Metaverse Standards Forum
Portable Personal Content

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Use Case Title

Portable Personal Content

Use Case Identifier

MSF2025-PPC-001
- Version 1.0
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Summary of Use Case

Description: A portable, interoperable framework is required for interactive assets to seamlessly travel with users and be shared across microverses, extending beyond static objects to include dynamic elements with lights, behaviors, and consistent interaction metaphors. This enables assets—ranging from personal accessories like jewelry or tools like flashlights and compasses to vehicles like autos or airplanes—to maintain uniform animations, affordances, and usability regardless of the hosting environment, ensuring realistic and intuitive engagement in diverse virtual worlds.

Benefits:

- Enables seamless asset portability, allowing users' personal items (e.g., jewelry, flashlights, compasses) to accompany them across microverses without loss of functionality or visual fidelity.
- Promotes cross-environment sharing of interactive assets with embedded lights and behaviors, fostering collaborative experiences where objects retain their dynamic properties in any compatible space.
- Ensures consistent interaction metaphors and animations, such as rolling wheels or turning steering on vehicles, to deliver predictable and intuitive controls that enhance user immersion and reduce learning curves.
- Supports realistic affordances in complex assets like metaverse vehicles, including functional headlights, dashboards, interior lights, and responsive buttons, making them universally recognizable and operable across disparate worlds.
- Facilitates high-fidelity personalization by preserving user-owned assets' states and customizations, enabling instant resumption of personalized setups in new environments.
- Unlocks enhanced social and exploratory dynamics, where shared or traveling assets enable synchronized interactions, such as group vehicle journeys with replicated lighting and controls for collective adventures.

Contributors and Supporters

- 3D Web Interoperability Working Group

- MSF Domains (Peer Review)
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Keywords

Asset Portability, Interoperability, Behavior Graph, Provenance, Authentication, Metadata, glTF, X3D, Scene Graph, Degrees of Freedom (DOF), Sensors, State Persistence / Restoration, Granular Consent, Verifiable Credentials, Privacy Layer, Authenticity/Ownership, Decentralized Storage, Multi-Scale Hierarchy, Environmental Adaptation, Real-time Synchronization, Cross-Platform Governance

Actors/Entities

- **Users:** Individual or collective participants who engage with metaverse ecosystems as creators, explorers, or collaborators, leveraging authenticated identities (e.g., decentralized wallets, SSO-based social logins with optional verifiable credentials) to access, customize, and transact across virtual, augmented, and hybrid spaces. They own portable avatars, assets, and data profiles stored in interoperable formats, enabling seamless transitions between environments while exercising control over privacy, consent, and interaction boundaries through embedded permissions and real-time feedback mechanisms.
- **Providers:** Platform operators, content creators, or infrastructure hosts that deploy and maintain metaverse instances, including virtual worlds, AR overlays, or asset marketplaces. They adhere to standardized protocols for interoperability (e.g., spatial linking, asset portability) to ensure reliable scaling, security, and monetization, while aggregating user-generated content, enforcing cross-platform governance, and facilitating discovery through shared registries that balance innovation with compliance to universal accessibility and ethical data handling standards.

Detailed Description of Use Case/Scenario

Preconditions:

1. **Asset Portability & Ownership**
   - Users maintain authenticated ownership of interactive assets (e.g., 3D models of vehicles or accessories) stored in secure, decentralized repositories, with metadata for behaviors, animations, and interaction states.
   - Assets include embedded standards for consistency, such as universal affordances (e.g., steering mechanics, light properties) and serialization formats for cross-environment transfer.
2. **Standards & Platform Capabilities**
   - Metaverse platforms support asset ingestion protocols that preserve dynamic elements (e.g., lighting, controls, animations) without alteration, including compatibility checks for device types and rendering engines.

- Services enable real-time synchronization of asset interactions across users, with fallback rendering for partial loads.

