

Model as the cyber-physical system driver

From deep learning to deep understanding

MBSE Lightning Round

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Imagine...

- ❖ You are a systems engineer in a large electric motor manufacturing company
- ❖ You just received an 8,754-page requirements document from a world-leading automobile producer for a new electric motor for their future 2030 and onward car
- ❖ Your boss gives you 2.5 days to respond with
 - ❖ Feasibility
 - ❖ A detailed conceptual model of the car
- ❖ You feed the 8,754-page requirements document into AGILO
- ❖ Within 2:13 min. you get a detailed model and a list of 234 mismatching requirements, each with an augmented explanation



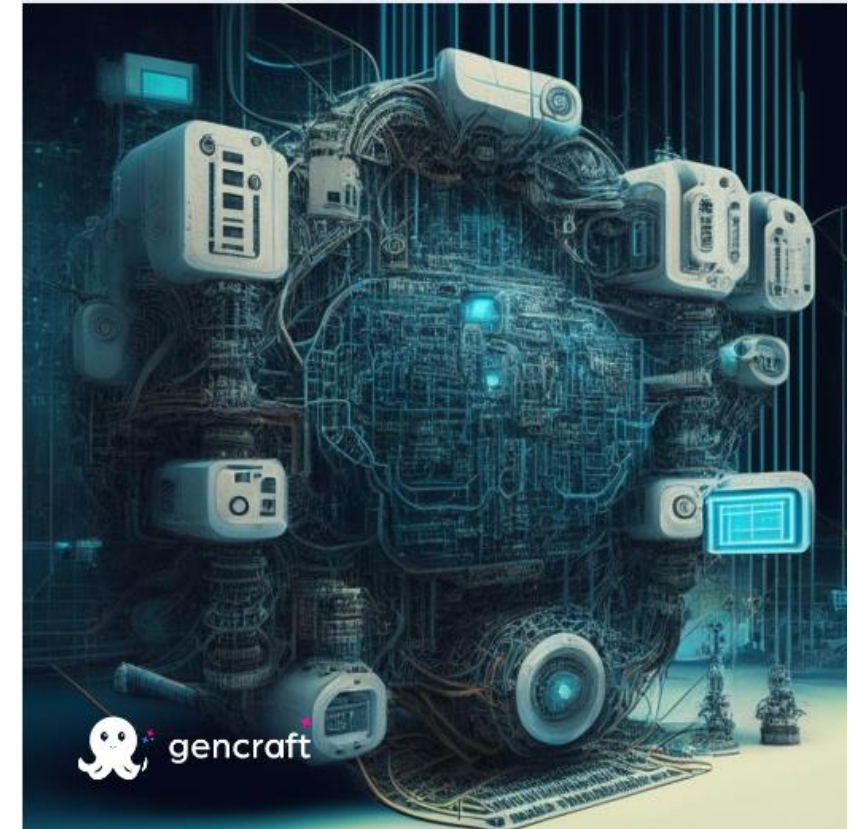
Credit: [Lifestyle Asia](#)

What is AGILO?

- ❖ Artificial general intelligence (AGI) systems are systems with intelligence that **compares with, and ultimately perhaps surpasses**, that of human beings (Goertzel, 2014).
- ❖ Large language models (LLMs), also known as **foundation models**, are neural networks, typically with many billions of weights, trained on large quantities of unlabeled text and/or images
- ❖ Object-Process Methodology (OPM) ISO 19450 is an MBSE language and methodology

❖ AGILO:

Artificial **G**eneral **I**ntelligence with **L**LM and **O**PM



Created by [GenCraft](#) to the prompt: “An image of an agile engineered complex socio-technical and cyber-physical system”

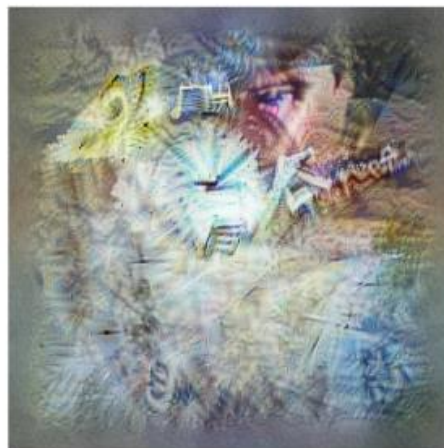
BriVL – Bridging-Vision-and-Language (Fei et al., 2022)

- ❖ trained for image-text matching
- ❖ demonstrates cross-domain learning
- ❖ transfer, and even
- ❖ imagination abilities:

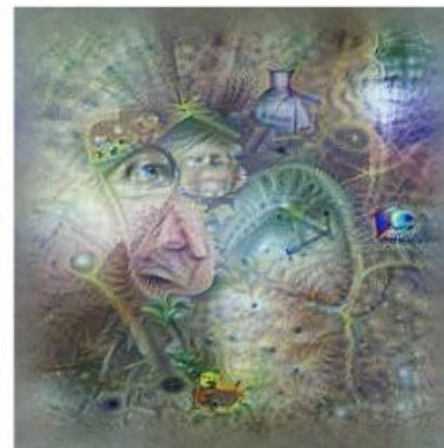
a



"nature"



"time"



"science"



"dream"

b



"Every cloud has
a silver lining."



