how they can merge with IoE. Finally, Sect. 6 concludes the paper.

2 Background and Current Research in IoE, AR, MR, and Edge Computing

2.1 Internet of Everything (IoE)

Internet of Things (IoT) is the network of physical objects accessed through the Internet. These objects contain embedded technology to interact with internal states or the external environment or sending their state through the Internet. Nowadays, we find IoT applications in most of the surrounding fields and the number of things expands exponentially.

IoT Analytics [6] predicts, as shown in Fig. 1a, in 2020 the number of IoT Devices will be 10 Million and double this number in 2025. This leads to a scalability problem in the near future because the amount of data generated from these devices will grow which leads to network congestions. Another challenge facing IoT which is the heterogeneity of communication protocols. IoT devices connect to The Internet through Ethernet, Wi-Fi or cellular networks, but most of the available devices that have non-TCP/IP connection, like Bluetooth, Zigbee or LoRa, are connected through Gateway. Another challenge is the heterogeneity of data models that describe the devices, as shown in Fig. 1b. It can be a simple data model or more complex and have sub devices inside it having their own data models.

Internet of Everything (IoE) has four pillars: people, process, data, and things as shown in Fig. 2. IoT is one pillar of IoE which is things. Besides Machine-to-Machine (M2M) protocols in IoT, IoE includes Machine-to-People (M2P) and technology-assisted people-to-people (P2P) interactions. IoE concerns also to make data into intelligence for better decisions and deliver the right information to the right person or machine at the right time because it relays on metadata for everything.

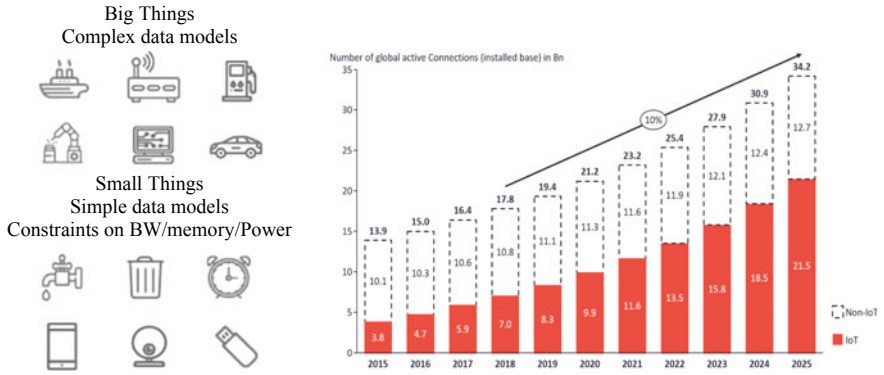
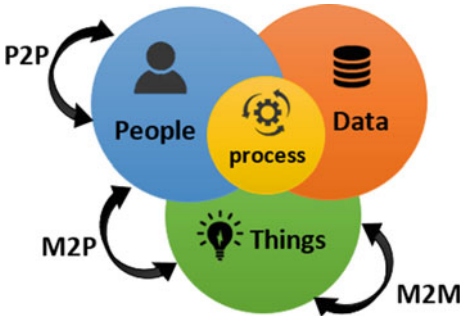


Fig. 1 **a** Total number of devices connections worldwide (right). **b** Types of IoT devices based on data model (left)

Fig. 2 IoE pillars



2.2 *Mixed Reality*

Milgram and Kishino [7] introduced the concept of Mixed Reality, which illustrated the merging between real and virtual worlds, and classified interactions between real and virtual elements. As shown in Fig. 3, on the right end is Virtual Reality (VR), where the entire scene is replaced by a computer-generated virtual content. On the opposite left end is the Real Reality (RR) where none of the user's scene is replaced by virtual content. Augmented Virtuality (AV) and Augmented



Fig. 3 Milgram's extended reality (XR) continuum

Reality (AR) is in between. Mixed Reality continuum depends on the rendered scene's objects biased for the real-world or the virtual world.

In the last few years, developers created separate applications that have one of the two technologies: AR or VR. There is also some separated hardware to execute these applications, for example, HTC Vive [8] and Oculus Rift [9] are headsets of VR applications, Microsoft HoloLens [10], and Google glass [11] are headsets for AR applications. Figure 4 shows the four devices mentioned.

