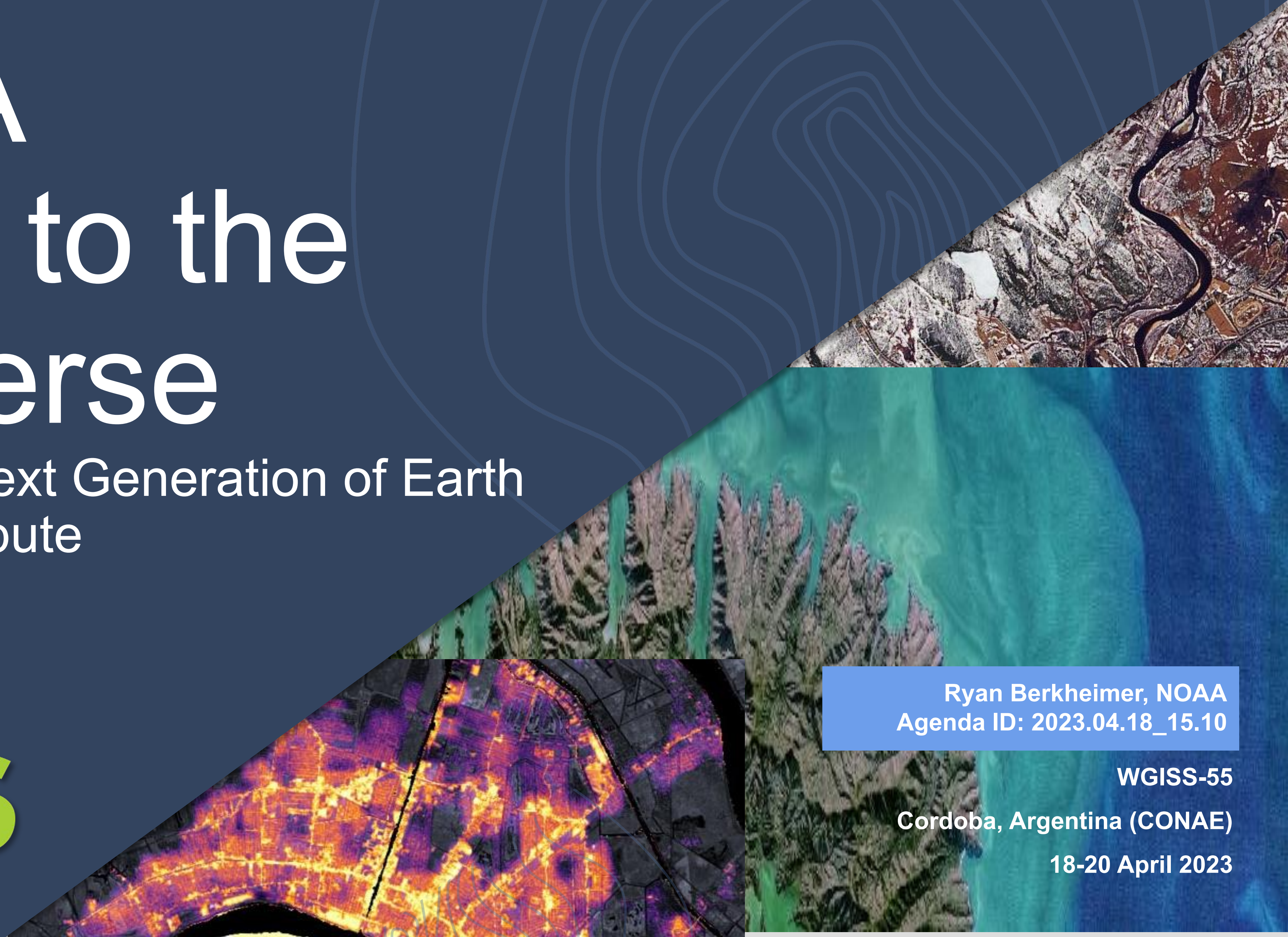
NOAA Steps to the Geoverse

Shaping the Next Generation of Earth Systems Compute



Ryan Berkheimer, NOAA

Agenda ID: 2023.04.18_15.10

WGISS-55

Cordoba, Argentina (CONAE)

18-20 April 2023

Committee on
Earth Observation Satellites

Executive Summary

- The UN-GGIM in the July 2022 Discussion Paper on the Geoverse recognizes the significance of a distributed and machine dominated world
  - It is understood that disruptive circumstances require disruptive solutions
- NOAA is currently developing a holistic capability to enable the Geoverse System of Systems (SoS) step change
  - Cloud based agile reference architecture for evolutionary governance and open innovation
  - Iterative inclusion and improvement of existing systems
- The capability is being driven by many requirements and considerations
  - Web 3.0 standards vision for full semantic interoperability - achieving the original vision of the WWW
  - Full definition and process provenance for trust and scientific reproducibility - treating process as data
  - Support of federated, multi-owner earth systems digital twins and sensor networks
- The capability is being pursued through many intra-agency and inter-agency partnerships
  - Interagency Study Groups - NOAA/NASA/CNES Coastal Zone Digital Twins
  - NSF - Open Knowledge Network ('next-gen public data infrastructure similar in scale to the internet'); the Public/Private I/UCRC
  - Strategic Alignment - NOAA's Societal Data Insights Initiative, PARR 2.0
  - Industry and Standards - OGC Disaster Pilot; Climate Resiliency Pilot; Testbed 19 for Interoperability and Agile Architecture

A **Big Idea** - Let's Build a Runnable, Trustable, Democratic Internet to Improve the Earth System

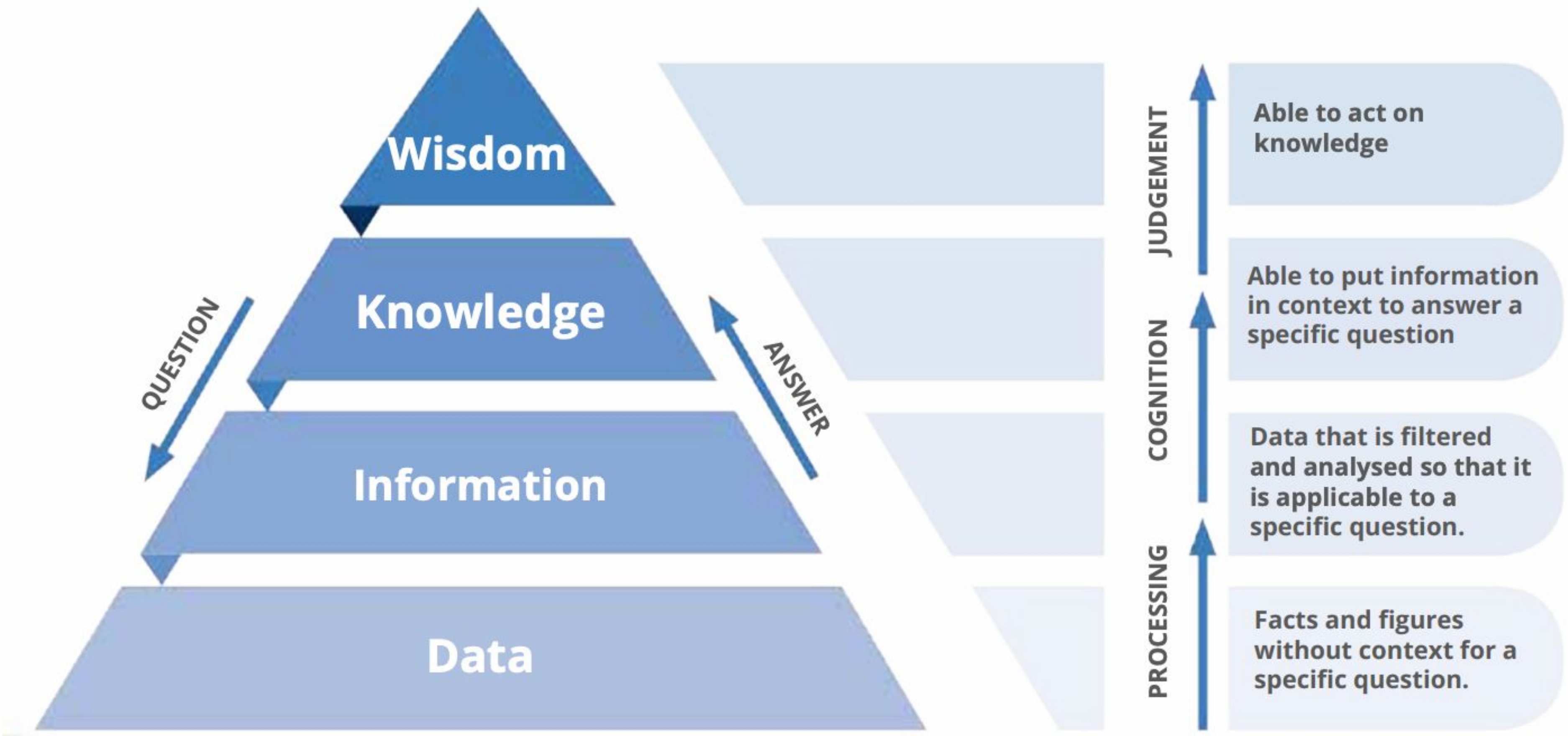


Figure 4. From data to information, knowledge and wisdom. Adapted from DIKW Model for knowledge management and data value extraction.

[Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geoverse]

Visualizing a Step Change to the Geoverse

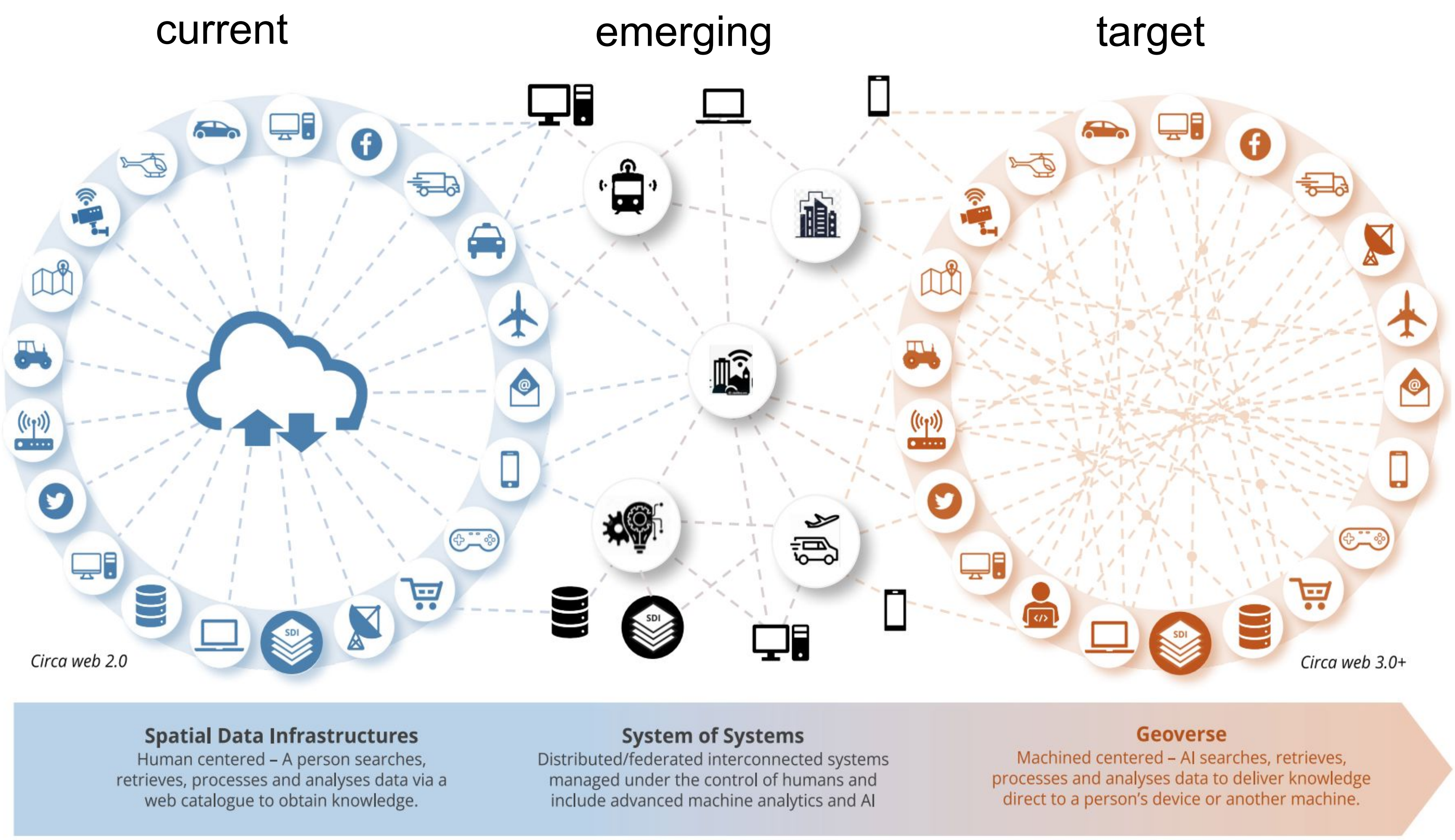
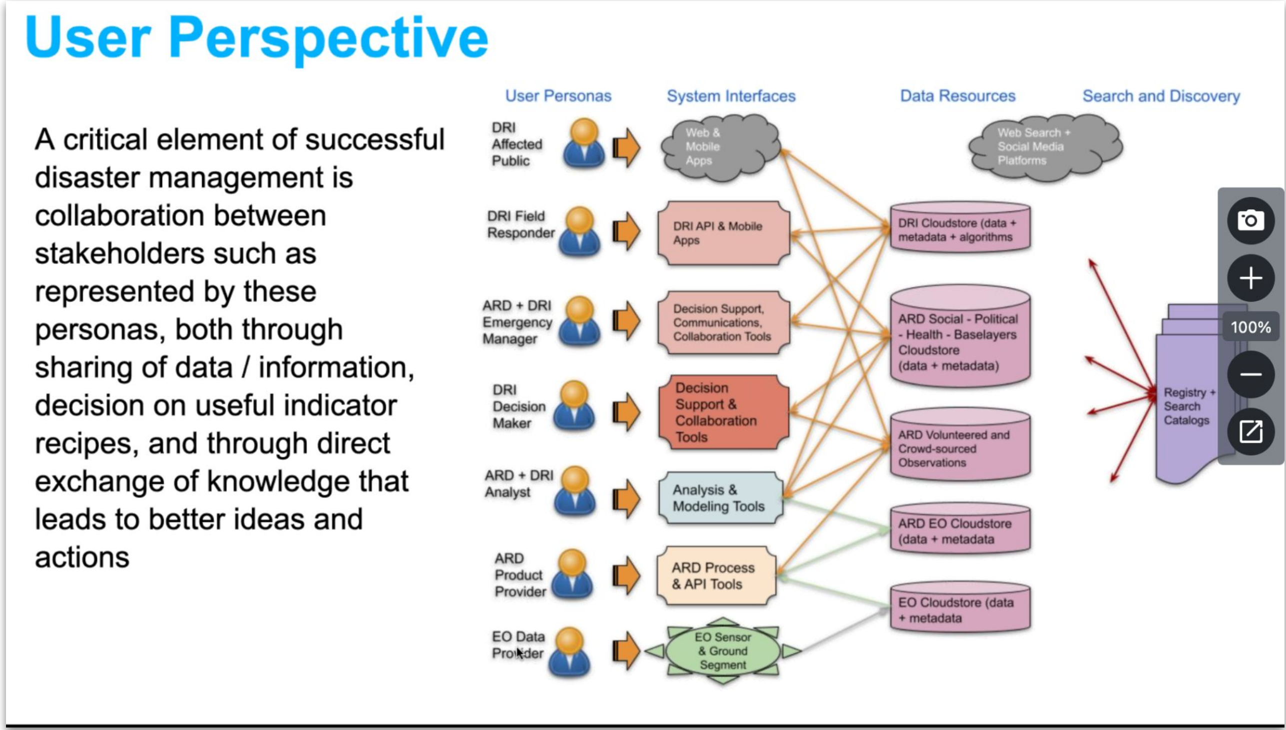


Figure 3. The future geospatial information ecosystem comprising SDIs, SoS and the Geoverse.
[Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geoverse]

- A democratized system of systems powered by machine to machine communication
  - Machines as users
  - Humans as users
- An open ecosystem in which all users can both consume and contribute information
- A federated framework of universally useful understanding

Why Haven’t Spatial Data Infrastructures Been Enough?

- **At every level** of the global spatial data infrastructure, **our system is characterized by data silos**
  - Data **access** is generally difficult
  - **Usage** is generally difficult
  - **Collaboration** is generally difficult
  - **Operationalizing** is generally difficult
  - **Universal Standards management** is nearly impossible - so how can we merge things?
  - ***The Big Idea*** *is nearly impossible to achieve under this condition*
- **Data Silos** are **expensive** and **limiting**
  - Resource overhead in duplicating efforts in **feature sets, maintenance, management**, etc.
  - Enormous costs incurred due to resolving conflicts of **definition, provenance, use rights,** etc.
  - **Service offerings** that don’t match data-driven **user preferences**
  - Inability to do holistic comparison of **competitive approaches** and/or **products**
  - Lack of **holistic quality** controls
  - **Reproducibility** crisis leading to trust issues
- **This problem isn’t limited to any particular enterprise**
  - **Data integration** in earth science **is** a **global** issue
  - Enormous value in enabling **connection between organizations** - global **system of systems**
  - **No one organization can solve this problem alone!!! It requires an orchestrated federation of players**



[OGC Disaster Pilot 2023](#)

We aren’t here quite yet

Using the Federated Global Infrastructure Framework (FGIF) as a guide and 'unit test suite'

- Geoverse enablement is a shared **social** problem
  - SDI methods have moved us forward
  - Geoverse is immensely more complex
  - A federated problem across boundaries
- The FGIF provides a high level framework for alignment of verification and validation of solutions by enabling semantic interoperability in communications
  - Highest level of understanding
  - Rises above agency and national solutions
  - Shared understanding of goals to shape
    - Policy
    - Solutions
- Treat the FGIF as a leveling framework
  - For a given solution we can ask -
    - how mature is it?
    - In what ways should it evolve to become more mature?

