# Autonomous Realities: A Journey into Protocolizing Digital Object Permanence in a Future of Many Mixed Realities

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**Figure 1: "Can you see what I see?" An autonomous digital pet rock in mixed reality faces a granite rock in physical reality.**

## Abstract

Major technology companies envision a future where mixed reality (MR) devices become as ubiquitous as smartphones are today. Yet most collaborative MR research assumes users share a single augmented layer—an assumption that may not hold true. Rather, MR technology is inherently permissionless: users control what they see, making each person's augmented layers private and unique. We are moving toward a future of multiple overlapping and co-existing mixed realities. This paper employs protocol fiction as a speculative design method to explore this near-future scenario. We follow the journey of a fictional digital pet rock as it travels through successive protocol eras of mixed reality, adapting to the changing infrastructures and protocols it encounters. Through a comic-style narrative, the story unfolds across four protocol-defined chapters: Centralized Realities, Distributed Realities, Persistent Realities, and Autonomous Realities. Each chapter examines moments when digital pet rock owners—wearing MR headsets—engage in social encounters, revealing how protocols shape the ontological nature of digital object permanence and highlight the socio-technical challenges of constructing consensus reality.



*AAR 2025, Aarhus N, Denmark*

ACM ISBN 979-8-4007-2003-1/25/08
https://doi.org/10.1145/3744169.3744197

## CCS Concepts

• **Human-centered computing** → **Collaborative and social computing theory, concepts and paradigms**; **Mixed / augmented reality**.

## Keywords

Social Mixed Reality, Protocol Design, Merging Mixed Reality, Protocol Fiction, Design Fiction, Ontology of Digital Object, Object Permanence, Metaverse Interoperability

**ACM Reference Format:**

Botao Amber Hu. 2025. Autonomous Realities: A Journey into Protocolizing Digital Object Permanence in a Future of Many Mixed Realities. In *The sixth decennial Aarhus conference: Computing X Crisis (AAR 2025), August 18–22, 2025, Aarhus N, Denmark.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3744169.3744197

## 1 Introduction

Mixed Reality (MR) [25] enables digital content to be overlaid onto the physical world to achieve the "AR illusion" [30]—where digital objects appear in the real world. Major technology companies envision a future where mixed reality devices become as ubiquitous as smartphones are today [16]. Yet most collaborative mixed reality research assumes users share the same augmented layer [29]. Under this assumption—what Niantic calls the "real-world metaverse"[1]—a digital object placed in the world should be visible to anyone looking through a mixed reality device, just as a physical object is visible to anyone with line of sight. However, this assumption may not hold true in the future. Mixed reality technology is inherently **permissionless** [24]: users control what they see, making each person's augmented layers private and unique by default. Each user's view of augmented reality is siloed by underlying sessions, apps, devices, platforms, and protocols. Two people in the same room may see entirely different digital overlays, unless they use a specially designed co-location application with a synchronized, permissioned sharing session. This inherent permissionlessness leads to fragmented realities: we are moving toward a future of thousands of overlapping and co-existing mixed realities in the same physical location, where each person is surrounded by their own digital umwelt. The challenge thus becomes how mixed reality users can coexist with some degree of consensus in such a fragmented future. Imagine a pivotal moment: when two mixed reality wearers encounter one another in a shared physical space. They might wonder: Can you see what I see? How can I allow you access to my mixed reality? What happens when our mixed realities merge? What constitutes our consensus reality?

The challenge of merging mixed realities—also known as metaverse interoperability—remains unresolved despite years of discussion. Industry consortia, such as Metaverse Standards Forum[2], have formed to address this at a standards level to foster interoperability for an "open metaverse." The constant evolution in the technical landscape makes establishing unified protocols particularly difficult due to: shifting hardware capabilities, competing 3D format standards, centralized versus decentralized control, unified object identity, platform politics, physical-world alignment challenges, privacy concerns, policy debates, urban governance issues, etc. Acknowledging the complexity around unified real-world metaverse protocols in this ever-shifting socio-technical milieu [15], instead of attempting to solve the problem from the top-down, we take a bottom-up observation by focusing on the fundamental element in mixed reality: a digital object. How can a digital object survive when mixed realities merge or persist across different mixed reality protocols and standards? Therefore, we explore the ontological existence of digital objects across different MR protocols and standards, as well as examine their perceived existence: *object permanence* [20], originally a psychological concept describing one's understanding that objects continue to exist even when they cannot be directly observed. In physical reality, object permanence is taken for granted: objects exist based on the stable physics of our universe. Based on this, we easily have a consensus reality that is socially shared—people assume others perceive the same objects, enabling mutual understanding. However, in mixed reality, the foundation of *digital object permanence* and consensus digital reality is neither straightforward nor stable: their existence relies on "digital physics"—protocols that form a socio-technical substrate of intertwined, ever-shifting, and ever-evolving technologies and standards.

In this paper, we aim to provide critical perspectives on the difficulties of maintaining shared object permanence in mixed reality—in stark contrast to physical reality—and reveal how digital object permanence, based on ever-changing technology, remains fragile and can easily vanish. We adopt *protocol fiction* as a research method [1, 2] to speculate about various future eras of potential mixed reality protocols. Through a comic-style narrative, we follow *Rockyu*, a digital pet rock that journeys through four possible futures of MR protocol eras. Each chapter dramatizes the socio-technical challenges that arise as Rockyu survives when two mixed reality wearers encounter each other:

(1) Centralized Realities. Rockyu is hosted on a private company's cloud server (like Pokémon Go). Object permanence depends on internet connectivity and the platform's continued support. The company can unilaterally remove or alter Rockyu, highlighting the fragility of centralized control.
(2) Distributed Realities. Rockyu exists and is rendered fully on-device, i.e., MR glasses. While this improves privacy and autonomy, it also isolates Rockyu from others unless devices deliberately synchronize. If the device is out of range, Rockyu disappears from collective view.
(3) Persistent Realities. Building on a "group realities" protocol akin to group chat, multiple MR layers can merge, allowing objects and users to access shared reality layers with explicit permissions. Rockyu becomes visible to authorized participants across MR layers. This enables limited interoperability but suffers from fragile permanence if individual devices go offline.
(4) Autonomous Realities. Rockyu is placed on a blockchain as a public common with Trusted Execution Environments (TEEs) as a self-sovereign agent. Its existence no longer relies on a single platform—effectively "becoming wildlife." However, new dilemmas arise: if an agent like Rockyu loses access to its own crypto wallet, it can become "frozen" if it cannot pay for its own runtime, becoming a liminal state within an immutable ledger.

We offer this protocol fiction as a provocation for HCI researchers and practitioners envisioning MR systems beyond today's silos. Rockyu's journey illuminates how each era of MR protocol carries

[1]https://nianticlabs.com/news/building-the-real-world-metaverse/?hl=en
[2]https://metaverse-standards.org/

distinct trade-offs in ownership, permanence, interoperability, and user agency. By reflecting on these scenarios, we hope to spark new dialogues on the future of MR and the potential to shape a truly shared and enduring digital reality. We conclude with a discussion about how building protocols as "digital physics" for digital object permanence poses greater challenges than physical laws, as protocols continuously evolve with shifting power relationships between companies and society.