"Let life be beautiful
like summer flowers."



"A few peach flowers
start to blossom outside
the bamboo grove."



"The sun goes down below
the mountains, and the Yellow
River flows into the sea."

- ❖ The new LLM generation is **bimodal**:
- ❖ **Text and Vision**

“Large language models fuse text and vision in marvelous ways”



A new cohort of LLMs

- ❖ From “*Sparks of Artificial General Intelligence*,” (Bubeck et al., 2023): “GPT-4 performs ***strikingly close to human-level performance***,” making it “*part of a new cohort of LLMs that exhibit **more general intelligence** than previous AI models.*”
- ❖ LLMs exhibit exceptional and **fast improving performance** on a wide range of tasks, and they can be harnessed to carry out feats that were unfathomable just a few years back, **limited only by human imagination.**

What has MBSE got to do with this?

- ❖ Can we feed a foundation model with a huge system requirements document and ask it to architect and design the system for us?
- ❖ No!!!
- ❖ Why?
- ❖ Because of LLMs' **explainability** and **interpretability** problems
- ❖ **eXplainable AI (XAI)** is required for **reasoning** about such tasks as **assigning responsibility** when an AI system makes a wrong decision that might be **fatal**, e.g., autonomous driving, design of a new manned mission to Mars...

Interpretability vs. Explainability

- ❖ **Interpretability:** humans' ability to understand and make sense of LLMs' predictions or decisions. *"...physicists, chemists and biologists are interested in identifying the hidden laws of nature ... Thus, only models which are explainable are useful in this domain."* (Samek et al., 2017)
- ❖ Similarly, engineers must not rely on a systems that cannot explain its decisions!
- ❖ **Explainability:** refers to the LLM's ability to provide a causal understanding of why and how it arrived at a certain prediction or decision.
- ❖ A model can be explainable but lack interpretability, and vice versa.
- ❖ Our focus: **Enhancing interpretability**—enabling humans to understand LLMs' output.

Causality: Establishing the relationship between cause and effect

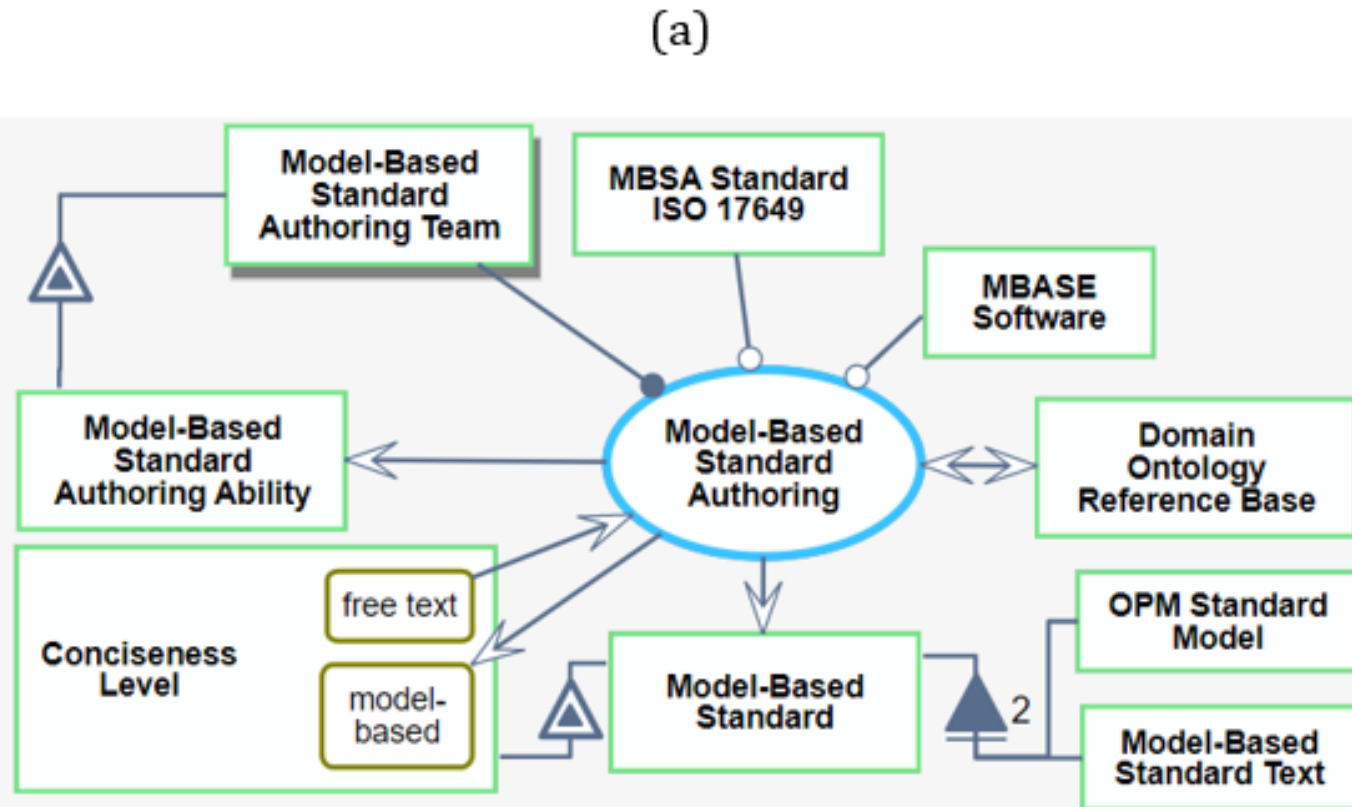
- ❖ Closely related to **interpretability**
- ❖ Can explain **relationships** between **variables** and **predict** future **events**
- ❖ Key concept in science, engineering, philosophy, psychology, and economics.
- ❖ Causal models are necessary to explain causality (Pearl, 2018).
- ❖ Knowledge-intensive, cognitively demanding human activities, such as scientific research and engineering of complex systems, mandate that each step along the way be subject to humanly understandable, logical argumentation
- ❖ Must be based on causality, common sense, and first-hand experiences of the real, physical world.