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Legislation	National policy and legal frameworks for the democratization of data	Global guidance for national policy and legal frameworks for the democratization of knowledge
Policies, Norms and Guides	Standalone geospatial policies and laws for data management, access and use.	Geospatial policies and laws interoperable with wider government digital policy and global knowledge management agendas
Governance and Accountability	A reliance on humans to comply with geospatial data policies and laws	Use of technology to enforce geospatial knowledge management and use, as well as internet compliance
Data Protection, Licensing and Sharing	Open data policy balanced with protection of sensitive material and respected rights	Knowledge creation and the ethical challenges of information bias, digital identities, usage and cybersafety

Figure 8. Policy and Legal Strategic Pathway – the Step Change

Data Themes	National data frameworks focusing on fundamental geospatial data themes	National use case frameworks contributing to priority challenges on a local to global scale
Custodianship, Acquisition and Management	Geospatial data to support the delivery of new products and services	Linked data and geoanalytics that enable knowledge on-demand
Data Curation and Delivery	Manual value-added data delivered via data catalogues	Automated real time knowledge delivered via AI and machine accessible data registries
Data Supply Chains	Centralised bi-directional supply chains	Decentralised multimodal communication interfaces

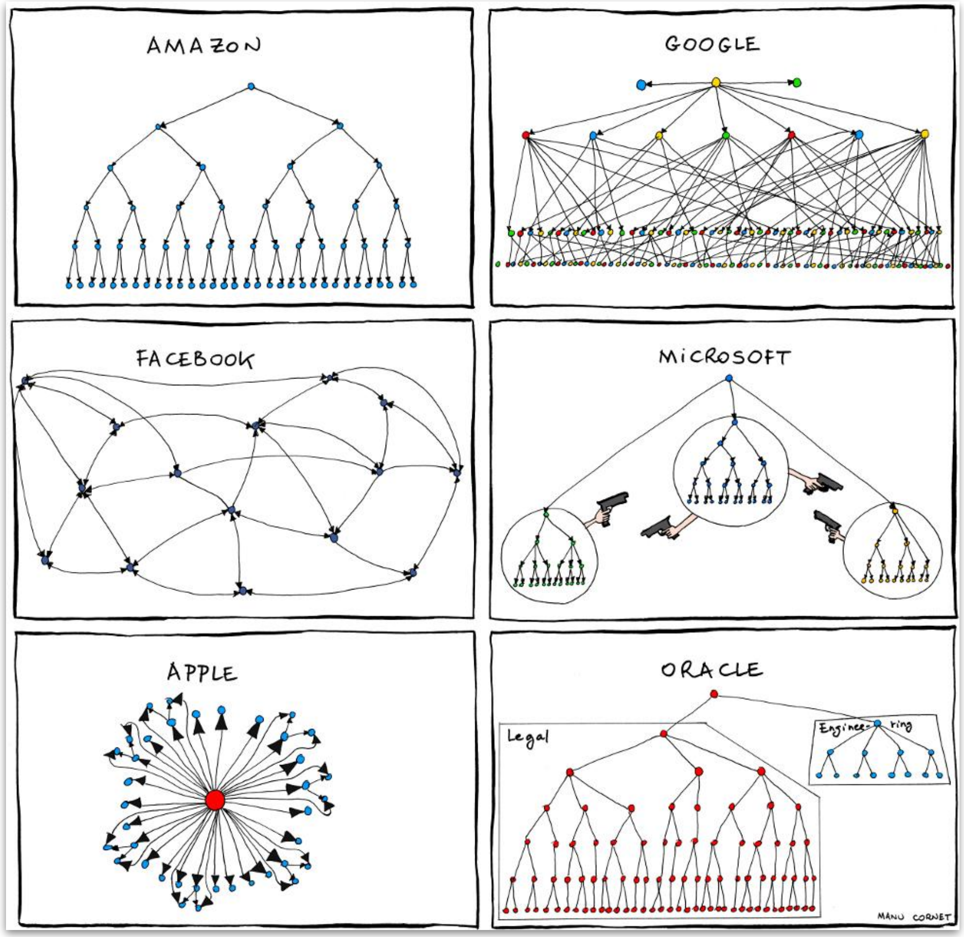
Figure 10. Data Strategic Pathway – the Step Change

Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geoverse

Grounding the Need for a Global Framework

- A full resolution earth is a **system of systems**
- Lots of humanity spanning effort to **measure, understand, and explain**
- **Data is fundamentally interoperable** due to scientific frameworks of understanding
- **But -** most holistic interoperability efforts fail in some way - why?

- **Conway's Law:** any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure
  - Conway's Law implies hard limits to large efforts in terms of **syntactic, schematic, semantic, and legal interoperability** constraints

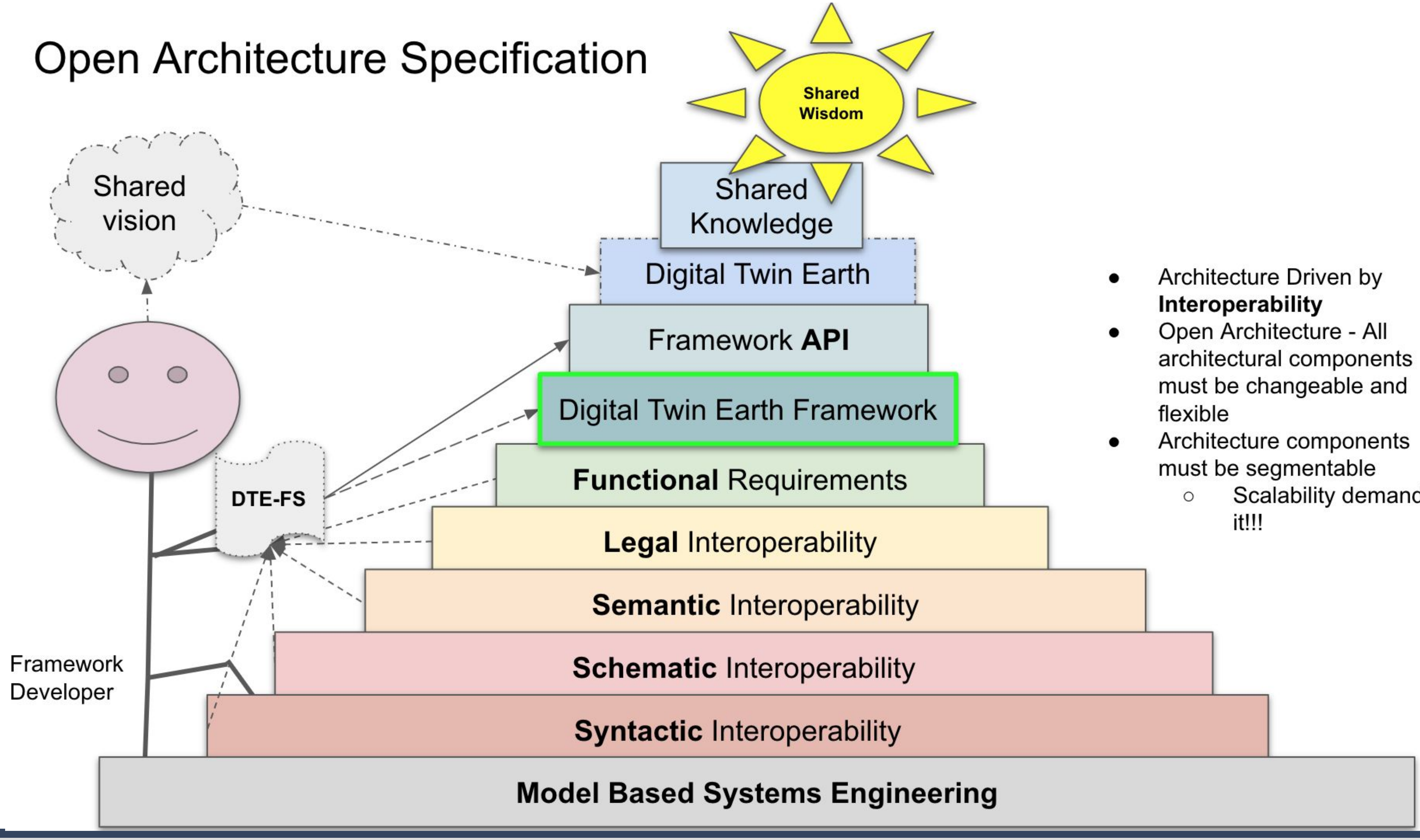


http://scrumbook.org/product-organization-pattern-language/conway-s-law.html

Reference Approach for Practical Implementation

- The FGIF gives us a **shared vision** and **validation framework** at the **global level**
  - **Needs lower level frameworks** to address **verification and validation of implementation**
- To this end, NOAA created the Digital Twin Earth Framework Specification (**DTE-FS**)
  - DTE-FS is a first-principles derivation of specific **actionable requirements** for **validating a framework** supportive of an **interoperable,** federated, & holistic **earth systems digital twin**
- Requirements for Federated Digital Twins as described by the DTE-FS represent an **operational blueprint to practical implementation** of the SoS step change toward the Geoverse
  - Categorized and leveled **interoperability**
    - Accommodation for Conway's Law
  - **Functional requirements** to address **uses and goals**
- NOAA has been implementing the DTE-FS as the Next Generation Archive and Access System
  - DTE-FS mapped and tailored to specific requirements
    - National **Open Knowledge Network** and the **Semantic Web** (5 star linked open data); **NARA** (full provenance) **and PARR 2.0** (open science); **FAIR and CARE** data

The DTE-FS in One Image

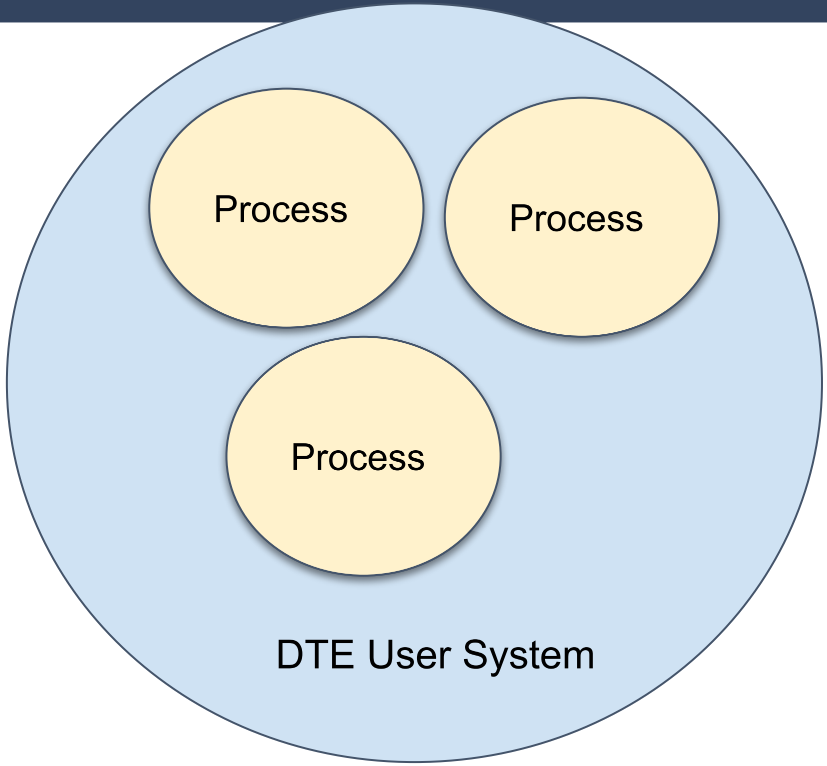


- Architecture Driven by **Interoperability**
- Open Architecture - All architectural components must be changeable and flexible
- Architecture components must be segmentable
  - Scalability demands it!!!

