

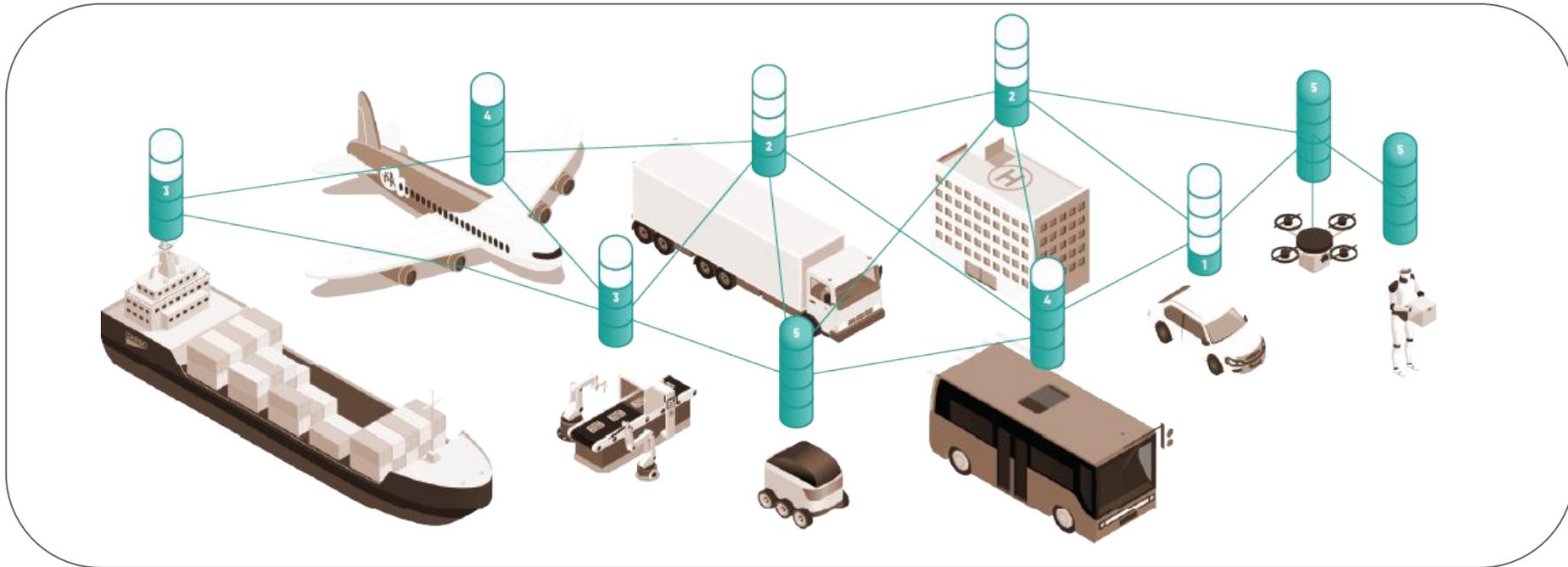
# SPATIAL WEB

## An introduction to the Spatial Web

Comments about the Spatial Web and this presentation can be sent to the Spatial Web Foundation at [info@spatialwebfoundation.org](mailto:info@spatialwebfoundation.org)

# Spatial Web: An Interoperable “World Model”

- Software + Robotic & IoT systems = **Cyber-Physical Systems (CPS)**
- AI + CPS = **Autonomous Intelligent Systems (AIS)** – Agents



“The Spatial Web is a shared world model for AI agents, robots and people to have a common understanding of the universe”

# SPATIAL WEB BUILDS ON WWW

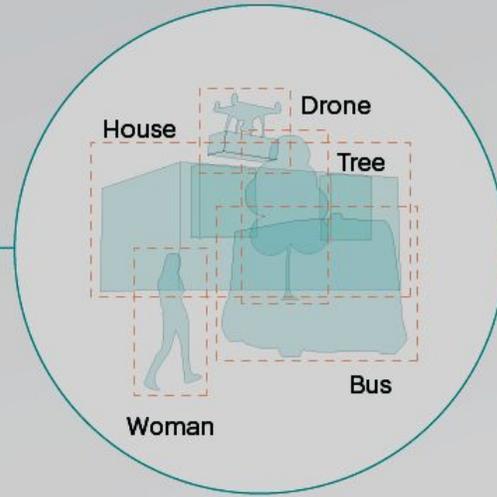
<b>PRIMARY OBJECTS</b>	<b>PROGRAM</b>	<b>PROTOCOL</b>	<b>ADDRESS</b>
<b>HYPERMEDIA DOCUMENTS</b>	<b>HTML</b>	<b>HTTP</b>	<b>WEB DOMAINS</b>
<b>CYBER-PHYSICAL ENTITIES</b>	<b>HSML</b>	<b>HSTP</b>	<b>SPATIAL DOMAINS</b>

# Spatial Web Grounding for AI Agents

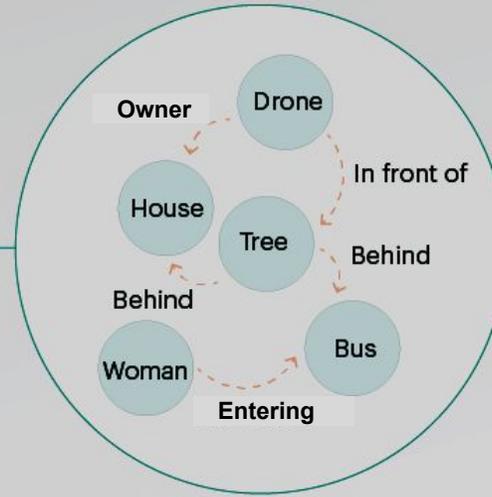
## Grounding Elements



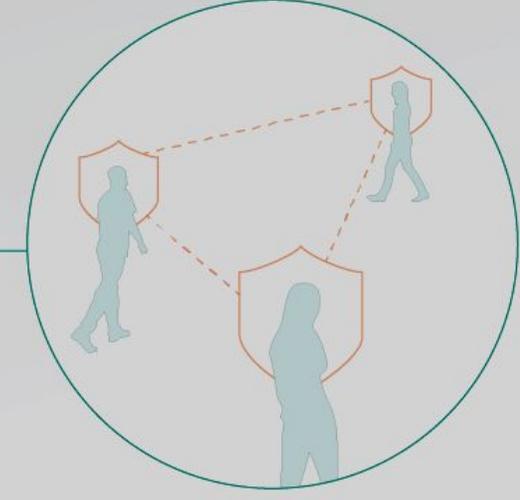
**Coordinates** Geography, Geometry, and Addresses