OPM conceptual models are causal models!

OPM models are especially **adept** at providing **cause-and-effect-based explanations** because they:

- (1) distinguish **physical** from **informatical** things
- (2) They are bimodal – visual diagrams (OPD) & auto-generated NL text (OPL)
- (3) explicate what **objects** are required for each process as enablers or inputs,
 - how object states change
 - what output objects result from each process
- (4) can specify such **chains of events** at any desired level of detail,
 - from a high-level view of a complex system
 - to its miniscule hardware and software components, and
 - from an entire organism to its organs, cells, and the molecular interactions in them.

Example: ISO 17649 – Model-Based Standards Authoring – OPM Model System Diagram (SD)



(b)

Conciseness Level of **Model-Based Standard** can be **free text** or **model-based**.

Model-Based Standard consists of **Model-Based Standard Text**, **OPM Standard Model** and two more parts.

Model-Based Standard exhibits **Conciseness Level**.

Model-Based Standard Authoring Team exhibits **Model-Based Standard Authoring Ability**.

Model-Based Standard Authoring changes **Conciseness Level** of **Model-Based Standard** from **free text** to **model-based**.

Model-Based Standard Authoring Team handles **Model-Based Standard Authoring**.

Model-Based Standard Authoring requires **MBASE Software** and **MBSA Standard ISO 17649**.

Model-Based Standard Authoring affects **Domain Ontology Reference Base**.

Model-Based Standard Authoring yields **Model-Based Standard** and **Model-Based Standard Authoring Ability** of **Model-Based Standard Authoring Team**.

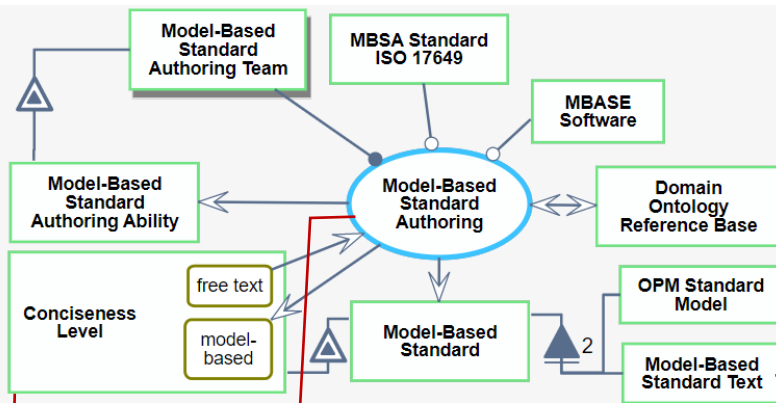
Figure 15. (a) SD of Model-Based Standards Authoring (b) the corresponding OPL paragraph

The OPL of the System Diagram (SD) interpreted by ChatGPT



An LLM such as ChatGPT can be used to rephrase the OPL into a humanly readable format.

Here is what ChatGPT produced in the first trial (without the colors):



The **Model-Based Standards Authoring** process involves creating standards using a model-based approach. The standards are composed of several components, including the **Model-Based Standard Text**, **OPM Standard Model**, and two additional parts.