3. **User Profile Integration**
   - Profiles link to asset libraries with personalization data (e.g., preferred control schemes, animation sensitivities), allowing automatic equipping and state restoration upon entry to new spaces.
   - Discovery mechanisms identify compatible environments for asset deployment based on spatial rules and event metadata.
4. **Privacy, Permissions & Consent**
   - Asset sharing requires explicit, verifiable consent for visibility and interaction, with granular controls (e.g., read-only vs. modifiable) enforceable via decentralized credentials.
   - Background scans detect and anonymize non-consenting elements in shared sessions.
5. **Environmental Adaptation**
   - Systems detect host environment constraints (e.g., physics engines, lighting models) and adapt asset behaviors accordingly, with user notifications for deviations.
6. **Performance & Accessibility**
   - Assets adhere to optimization guidelines (e.g., LOD for complex models, modular loading for behaviors) to ensure seamless performance across devices from mobile to high-end workstations.
   - Accessibility features, such as simplified controls or haptic feedback, are configurable and persisted per user.

Main Flow:

- **Scenario 1:** Personal Vehicle Cruising in the Metaverse

1. Joe, equipped with a mobile device or high-performance 3D workstation, authenticates into his profile and selects his custom race car asset from his portable library.
2. The system loads the asset with full fidelity, initializing dashboard lights, controls (buttons, pedals, gears, steering, moon roof), and behaviors like wheel rotation and headlight beams.
3. Joe enters a metaverse highway district, where the car seamlessly integrates with the environment's physics and traffic rules.
4. He engages familiar interactions—accelerating via pedals, turning the steering wheel, toggling interior lights—maintaining Earth-like predictability.
5. During the cruise, the system synchronizes Joe's position and asset state in real-time for any encountered users or events.
6. Joe pauses at a virtual pit stop, saves the car's current configuration (e.g., gear settings, light orientations), and exits, with the asset persisting in his profile.
7. Later, from his workstation, Joe resumes the session, restoring the exact state for continued exploration.

- **Scenario 2:** Accessory Equipping for Social Events

1. Sue, new to virtual worlds and using a basic XR headset, accesses a 3D museum via her profile and discovers the ancient necklace asset.

2. She interacts with the model, clicking parts to trigger unfolding animations and rune revelation with emanating holy light effects.
3. Sue claims ownership, adding the necklace to her portable asset library with personalized metadata (e.g., animation sensitivity, light intensity preferences).
4. Transitioning to the concert venue, the system automatically equips the necklace on her avatar, adapting glow effects to the event's lighting while preserving behavioral fidelity.
5. During the concert, Sue clicks the necklace to activate its rune animation, drawing interactive responses from nearby avatars or stage elements.
6. The asset maintains consistent behaviors, such as predictable click affordances and light propagation, across the crowded venue.
7. Sue shares a snapshot of her equipped avatar, embedding asset metadata for friends to preview or replicate the effect.
8. Post-event, the necklace's state (e.g., last animation triggered) is saved to her profile for future wear.

Alternative Flow

- **Scenario 1 Alternatives:** Personal Vehicle Cruising in the Metaverse

1. **Asset Rendering Incompatibility**
   - Joe enters a low-fidelity district where his race car's complex shaders exceed device limits:
     - The system detects the mismatch and applies progressive LOD, simplifying lights and controls while preserving core interactions.
     - It notifies Joe: "High-detail mode reduced for optimal performance; upgrade device for full fidelity."
     - Joe can toggle back to a parked "showcase" view to admire the full model without mobility
2. **Environmental Physics Conflict**
   - The highway introduces custom gravity rules incompatible with the car's wheel behaviors:
     - The system simulates a "compatibility bridge," adjusting suspension and steering ranges dynamically.
     - It provides an in-car HUD warning: "Adapted to local physics—handling may feel enhanced."
     - Joe opts to save a venue-specific variant of the car for future visits
3. **Multi-User Collision During Cruise**
   - Joe encounters a group event blocking the road, causing unintended asset interactions (e.g., bumping controls):
     - The system enqueues collision resolution, pausing affected animations and rerouting traffic.
     - Participants receive haptic/audio cues, with Joe's car entering a brief "bubble shield" mode.
     - Post-resolution, the session logs the event for Joe's profile analytics

- **Scenario 2 Alternatives:** Accessory Equipping for Social Events

1. **Animation Trigger Failure**

- Sue clicks the necklace at the concert, but venue audio interference disrupts the rune light effect:
  - The system isolates the asset's behaviors, queuing the animation for a stable moment.
  - It displays a subtle tooltip: "Effect delayed—retry in quieter zone."
  - Sue receives a personalized tip on optimizing for noisy environments