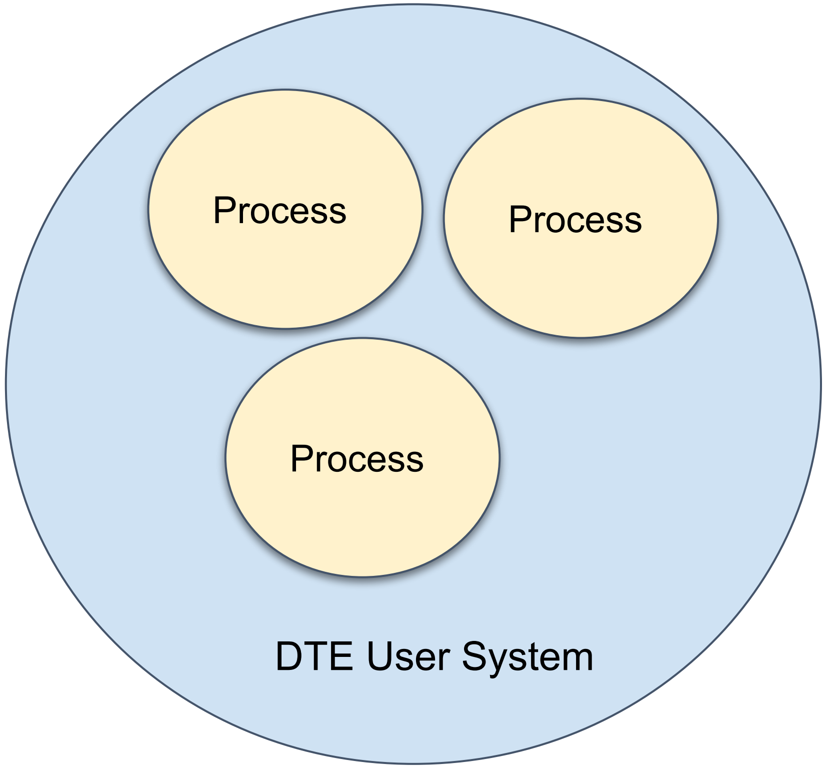
Reference Model and Requirements

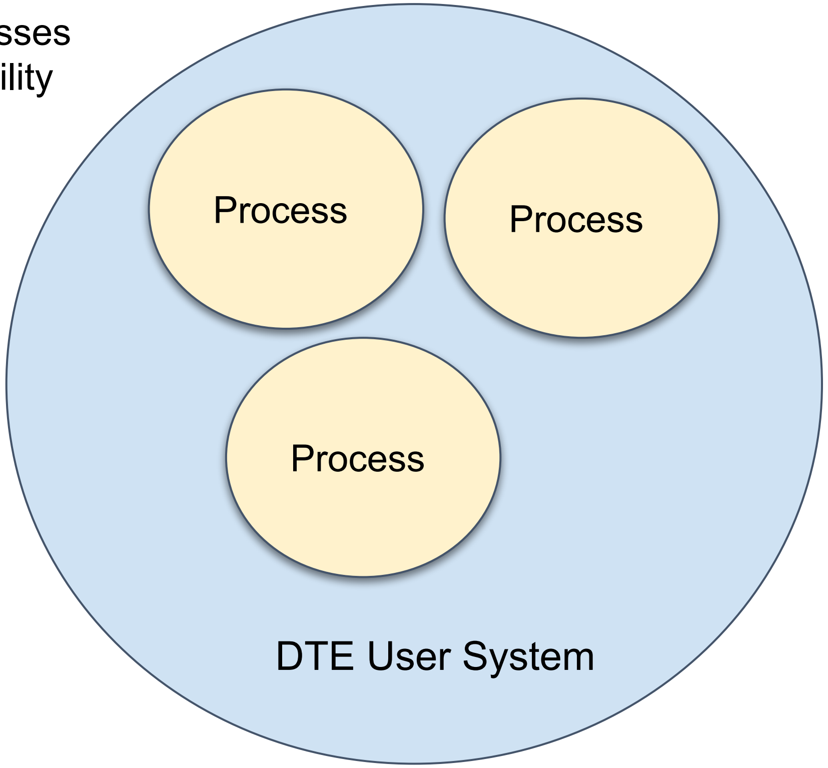
Critical Understanding #1: **Process** as a **Dataset**

- Process is ‘space complete’
- We can describe any system as a set of processes
- Process-as-data enables syntactic interoperability
    - Request/Response/Records

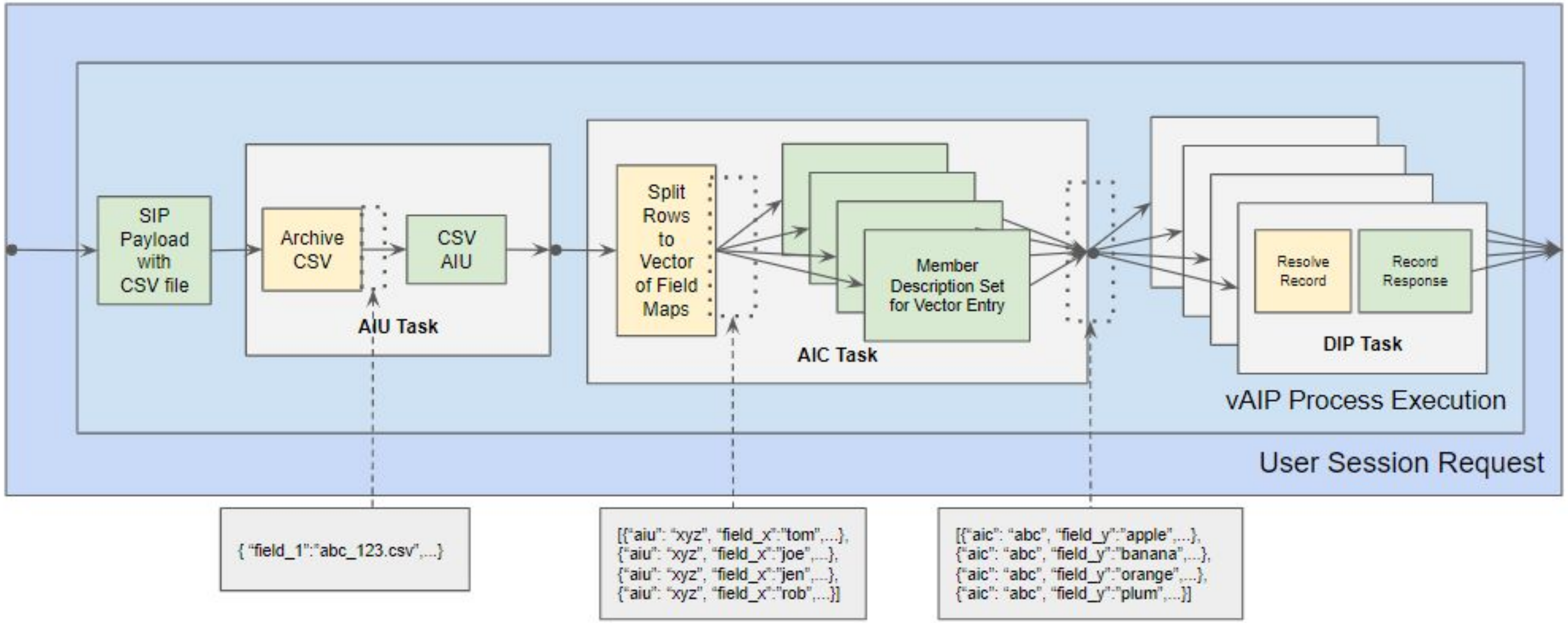


I can **create** processes
I can **share** processes
I can **discover** processes
I can **inspect** processes
I can **evolve** processes
I can **copy** processes
I can **link** processes
I can **process shop**
My machine can do all these things, too!