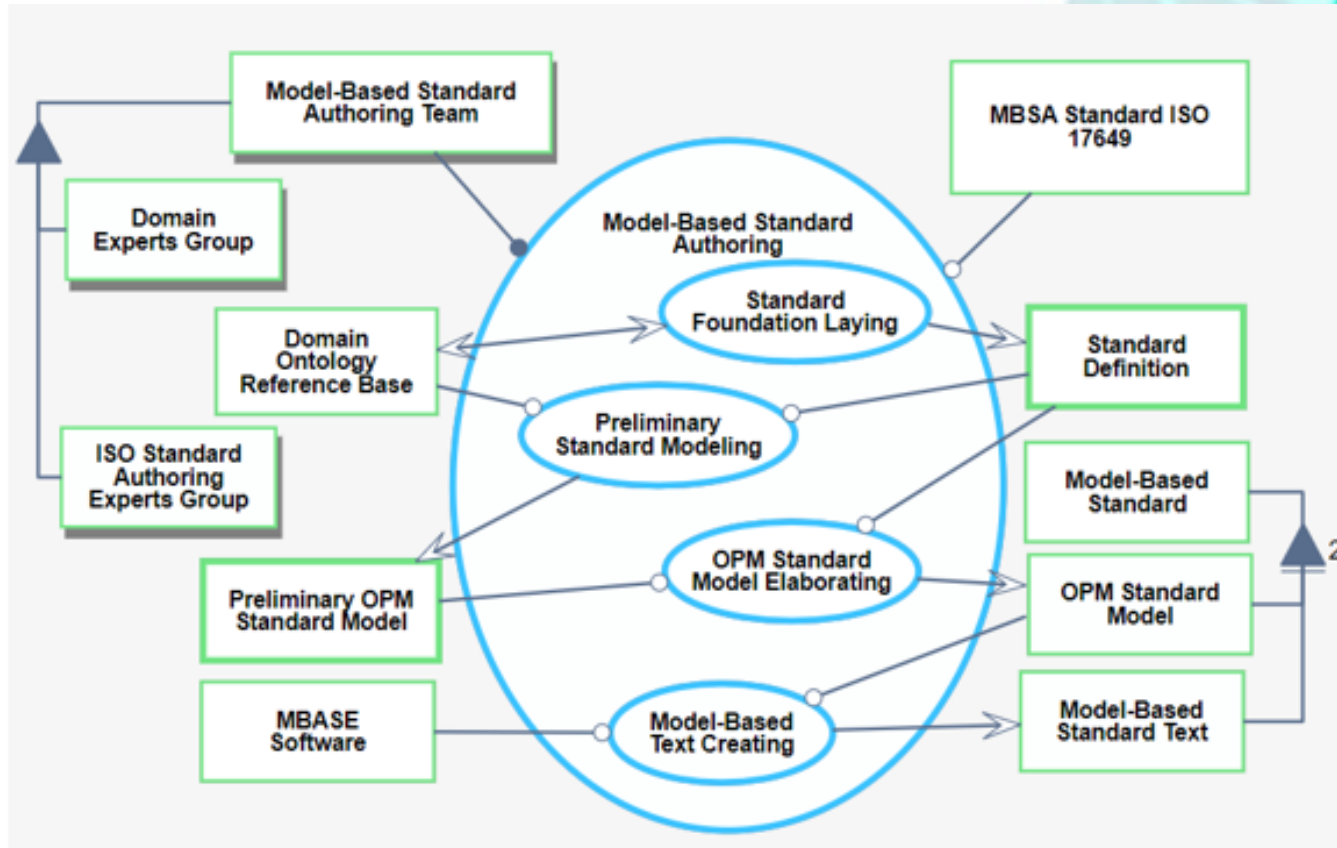
One important aspect of a **Model-Based Standard** is its **Conciseness Level**, which can be either expressed as free text or in a model-based format. The **Model-Based Standard Authoring Team** is responsible for creating these standards and possesses the necessary skills and expertise in **model-based standard authoring**.

During the authoring process, the team transforms the **Conciseness Level** of the **Model-Based Standard** from **free text** to a **model-based** representation. This conversion is facilitated by using the **MBASE Software** and adhering to the **MBSA Standard ISO 17649**, which provide tools and guidelines for **model-based standard authoring**.

The act of authoring the **Model-Based Standard** has implications beyond the standard itself. It also affects the **Domain Ontology Reference Base**, which is a collection of knowledge and concepts specific to the domain addressed by the standard.

Ultimately, the **Model-Based Standards Authoring** process results in the creation of a **Model-Based Standard**, which includes the **Model-Based Standard Text**, **OPM Standard Model**, and the other associated components. Additionally, it enhances the **Model-Based Standard Authoring Ability** of the authoring team, as they gain experience and expertise in creating model-based standards.

SD1: Model-Based Standards Authoring in-zoomed



Model-Based Standard Authoring from SD zooms in SD1 into **Standard Foundation Laying, Preliminary Standard Modeling, OPM Standard Model Elaborating, and Model-Based Text Creating**, which occur in that time sequence.

Model-Based Standard consists of **Model-Based Standard Text, OPM Standard Model** and two more parts.

Model-Based Standard Authoring Team consists of **Domain Experts Group** and **ISO Standard Authoring Experts Group**.

Model-Based Standard Authoring Team handles **Model-Based Standard Authoring**.

Model-Based Standard Authoring requires **MBSA Standard ISO 17649**.

Standard Foundation Laying affects **Domain Ontology Reference Base**.

Standard Foundation Laying yields **Standard Definition**.

Preliminary Standard Modeling requires **Domain Ontology Reference Base** and **Standard Definition**.

Preliminary Standard Modeling yields **Preliminary OPM Standard Model**.

OPM Standard Model Elaborating requires **Preliminary OPM Standard Model** and **Standard Definition**.

OPM Standard Model Elaborating yields **OPM Standard Model**.