2. **Consent Violation in Shared View**
   - A friend previews Sue's snapshot, but the necklace's glow inadvertently highlights non-consenting avatars nearby:
     - The privacy layer auto-dims the effect in previews, anonymizing affected elements using techniques like zero-knowledge proofs for privacy preservation.
     - Sue gets a post-share alert: "Adjusted for privacy; full view requires mutual consent."
     - The friend sees a blurred demo, with an invite to join a consented session.
3. **Device Accessibility Mismatch**
   - Sue switches to her mobile during the concert, where fine-click interactions on the necklace become imprecise**:**
     - The system activates fallback gestures (e.g., swipe-to-unfold) based on her profile settings.
     - It offers: "Simplified controls enabled—voice command alternative available."
     - Sue's preferences update automatically for future mobile uses.

Postconditions

1. **Asset State Persistence & Versioning**
   - Interactive assets (e.g., Joe's race car configurations, Sue's necklace animations) are serialized with full metadata (behaviors, lights, user tweaks) and committed to user profiles for cross-session recall.
   - Version history tracks modifications, allowing reversion to baseline models or forking event-specific variants.
2. **Interoperability & Consistency Enforcement**
   - All asset deployments respect platform standards, with logs verifying uniform interactions (e.g., predictable controls) across environments.
   - Deviations from ideal fidelity are flagged for user review, with automated suggestions for optimizations.
3. **Privacy & Interaction Logging**
   - Consent enforcement persists through all asset uses, with changes to permissions propagating to linked profiles and shared instances ensuring compliance with global data protection regulations like GDPR.
   - Logs capture interaction events (e.g., clicks, state changes) while anonymizing non-essential data for privacy compliance.
4. **Accessibility & Personalization Persistence**

- User-specific adaptations (e.g., Joe's control schemes, Sue's gesture fallbacks) are embedded in profiles, auto-applying on re-equip.
- Device telemetry informs future loads, ensuring seamless transitions between mobile and workstation sessions.

5. **Performance Analytics & Optimization**
   - Aggregated, anonymized data on asset loads (e.g., rendering times, interaction success rates) feeds platform improvements.
   - High-usage assets like vehicles or accessories gain priority caching for faster global access.
6. **Recovery & Continuity Mechanisms**
   - Mid-session asset disruptions trigger local backups, enabling resumption without state loss.
   - Collaborative interactions (e.g., shared cruises or concert dances) maintain sync points for multi-user recovery.
7. **Discovery & Sharing Enhancements**
   - Post-use, assets integrate with social feeds via embeddable previews, boosting discoverability while respecting retention rules (ephemeral vs. permanent).

Implementations and Demonstrations or Technical Feasibility

Implementations and Demonstrations

- **X3D and glTF Integration for 3D Interoperability:**
  - ISO/IEC 19775-1:2023 X3D Architecture and Base Components (Extensible 3D), Edition 4 (**X3Dv4**) extends **Dec3D (Declarative 3D)** to support common scene graph representations, including dedicated nodes for programmable lighting and behavior graphs for scripted interactions, with **enhanced WebGL 2.0 support for real-time rendering**.
  - Open-source frameworks like **X3DOM (X-Freedom)** and **X_ITE** demonstrate interoperability by combining X3D with glTF for efficient asset loading and HTML/JavaScript for dynamic manipulation, ensuring assets render consistently via **WebGL** while preserving lighting fidelity (e.g., shadows, attenuation) and behavioral consistency (e.g., animations, event triggers).
- **ISO X3D Interactive and Immersive Profiles for Scene Graphs**: These ISO-standardized profiles provide robust scene graph architectures with typed Transformation Graphs for hierarchical spatial positioning and Behavior Graphs for predictable interactions. As demonstrated in runtimes like X3DOM, they ensure repeatable experiences through consistent event-handling (e.g., ROUTE nodes for signal propagation), where asset behaviors—such as a complex animation or mechanical response—execute identically across platforms from web browsers to XR devices.
- **W3C Web Standards for URL-Based Asset Access**: Web standards enable assets or dynamic experiences to be treated as resolvable URLs, supporting both network-based retrieval and data-centric models with embedded authentication and encryption. Furthermore, implementations can leverage WHATWG's **DOM** and **Fetch APIs**, with

prototypes extending X3D to include per-node encryption (via the [Web Crypto API]) for protecting sensitive behaviors. This allows a URL to resolve to a fully functional, authenticated model ready for integration into any compatible scene.