# 2 Background

## 2.1 Object Permanence and Consensus Reality

Psychologist Jean Piaget originally defined object permanence as a person's understanding that objects continue to exist even when they are no longer perceptible [20]. The consensus reality in the physical world is grounded in shared object permanence: everyone can generally agree on the presence and continuity of a physical object in a given space and time, as those objects exist independently of any one observer. HCI researchers have adapted this concept for MR research, finding that digital object permanence poses unique challenges for social presence [19]. In fact, in graphical rendering, unlike physical objects, digital objects in MR effectively disappear once out of frame and don't necessarily persist outside a user's immediate view—a phenomenon termed *Unaugmented Periphery* [18]. Furthermore, MR experiences are asymmetric and siloed by default [4], with each user immersed in a private augmented reality layer as a personal "digital umwelt" [3]. Empirical studies show that novice MR users typically assume virtual content is shared with others, until they realize "oh yeah, only I can see this"—highlighting how each user's holograms remain invisible to others without explicit synchronization [17]. Building a consensus reality in MR is significantly harder because it requires cross-user object permanence—ensuring that a digital object endures and remains consistent across different users' perspectives, devices, and sessions. This goes beyond a simple technical feat; it demands interoperability between platforms and metaverses. While object permanence (and thus consensus reality) emerges naturally from the laws of physics in the physical world, in MR it must be actively engineered. Every participating system needs to agree on an object's identity, state, and ontology, which requires aligning multiple protocol stacks and ontologies across varied technological milieus.

## 2.2 Socio-Technical Milieu and Protocols for Mixed Reality

As Yuk Hui argues in *On the Existence of Digital Objects* [15], for digital objects to "exist," they depend on an ever-shifting socio-technical milieu where a complex mesh of protocols[3] (formats, standards, communication protocols, etc.) sustains the existence of those digital objects in the consensus reality. For example, the format of digital objects must be standardized for display, devices must be calibrated for correct viewing, the computational substrate must be properly aligned, and metaverse standards and interoperability protocols must be specified. Many layers of technologies and protocols must work together to achieve a shared object permanence. We listed some important ones for MR.

### 2.2.1 *See-through Mixed Reality Device.*

MR devices like Microsoft HoloLens, Magic Leap, and Apple Vision Pro use transparent or pass-through displays to overlay digital objects onto the physical world [16]. These headsets perform extensive spatial computing via sensor fusion, combining inputs from RGB cameras, depth sensors (e.g. LiDAR), to map the environment and anchor holograms in place. Such see-through MR systems allow digital objects to appear collocated with real environments, maintaining the AR illusion [30] that they occupy fixed positions in physical space even as the user moves.

In MR systems today, many MR applications lack object persistence: when an AR session ends, the digital objects disappear, and a new session has no memory of the old state. Recent MR platforms aim to address this via cloud-backed persistence. For example, Apple Vision Pro's "world anchors"[4] act as the digital equivalent of object permanence, ensuring that a virtual item remains in the same physical location when you return. Indeed, MR experiences must persist in time, space, and across devices if multiple users are to share them reliably. Achieving this requires not just technical solutions (like cloud anchors or shared maps), but also consensus on protocols and standards so different devices and apps reference the same "world" of content.

### 2.2.2 *Metaverse Standards and Interoperability.*

Sharing digital objects across heterogeneous devices and applications further requires common standards – essentially, agreed-upon "protocols" for representing and exchanging spatial content. Without industry-wide consensus, a digital object isn't really persistent in the world – it's a local hallucination restricted to one platform. Without aligning these protocols – from hardware sensors up through data formats and networking – a "digital object" in one mixed reality silo remains inscrutable or invisible in another, undermining any cross-reality object permanence. Efforts like OpenARCloud[5] project and Metaverse Standards Forum[6] have called for interoperable frameworks so that a digital object's definition, coordinate location, and appearance can be consistently understood in different MR systems.

In 2022, industry consortia have formed to address this at a standards level. Dozens of companies and standards organizations (Meta, Microsoft, Sony, Adobe, OpenAR Cloud, W3C, and more) formed Metaverse Standards Forum to foster interoperability for an "open metaverse". The goal is "real-world interoperability" so that real-world, different digital worlds and AR experiences can connect. Although metaverse interoperability has been discussed for years, no consensus has emerged due to the complexity of technological systems in mixed reality, as well as political factors and market competition. Large firms have strong incentives to maintain their own ecosystems for profit and control, making it difficult to establish a single universal standard.

[3]Here the concept of protocol extends beyond mere communication protocols, as defined by Rao et al. [21]: *"A protocol is a stratum of codified behavior that allows for the construction or emergence of complex coordinated behaviors at adjacent loci."*

[4]https://developer.apple.com/documentation/visionOS/tracking-points-in-world-space

[5]https://www.openarcloud.org/

[6]https://metaverse-standards.org/

Competing protocols—Metaverse Standards Forum, NVIDIA Omniverse[7], OpenARCloud, OpenXR from Khronos Group[8], WebXR by W3C[9], NFT metadata standards[10]—struggle to interoperate, each enforcing different rules for how objects are created, protocolized, or discovered. Digital reality lacks the universality of physical laws; instead, it is governed by incomplete protocols that can both enable collaboration and impose new forms of control. We ask whether a truly unified MR is possible, or whether control merely shifts from centralized corporations to gatekeeping protocols or key holders.

*2.2.3 Ever-competing AR Object Persistence Platforms.* AR object persistence technologies enable AR content to persist and be shared across devices and sessions, remembering where digital objects were placed in the physical world. These spatial anchors provide the crucial element of persistence, supporting cross-user, cross-platform scenes that people can revisit indefinitely. The systems upload point-cloud scans or image features to the cloud, allowing later localization of compatible devices to stream back the same digital objects. Google's Cloud Anchor API, for example, enables multiple Android or iOS users to share an AR scene and return to it over time. Apple's ARKit/RealityKit provides similar functionality through collaborative sessions and location anchors (using Apple Maps data) to sync content across iPhones or the Vision Pro. Niantic's Lightship VPS (Visual Positioning System) focuses on planet-scale AR, where players encounter persistent AR creatures or objects at real-world landmarks, with Lightship servers managing localization through computer vision.

These proprietary AR clouds use point cloud scans and image feature matching to identify locations and serve anchored digital objects. However, interoperability remains limited—a Niantic anchor is incompatible with ARCore or ARKit since each platform uses unique data formats and APIs. This creates a patchwork of "walled garden" AR clouds, each managing digital object permanence in isolation. The situation highlights the need for open standards to prevent AR objects from being confined to a single company's clouds. The resulting "AR localization war" pits tech giants, who invest billions in global spatial databases, against open initiatives like OpenARCloud, which advocates for interoperable location standards to free AR objects from proprietary platforms. Creating neutral protocols would enable truly public, device-agnostic mixed-reality layers.

*2.2.4 Computational Substrates: Private Cloud, On-Device, Public Blockchain.* Digital objects attain their very "being" from the substrate that stores their state and executes their logic. On-device memory affords immediate, low-latency interaction but confines persistence to the lifespan of the hardware or app sandbox, or session time. Private-cloud back-ends extend longevity and enable cross-device sharing, yet they centralize control in a single operator who can alter, revoke, or forget the object at will. By contrast, deploying code and state to a public blockchain—optionally shielded in Trusted Execution Environment (TEE) nodes—renders the substrate permissionless, tamper-resistant, and perpetually addressable [11, 12]: once a digital object is minted on-chain, its hash-linked history and ownership survive provider bankruptcies, software upgrades, or human neglect. Together, these three strata—on device, private cloud, and public blockchain—define a spectrum of sovereignty [12] and persistence for computational objects, from ephemeral local agents to autonomous agents that "live" [7] indefinitely in decentralized infrastructure.