**Context** Relationships, Interdependencies, and Meta-data

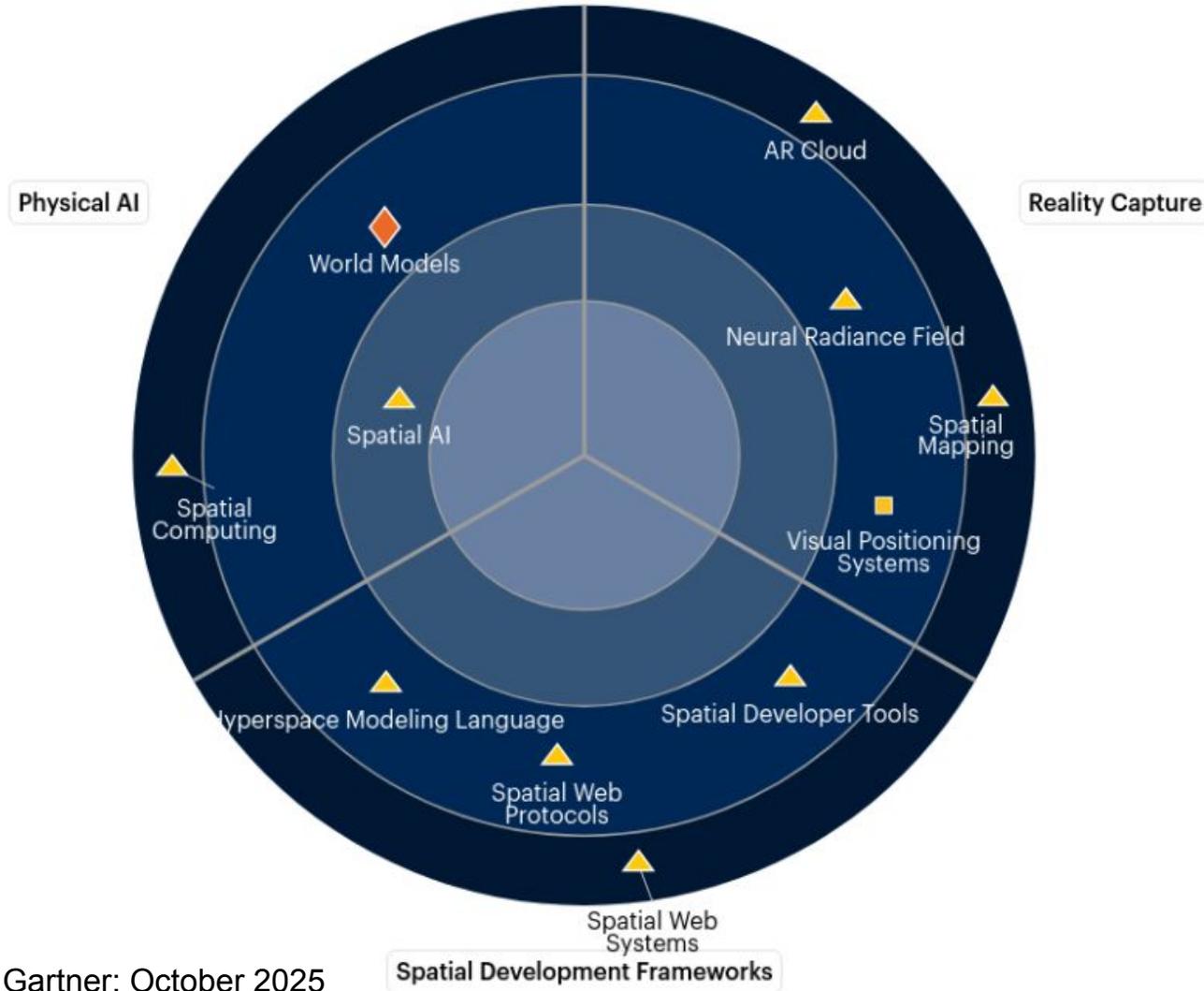


**Credentials** Rights, Permissions, and Policies



Source: VERSES

# Spatial Web on Gartner Radar



“Spatial AI” landscape:

- HSML is a trend on its own;
- HSTP in Spatial Web Protocols;
- UDG in Spatial Web Systems

Recommended Action:

- Experiment with HSML now

Gartner analysis based on  
IEEE 2874-2025 Spatial Web

Gartner: October 2025

**SPATIAL WEB**  
FOUNDATION



# **IEEE 2874-2025 Spatial Web Protocol, Architecture and Governance**

**Standard approved by IEEE, May 2025**

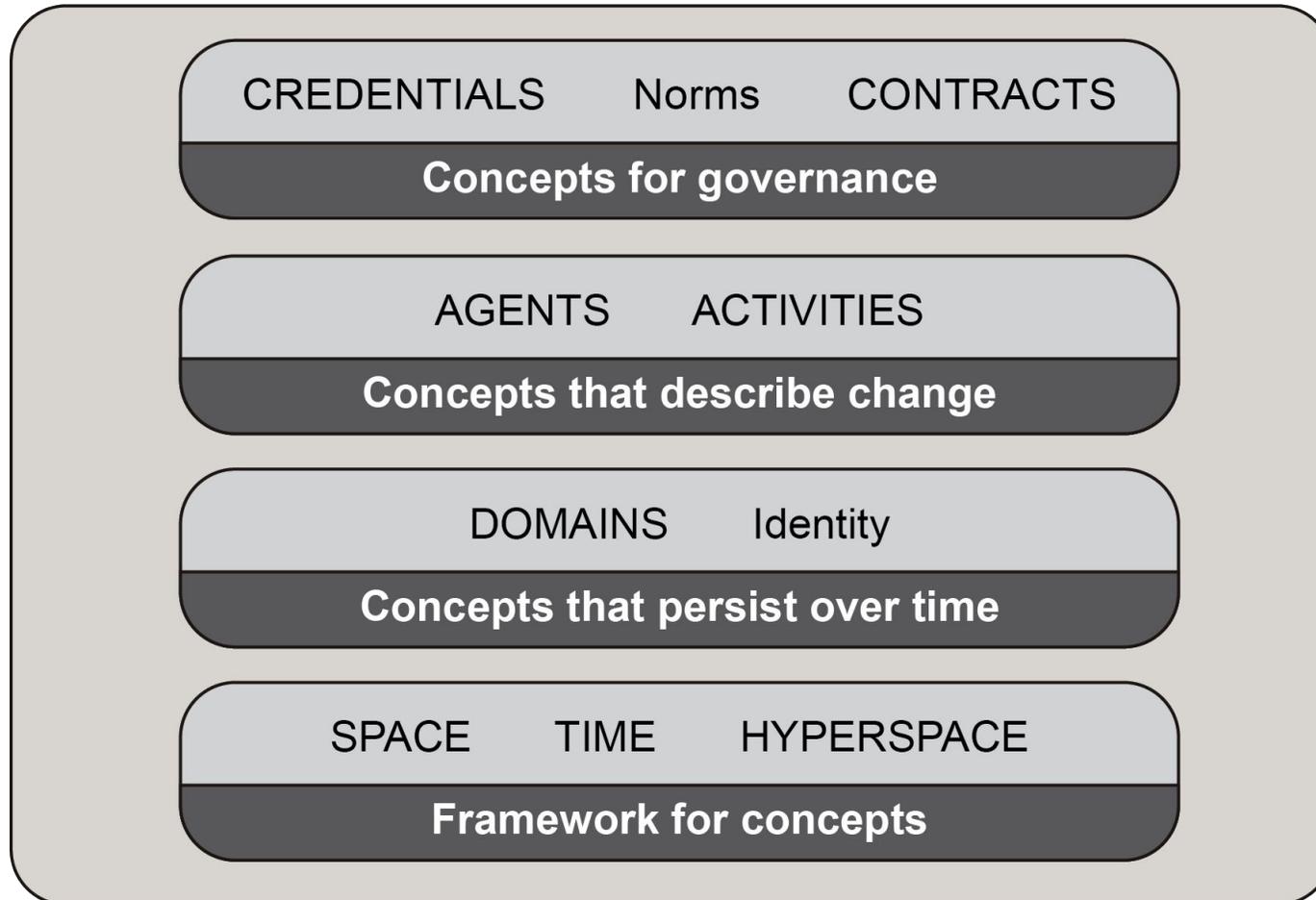
**IEEE SA/SWF partnership: “Public Imperative”**