Technical Feasibility:

- **X3Dv4 Scene Graphs for Behavioral Consistency:** The maturity of X3D's Behavior Graph in ISO profiles offers a proven path to interoperable asset portability. Open-source examples in X3DOM and X_ITE confirm that lighting and interaction scripts can be serialized and deserialized without loss, ensuring event cascades remain deterministic and platform-agnostic
- **glTF + HTML/JavaScript in Open-Source Frameworks**: The combination of glTF's efficient binary format with JavaScript in frameworks like X3DOM demonstrates high feasibility for cross-environment asset rendering. Widespread browser support for WebGL ensures low-barrier adoption, with prototypes confirming fast load times for complex assets, making transitions from mobile to VR environments viable.
- **W3C-Enabled Authentication at Node Level**: Integrating W3C standards with X3D's node-level security is technically viable using established APIs like Web Crypto API for encryption. Prototypes validate that encrypted behaviors can be unlocked at runtime via user credentials, enabling secure, data-centric access without compromising the URL-based resolution mode.

Challenges:

- **Asset Representation & Fidelity Challenge:** Establishing a comprehensive and extensible schema for digitally encoding interactive assets to fully capture their lighting configurations (e.g., color, orientation, beam widths), behavioral scripts (e.g., animations, state transitions), and interactive affordances (e.g., button presses, gesture responses), ensuring these elements translate predictably across heterogeneous metaverse environments without degradation or reinterpretation that could fragment user experiences and undermine seamless portability particularly in light of varying rendering engines.
- **Asset Sharing & Rights Management Challenge:** Navigating commercial, proprietary, or geopolitical constraints that limit the dissemination of user-owned inventory assets, such as licensed intellectual property or region-locked behaviors, requires balanced protocols that respect creator rights while enabling controlled interoperability (e.g., using blockchain for DRM enforcement). The challenge lies in designing opt-in mechanisms that prevent unauthorized replication without stifling collaborative sharing or economic incentives for asset creation.
- **Multi-Scale Spatial Hierarchy Challenge**: Establishing coherent hierarchical action spaces for assets of varying scales—from large entities like vehicles where global navigation and collision detection operate at the parent level, to small wearables where the avatar serves as the authoritative parent for localized interactions. This demands unified physics and input standards to prevent desynchronization, clipping artifacts, or unresponsive behaviors across different platform implementations.
- **Distributed Inventory Resolution Challenge:** Accommodating varied storage paradigms for user inventories—ranging from local device caches to remote URLs on federated servers—necessitates resilient authentication flows, potentially leveraging blockchain for

provenance verification or zero-knowledge proofs for privacy. The challenge centers on creating fault-tolerant resolution systems that handle intermittent connectivity, credential drift, or validation failures while ensuring assets remain accessible and tamper-evident without compromising performance.

Requirements:

Technical and Functional Requirements

- **Comprehensive Asset Composition**: Shared asset representations must encompass multiple modular components, including geometry for structural forms, appearances for visual materials and textures, integrated lights for dynamic illumination (e.g., point, directional, or animated sources), sensors for environmental responsiveness, and animation systems for behavioral sequences, enabling complex, interactive objects to function holistically within metaverse scenes. This composition should support declarative scripting interfaces (as defined in X3D 4.0 Behavior Graphs) for runtime modification and composition of these elements.
- **Sensor-Driven Interaction Mapping**: Sensors within asset representations must precisely map 3D user interactions—such as gestures, haptics, or gaze—to specific Degrees of Freedom (DOF) in the underlying Behavior Graph, supporting predictable responses like steering rotations in a race car or rune activations on a necklace, while allowing for real-time adjustments based on device capabilities to maintain intuitive usability. The mapping system should include calibration protocols to ensure DOF interpretations remain consistent across different interaction hardware and platforms.
- **Behavior Graph Integration**: The system must support extensible Behavior Graphs that orchestrate asset interactions, linking sensors, animations, and lights through declarative nodes (e.g., in X3D standards), ensuring that composed assets exhibit consistent, scriptable behaviors across varying environmental constraints without requiring manual reconfiguration. The graphs should implement version-tolerant parsing to maintain backward compatibility as behavior specifications evolve.