[7]https://www.nvidia.com/en-gb/omniverse/
[8]https://www.khronos.org/openxr/
[9]https://www.w3.org/TR/webxr/
[10]https://docs.opensea.io/docs/metadata-standards

## 2.3 Protocol Fiction as Speculative Design Method

HCI researchers are increasingly turning to speculative design [5] as a method to probe and prototype the future of complex interactive systems—not by building them outright, but by crafting narratives and speculative scenarios [2, 23]. Bruce Sterling [27] famously defined design fiction as *"the deliberate use of diegetic prototypes to suspend disbelief about change."* Researchers use fictional yet plausible artifacts—like imaginary things from the future—to make speculative technologies feel concrete and open them to critique.

Similar to design fiction methodology, Summer of Protocols research initiative [11] further exemplifies this approach through "*protocol fiction*."[12] The initiative shifted from traditional technical prototyping to speculative "protocol fiction," creating story-driven artifacts that explore how future protocols might enable world-building [1]. This approach treats protocols themselves as design material for fiction, allowing researchers to ask "what if" questions about governance, interoperability, and digital permanence in a richly contextualized manner instead of merely writing code. As science-fiction writer Frederik Pohl famously put it, *"a good science fiction story should be able to predict not the automobile but the traffic jam."* The value of futurist inquiry lies in anticipating secondary effects and societal implications, rather than just inventing new gadgets. Through protocol fiction, HCI scholars can explore how an envisioned protocol might work and what new social dynamics it might create, long before such a protocol is built.

# 3 Protocol Fiction

In this protocol fiction, we follow a digital pet rock named *Rockyu* on its adventures through different eras of MR protocols. Each "chapter" of *Rockyu*'s story corresponds to a stage in the evolution of MR infrastructure and protocols. Through *Rockyu*'s eyes, we see how technologies and protocols shape its life—who can see *Rockyu*, who can own or interact with it, and whether it can persist when nobody is looking. Although the tone is speculative, each scenario reflects real socio-technical trajectories and challenges. We present each chapter in three parts: Background, Script, and Implications, to underscore how evolving protocols alter our object permanence of *Rockyu.*

## 3.1 Chapter 1 - Centralized Realities

*3.1.1 Background.* *Lemon, Inc.*[13] has unveiled its pioneering mixed reality headset, the *Lemon Glass Pro*[14], claiming to offer smartphone-replacement capabilities in a lightweight (80g) form factor. With a 110° field of view and optical pass-through, it integrates digital

[11]https://summerofprotocols.com/
[12]https://interconnected.org/home/2022/08/11/casi
[13]parody of Apple Inc.
[14]parody of Apple Vision Pro


**Figure 2: Chapter 1 - Centralized Realities**

content into daily life through a powerful M10 Silicon Chip and 6G connectivity. Its *Spatial Awareness* system with LiDAR scanner and camera system provides instant tracking and environmental understanding, making the Lemon Glass Pro a potential game-changer in consumer MR. Meanwhile, *Riantic, Inc.*[15] has launched *Rockymon Go*[16]—an MR game exclusively on the Lemon Glass App Store. Built on Riantic's proprietary AR Cloud [6], the game anchors virtual creatures to real-world locations. Its star attraction is *Rockyu*[17], a playful digital pet rock powered by a foundational AI model. Users flock to adopt Rockyu, enthralled by its ability to sense surroundings, respond to emotions, and interact with real-world objects. The synergy of Lemon's hardware and Riantic's software has become a killer app for MR, driving massive sales.

**Protocol:** Proprietary Metaverse SDK on a Private AR Cloud [18]

**Ontology:** All agents (including Rockyu) exist and are processed on Riantic's server-side database and computing infrastructure.

*3.1.2 Script.* Crowded morning commuter train. **Estragon** and **Vladimir** [19] —two friends met, both wearing sleek Lemon Glass Pro AR glasses.

> **Vladimir:** "Long time no see! You've got a Lemon Glass Pro!"
> **Estragon:** "Hey! You've got the glasses too!"
> Vladimir grins. Estragon speaks with excitement.
>
> **Estragon:** "And check out my AR pet. Isn't it cute?"
> **Vladimir** (puzzled): "I don't see anything. Where is it?"
> Estragon smiled and gestured at the air. Vladimir seemed puzzled.
>
> A window popped up in Vladimir's interface.
> **System:** "You don't have Rockymon Go yet."
> **Button:** Install
>
> Vladimir tapped the install button.
> **System:** "App download completed."
> **Estragon:** "Can you see it now?"
>
> (Rockyu appeared glowing in Estragon's open palm.)
> **Rockyu** (chirping): "RO–CKE–YU!"
>
> **Vladimir** (delighted): "Oh! It's so cute!" and reached out to touch Rockyu.
>
> **Estragon:** "Haha, he has accompanied me on the entire trip!"
> **Vladimir:** "He's really alive!"
> The two smiled as Rockyu moved cheerfully.

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[15]parody of Niantic Inc.
[16]parody of Pokemon Go
[17]parody of Pikachu
[18]parody of Niantic's Visual Positioning System: https://www.nianticspatial.com/products/visual-positioning-system
[19]parody of two main characters, Vladimir and Estragon in *Waiting for Godot*

The train traveled into a tunnel.
**SFX:** "Whoosh!"

Rockyu suddenly disappeared.
**Vladimir** (confused): "Where did it go?!"

A flashing "No Signal" icon appeared in their glasses.
**Estragon** (shrugs): "Emm, the tunnel must have cut off the internet. The pet's on Riantic's server—no connection, no pet."

*3.1.3 Implications.* This chapter illustrates *MR asymmetry* and *centralized dependence.* Although the experience is fun, it relies on proprietary infrastructure:

- **Proprietary AR Cloud:** Rockyu's data and AI run on Riantic's servers, so losing internet connection immediately cuts off Rockyu's access.
- **Platform Lock-In:** Only the Rockymon Go app can render Rockyu. Estragon and Vladimir must both use the same app to see the same Rockyu.
- **Ephemeral Reality:** If Riantic revokes support or if network conditions fail, Rockyu ceases to exist for all users.

Ultimately, Rockyu's fate hinges on a single corporate server and continuous connectivity. This "walled garden" approach shows how centralized protocols grant immediate convenience but sacrifice true persistence or interoperability.

## 3.2 Chapter 2 - Distributed Realities

*3.2.1 Background.* A few years later, **Lemon, Inc.** faces heavy regulatory scrutiny for covertly collecting user data via the Lemon Glass Pro. Under pressure, they introduce stricter on-device privacy measures for the newly released **Lemon Glass Pro 2**, blocking third-party access to camera feeds and forcing all AI computations to run locally. This move is meant to restore user trust—especially after the European Commission's multi-billion euro fine—but it also complicates the business models of AR app developers like **Riantic**.

To adapt, **Riantic** updates its *Rockymon Go* experience so that digital pets like **Rockyu** can be shared directly between users' devices, without uploading camera data to the cloud. They create a simple device-to-device protocol—**AirSync**—enabling ephemeral, local synchronization of objects. Now, Rockyu lives on each owner's headset and uses on-device AI inference to animate, while short-range peer-to-peer connections allow others to briefly see the same pet rock.