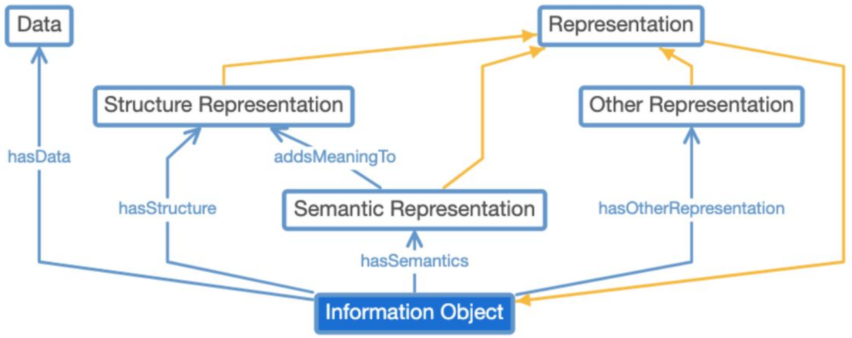


Illustrative Example - Dynamic Process Provenance

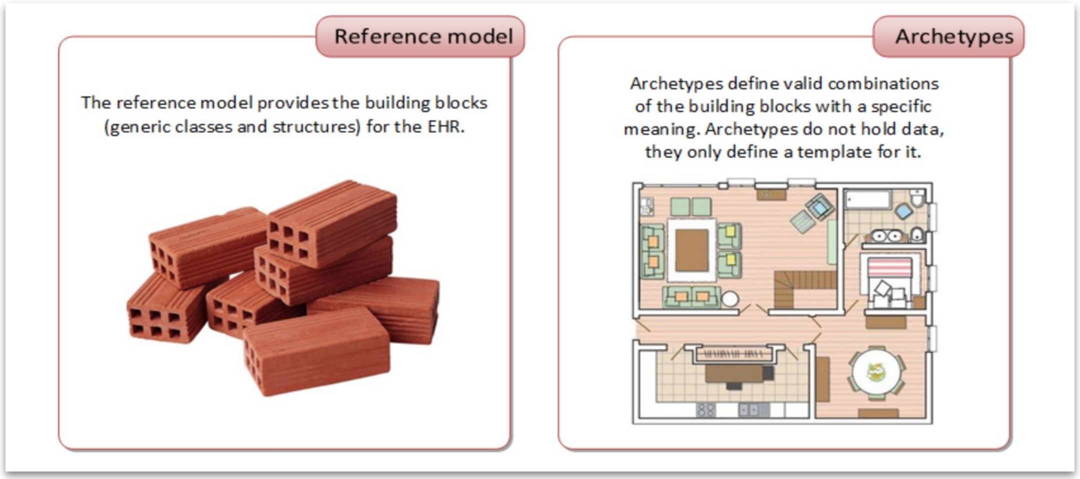


Critical Understanding #2: **Semantic Interoperability**

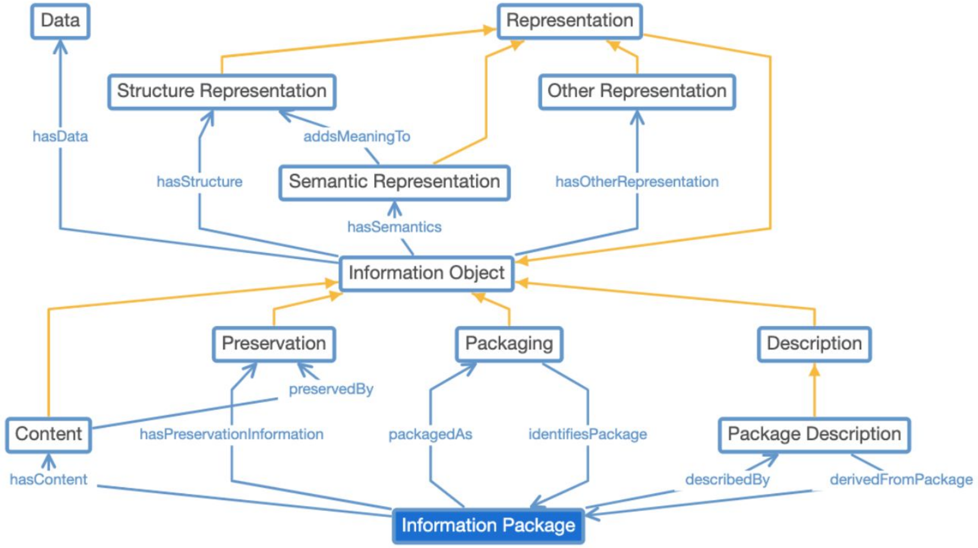
- Process-as-data alone cannot solve interoperability
- Semantic interoperability within a shared reference model is required to enable automated terminology resolution, value transformation, and evolutionary governance
- Critically, Semantic interoperability enables **higher order legal interoperability automation**
- Critically, Semantic interoperability enables decision definition and capture, enabling automated feedback and introduces observability to system improvement



The basic building block - recursive and generic

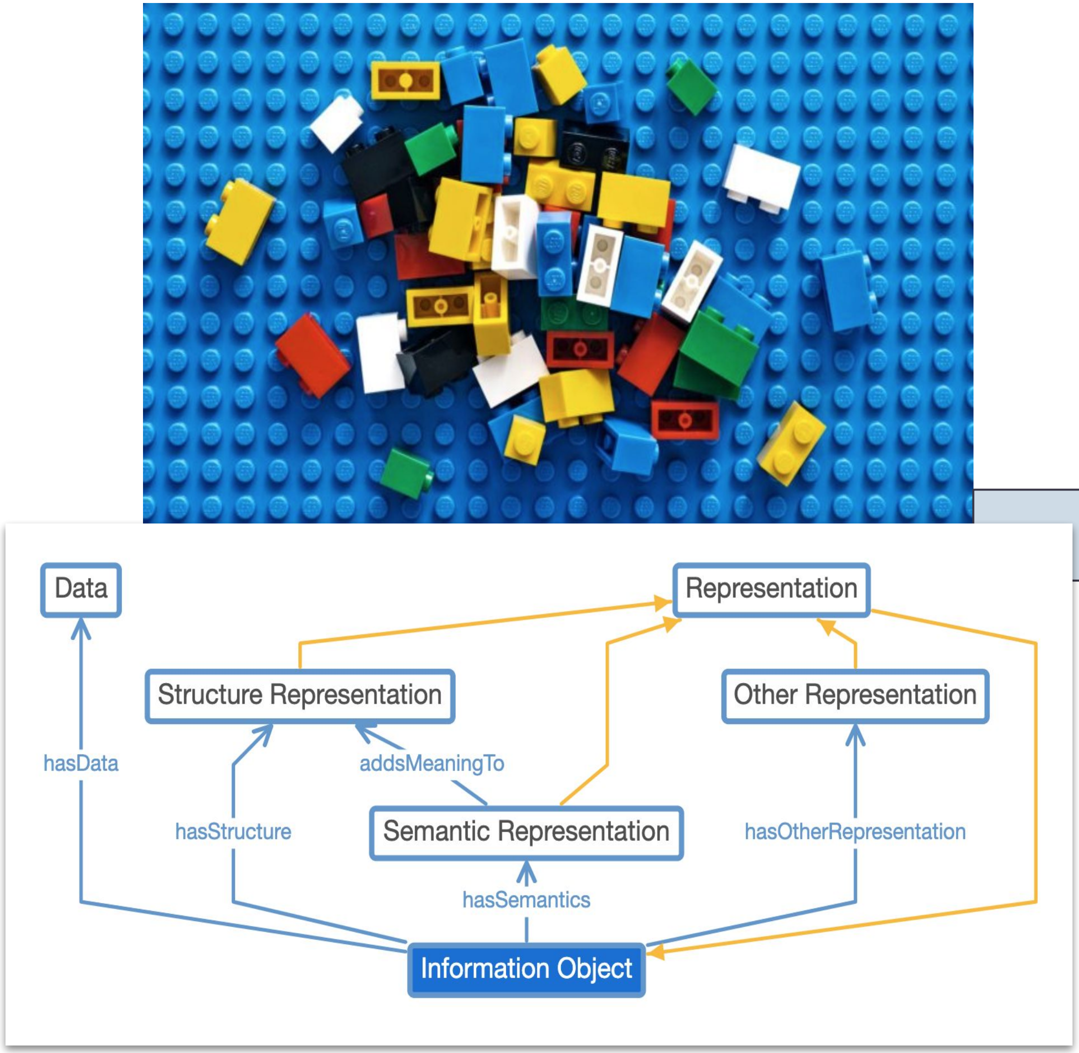


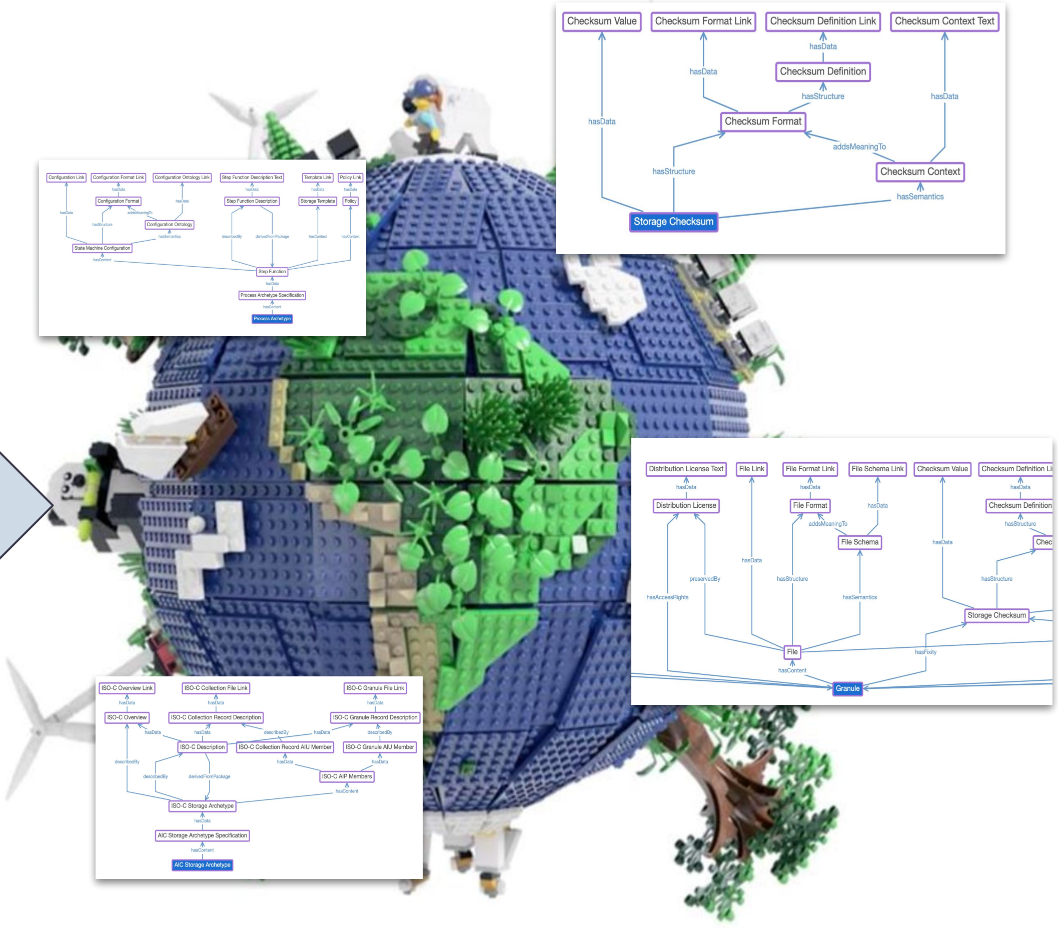
[Archetypes: Constraint-based Domain Models for Future-proof Information Systems](#) ISO 13606