Interoperability Requirements

- **Standardized Shared Representation**: Asset representations must adhere to open, royalty-free formats (e.g., X3D with glTF extensions) that preserve composition details—geometry, appearances, lights, sensors, and animations—across platforms, facilitating seamless portability and reconstruction of interactive elements in diverse metaverse ecosystems, as outlined in foundational works on open metaverses (Havele et al., 2022). The representation should include fallback descriptors for partial rendering in systems with limited capabilities.
- **Cross-Platform DOF Consistency**: Protocols must enforce uniform mapping of interaction DOF from asset sensors to host environments, enabling shared assets to retain behavioral fidelity (e.g., consistent animation triggers) regardless of the rendering engine or device, while providing fallback hierarchies for partial compatibility to avoid interaction silos. This includes standardized testing suites to verify DOF consistency across implementations.

Other Key Considerations:

- **Privacy:** Privacy mechanisms must govern the embedding of user-specific data in shared asset representations, such as customized sensor sensitivities or animation states, allowing granular consents for what elements (e.g., personal light preferences) are exposed during portability, with automatic redaction of identifiable metadata to prevent unintended profiling in collaborative sessions. Privacy controls should extend to behavioral analytics derived from sensor interactions.
- **Cybersecurity:** Robust encryption and integrity checks are required for asset components like Behavior Graphs and sensor mappings, protecting against tampering (e.g., malicious DOF alterations) during transmission or storage; this includes digital signatures for composed geometries and lights to verify authenticity upon resolution in remote environments. Security protocols should address runtime protection against behavioral hijacking of active assets.
- **Identity Verification:** Verification processes must integrate with asset ownership claims, using decentralized identifiers to authenticate users before loading shared representations, ensuring that only authorized parties can activate sensitive interactions (e.g., proprietary animations) and preventing unauthorized forks of inventoried items. Verification should support granular permission levels for different asset components.
- **Networking and Latency:** Optimization strategies, such as modular pre-loading of asset sub-components (e.g., lights and sensors separately from geometry), must minimize latency in resolving shared representations over networks, incorporating edge caching for high-DOF interactions to deliver fluid performance in bandwidth-variable metaverse districts. Priority streaming protocols should ensure critical behavioral components load first.
- **Ownership:** Users must retain verifiable sovereignty over their asset compositions, with tools for revoking, versioning, or transferring rights to elements like custom animations, supported by blockchain-linked provenance to trace modifications without compromising the portability of the core representation. Ownership systems should enable partial rights management for collaborative assets.
- **Digital Ethics:** Ethical guidelines must prohibit biased implementations in asset sensors or Behavior Graphs (e.g., DOF mappings that favor certain user demographics), promoting inclusive design in shared representations and requiring audits for representations that could enable exclusionary interactions in social metaverse contexts. Ethical review should be integrated into asset certification processes.
- **Provenance:** Immutable tracking of asset evolution—from initial composition of geometry and appearances to updates in lights or sensors—must be embedded in representations, providing a tamper-proof ledger (e.g., via X3D metadata extensions) to validate the historical integrity of portable items during cross-environment use. Provenance data should be selectively disclosable to verify authenticity without exposing proprietary information.
- **Accessibility:** Representations must incorporate adaptive features, such as scalable DOF mappings for alternative inputs (e.g., voice-activated animations) and fallback visuals for low-vision users (e.g., simplified light cues), ensuring that shared assets remain operable and perceivable across diverse abilities without altering core behavioral fidelity. Accessibility features should be discoverable and configurable at runtime.