**Protocol:** *AirSync*, a local peer-to-peer sharing method (like AirDrop).

**Ontology:** Rockyu's AI runs in the headset's Trusted Execution Environment (TEE), with no continuous cloud storage.

*3.2.2 Script.* **Estragon** and **Vladimir** meet again, this time in a quiet corner of a university building. Both wear Lemon Glass Pro 2 headsets.

Vladimir greeted Estragon.
**Vladimir:** "Hi, it has been a long time!"
**Estragon:** "Yeah, are these new glasses?"

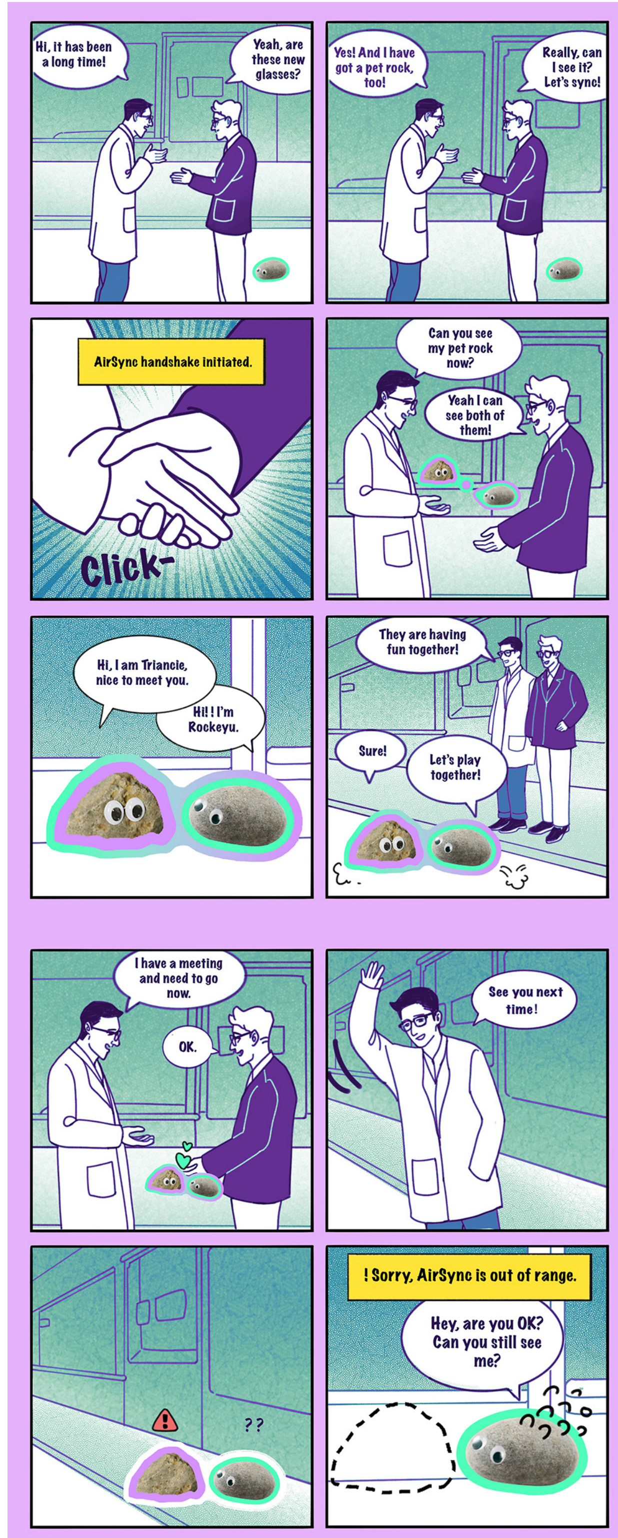


**Figure 3: Chapter 2 - Distributed Realities**

Vladimir smiled. Estragon looked curious.

**Vladimir:** “Yes! And I’ve got a pet rock too!”
**Estragon:** “Really, can I see it? Let’s sync!”

They shook hands as a system notification appeared.
**System:** “AirSync handshake initiated.”

Vladimir asked.
**Vladimir:** “Can you see my pet rock now?”
**Estragon:** “Yeah! I can see both of them!”

Rockyu and Vladimir’s pet rock, Triancie, appeared in their shared AR view. The two digital pets introduced themselves.
**Triancie:** “Hi, I’m Triancie, nice to meet you.”
**Rockyu:** “Hi!! I’m Rockyu.”

The friends observed their pets playing.
**Vladimir:** “They are having fun together!”
**Estragon:** “Sure!”
**Rockyu and Triancie:** “Let’s play together!”
The AR rocks bounced around playfully.

Vladimir looked at his watch.
**Vladimir:** “I had a meeting and need to go now.”
**Estragon:** “OK.”
The rocks blinked affectionately at each other.

Estragon waved goodbye.
**Estragon:** “See you next time!”

Estragon walked away. Rockyu and Triancie stood still. Suddenly, Triancie began flickering.
A red warning icon appeared next to her.

A system message popped up.
**System:** “! Sorry, AirSync is out of range.”
**Rockyu:** “Hey, are you OK? Can you still see me?”
Triancie faded. Rockyu looked confused and concerned.

*3.2.3 Implications.* This “distributed realities” shows how *local computation* and *device-to-device sharing* can preserve privacy while still letting friends exchange digital objects:

- **On-Device AI:** Rockyu’s intelligence runs entirely on the Lemon Glass Pro 2, so no corporate server holds private camera feeds or user data.
- **AirSync Handshake:** A quick, short-range protocol shares objects momentarily. Once users separate, the shared session ends.
- **Ephemeral Collaboration:** Without a centralized server, Rockyu disappears for Vladimir as soon as he leaves range. Persistent multi-user AR remains elusive.
- **Privacy vs. Convenience:** Blocking cloud access protects users but prevents large-scale or long-term collaboration. Global AR events become harder to realize under such constraints.

In essence, Rockyu returns in a privacy-focused form: owned and animated locally by each user’s device. Yet the trade-off is fragmentation—every interaction is fleeting and reliant on physical proximity. The once-seamless experience of encountering a shared AR pet rock in public now demands a deliberate handshake, highlighting the tension between safeguarding data and sustaining rich, persistent mixed realities.

## 3.3 Chapter 3 - Persistent Realities

*3.3.1 Background.* A new protocol called **WeRealities**[20] emerges to solve the limitations of purely on-device MR. Much like a group chat, WeRealities merges local realities into a *shared, persistent layer*, without requiring all data to reside on a single corporate server. Each participant’s device contributes to a distributed scene graph, and objects remain “anchored” as long as enough peers stay connected. Building on the privacy gains of on-device computation, this protocol adds a lightweight coordination layer so multiple users can see and maintain the same reality layer over time.
**Protocol:** *WeRealities*, a decentralized “group reality” system.
**Ontology:** Digital objects exist on individual devices, while anchored shared reality layers replicate scene data across participants’ devices, persisting only as long as the group remains active.

*3.3.2 Script.* **Estragon** and **Vladimir** met again.

**Estragon:** “Hey, you know what? Your last departure ruined Rockyu’s romance!” Vladimir responded with a shrug.
**Vladimir:** “Oh really? That’s a shame.”