Extended reality (XR) or immersive reality applications can mix between VR, AR, and MR, so some scenes immerse users in a fully artificial digital environment like VR and others overlay virtual objects on the real-world environment like AR or MR. In MR the overlays of virtual objects not like AR, but it anchors virtual objects in the real-world seamlessly like real objects and allows the user to interact with them. Figure 5 clarifies the difference between VR, AR, and MR for the same virtual object.

Mixed Reality can improve many Industries, it can be used in the aircraft industry for training engineers involved in repairing engines by wearing special headsets through which they can view the holographic image of engines with various image and voice features and no longer required to extract a real engine out of an aircraft. MR can help senior supervisors in the construction industry or shipyards or any type of construction industries to manage workers and workflow



Fig. 4 AR and VR headsets

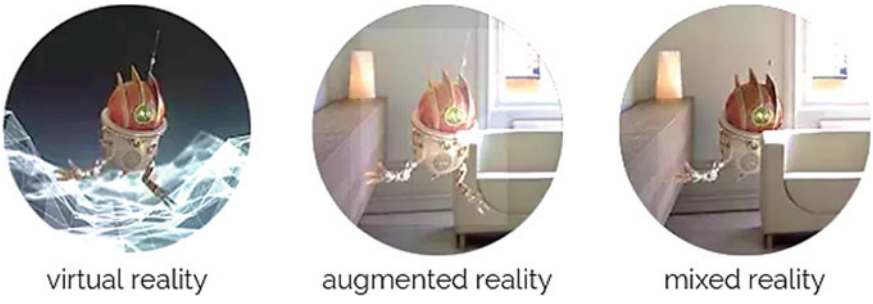


Fig. 5 The difference between VR, AR, and MR

through visual signals for moving the required equipment or raw materials to the working space. It can also help managers to see real-time information about the overall workflow. MR can also improve the medical industry by helping the medical students to perform virtual surgeries. It can improve their skills or used as imaging layers on a patient for diagnostics. Figure 6 shows some examples of MR applications.

MR applications require the most advanced surface mapping algorithms to create the perfect illusion for users, more quality of graphics, and the new rendering algorithms that interacting with the real-world. Therefore, MR needs more powerful hardware to process these heavy algorithms that include deep learning algorithms and artificial neural networks (NN). Neural Processing Units (NPUs) are designed as hardware accelerators for NN and machine vision applications. Figure 7 contrasts the difference between NPUs and CPUs and demonstrates the time needed to recognize 200 photos on each of them [12]. NPUs can improve the performance of some algorithms of MR applications and it creates a reality that we can make a mixed reality.

Another technology that can help in developing MR applications is 5G networks. They are used to cover a wide area of a vast number of devices with low latency. So, it is building a very reliable network for latency-sensitive MR applications compared to 3G and 4G networks.



Fig. 6 Applications of mixed reality

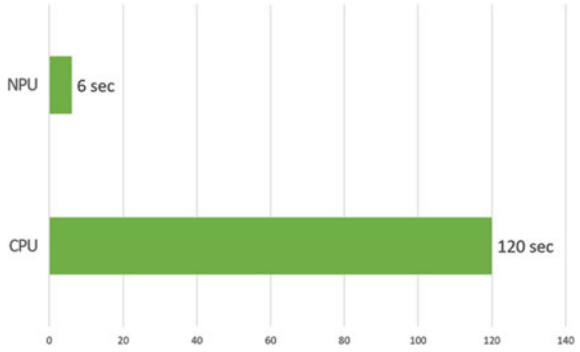


Fig. 7 Difference between CPU and NPU

2.3 Edge Computing

Edge computing is an extension of cloud computing that directs computational data and applications away from cloud servers to the edge of a network. It's used for high bandwidth, ultra-low latency, and real-time access to the network information that can be used by several applications. Edge computing minimizes the cloud load by providing resources and services in the edge network and enhances the end user service by reducing the number of multi-hops on their distance on the Internet. Edge computing is location-aware and high mobility support and using a distributed model for server distribution compared to the cloud which uses a centralized model. On the other hand, edge computing has some limitations like the area coverage is limited compared to the globe scope of cloud and has fewer resources than the cloud.