Relevant Domain Working Group (WGs):
● Standards Registry ● 3D Asset Interoperability using USD and glTF ● Interoperable Characters/Avatars ● Digital Asset Management ● Real/Virtual World Integration ● Privacy, Cybersecurity and Identity ● Network Requirements and Capabilities
Relevant Pre-qualified Organizations and Groups (POGs):
● **Web3D Consortium**: As the steward of the ISO X3D standard, this consortium advances the royalty-free specifications for 3D scene graphs, transformation hierarchies, and behavior modeling essential for the metaverse. Its work on Interactive and Immersive Profiles ensures assets maintain consistent lighting, animations, and event handling across platforms, directly supporting interoperable "traveling" objects. ● **Khronos Group**: This consortium develops the foundational, royalty-free APIs for 3D graphics and XR. Its standards—glTF for efficient asset interchange and WebGL for browser-based rendering—are critical for the seamless portability of interactive elements with preserved behaviors and lighting fidelity across diverse platforms. ● **W3C (World Wide Web Consortium): ** The W3C provides the core web standards that enable a networked metaverse. Specifications for the Web Crypto API facilitate the node-level authentication and encryption required for secure, resolvable, and dynamic content in decentralized ecosystems. ● **WHATWG (Web Hypertext Application Technology Working Group):** The WHATWG maintains the living standards for the core web technologies that are foundational to URL-based asset access, including the **URL**, DOM, and Fetch Standards. ● **Fraunhofer IGD:** A leading research institute responsible for pioneering the X3DOM open-source framework. By integrating X3D with HTML/JavaScript and supporting glTF, Fraunhofer IGD provides a critical reference implementation that demonstrates behavioral fidelity in web-based scene graphs, offering a proven blueprint for asset portability in collaborative virtual spaces.
Relevant Specifications, Publications and Projects (SPPs):
● **glTF 2.0**: This Khronos Group royalty-free specification is the cornerstone for efficient 3D asset delivery, encapsulating geometry, materials, animations, and lights in a compact, web-optimized format. It ensures that the core visual representation of portable assets—from vehicles to jewelry—loads quickly and renders consistently across different metaverse platforms and engines like Babylon.js, forming the visual foundation of portable personal content.

- **ISO/IEC 19775-1:2023 X3D Architecture and Base Components (Extensible 3D), Edition 4**: Maintained by the Web3D Consortium, this international standard provides the declarative scene graph and behavior model for interactive 3D. Through nodes for sensors, scripts, and interpolation, X3D defines how portable assets behave, ensuring that interactive elements—like a car's steering or a necklace's unfolding animation—trigger predictably and consistently across environments, thereby preserving functional fidelity alongside visual appearance.
- **Universal Scene Description (USD)**: Developed by Pixar and stewarded by the Alliance for OpenUSD, this framework solves the challenge of compositional portability. Its layered, non-destructive architecture allows personal assets to cleanly integrate into host worlds, managing complex hierarchies and variants so that a user's vehicle or accessory composes correctly with a new environment's physics and lighting without losing its inherent properties.
- **Metaverse Universal Manifest (MUM) v1.0**: This standardized metadata framework, released as a use case by the Metaverse Standards Forum in September 2025, acts as a "passport" for portable personal content. Using a JSON-LD structure, it links an asset's glTF/X3D data to its decentralized storage location (e.g., on IPFS), verifiable credentials for ownership (via DIDs and VCs), and user-defined preferences. MUM is critical for resolving, authenticating, and synchronizing assets across platforms, addressing portability at the system level through real-time conflict resolution, provenance tracking, and granular privacy controls.
- **The Keys to an Open, Interoperable Metaverse (Havele et al., 2022)**: This seminal Web3D Consortium position paper provides the strategic foundation, advocating for the use of open standards like X3D and glTF to achieve asset portability. It directly addresses the need for decentralized storage and authentication, offering a blueprint for the very ecosystem required to enable user-controlled, portable inventories.
- **X3DOM (Open-Source Framework)**: This MIT/GPL-licensed runtime serves as a vital proof-of-concept. By integrating X3D as native HTML5 DOM elements and rendering via WebGL, it demonstrates that the vision of browser-based, interactive portable content is achievable today, providing a working reference for how assets with complex behaviors can be instantiated anywhere on the web or in WebXR.

Related Use Cases

- Consistency of Experience (MSF2025-COE-001)
- Metaverse Bookmarks (MSF2025-MEB-001)
- Metaverse Universal Manifest (MUM, MSF2025-MUM-001)

Additional Comments

- This document is a living artifact and may be subject to revisions on a periodic basis to reflect the future state of Portable Personal Content, and or based on feedback received from MSF stakeholders that warrants an update in the future.