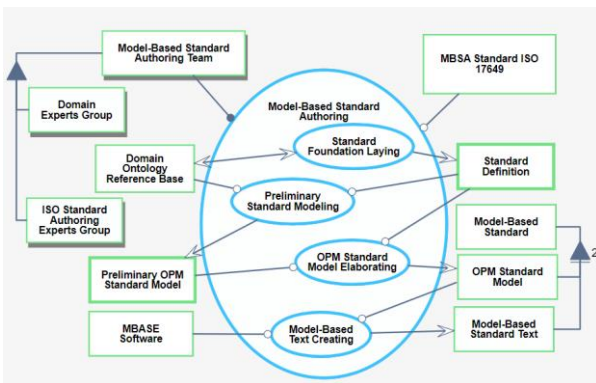
Model-Based Text Creating requires **MBASE Software** and **OPM Standard Model**.

Model-Based Text Creating yields **Model-Based Standard Text**.

Figure 17. SD1: Model-Based Standard Authoring in-zoomed

The OPL of SD1 interpreted by ChatGPT

Here is the text ChatGPT produced for SD1:



The **Model-Based Standards Authoring** process can be further elaborated as follows:

Model-Based Standard Authoring begins by zooming in on SD1 (Standard Development) and focuses on the various stages involved in creating a **model-based standard**. These stages occur in a specific time sequence and include **Standard Foundation Laying**, **Preliminary Standard Modeling**, **OPM Standard Model Elaborating**, and **Model-Based Text Creating**.

The **Model-Based Standard** comprises several components, namely the **Model-Based Standard Text**, **OPM Standard Model**, and two additional parts.

The **Model-Based Standard Authoring Team** is composed of two groups: the **Domain Experts Group** and the **ISO Standard Authoring Experts Group**. Together, they handle the entire process of model-based standard authoring, leveraging their expertise in their respective domains and standardization practices.

To facilitate the authoring process, the team relies on the guidance provided by the **MBSA Standard ISO 17649**, which serves as a framework for model-based standard development. The initial stage, **Standard Foundation Laying**, plays a crucial role as it lays the groundwork for the standard by defining its scope, objectives, and requirements. It also has an impact on the **Domain Ontology Reference Base**, which represents the collection of domain-specific knowledge and concepts. The output of the **Standard Foundation Laying** stage is the creation of a **Standard Definition**, which provides a clear and concise description of the standard's purpose and content.

Moving forward, the **Preliminary Standard Modeling** stage requires the utilization of both the **Domain Ontology Reference Base** and the **Standard Definition**. This stage involves creating an initial model that captures the essential elements and relationships of the standard. The output of this stage is the **Preliminary OPM Standard Model**.

The subsequent stage, **OPM Standard Model Elaborating**, builds upon the preliminary model by further refining and elaborating the **OPM Standard Model**. This stage requires the involvement of the **Preliminary OPM Standard Model** and the **Standard Definition** as inputs. The output of this stage is the finalized **OPM Standard Model**, which represents a comprehensive and detailed model of the standard.

Finally, **Model-Based Text Creating** involves the use of the **MBASE Software** and the **OPM Standard Model**. This stage focuses on transforming the **OPM Standard Model** into the **Model-Based Standard Text**. The output of this stage is the finalized **Model-Based Standard Text**, which represents the standard in a textual format, ready for dissemination and implementation.

By following this sequential process, the **Model-Based Standards Authoring team** can create high-quality, model-based standards that capture the essential elements of the standardization domain.

The complementary attributes of LLM and OPM

Attribute \ Model	Attribute value	
	LLM	OPM
Automation Level	high (no human intervention after fine-tuning)	low (human professionals build the models)
Interpretability	low (inability to explain the result, conclusion, or recommendation)	high (built-in causality of how processes transform objects)
Causality-based querying ability	low (inability to query for causality)	high (via graph databases; Medvedev et al., 2021)
Underlying paradigm	neural networks, statistics	universal object-process ontology
Required preparation	model pretraining & fine-tuning	OPM model generation
Key applications	natural language processing (NLP) tasks: rephrasing, translation ...	formal specification & communication of systems & phenomena
Output knowledge representation modality	textual: natural language; visual: images	visual: diagrammatic – OPDs; textual: plain English – OPL
Required input	natural language text	

First Images from the James Webb Space Telescope

July 12, 2022

A composite image of the Cosmic Cliffs in the Carina Nebula, created with the Webb telescope's NIRCam and MIRI instruments. (Image credit: NASA, ESA, CSA, and STScI)