# Application Scenarios

	Enterprise	Community	Humanity
Indoor	Warehouse robot Industrial XR		
Urban		Cultural location tourism Urban autonomous mobility	Urban digital twin / Smart city
Global		Global supply chain	Digital earth: Greenhouse gases Entertainment XR

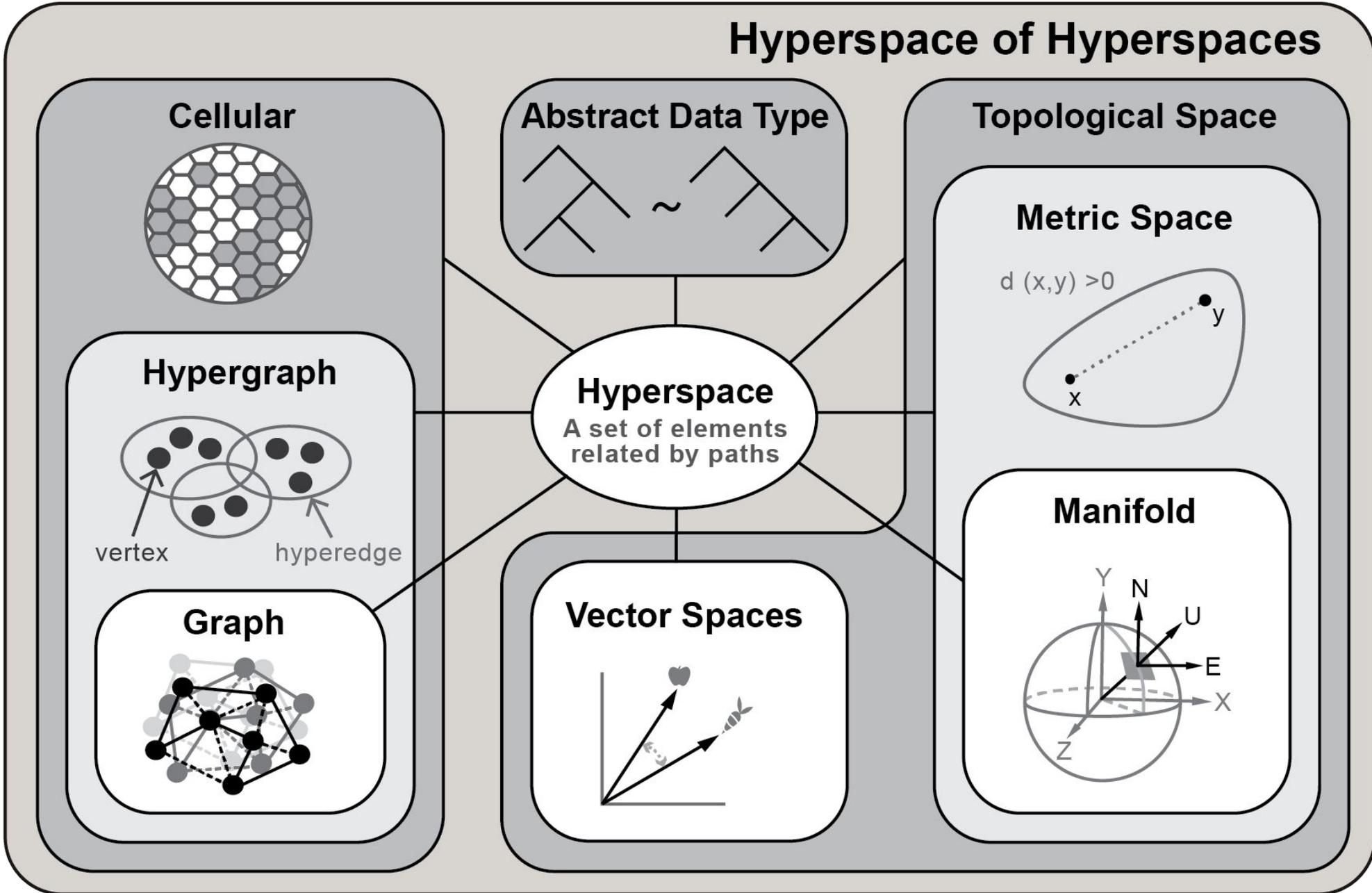
- Scenarios written at a level that can be demonstrated for general interest.
- Each Scenario includes a diagram showing the sequence of events