A complete generic model for DTE-FS data

Illustrative Example - Fuzzy Semantics

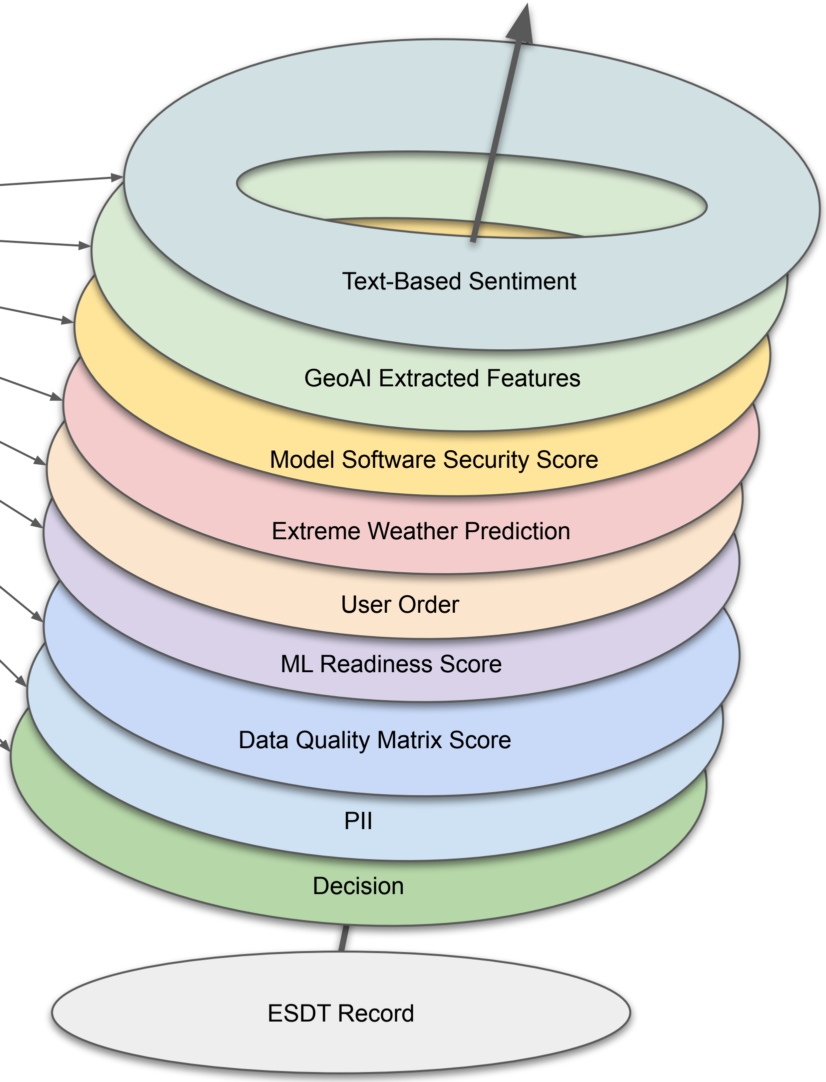




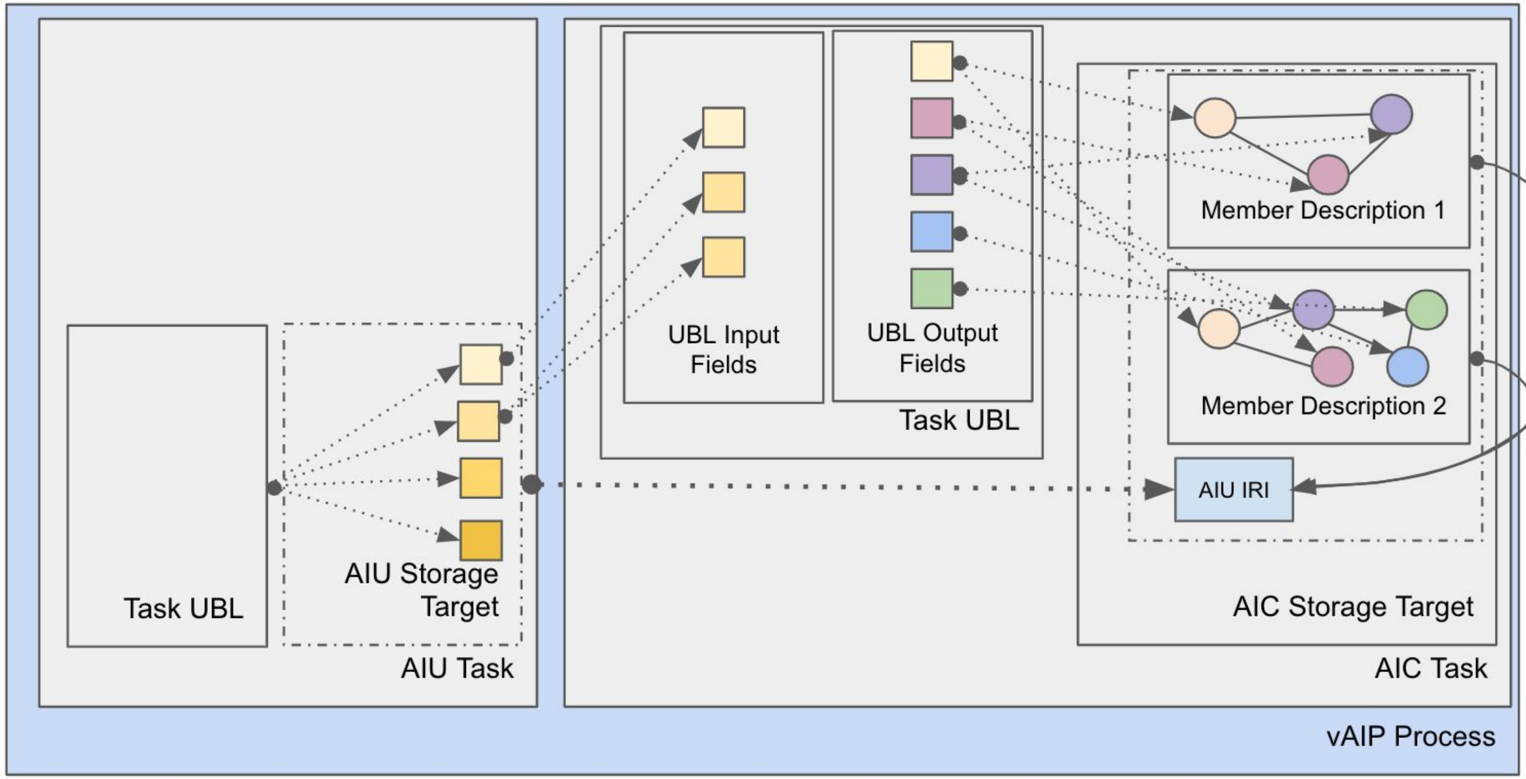
Critical Understanding #3: **Process** as a **Digital Thread**

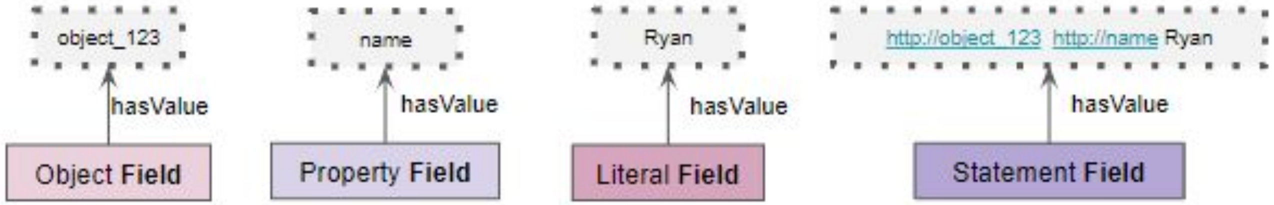
- Structured KOS
- FAIR
    - Findable
    - Accessible
    - Interoperable
    - Reusable
- CARE
    - Fine-grain access rights
- Knowledge Graph held
- Independent spaces
- API Discovery