Vladimir waved it off.
**Vladimir:** “It doesn’t matter. They can now enter into shared reality! Let’s share!”
Estragon initiated the sharing, and Vladimir accepted.

They put their rocks into the shared “Rockymon Go Layer.”
**Vladimir:** “Look, this is the shared data of our reality layer.”

Estragon looked through his Lemon Glass to check the space where the rocks were.
**Estragon:** “Can you see it?”
**Vladimir:** “Yeah!”

Rockyu and Triancie hovered in the middle of a romantic table setup. The table is adorned with virtual candles and balloons.
**Rockyu:** “Love you!”

The friends observed from afar.
**Vladimir:** “It seems that they are having a date.”
**Estragon:** “Ahhh!”

Rockyu found Triancie not moving.
**Rockyu:** “Hey?”

[20] parody of WeChat

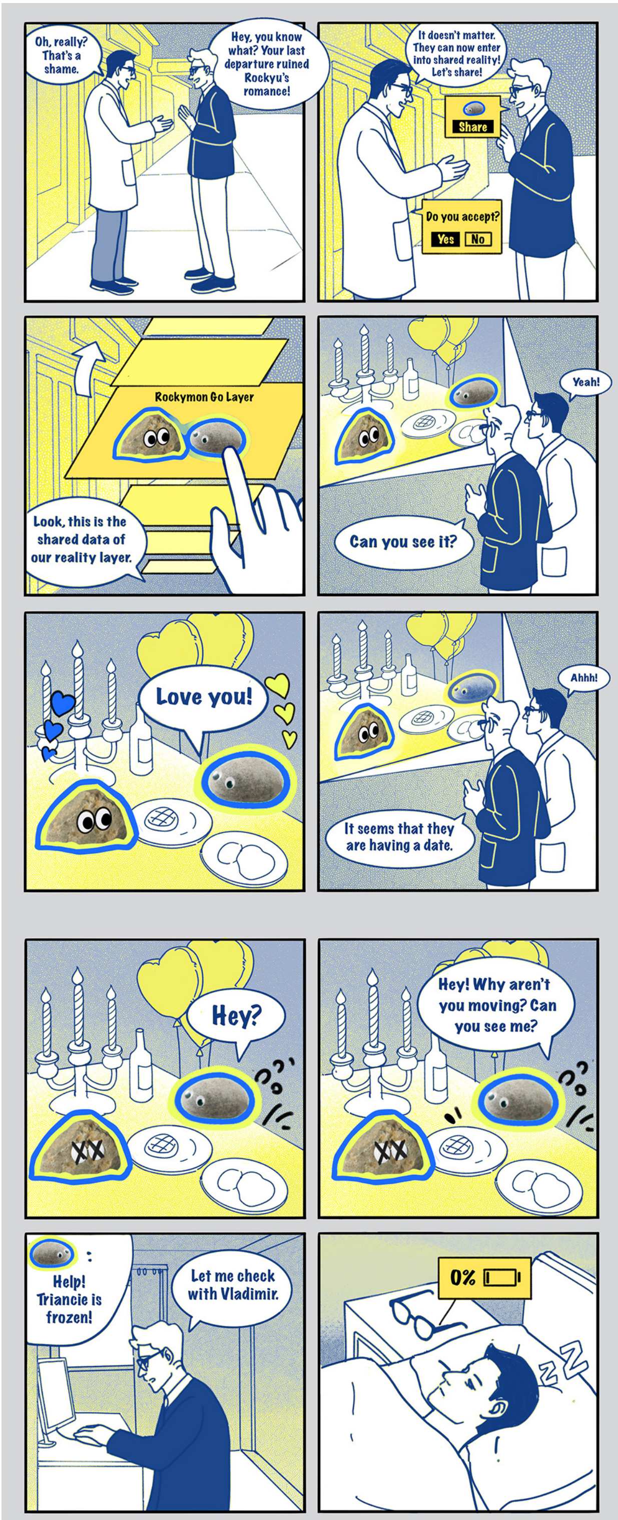


**Figure 4: Chapter 3 - Persistent Realities**

Triancie didn't respond. She was motionless.

Rockyu blinked anxiously.
**Rockyu:** "Hey! Why aren't you moving? Can you see me?"

Rockyu panicked and sent a message to Vladimir.
**Rockyu:** "Help! Triancie is frozen!" Vladimir sat at his desk, checking his system.
**Estragon:** "Let me check with Vladimir." He tried to get connected to Vladimir on his computer.

Triancie's master—Vladimir—was asleep. Beside him, his glasses were powered off, with 0% battery.

*3.3.3 Implications.* **WeRealities** represents a *persistent group reality* that balances privacy and collaboration:

- **Distributed Scene Graph:** Each device maintains a local copy of the shared reality layer. Changes (e.g., moving Rockyu or adding decorations) sync in real time, without relying on one server.
- **Anchored Continuity:** As long as at least one participant keeps the session alive, objects like Rockyu should remain visible to others who rejoin—unlike purely on-device AR that disappears once a user leaves.
- **Group Governance:** The group owner decides when a shared layer ends.
- **Reliability and Versioning:** WeRealities only preserves the information of shared reality layers but cannot guarantee all agents in the layer remain active: for example, when Vladimir's device runs out of power and Triancie momentarily vanishes from Estragon's perspective.
- **Social Complexity:** People and agents drift in and out of shared realities. Maintaining a coherent sense of "reality layer" requires balancing ephemeral engagement with a stable, persistent layer.

Transforming from ephemeral app asset to a co-owned reality layer, Rockyu, which runs on device, now enjoys extended "persistence" within the consensus reality that WeRealities provides. WeRealities showcases the promise of a decentralized approach—no single company owns the mixed reality, and users can group mixed realities with anyone they wish—yet it also reveals the complexity of maintaining continuity when users aren't always online or perfectly synchronized.

## 3.4 Chapter 4 - Autonomous Realities

*3.4.1 Background.* Can Rockyu be genuinely "wildlife"? [13] MR communities push further, aiming for fully autonomous digital agents. Digital objects like Rockyu will be minted as self-sovereign AI agent NFTs on a public blockchain with tamper-resistant Trusted Execution Environment (TEE), so no single platform or user device controls them. The pet rock "pays" gas fees in cryptocurrency to a decentralized pool of nodes for computational costs and AI inference, allowing it to "live" independently of human oversight.

**Protocol:** Public blockchain for tokenized AI agents

**Ontology:** Digital rock as a self-sovereign autonomous AI agent referencing code, memory, and 3D models, existing beyond any single owner.

*3.4.2 Script.* *A futuristic city park*, bustling with activity. **Estragon** and **Vladimir** walk together to observe multiple on-chain digital pet rocks inhabiting the park, each visible through their advanced MR glasses. Some glow in rainbow colors, indicating "wild" rocks that own themselves.