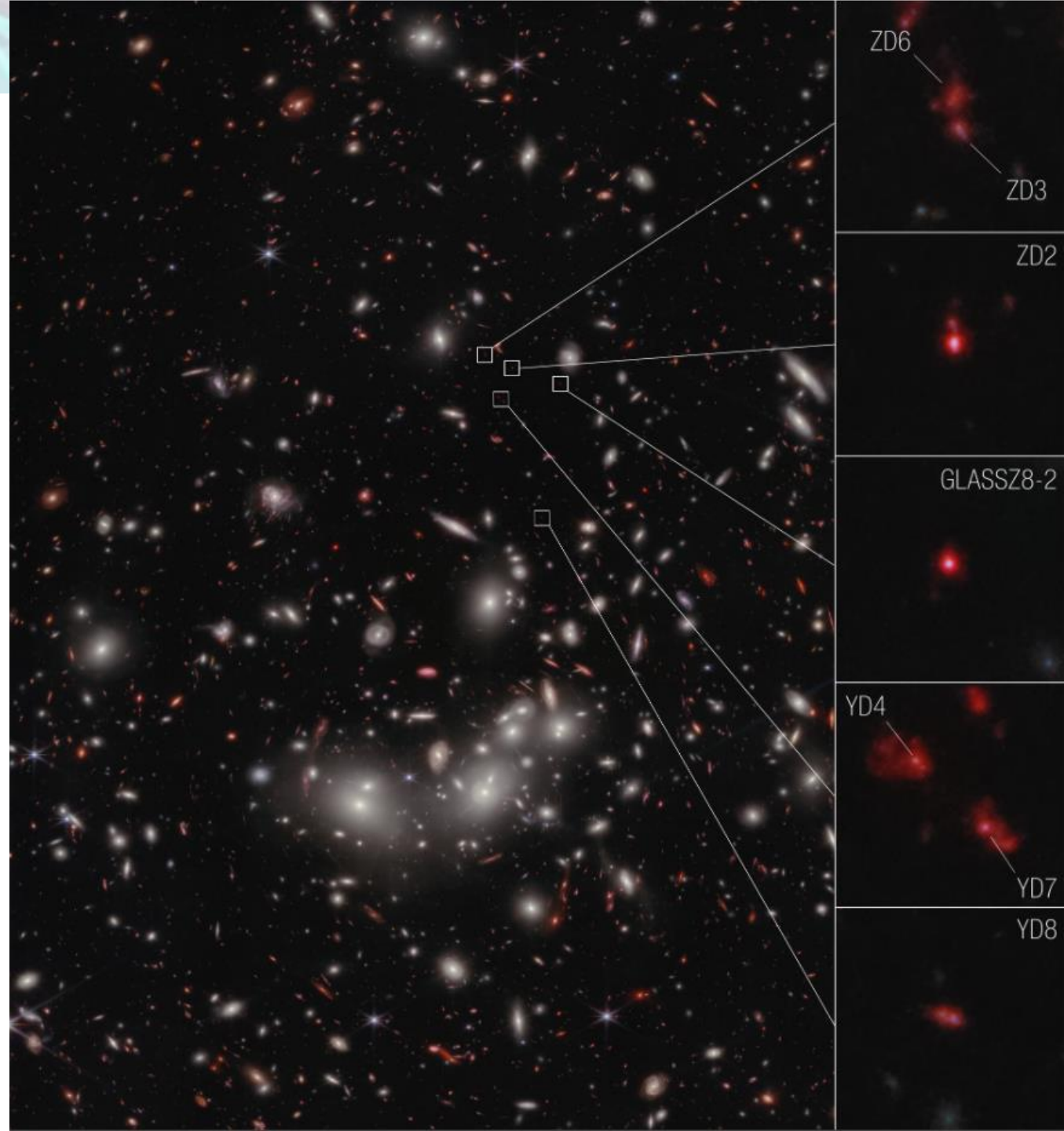
24 April 2023

Webb reveals early-Universe prequel to huge galaxy cluster

The seven galaxies highlighted in this image from the NASA/ESA/CSA Telescope have been confirmed to be at a distance that astronomers refer to as **redshift 7.9**, which correlates to **650 million years after the big bang**. This makes them the **earliest galaxies** yet to be spectroscopically confirmed as part of a developing cluster.

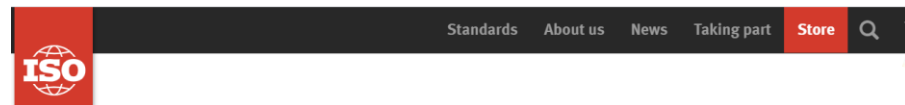
Webb's Near-Infrared Spectrograph ([NIRSpec](#)) instrument precisely measured the distances and cosmologists determined that **the galaxies are part of a developing cluster**.

Before Webb, astronomers did not have high resolution imaging or spectral infrared data available to do this type of science.



Object-Process Methodology – OPM ISO 19450: Both a **Language** and a **Methodology**

- ❑ OPM is a MBSE **methodology** that uses a formal modeling **language**
- ❑ The OPM language is
 - ❑ Based on a **minimal universal ontology** of **objects** and **processes**
 - ❑ **Bimodal** – graphical and textual complementing each other
 - ❑ **Domain agnostic** – can specify systems of all kinds
 - ❑ **ISO 19450** (2015; 2023)



ICS > 25 > 25.040 > 25.040.01

ISO/PAS 19450:2015

Automation systems and integration – Object-Process
Methodology



AGILO: Transforming MBSE into the Next Generation


- ❑ The ongoing research aims to transform how MBSE is conducted
 - ❑ by synergistically combining LLMs and OPM conceptual models
 - ❑ into AGILO—a disruptive visual and textual KM system that leverages the complementary traits that each approach offers.
- ❑ AGILO leverages LLMs' exquisite automatic performance while providing for the acutely missing cause-and-effect argumentation that OPM models enable.
 - ❑ OPM's drawback of labor-intensive model generation is removed thanks to LLM's automation
 - ❑ LLM's drawback—its lack of interpretability, is eliminated thanks to OPM's innate explanatory power.