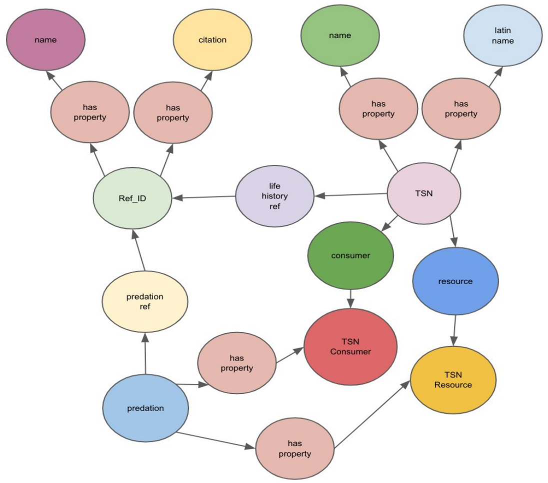
- Process as a digital thread allows us to compose identity, transformation, and delivery tasks that can use one or more of any preexisting, well-defined ontologies available on the semantic web (e.g. SSN, SOSO, Schema.org, SensorML, Dublin Core, GCMD, etc.), and/or make use of newly minted, user defined ontologies
- Process as a digital thread enables root cause analysis
- Process as a digital thread enables full provenance for reproducibility
- Process as a digital thread enables dynamic ‘at a distance’ composability
- Process as a digital thread enables process shopping
    - Pre-flight cost estimation via describe plans
- Process as a digital thread enables evolutionary plug-and-play

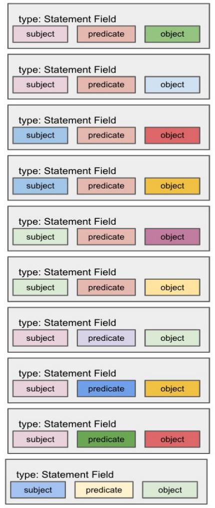


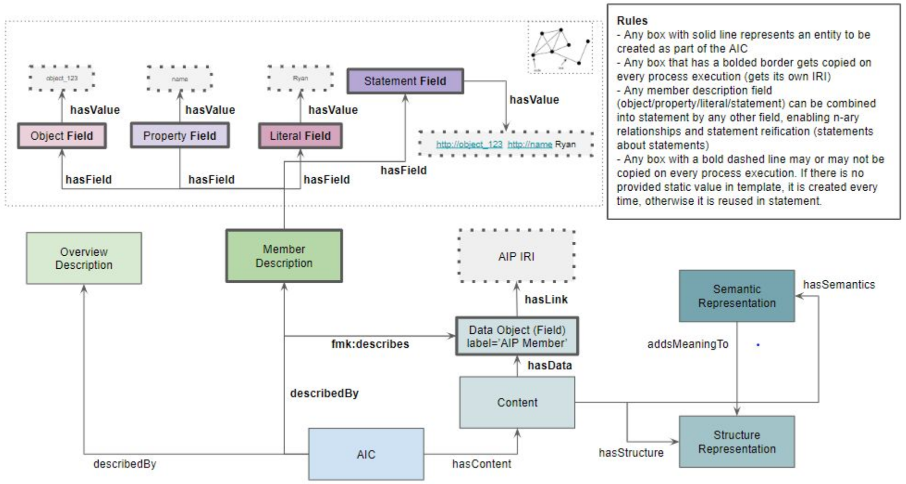
Illustrative Example - Process as a Digital Thread





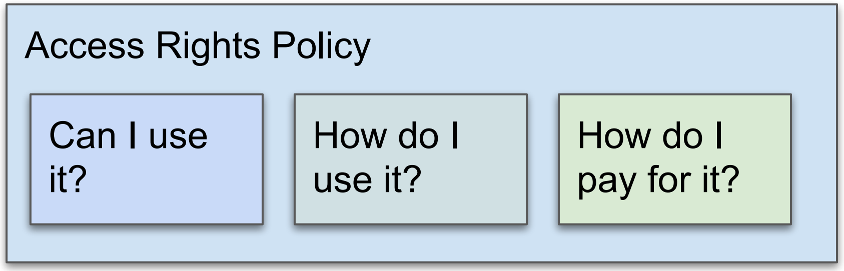


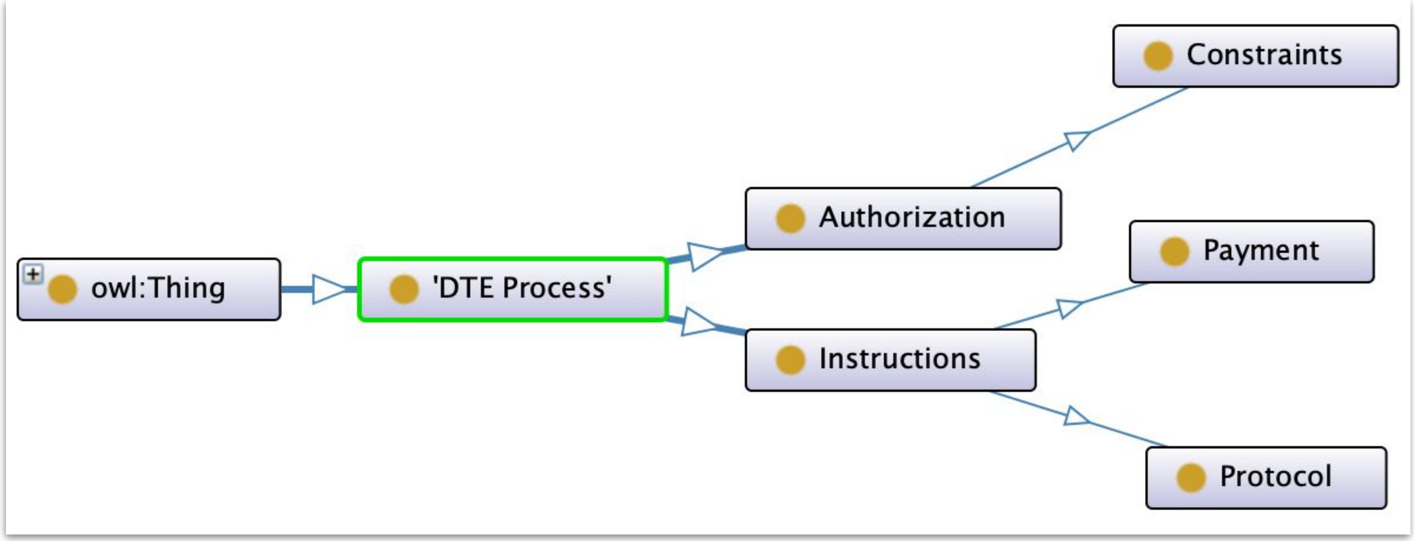




Critical Understanding #4: **Legal Interoperability**

- Legal interoperability deals with ability to
  - discover other processes
  - understand access rights of processes
  - understand payment requirements for using processes
  - use processes and pay for them automatically
- Approaching legal interoperability in this way, in combination with a process-as-data view, allows us to federate globally
- Legal interoperability allows us to democratize existing funding models
  - More agile
  - Better results
  - Credit where credit is due
  - Fair use
  - Trusted use





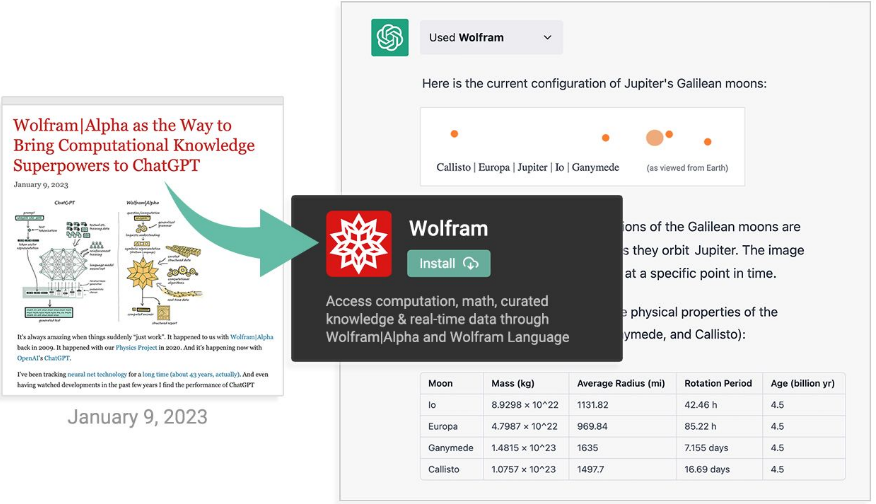
Tangible Takeaways - What Are We Enabling?

We are creating an architecture to host the emerging generation of disruptive technology in a way that harnesses it for trustworthy science and makes it available to all.

We are enabling new insights to answer our most challenging problems.

ChatGPT Gets Its "Wolfram Superpowers"!