Fog computing, Cloudlets and Mobile Edge Computing (MEC) are the main paradigms of edge computing, all these paradigms not intended to replace cloud computing; they are complementary, Fig. 8 illustrates the difference between cloud computing paradigm vs edge computing paradigms. In [3] classified the Edge computing (Cloudlets, Fog, and MEC) according to the application domain and their areas such as real-time applications, security, resource management, and data analytics, and in [4] surveying architectures of edge computing, applications, challenges facing it, and some paradigms of it like fog, cloudlets, micro data centers, and MEC.

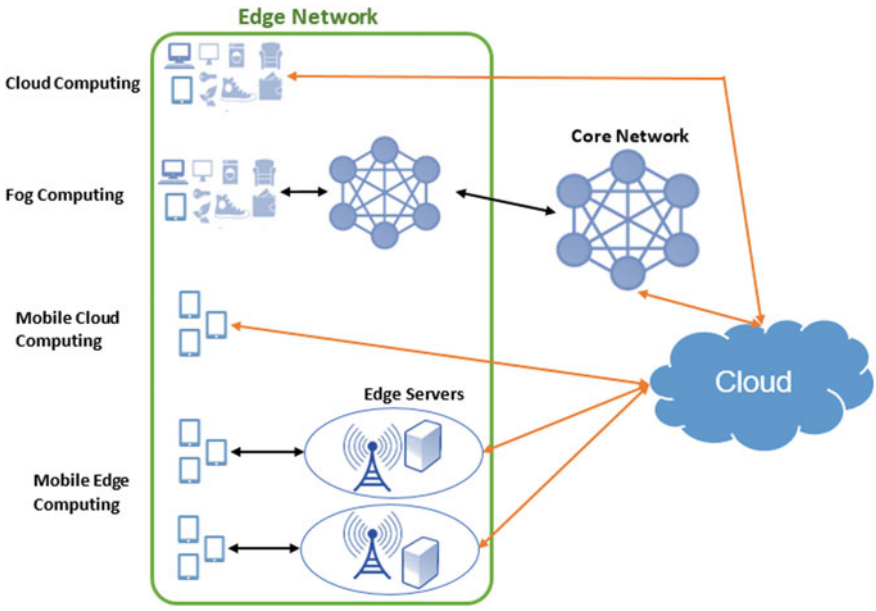


Fig. 8 Cloud computing and edge computing types

MEC, which was coined by ETSI, developed system architectures and standards for a number of APIs, providing capabilities within Radio Access Network (RAN) in close proximity to mobile subscribers like ultra-low latency and high bandwidth, as well as direct access to real-time RAN information, therefore, accelerating services and applications responsiveness from the edge. The deployment of services will not be limited to mobile network operators, but it will also be opened to third party service providers as well. Some of the expected applications include mixed reality, intelligent video acceleration, connected cars, and IoT gateways, among others.

There are some applications that mix the technologies with edge computing, like in [13] which presents a vehicular fog computing for city-wide traffic management system using the integration between cloudlets and fog nodes to reduce the response delay. All the results of the article clarify the huge difference when using edge computing.

3 Fog Computing and IoT

The term of fog computing was coined by "Cisco" [14] in 2012 and has an analogy of real-life fog. As the clouds are said to far above the sky, while the fog is said to be closer to the earth, the same concept is used by fog computing whereas fog computers level is closer to the end devices network, located between the cloud and the users' end devices as shown in Fig. 9. This makes the data transfer easier and faster in wireless and distributed environments. It's meant to be a provision for IoT as a decentralized computing infrastructure can reduce the transferred data to the cloud. Doing so can provide more efficiency, security, and privacy [15]. Some research directions of fog computing development include context-aware resources/services and how to provide sustainable and reliable computing for real-time applications.

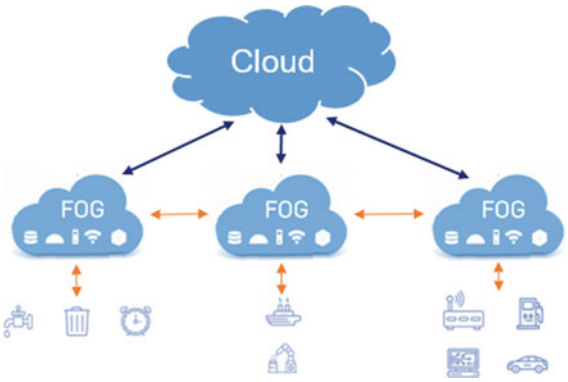


Fig. 9 Fog computing paradigm

Fog computing has a large storage facility to avoid the need for large-scale storage on cloud, and has processing resources to perform some analytics, control, and management on data received. So, it must support protocols that can handle these requirements. Many application layer communication protocols and their potential of integration in IoT-to-fog-to-cloud system architectures have been proposed including objectives like latency and network throughput [16].