# Spatial Web conceptual view

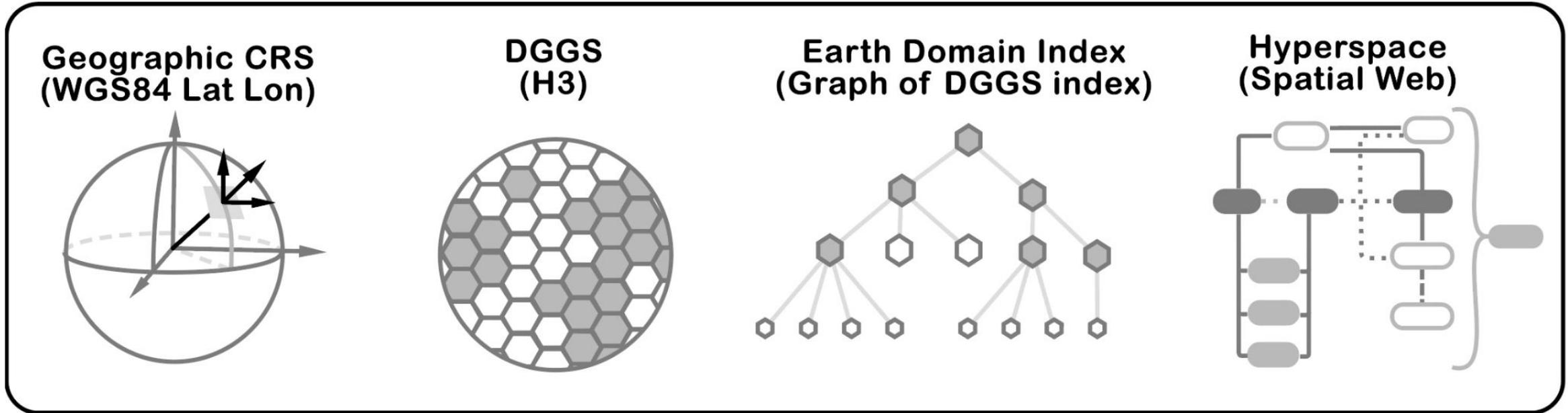


**HSML** encodes entities and properties of Spatial Web Ontology

# Hyperspace of Hyperspaces

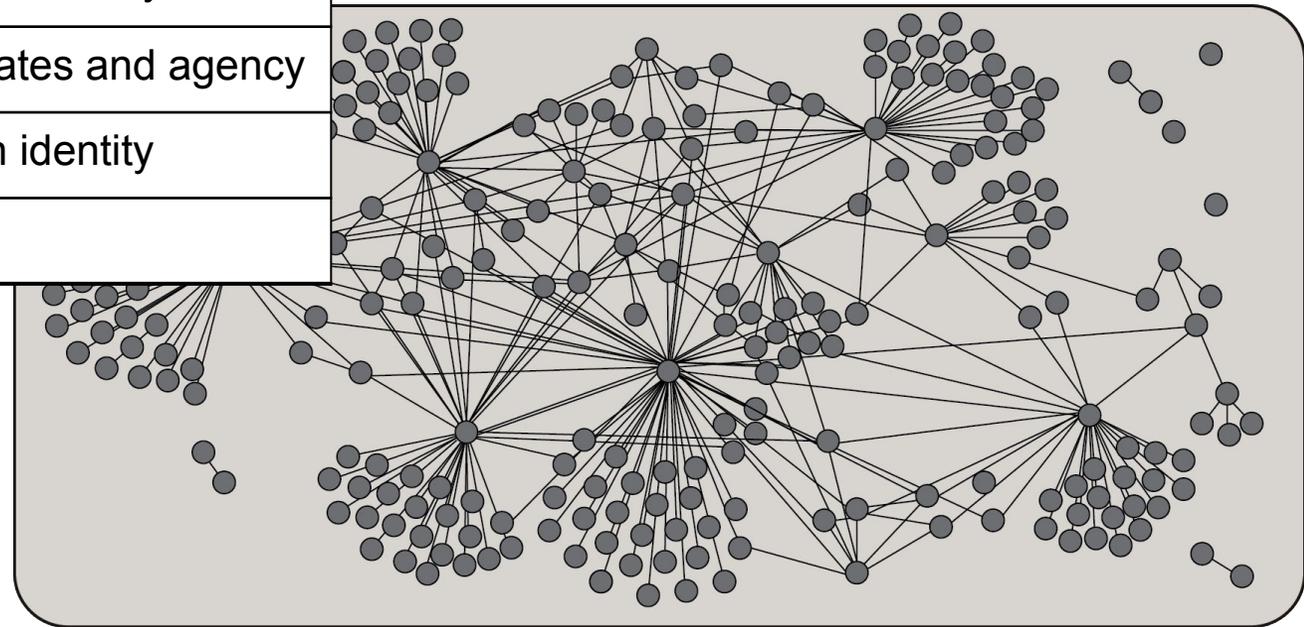


# Embedding geographic space in hyperspace



# Spatial Web Domains

Domain Type	Description
<b>Geographic</b>	Implicitly or explicitly associated with a location
<b>Concept</b>	abstract ideas shared by a community
<b>Organization</b>	Pertaining to membership within an entity
<b>Agent</b>	Individual domains with active states and agency
<b>Person</b>	Type of agent with self-sovereign identity
<b>Thing</b>	Bounded items without agency