AGILO: Three development stages

- ❑ Converting free natural language text to an OPM model
 - ❑ LLM selecting & fine-tuning
 - ❑ Converting systems knowledge (e.g., requirements) into OPM models
- ❑ System architecture and scale-up
 - ❑ Problem model vs. solution models and their evaluation
 - ❑ Enriching solution models by considering similar patterns from other domains
- ❑ MBSE knowledge management, creativity fostering, usability, and user experience
 - ❑ Model repository managing
 - ❑ Creativity & inventiveness fostering
 - ❑ Unparalleled user experience


Finetuning for the NL2OPL NLP task

The finetuning dataset is prepared by paraphrasing OPL sentences into NL ones:

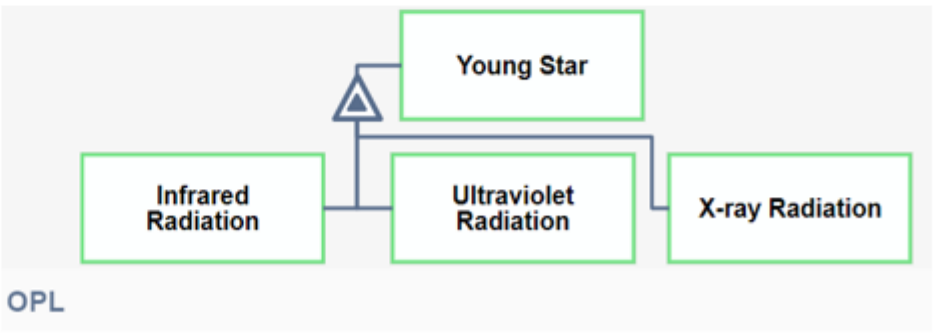
OPL	Paraphrased sentence
<p>Universal Knowledge Managing changes Knowledge Management Mode of Humanity from text-based to text- & graph-based.</p> 	<ol style="list-style-type: none"> (1) When Universal Knowledge Managing is implemented, Humanity's Knowledge Management Mode shifts from being solely text-based to incorporating text and graphs. (2) The management of universal knowledge alters humanity's mode of managing knowledge from text-only to a combination of text and graphs.

Finetuning for the NL2OPL NLP task

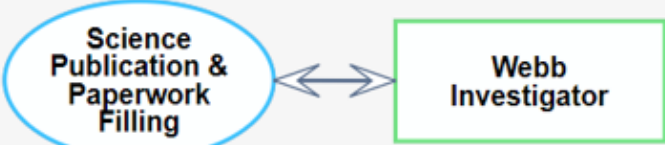


- ❖ The finetuning dataset of (NL, OPL) pairs is prepared by paraphrasing OPL sentences into NL ones.
- ❖ Below, two (NL, OPL) pairs were generated:

OPL	Paraphrased sentence
<p>Universal Knowledge Managing changes Knowledge Management Mode of Humanity from text-based to text- & graph-based.</p> 	<p>(1) When Universal Knowledge Managing is implemented, Humanity's Knowledge Management Mode shifts from being solely text-based to incorporating text and graphs.</p> <p>(2) The management of universal knowledge alters humanity's mode of managing knowledge from text-only to a combination of text and graphs.</p>

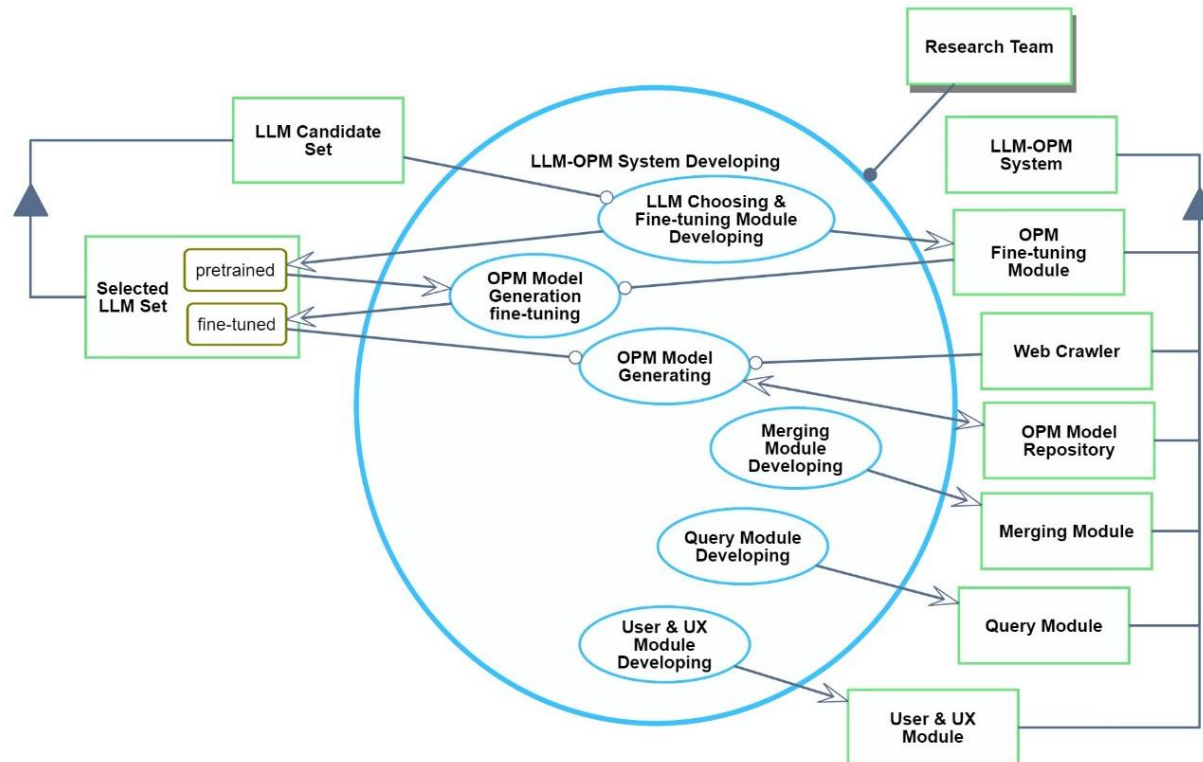
Syntactic and semantic correctness of NL2OPL-generated OPL sentence examples