Fog distributed infrastructure for IoT/IoE provides location awareness, low latency, mobility, real-time interactions, interoperability and supporting heterogeneous devices. It can be one layer between cloud and IoT devices, or it can be multiple layers for applications requiring more interoperability between other systems. This realizes a quick response computing with high processing power at neighborhood-wide, community-wide, and city-wide levels, providing the basic infrastructure for high performance and more intelligence in future smart cities. Some of the existing edge IoT solutions and their architecture, functionality, and operational issues are given in [17]. Their demonstration was on healthcare application and the results were clear that bandwidth between IoT cloud systems and local edge devices can be increased and the processing latency can be decreased significantly. In [18], fog computing was directed towards education and the results showed that the amount of traffic was reduced up to five times among all devices in the architecture even using limited resource devices in the fog layer.

4 Mixed Reality and IoE

In Mixed Reality, virtual objects need to be interactive with the real-world and must be rendered to act like real objects. IoE can increase the interactivity between the real-world and the virtual objects, so the data read from the IoT devices can be converted to a process helping rendering scene process. User gestures in MR can also make physical actions in the real-world by IoT actuators.

As in Fig. 10, MR supported by IoE (MRIoE) adds more value to the MR applications because the interactions can flow in both ways; the physical world and the virtual world. IoE models and semantic architecture improve the data flow between the physical objects and the virtual objects and vice versa. IoE also makes it easy to share some virtual objects between multiple users like some objects in a game shared between players, like in Fig. 11, or objects shared between trainer and trainees.

MRIoE can be used in the near future to perform remote surgery that doctors who are trained on MR surgery can operate them online by connecting the doctors with some kind of robots. Another application controls smart devices in homes, production lines or even space by virtual Interactive user interface in the air without any physical switches or controllers.

In [19], a survey on the joint between IoT and AR architecture is given, including the technological aspects of implementation, applications for IoT and AR, which are already developed to its published date. In [20, 21], a generic and scalable



Fig. 10 User gesture change light density

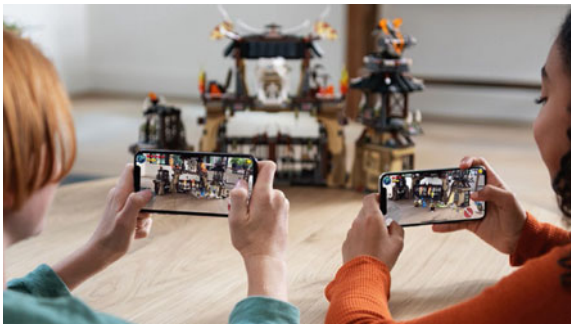


Fig. 11 Game shares the same object between players

augmented reality framework is extended by IoT infrastructure called ARIoT and implementing an application to demonstrate the instructions of Interactions between IoT and AR devices. ARIoT can dynamically identify and filter candidate devices in the AR device perimeter for augmentation then uses a quick guided recognition and tracking objects. It's also concerned about scalability by distributing the information onto some devices and directly communicating with them.

There are several scientific articles that have addressed the issues of interaction between IoE and MR, and their experiments had different scenarios. In [22], AR-middleware is built on IoT gateway of static Wireless Sensor Network (WSN) to enable the relational localization of devices and building the virtual objects based on the calculated location.

Other work used MR and IoT for novel applications, such as in [23] which presents a framework for robot-IoT tasks. These mobile robots serve as binding agents to link static IoT devices and perform a collaborative task. The interface of reprogramming mobile robots is used via AR Interface.

In [24], a prototype for monitoring the current density distribution of a fuel cell in MR that uses MQTT protocol is introduced to connect with the fuel cells which act as IoT devices. In [25], MR is used in the emergency management system by bringing the virtual evacuation simulations into real-world using real-time geometric and semantic data about the built environments, which is provided by the integration between geographic information systems, building information modeling, and IoT.