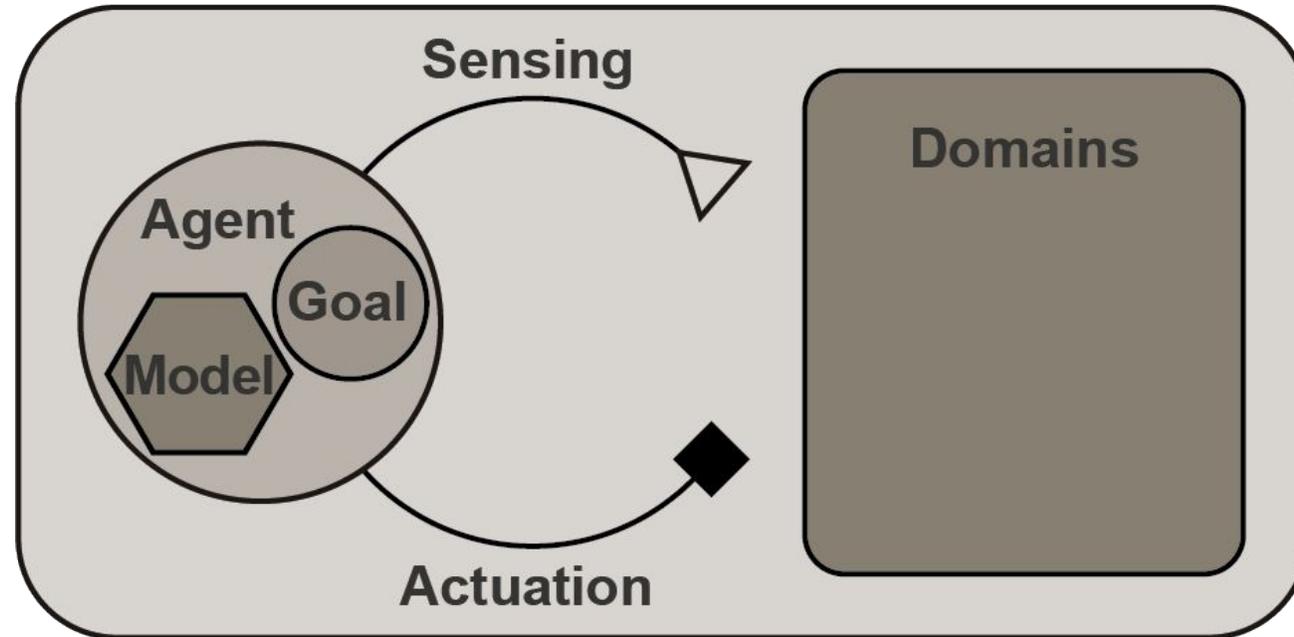


Universal Domain Graph

# HyperGeography

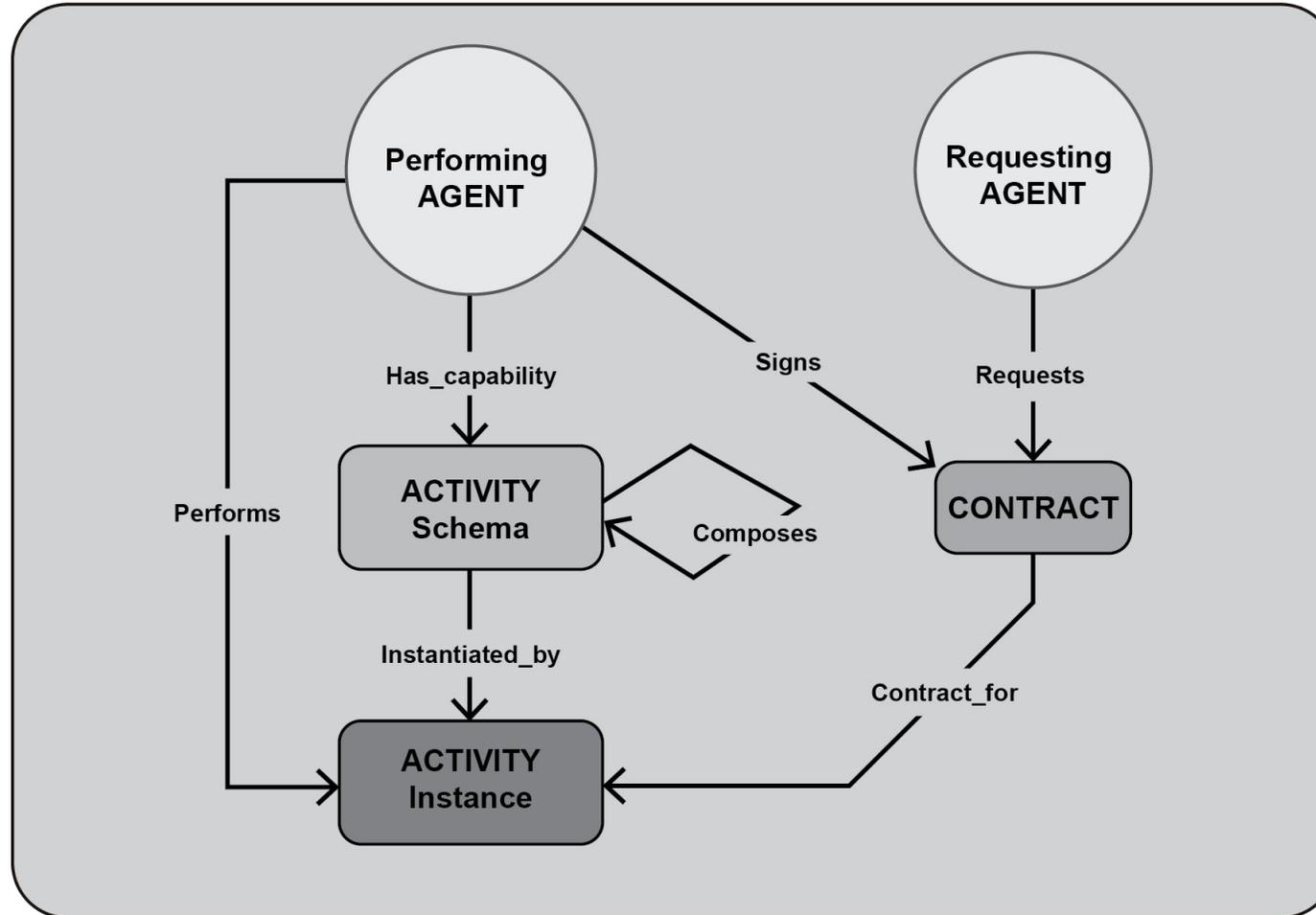
- Spatial Embedding (tech behind LLMs)
  - Hyperdimensional Computing (Kanerva, 2009)
  - Word2Vec extended to World2Vec (LeCun)
  - Analogy calculation: Russia:Moscow::USA:?
  - Universal Geometry of Embeddings (Jha, 2025)
- Hyperworlds
  - Hyperspace Reference Systems (HRSs)
  - Features in Hyperspace (eigenvectors)
  - 1st law of hypergeography

# Spatial Web Agent

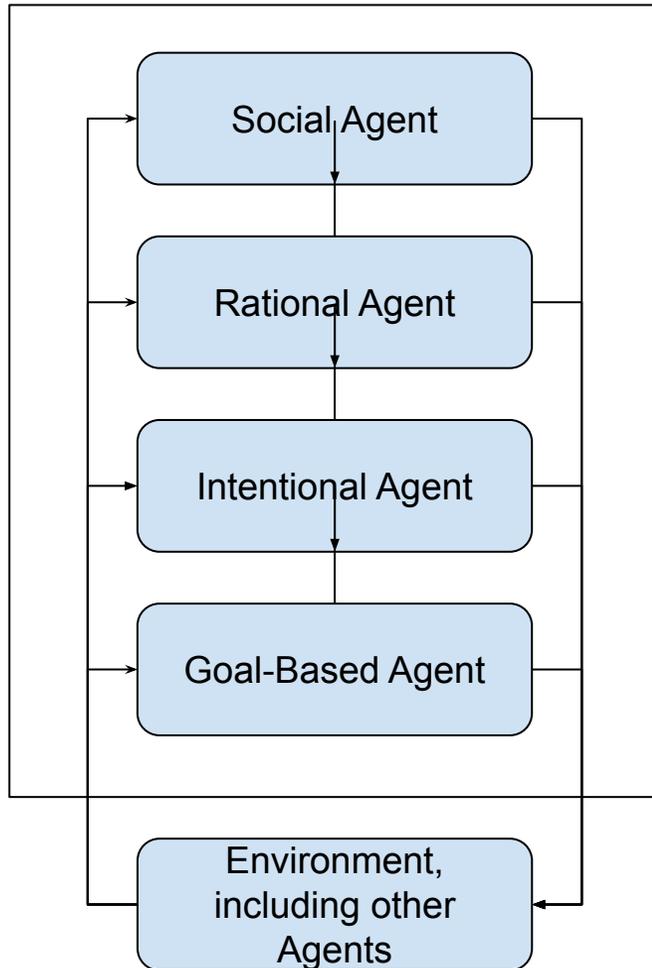


AGENT is an ENTITY that senses, responds, and maintains a model of its environment, while performing ACTIVITIES to achieve its goals.

# Agent-Contract-Activity relationships



# Spatial Web Agent Types



Agent Type	Agent Functions (cumulative going up)
<b>Social Agent</b>	<ul style="list-style-type: none"> <li>- Joint goals with other agents</li> <li>- Joint planning; Coordinating roles during activities</li> <li>- Awareness of rational and moral norms; Mediation between agents</li> <li>- Shared world models; Care</li> </ul>
<b>Rational Agent</b>	<ul style="list-style-type: none"> <li>- Causal models: plan for future goals, causal learning</li> <li>- Assess value of additional information, prior to decision</li> <li>- Reflective executive tier; Controller selection</li> <li>- Attribute mental states to other agents</li> </ul>
<b>Intentional Agent</b>	<ul style="list-style-type: none"> <li>- Models beliefs, goals, intentions (what it's committed to doing).</li> <li>- Utility based planning and decision-making</li> <li>- Curiosity; Vicarious, trial and error: OODA loop</li> <li>- Monitoring uncertainty in decisions: inhibition, cognitive flexibility</li> </ul>
<b>Goal-Directed Agent</b>	<ul style="list-style-type: none"> <li>- Sense and actuate the environment; Memory</li> <li>- Model creation and update; Goal recognition</li> <li>- Feedback control based on model and goals</li> </ul>

# Active Inference-based Agents

- Have **human-like introspection** capabilities
- Operate on **world models or digital twins**
- Understand **causal relationships**
- Which enables **continuous learning, adaptation, explainability and transparency**
- This will enable Agents to become truly **autonomic, seeking equilibrium within ecosystems**

# HSML Modeling Guidelines



## Define a Solid HSML Core

Start with a simple, universal base class. In HSML Core, it defines the base class **hsml:Entity** and its core subclasses and relationships. All extensions must build upon this core.



## Minimal Commitment

Keep the core ontology as simple as possible. Avoid overly restrictive axioms to allow for maximum flexibility and extensibility by other users and systems.



## Extend with Standards

For vertical extensions (e.g., IoT), build upon existing standards like the W3C Web of Things (WoT) or SAREF whenever possible to maximize interoperability.