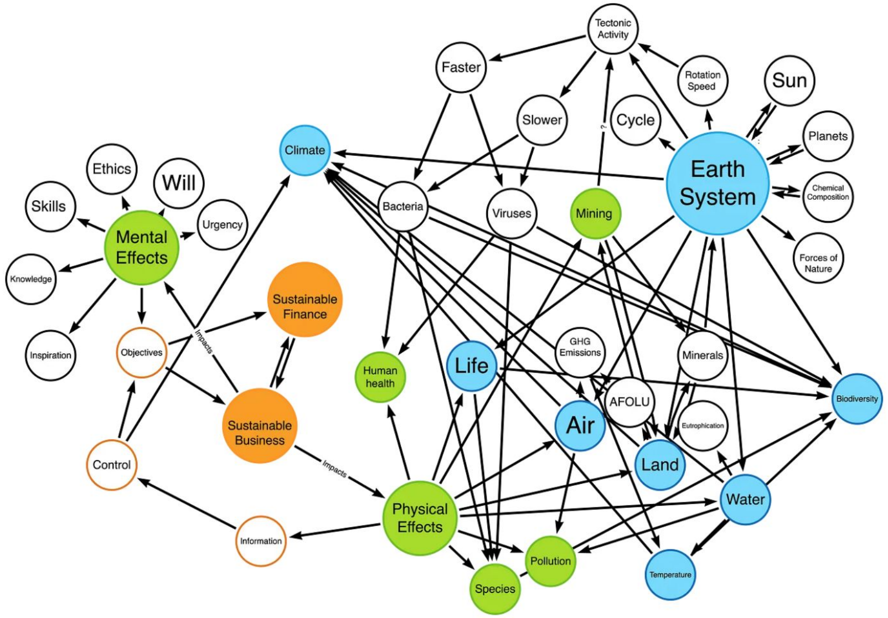
March 23, 2023



January 9, 2023

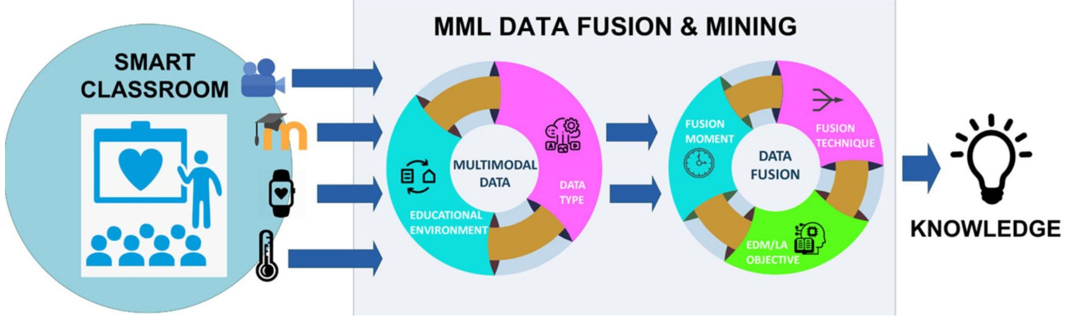
March 23, 2023

[ChatGPT Gets Its "Wolfram Superpowers"!]



Knowledge graph model of relationships between finance, business, and sustainability of the biosphere and the Earth Systems, © Olaf Brugman, 2022.

https://olafbrugman.medium.com/sustainable-business-and-the-earth-system-4aa33630950b



https://wires.onlinelibrary.wiley.com/doi/full/10.1002/widm.1458

What’s next?

- NOAA continues to socialize and coordinate integration with the framework in a controlled environment (the NESDIS Common Cloud Framework)
  - Refining implementation details
  - Assessing and improving performance
- Partnership contexts are refining and validating higher order interoperability and functional requirements
- Continuously mapping back to Geoverse goals and milestones to get a sense of gaps and timelines
- Tackling problem of legal interoperability using widespread collaborations

Reference and Backups

FGIF Tables

The following slides contain the pulled-out tables from the UN-GGIM Future Global Infrastructure (FGIF) Discussion Paper. Tables contain step changes and gap analysis tools for use in determining if the geoverse is being enabled or how to approach enablement in the case of identified gaps.

Organizational Migrations - Governance/Institutions

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Leadership	Strategies and plans on geospatial data management	Global interconnectivity to leverage knowledge creation opportunities
Institutional Arrangements	Traditional hierarchical SDI governance arrangements	Agile non-hierarchical inclusive multi-actor governance configurations
Value Proposition	Access to fundamental data	Affordable and equitable access to knowledge
Governance Model	SDI data governance models	Global Geospatial Knowledge Governance Framework

Figure 7. Governance and Institutions Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Policy/Legal

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Legislation	National policy and legal frameworks for the democratization of data	Global guidance for national policy and legal frameworks for the democratization of knowledge
Policies, Norms and Guides	Standalone geospatial policies and laws for data management, access and use.	Geospatial policies and laws interoperable with wider government digital policy and global knowledge management agendas
Governance and Accountability	A reliance on humans to comply with geospatial data policies and laws	Use of technology to enforce geospatial knowledge management and use, as well as internet compliance
Data Protection, Licensing and Sharing	Open data policy balanced with protection of sensitive material and respected rights	Knowledge creation and the ethical challenges of information bias, digital identities, usage and cybersafety

Figure 8. Policy and Legal Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Financial

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Business Model	Traditional bi-directional Purchaser/Provider Models	Decentralized autonomous business models enabled by advanced internet technologies
Opportunities	Creation of geospatial data to support the delivery of new products and services	Creation of geospatial analytics to support knowledge on-demand
Investment	Investment in geospatial data and interfaces for SDI programs and projects	Investment in machine-readable data, AI, blockchain etc. enabling participation in global digital connectivity
Benefits Realization	Economic development and societal benefits derived from geospatial products and services	New revenue and cost savings from tokenized multimodal business opportunities

Figure 9. Financial Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Data

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Data Themes	National data frameworks focusing on fundamental geospatial data themes	National use case frameworks contributing to priority challenges on a local to global scale
Custodianship, Acquisition and Management	Geospatial data to support the delivery of new products and services	Linked data and geoanalytics that enable knowledge on-demand
Data Curation and Delivery	Manual value-added data delivered via data catalogues	Automated real time knowledge delivered via AI and machine accessible data registries
Data Supply Chains	Centralised bi-directional supply chains	Decentralised multimodal communication interfaces

Figure 10. Data Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Innovation

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Technological Advances	Digitization and diversification of data sources, and cloud computing	4IR technologies, Internet, geoanalytics, semantic tools, sensor networks, AI and edge computing
Innovation and Creativity	Business innovation: data, products and services	Social innovation: knowledge on-demand and ethical human-centered design.
Process Improvement	Digital transformation, increased productivity and improved data quality	Enriched knowledge economies, responsive communications and enhanced reliability of knowledge
Bridging the Digital Divide	G2G relationships that deliver hardware, software and knowhow	Knowledge sharing that delivers inclusivity and digital equity for communities

Figure 11. Innovation Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Standards

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Standards Governance and Policy	A commitment to assess, establish, and maintain a common standards framework	A commitment to adopt standard models for knowledge representation
Technology and Data Interoperability	Voluntary standards for data and technology	Anticipatory regulations, FAIR data and human-centered standards for knowledge creation
Compliance Testing and Certification	Regular assessments, training, government mandates, performance metrics, testing and certification	Regulatory sandboxes, proof of concepts and incentives for deploying and scaling 4IR technologies
Community of Practice	Sharing and leveraging data and technology standards	Inclusive and participatory roles in data vocabularies, digital twins, and other 4IR standards development

Figure 12. Standards Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Partnerships

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Cross Sector and Interdisciplinary Cooperation	Investment, data and resource sharing	New horizons for innovation and knowledge creation
Private Sector and Academia Collaboration	Government led regulated public-private-partnerships	Private and academia sector led decentralized collaborations
Community Participation	Use of VGI and crowdsourcing to collect local information	Citizen sensing technologies that lead to new innovations and problem solving
International Collaboration	Strategic partnerships that support national initiatives and agendas	Collaborations that support both national and global innovations

Figure 13. Partnerships Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Capacity/Education

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Awareness	Advocacy and promotion on the value of geospatial information	Education and outreach on the potential of disruptive innovations using integrated data
Formal Education	Deep subject expertise in surveying, geospatial, geography and geodesy	Foundational concepts in computer and Internet science and 4IR information technologies
Professional Training	Lifelong learning and development through hands-on experiences	Intensive development in new and emerging paradigms
Entrepreneurship	Capacity development leading to innovation and new business ventures	Collaborative innovation hubs that stimulate growth in interconnected products, value chains and business models

Figure 14. Capacity and Education Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

Organizational Migrations - Communication/Engagement

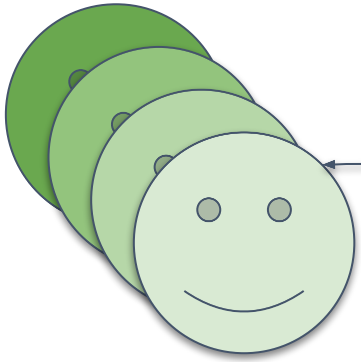
Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Stakeholder and User Engagement	Narrow focus on government user engagement	Broad spectrum, diverse and inclusive
Strategic Messaging	Limited brand awareness, complicated messaging and inconsistent terminology	Unified brand and terminology, and clear messaging that sparks conversations and imagination
Communication Strategy, Plans and Methods	Project and program focussed communications	Strategic, targeted and impactful communications that keep pace with changing times
Monitoring and Evaluation	Surveys and metrics on effectiveness and efficiency of communications	Knowledge analytics and metrics on participation rates, understanding and change in usage

Figure 15. Communication and Engagement Strategic Pathway – the Step Change

Source: UN-GGIM July 2022 Discussion Paper on Future Data Systems

NOAA System Details

Web Crawler - JSON-LD



Web Crawler Endpoint

https://ncei.nesdis.noaa.gov/archive/{{namespace}}/{{type}}/{{thing_id}}/

Example:
https://ncei.nesdis.noaa.gov/archive/records/aiu/abc_123.jsonld (full document)

context:{"http://rdf.org",...}
body: { "pattern": "http://ncei.nesdis.noaa.gov/archive/patterns/aiu/xyz_123.jsonld",
", "template": "...", "type": "AIU", "description": …,
"content": "…"

S3 Metadata Bucket

Namespace = **Core**
Reference Model Classes
Small and immutable-per-reference-model surface. Recursive classes provide ability to compose inherently interoperable structures

Namespace = **Patterns**
Unvalued Schema Individuals
Potential for ontologically rich augmentation via overloaded labeling and tagging

Namespace = **Templates**
Partially Valued Schema Individuals
Serves as a fast-query inference layer at data-stream resolution of descriptions and representation networks

Namespace = **Records**
Fully Valued Schema Individuals
Mesh layer, high write velocity, fully featured inferencing, rich membership content