5 Mixed Reality and Edge Computing

Edge computing can improve MR and solve some challenges facing MR applications including latency reduction, as well as add more processing and storage resources near MR devices for verity usages. In some researches, edge computing is used to solve the latency issues of MR applications. MEC is the most recent paradigm used in the last few years with MR. The work in [26] offers a framework based on MEC for current AR applications to optimize energy efficiency and processing delay. It's integrating the communication, computation, and control functions at the edge layer then taking full advantage of both edge and cloud computing.

In [27], a lightweight and cross-platform solution for AR is proposed which is Web AR using MEC to improve the performance and latency of rendering. It's also discussing the challenges of this solution under 3G, 4G, and 5G networks. In [5], a survey on Web AR was presented and focused on the implementation approaches of mobile AR, challenges of Web AR, and the enabling technologies for reliable Web AR applications including MEC and 5G networks.

In [28], Navantia's Industrial AR (IAR) architecture in shipyards is described which uses cloudlets and fog computing to reduce latency. It was compared with the traditional cloud-based system, and the cloudlets and fog computing were also compared when sending different sizes of payload. In [29], the recent studies that focus on caching and computing at the edge were surveyed, discussing the various types of caching techniques at the network core and network edge, and summarizing the combination of various kinds of caching techniques that reduce the duplicity and eliminate redundant traffic in the network.

On the other hand, Mixed Reality applications that collaborate with IoT devices have a big impact on quality of experience but have one main issue which is latency. As a result, adding fog computing to enhance both IoT layer and MR processing layer became mandatory. Figure 12 shows a fog computing architecture for MR and IoT devices. Some previous work has mentioned this idea in some way or another but not focusing on it directly.

While the work in [28] mentioned that there are Industrial IoT frameworks (IIoT) that can be integrated with IAR in the same level of cloudlets or fog computers. In [30], multi-level cloud service architecture like cloudlets for AR application with IoT Infrastructure was introduced to decrease the number of calls to cloud services. By simulation, modeling and examining three-tire cloud architecture, the results show the average data of delivery time is almost half the time.

In [31], the challenging problem of integrating lightweight virtualization with IoT edge networks was examined by discussing the current issues involving edge computing and IoT network architectures. AR application is one of the scenarios discussed in this article which has all the critical requirements that must be covered such as scalability, multi-tenancy, privacy, security, latency, and extensibility.

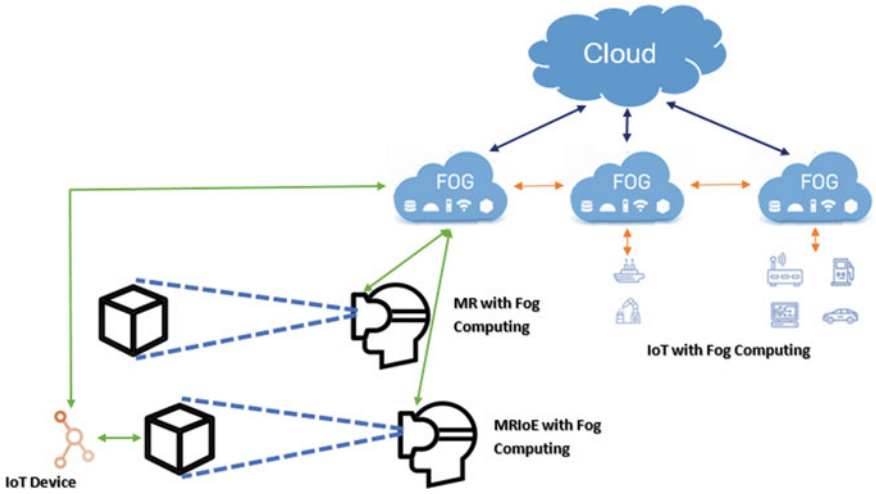


Fig. 12 Fog computing with MR and MRIoE applications

6 Conclusion

In this paper, we have presented the three pillars of three of the most interesting and powerful current technologies. Firstly, the definition of IoE is given and then the difference between IoE and IoT was highlighted. Secondly, the Mixed Reality technology, its applications in different industries, and the challenges facing this technology are summarized. Finally, how Edge computing and Fog computing architectures are used currently to improve IoT and MR. Some of the recent research in IoT, MR, and Edge computing used to improve MR applications are mentioned.

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