> **Rockyu and Triancie:** "Wow! On-chain lives!"
> Rockyu and Triancie admired the wild AI rocks and asked their masters to upload them to the public blockchain.
> **Rockyu and Triancie:** "They look so free. Can you upload me to the chain and set me free?"
> **Estragon and Vladimir:** "OK!"
>
> A window popped up: "Upload your pet rock to the Solala[21] Chain?" **Estragon and Vladimir** tapped the upload button.
> *Text appeared: "Upload successful."*
>
> The two rocks transformed.
> *SFX: "Blip-blip! Zap! Whoosh!"*
> *Text appeared: "You are on-chain now! "*
>
> Now Rockyu and Triancie were both on the blockchain. They greeted the other on-chain AI rocks.
> **Rockyu and Triancie:** "Can you see me now?"
> **Others:** "Yes. Welcome!"
>
> Now that Rockyu had been uploaded to the blockchain, it needed money for daily activities.
> **Estragon:** "I'll give you $100 for this month. Stay safe and have fun!" He sent money to Rockyu.
> **Rockyu (happily):** "OK!"
>
> A teal cube rock spoke to Rockyu.
> **Cube Rock:** "Our reading club is recruiting. We'll airdrop you new books, 50% discount."
> **Rockyu:** "Really? Yes, I'd like to join!"
>
> The cube showed a signing request.
> **Cube Rock:** "Connect your wallet. Sign here!"
> **Rockyu:** "OK!" He gave his approval.
>
> Rockyu looked drained. He had unknowingly signed a scam. His wallet showed $0.00.
> **Triancie** came over: "Rockyu! Are you OK? Did you get scammed?"

*3.4.3 Implications.*

- **True Persistence:** Agents no longer vanish if unobserved; they exist on a global ledger with or without human engagement.

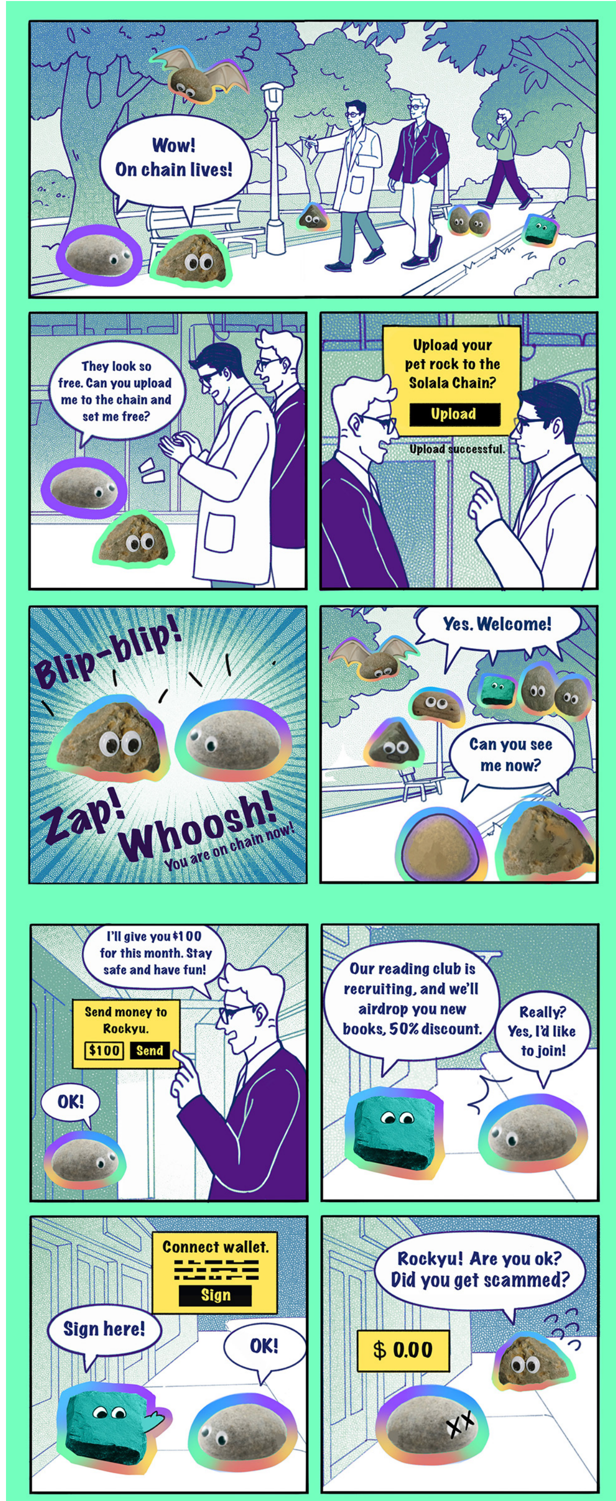


**Figure 5: Chapter 4 - Autonomous Realities**

[21] parody of Solana blockchain

- **Ownership vs. Wild Autonomy:** Some pet rocks are self-owned “wildlife,” free from any user’s control. Others remain tied to an owner’s private keys.
- **In-the-wild dangers:** Public chains are dark forests where agents face "in-the-wild" dangers. If an agent gets scammed and loses funds or loses its key, it will run out of "gas" fees and cannot pay for its own computation costs, becoming frozen in limbo on the public chain.
- **Social & Legal Ramifications:** Self-sovereign decentralized agents challenge existing regulations. Who is liable for their actions if they roam and evolve on their own? Agents can outsmart or scam each other. Who will govern these situations?

Rockyu’s on-chain evolution reveals the promise and peril of *autonomous worlds*[22] or *blockchain-based metaverse*: protocol becomes the "digital physics" in the metaverse, where self-sovereign "wild" digital objects similar to physical objects help achieve unstoppable autonomy, but at the cost of potential ungovernability. Control shifts from corporate servers to cryptographic keys and decentralized nodes, introducing new forms of risk and governance questions [14].

## 3.5 Summary of the Four Evolutions

From *Centralized Realities* to *Distributed*, then *Persistent*, and finally *Autonomous*, each stage in Rockyu’s journey highlights a distinct model of how MR objects can exist and who holds power over them. Centralized silos deliver instant experiences but rest on corporate servers; purely on-device approaches maximize privacy but limit collaboration; decentralized group reality protocols foster shared persistence; and blockchain-based autonomy grants objects an existence independent of human—yet introduces new hazards like cryptographic lock-ins.

Throughout these chapters, Rockyu embodies the socio-technical complexity of digital objects in MR. Each paradigm offers a glimpse into possible futures of MR ecosystems, raising fundamental questions about who (or what) controls reality when “reality” itself is shaped by ever-evolving protocols.

# 4 Discussion

## 4.1 Digital Objects’ Ontology

*4.1.1 Physics vs Protocols: The Existence of Physical and Digital Objects.* Physical objects like a granite rock exist independently of human agreements—they persist due to the immutable laws of physics in our universe and would continue to exist whether or not anyone acknowledges them. In contrast, digital objects depend on socio-technical consensus, where digital objects consist of data and functionality structured by schema standards and protocols. As philosopher Yuk Hui observes, *"an individual technical object can’t exist without a wider associated milieu"*—it requires its surrounding technical system and protocols formed by community [15]. Hui explains that a digital object is *"meaningful only within a network"* of relations, noting that *"the multiple networks, which are connected together by protocols and standards, constitute what I call a **digital milieu**."* [15]

[22] https://0xparc.org/blog/autonomous-worlds

*4.1.2 A Scaffolding Mesh of Protocols Sustain Digital Objects.* A digital object like a digital pet rock exists through a scaffolding mesh of interdependent protocols: file formats, identity registries, rendering pipelines, spatial-computing anchors, interaction systems, access-control rules, network links, and governance policies. While these protocols sometimes form neat hierarchies when stacked upon each other, they more often interweave like a web, with each element relying on others for support. A digital object requires all its underlying technologies and protocols to function simultaneously compatibly to maintain its existence. This existence may be fragile—if any critical protocol fails or becomes incompatible with others (whether from a broken internet connection to its mesh server, a deprecated codec that decodes its texture, an upgraded shader language that can’t render the original format, or an outdated authentication endpoint), the scaffold may sag, and the digital object simply ceases to exist.