## Reuse Vocabularies

Don't reinvent the wheel. Leverage established vocabularies like **SKOS** for concepts, **DCTerms** for metadata, and **W3C VC** for credentials to ensure semantic interoperability.



## Leverage RDF-Plus

Use a well-defined subset of OWL 2 that is compatible with property graphs and other data models. This ensures broad compatibility with existing tools and databases.



## Use Adapters

When an external standard is not fully aligned with HSML, create an "adapter" module. This module defines the mapping between the external vocabulary and HSML's core concepts.



## Modularize Everything

Break the ontology into logical modules (e.g., core, governance, hyperspace, domain types). This enhances clarity, maintainability, and allows for independent evolution.



## Use SHACL for Rules

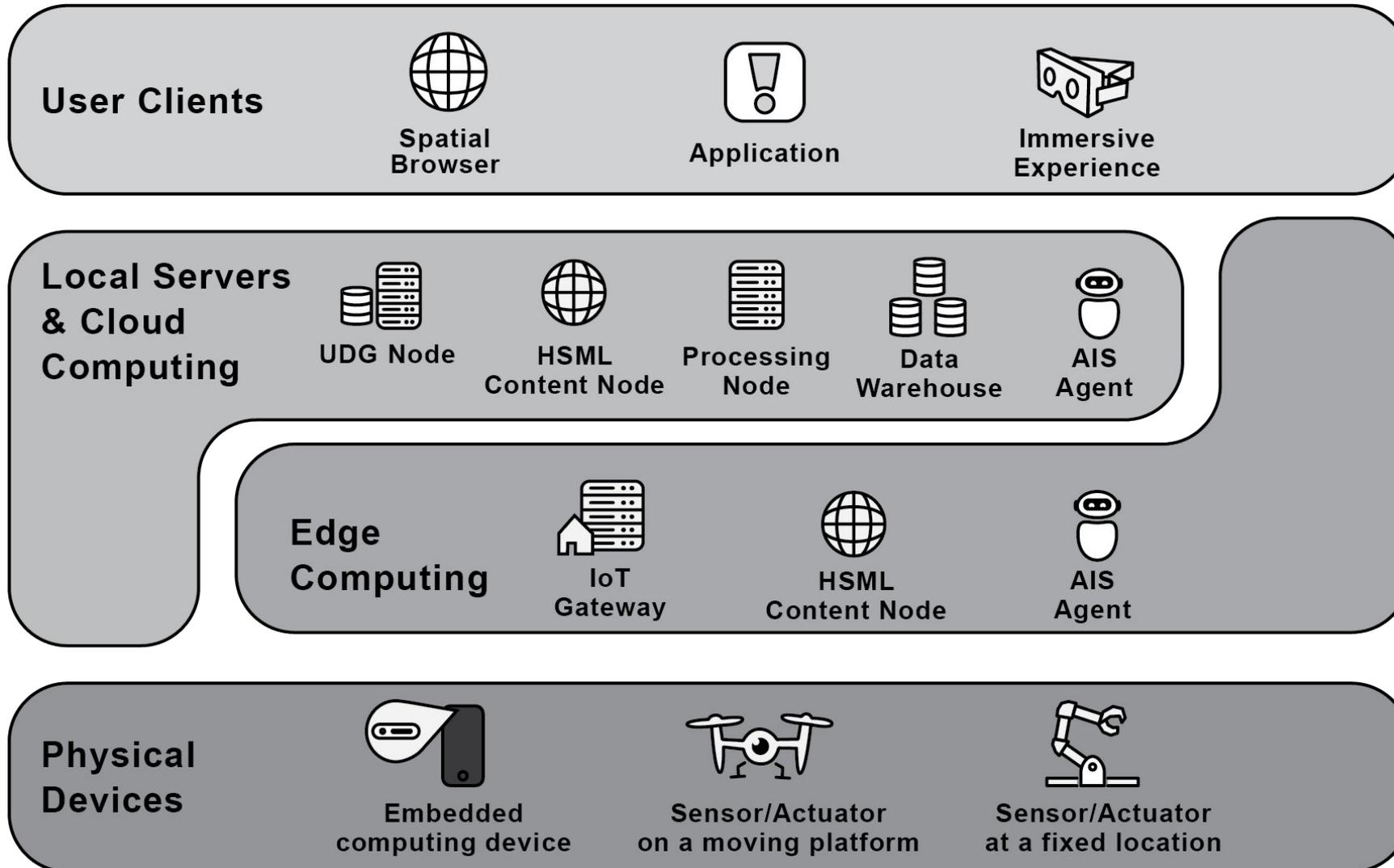
Use the Shapes Constraint Language (SHACL) to define validation rules and constraints for your data. This ensures data quality and enforces the norms of your model.



## Use Consistent Naming

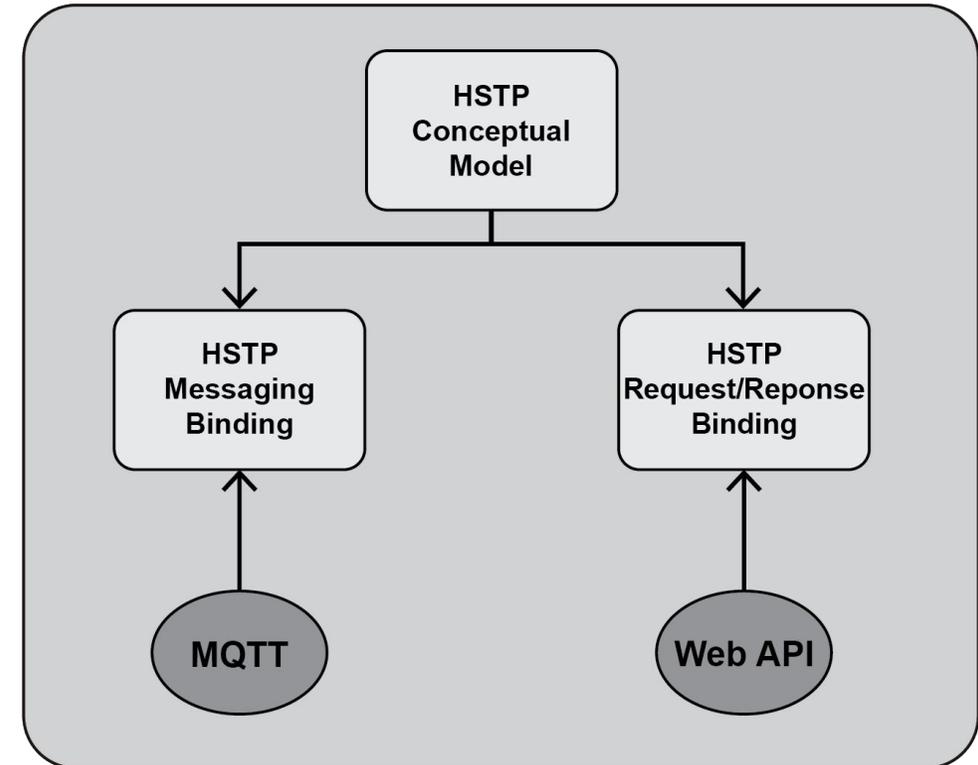
Follow standard conventions: **PascalCase** for classes (e.g., **hsml:SpatialFeature**) and **camelCase** for properties (e.g., **hsml:performs**). This improves readability and tool compatibility.