	Source NL sentence	NL2OPL-generated OPL sentence	OPL Syntax OK?	Same Semantics?
1	Most Common Star Type, red dwarf, yields Rocky Exoplanet Orbit.	Red Dwarf Star exhibits Red Dwarf Star and two more attributes.	+	-
2	Cool Star, such as red dwarf, requires Closest Orbit of Planet to hug it closely enough to maintain Liquid Water.	Planet can be warm or cool.	+	-
3	Such stars are also active, particularly when they are young, releasing ultraviolet and X-ray radiation that could destroy planetary atmospheres.	<p>Young Star exhibits Infrared Radiation, Ultraviolet Radiation and X-Ray Radiation.</p>  <p>OPL</p> <p>Young Star exhibits Infrared Radiation, Ultraviolet Radiation and X-ray Radiation.</p>	+	+

Syntactic and semantic correctness of NL2OPL-generated OPL sentence examples

	Source NL sentence	NL2OPL-generated OPL sentence		OPL Syntax OK?	Same Semantics?
7	Many Webb investigators, however, are also taking advantage of the way that the scientific publication landscape has changed in the last decade.	Science Publication & Paperwork Filling affects Webb Investigator.	 <p>OPL</p> <p>Science Publication & Paperwork Filling affects Webb Investigator.</p>	+	+
8	Scientific peer review is a long-established, quality-control system, where new scientific discoveries are scrutinized by experts before they are published in a journal.	Research & Approving yields Published Paper.	 <p>OPL</p> <p>Research & Approving yields Published Paper.</p>	+	+
9	NASA relies on this peer-review process to ensure quality and accuracy of scientific results before sharing them with the public.	Peer Review Performing yields Quality & Accuracy of NASA Science Report at state high.	 <p>OPL</p> <p>NASA Science Report can be high or low. Peer Review Performing yields NASA Science Report at state high.</p>	+	+

Overview of the envisioned AGILO system



(a) OPL: Research Team handles LLM-OPM System Developing. LLM-OPM System Developing requires LLM Candidate Set. LLM-OPM System Developing from SD zooms in SD1 into LLM Choosing & Fine-tuning Module Developing, OPM Model Generation fine-tuning, OPM Model Generating, Merging Module Developing, Query Module Developing, and User & UX Module Developing, which occur in that time sequence. Selected LLM Set can be fine-tuned or pretrained. LLM Candidate Set consists of Selected LLM Set. LLM-OPM System consists of Merging Module, OPM Fine-tuning Module, OPM Model Repository, Query Module, User & UX Module and Web Crawler. Research Team handles LLM-OPM System Developing. LLM Choosing & Fine-tuning Module Developing requires LLM Candidate Set. LLM Choosing & Fine-tuning Module Developing yields OPM Fine-tuning Module and Selected LLM Set at state pretrained. OPM Model Generation fine-tuning changes Selected LLM Set from pretrained to fine-tuned. OPM Model Generation fine-tuning requires OPM Fine-tuning Module. Merging Module Developing yields Merging Module. User & UX Module Developing yields User & UX Module. OPM Model Generating requires Web Crawler and Selected LLM Set at state fine-tuned. OPM Model Generating affects OPM Model Repository. Query Module Developing yields Query Module.

(b) Paraphrased NL Text: The LLM-OPM System is developed by a research team and involves several modules. The first step is to choose a set of LLM candidates, which is used in the LLM Choosing & Fine-tuning Module Developing process to develop the OPM Fine-tuning Module and the Selected LLM Set at a pre-trained state. The OPM Model Generation fine-tuning module is then used to fine-tune the Selected LLM Set, which requires the OPM Fine-tuning Module. The Merging Module is developed separately, as is the Query Module and the User & UX Module. Finally, the OPM Model Generating module requires the Web Crawler and the Selected LLM Set at a fine-tuned state [to generate the OPM Model], which affects the OPM Model Repository.

In summary, the process of developing the LLM-OPM System involves selecting a set of LLM candidates, fine-tuning the LLM set, generating the OPM model, merging the modules, developing the query and user modules, and utilizing a web crawler. The research team is responsible for overseeing this entire process.