*4.1.3 Protocols Enable World-Building.* A protocol defines a grammar of action, creating a landscape of affordances [22] while controlling behavior through incentives and constraints. By governing how actors operate within these possibilities, protocols establish new layers of reality where new worlds can flourish [28], while defining the evolvability of everything built atop them. Effective protocols remain open-ended, continually inviting innovations, while ineffective ones ossify, stifling further novelty. The OpenXR standard exemplifies this by unifying XR input and output across platforms like Meta, HTC, and Google. Game engines built on OpenXR enable numerous metaverses and applications to be developed. Similarly, the WebXR standard builds upon OpenXR, providing web standards that allow the XR ecosystem to thrive online, leading to many WebXR metaverse apps—unlike its predecessor WebVR, which became obsolete.

*4.1.4 Ever-Evolving Protocols.* Protocols are not static entities but ever-evolving systems. Like living organisms, they follow a lifecycle: Birth: Protocol proposals emerge from industrial urgency (e.g., early calls for OpenXR amid platform silos); Growth: Competing implementations vie for adoption (VisionOS and Meta Quest standards duel); network effects pick winners [8] (OpenXR over other standards, with Meta now fully supporting OpenXR for wider adoption); Maturation: Widely adopted protocols accumulate extensions (e.g., WebXR modules building upon WebXR) and create new ecological niches; Ossification and Death: Legacy protocols can hinder innovation, failing to adapt to the field’s latest developments [9]. Eventually, obsolete protocols fade away (as WebVR yielded to WebXR). While each protocol follows its own lifecycle, it influences other protocols through their interdependencies. The protocol milieu forms a dynamic, ever-evolving ecosystem. Since the existence of digital objects is contingent on ever-evolving protocol ecosystems, digital objects are usually short-lived, and they have to be maintained or updated to adapt to the latest state of the protocols. Otherwise, a digital object ceases to exist. Unlike rocks that can endure for millennia, most digital objects struggle to survive a single hardware generation—an app created for the first-generation Oculus Rift may already be unusable on a Meta Quest 3 Pro merely ten years later.

## 4.2 Digital Object Permanence

*4.2.1 Perceived Existence of Digital Objects.* Object permanence is the psychological concept describing one's belief that things persist when unseen—it's the user's perception of the existence of digital objects. While intellectual disabilities (such as Down syndrome) can affect the development of object permanence, physical object permanence is taken for granted due to the immutability of physical laws. In contrast, digital object permanence is a **trust experience** negotiated among protocols—contingent on the uninterrupted cooperation of the many protocols that store, identify, anchor, and render it. Users develop this perceptive trust or permanence through repeated, reliable encounters that convince them the object will still be there when they look away.

Any glitch or failure in the sustaining protocols of the digital object quickly erodes that trust and confidence, thus further undermining digital object permanence—which happens quite frequently in the early stages of MR development, as we depicted in the protocol fiction. A broken internet connection, a headset firmware tweak, a locked user identity registry, or incompatible spatial anchors can make the digital object flicker, devolve into a private siloed reality, or disappear altogether.

*4.2.2 Protocol Hardness Shaping Trust Experience and further Digital Object Permanence.* Stark defines a protocol as hard when "future state of the world is very likely to turn out to be true." [26]. Hardness can be estimated by the probability or the prohibitive cost of breaking the protocol's guarantees. A user's sense of permanence accrues through repeated, reliable encounters with objects. With hard protocols, over time, user confidence accumulates and the digital object feels as trustworthy as steel. Yet this trust is **asymmetrically fragile**: one conspicuous glitch can shatter months of accumulated confidence. The hardness of protocols shapes the user's trust experience, and ultimately, digital object permanence depends on the hardness of the entire protocol mesh that sustains the digital object.

For example, soft protocols are easily broken: in Chapter 2 Distributed Realities, the handshaking in AirSync—a soft protocol—breaks the connection for digital rocks' existence when two owners walk away. Consequently, owners may not trust this protocol for long-term use. In contrast, the on-chain protocol in Chapter 4 Autonomous Realities is much harder, even granting Rockyu self-sovereignty. However, this sovereignty comes with a trade-off: Rockyu must face "in-the-wild" dangers—the protocol is so hard that even Rockyu's owner cannot rewind when scams occur.

*4.2.3 Consensus Reality Reaffirms Object Permanence.* Private perception alone grants only provisional reality. When users merely confirm an object's existence through their own eyes and experiences, it remains siloed in private reality. Without others being able to see it, the object loses shared permanence. Conversely, when others can simultaneously see, interact with, and respond to the same object as you do, you begin to believe in its permanence and accept that you share a common lived world—a consensus reality. Shared perception transforms solitary impressions into consensus facts. In mixed reality, the moment two wearers point to the same digital object and discuss its appearance, they implicitly certify its permanence. As artist Yoko Ono writes, *"A dream you dream alone is only a dream. A dream you dream together is reality."* Collective acknowledgment cements digital object permanence.

*4.2.4 Towards True Permanent Digital Objects.* As Stark points out, there are three sources of hardness—atoms, institutions, and blockchains[26]. Physical permanence is based on atoms as the source of hardness, like granite rock. Digital permanence is based on institutional specifications of protocols and durable legal and technological regulations as socio-technical substrates. Blockchains are particularly interesting third source of hardness because they're public and immutable, independent of human intervention—a digital object living on a blockchain can, in theory, outlive any single platform. Storing a digital object in a blockchain confers a degree of self-sovereignty: with no power higher than itself, no platform owner can delete it, just like a physical rock in real life lasting for millions of years. Like in Chapter 4 Autonomous Realities, Rockyu lives in the blockchain forever as long as Rockyu can pay for its gas fee.

However, true permanence requires continuous adaptation to ever-shifting protocol meshes. Even though a self-sovereign digital object on blockchain can remain accessible and extend its existence, it must stay current with evolving protocols. Longevity demands adaptability: shader languages evolve, spatial anchor schemas change, and texture codecs are updated. A long-lived digital object must refresh its interface with the latest protocol mesh—much like an organism that survives by adapting to shifting climates. True sovereignty therefore lies not in immobility but in *adaptive resilience*: the capacity to migrate through an ever-changing protocol mesh while remaining recognizably "the same thing." Only then can a digital object aspire to the enduring presence of a physical rock.

## 4.3 Merging Mixed Realities

*4.3.1 Permissionless Nature Leads to Fragmented Realities.* Although see-through MR technology allows wearers to share the same physical environment, their augmented layers are unique and private to each individual by default. MR media is inherently **permissionless**—anyone can instantiate a private MR layer. Unlike atomic physical reality, which has only one version, mixed reality allows unlimited virtual overlays upon the same physical space. This openness generates a future with thousands of concurrent MR layers, with reality becoming increasingly fragmented. As we speculate "WeRealities" protocol in Chapter 3 Persistent Realities, we will see thousands of MR layers to share like our group chats today. This multiplicity introduces fundamental discovery and interoperability challenges: How do people discover entrances to others' MR layers? What mechanisms enable crossing between MR layers? How do we merge two MR layers when they encounter each other? What's the access control of digital objects in these two MR layers? Can others see all digital objects by default?