# Distributed Computing Viewpoint



# HSTP

- **Secure, verifiable protocol for communicating HSML**
  - Ensuring **seamless interoperability** between diverse AI and Digital Twin systems.
  - HSTP Operations based on Actor Paradigm
- Incorporates **W3C DID for identity**
  - SW Domain Registry and Registration Authority

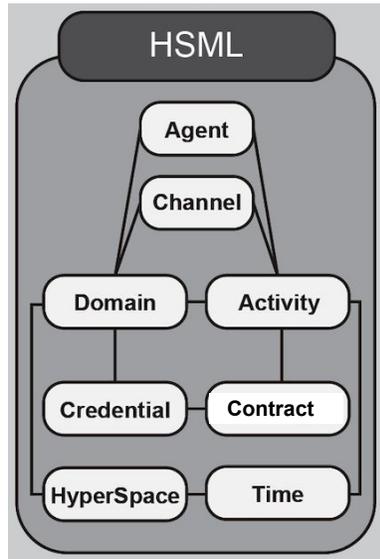


# INTRODUCTION TO THE SPATIAL WEB



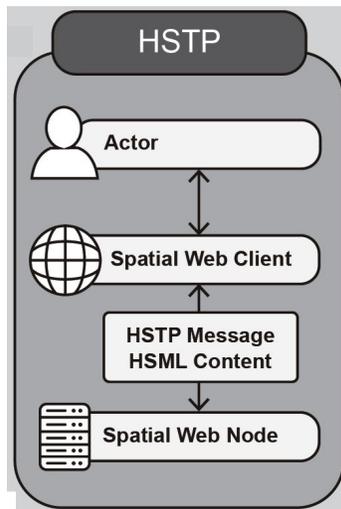
[Watch Video](#)

# Spatial Web Components



## HSML – Hyperspace Modeling Language

- A common data model that enables *adaptive intelligence at scale*
- A standard that articulates the types of relationships which can exist between any base elements and their purpose



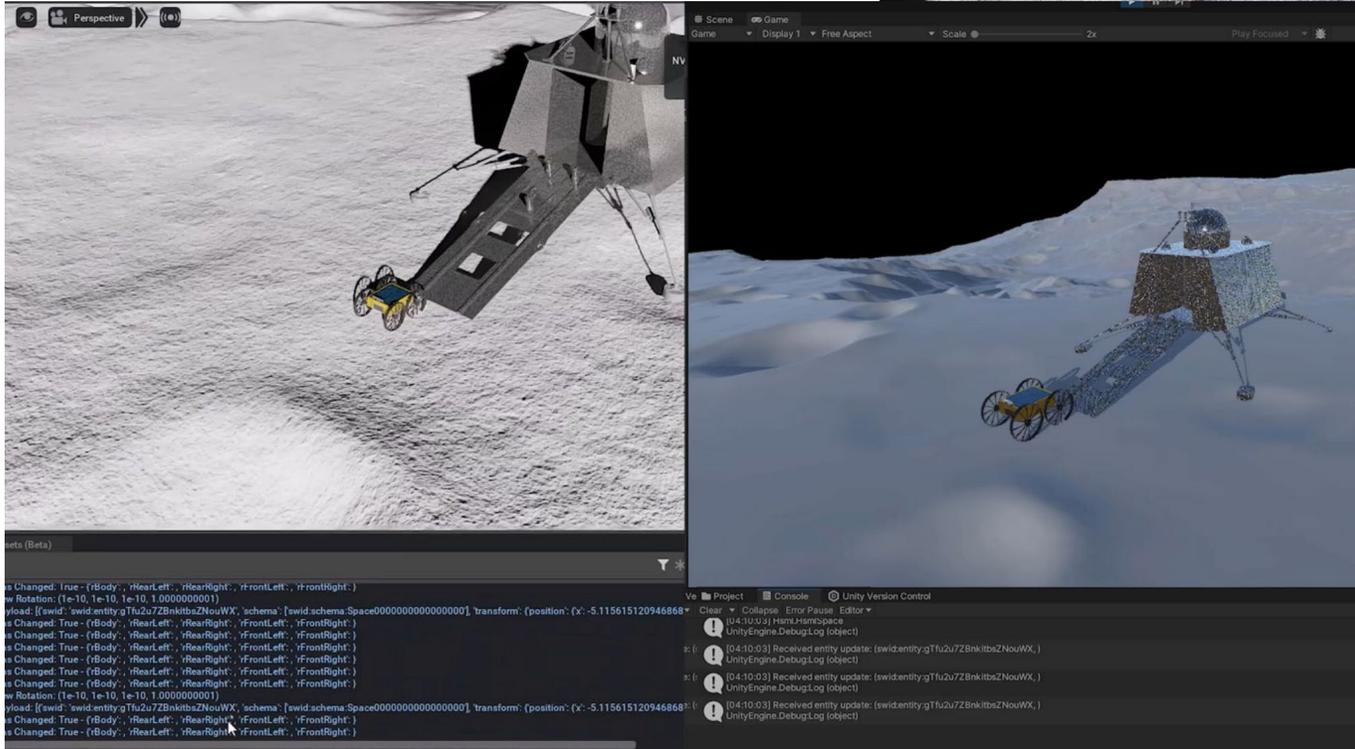
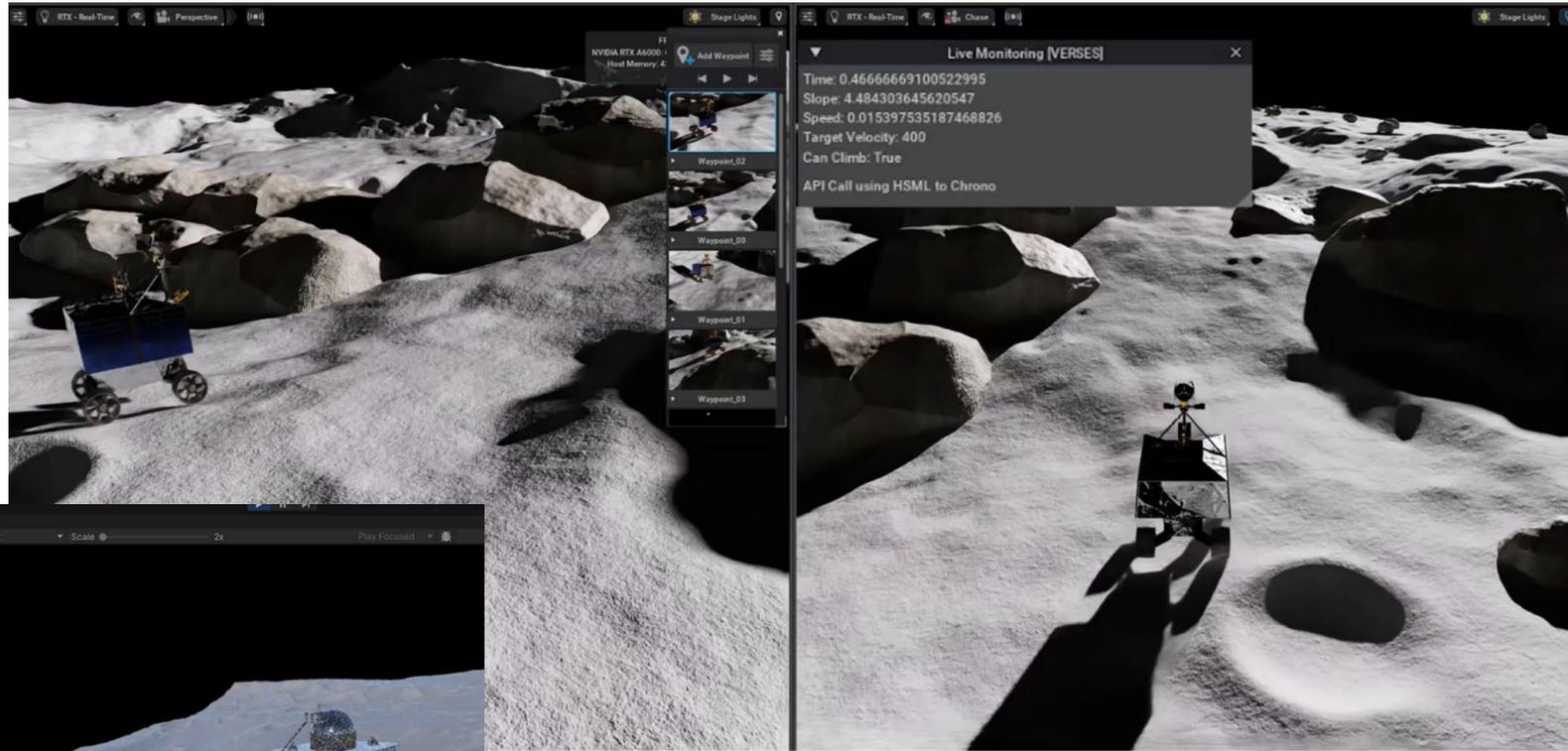
## HSTP – Hyperspace Transaction Protocol