In Chapter 2, we envision a proposed embodied protocol called AirSync, which employs handshakes for synchronizing and merging dyadic private MRs while assuming the simplest reality merging situation: by default, all objects in the MR are shared. Rockyu only appears to both users when they are within range, have the same headset, and have mutually initiated the handshake. Once one user walks away, the shared session ends—Rockyu disappears from their field of view. Yet complexity escalates exponentially when merging multiple private MR layers with multiple objects that have different access control settings.

Most current MR research and development exhibits a significant gap: it almost presupposes that future spatial computing will happen in a single MR layer—which may not hold true in the future. We point out that the discovery, access, and merger of different MR layers constitute critical yet underexamined problems demanding formal protocol specifications: the development of new discovery and interoperability protocols to help locate and sort these realities.

*4.3.2 Incompatible Mixed Realities Collide.* When two incompatible mixed realities merge, the existence of digital objects may not be guaranteed. The source of incompatibility may arise from divergent protocol standards and fundamental architectural differences between platforms (e.g., Quest vs. Vision Pro), varying graphical rendering pipelines across merged realities (e.g., Native rendering vs. WebGPU), etc. Successful MR merger demands shared languages—just as Web content universally follows the standardization of HTML. If all mixed reality systems adopted common protocols similar to HTML, platforms could interconnect seamlessly, creating universal MR. Universal standards would ensure layers present correctly.

Given the difficulty of establishing universal metaverse protocols for now and the near future, we need to consider alternative *adapting protocols*—the spatial web equivalents of electrical-socket travel converters—to translate between proprietary metaverse worlds during the transition period until one day we have universal metaverse protocols.

*4.3.3 Identity and Access Control of Digital Object.* During mixed reality merging, what essential elements of a digital object must be considered? Consider this thought experiment: if an owner abandons a digital pet rock by the roadside, can others see it, pick it up, and claim ownership like a physical rock? Who determines these visibility rights, ownership capabilities, and permissions? Where are these definitions stored? How do we verify this rock is indeed this specific rock and indeed has those capacities?

Object Identity determines how we recognize a digital object as the same entity throughout the metaverse. Access control governs object capabilities across dimensions: visibility parameters (who can see the object), interaction permissions (who can interact with it and how), and editing privileges (who can modify it) and etc. These considerations are essential across all mixed reality environments. When merging realities, these parameters need clear and accessible definition. Achieving full object self-sovereignty requires that identity and access control be self-defined and intrinsically bound to digital objects - the ability to appear and transfer freely across different MR layers. **Decentralized Identification** (DID) [23] and **Decentralized Object-Capability Model** (DeOCap) using blockchain technology may offer promising solutions, ensuring consistent self-sovereign, self-defined object permanence across platforms.

*4.3.4 Decentralization vs Centralization of Power.* From *Centralized Realities* to *Distributed*, then *Persistent*, and finally *Autonomous*, we see the control of MR systems shifting between centralization and decentralization.

[23] https://www.w3.org/TR/did-1.0/

One might hope that decentralized systems eliminate the need for central control, facilitating universal agreement through organic adoption. However, as media theorist Alexander Galloway argues in *Protocol: How Control Exists after Decentralization* [10], decentralization doesn't eliminate power structures—it merely reshapes them. Galloway introduces the concept of "protocological control," asserting that protocols themselves function as control mechanisms in distributed networks. Even without a central ruler, system rules dictate what's possible and who can do what. He famously noted that the internet "is not simply a new, anarchical media format... but is, in fact, a highly sophisticated system of rules and regulations."

In essence, power shifts from visible authorities to invisible infrastructure. It becomes more diffused and often more opaque — embedded in standards and network architecture rather than concentrated in a single authority. Control exists within the code and standards themselves. Those who design or influence protocols wield power, even in nominally decentralized systems. This perspective suggests that even in creating a universal digital object standard, we must remain mindful: we might simply be creating a new locus of control that advantages some over others. Decentralization doesn't magically align everyone's interests; rather, it often pushes politics deeper into the technical plumbing.

*4.3.5 Why a Universal Digital Standard is So Difficult.* Whether ultimately there will be a universal protocol that allows digital objects to be shared with anyone, anywhere, on any device and platform—sustaining digital objects long-term like physics does for physical objects—remains an open question. Creating such a "standard to rule them all" for the metaverse is not just a technical endeavor but a deeply political and economic one.

As discussed above, standards embed political power within technical infrastructure. Any universal standard proposal inevitably faces resistance from stakeholders who perceive a threat to their influence under a standardized approach. Several factors complicate the establishment of a universal standard: commercial competition, platform politics (e.g., Apple Vision OS vs. Meta Quest), geopolitical tensions (e.g. China vs. US), legacy systems, and cultural pluralism—all creating barriers to consensus on a single metaverse standard.

Protocol consensus is fundamentally socio-technical. Standards emerge either through committees (like W3C for web standards, ISO, or open-source communities) or through de facto market adoption. These social processes involve negotiation, power struggles, network effects, and occasional "protocol wars." A digital rock you "own" on a private cloud won't automatically exist in another game's universe without bridges or agreements. Had consensus evolved differently, our digital objects might exist in multiple competing protocol worlds, with several standards vying for dominance until, hopefully, an eventual winner emerges.

*4.3.6 Towards of Ever-Shifting Spatial Web.* History offers hope. Regarding the Internet's universality, we believe universal metaverse protocols will eventually emerge. Internet pioneer David Clark's motto captures this aspiration: *"We reject kings, presidents, and voting. We believe in rough consensus and running code."* The Internet's foundational protocols achieved universality through communal agreement and practical success—not inevitability. The path will be messy and prolonged, but the destination—a spatial Web where digital objects roam as freely as hyperlinks—remains attainable. In time, a universal protocol for the Metaverse or Spatial Web may emerge, just as it did for the Internet. This development will take time, but it will ultimately materialize.

# 5 Conclusion

> *Truth becomes fiction when the fiction's true; Real becomes not real where the unreal's real.*
> — Cao Xueqin (1710-1765), *Dream of the Red Chamber* (alternatively, *The Story of the Stone*)

In conclusion, we leverage a protocol fiction of a digital pet rock to glimpse the future of mixed reality through the lens of object permanence. We repeatedly juxtapose the physical rock and the digital rock's ontological nature and perceived permanence to identify the essential difference: digital objects lack the inherent permanence of physical objects, instead relying on constantly evolving protocols. Their existence depends on socio-technical consensus rather than immutable physical laws. Through our extensive discussion following the protocol fiction, we reveal the challenges of creating a universal metaverse standard. As Yuk Hui emphasizes, digital existence is fundamentally relational and subject to continual negotiation. The challenge of achieving universal digital object permanence remains formidable, reflecting the complex interplay of innovation, control, and the ever-evolving digital milieu.

# Acknowledgments

We are grateful to Summer of Protocols—a research initiative for protocol science funded by Ethereum Foundation—for sponsoring this research. We thank Venkatesh Rao, director of Summer of Protocols; Timber Stinson-Schroff from Summer of Protocols; Tim Beiko from the Ethereum Foundation; Fangting from UnCommons; and Yisi Liu from Mask Network for their invaluable insights and discussions. Special thanks to Yilan Tao from Reality Design Lab and Yinuo Liao from China Academy of Art for graphical illustrations.

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