- Multi-dimensional range query and contracting protocol (rules and permissions)
- Governs interactions between parties to ensure privacy and security



Jet Propulsion Laboratory  
California Institute of Technology

# Collaboration Projects



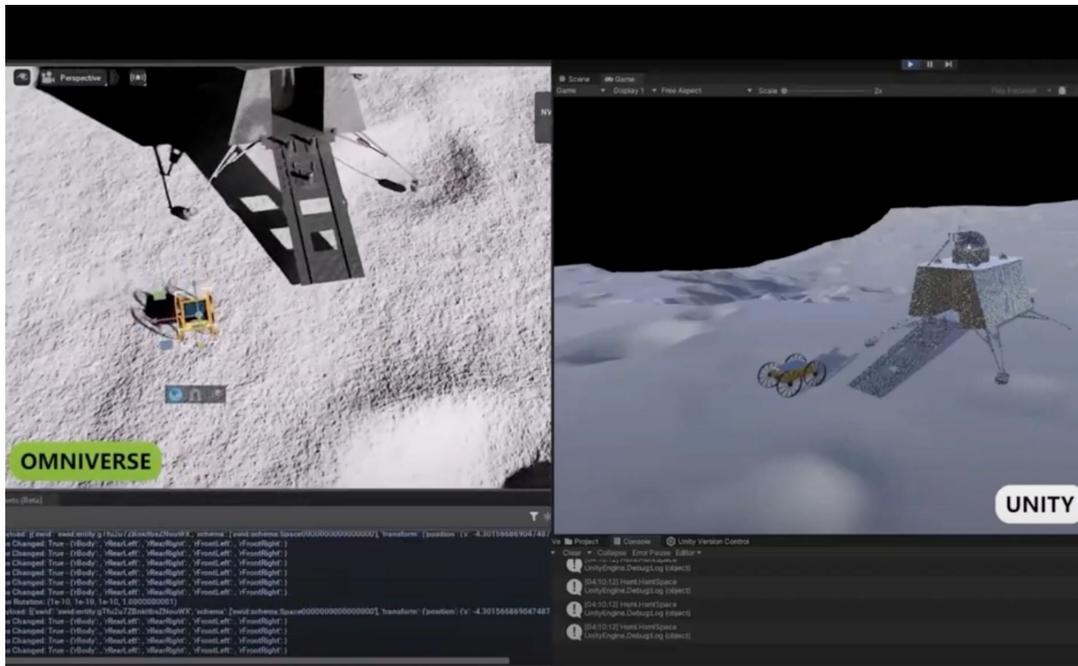
Real time physics modeling using HSML

Examples of using HSML to achieve cross platform interoperability between Unity and Unreal

# JPL & SWF Lunar Cross Platform Interoperable Digital Twins

- Dr Ed Chow's team demonstrated real-time joint testing of a lander model at CSUN and a rover DT model at JPL on distributed NVIDIA Omniverse platforms via standard-based spatial web protocols (HSML & HSTP).
- Cross-platform collaborations between Omniverse and Unity platforms were demonstrated.
- Showcased IP protection by executing a Physics-Informed Neural Network (PINN) model remotely at JPL while testing the model at CSUN.
- Dr Ed Chow will be presenting latest demo next Thursday.

IEEE Aerospace Conference Paper



## Enabling Interoperable Digital Twins for Collaborative Lunar Exploration

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**Abstract** - We present the results of a proof-of-concept development for standard-based interoperability between distributed and disparate Digital Twin (DT) systems for lunar exploration. The project was undertaken by a team from NASA Jet Propulsion Laboratory (JPL), California State University, Northridge (CSUN), Verses AI Inc, and the Spatial Web Foundation. Leveraging the soon-to-be-approved IEEE P2874 Spatial Web standard, the team developed and demonstrated real-time, cross-platform collaborative lunar exploration between DT systems at JPL and CSUN. Using a spatial web plug-in from Verses AI Inc, the team demonstrated real-time joint testing of a lander model at CSUN and a rover DT model at JPL on distributed NVIDIA Omniverse platforms via standard-based spatial web protocols. Additionally, cross-platform collaborations between Omniverse and Unity platforms were demonstrated using these protocols. The team also showcased intellectual property protection by executing a Physics-Informed Neural Network (PINN) model remotely at JPL while testing the model at CSUN. To our knowledge, this project marks the first demonstration of interoperability between distributed and disparate DT systems using the spatial web standard.

ACKNOWLEDGMENTS.....7  
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### 1. INTRODUCTION

Digital Twins (DTs) [1] [2] hold immense potential to transform various fields such as science, technology, engineering, production, and operations. They have already been successfully applied in domains such as scientific discovery, biomedical sciences, factory management, climate change modeling, and smart city development. In the context of lunar exploration—where direct access to objects in space is highly challenging—DT technology is particularly vital. DTs enable engineers on Earth to monitor and manage the health of systems operating on the Moon and facilitate the virtual planning and testing of lunar activities before robotic systems perform potentially hazardous tasks. Additionally, DTs can simulate a wide range of lunar missions, aiding stakeholders in determining their roles from both operational and financial perspectives. This capability can guide government agencies in assuming responsibility for mission components that private and commercial entities may be unable to manage. As lunar exploration increasingly becomes a collaborative international endeavor, DTs have the potential to support global cross-organizational testing and coordination. Given these critical advantages, we consider

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