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# A knowledge-driven structural modeling formalism: fresh perspective

Imadeddine Laouici

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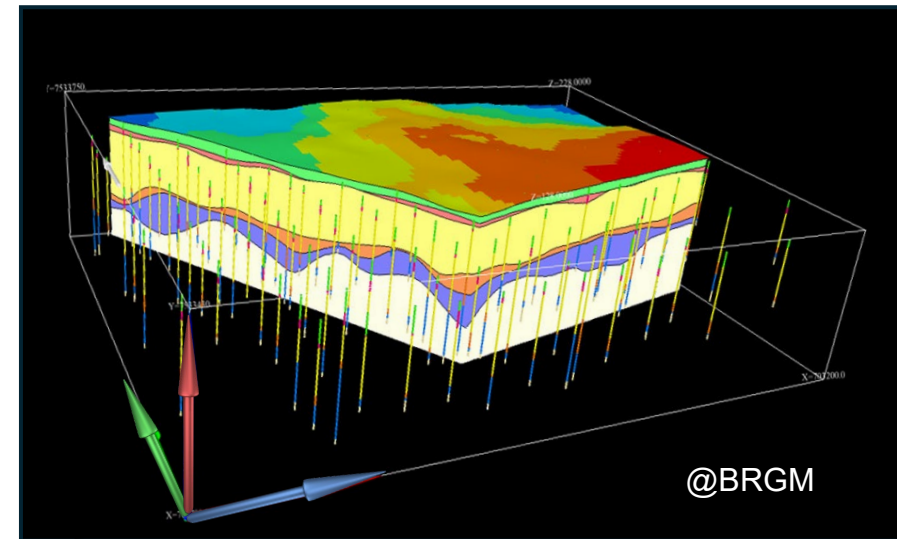


## Geomodels: Overview

# Structural models and their usage

Three-dimensional representations of the subsurface architecture (Wellmann and Caumon, 2018)

- Understanding Geological History
- Resource Exploration
- Groundwater Management
- Geological Hazard Assessment
- Engineering and Construction



~~This is a structural geomodel~~

This is a geometric representation of a structural geomodel

## Software ?



Loop3D/  
LoopStructural



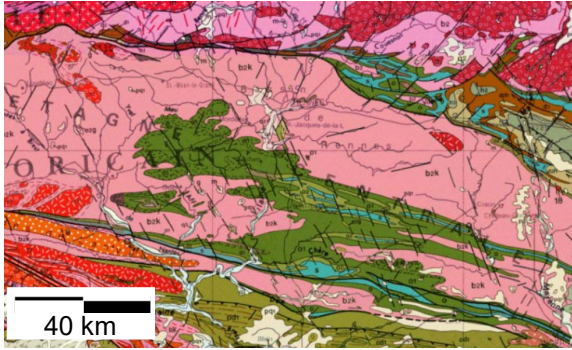
Shared earth—critical insight

Information Géologique  
Modélisation et visualisation

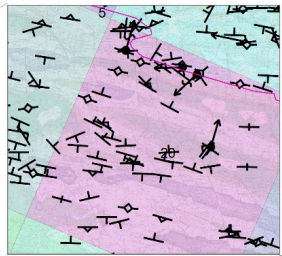


## Geomodels: Systems & Interpolation-based paradigm

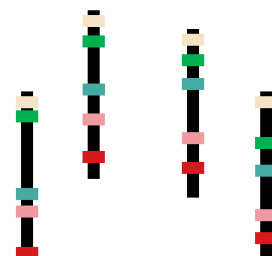
### Typical geomodelling inputs



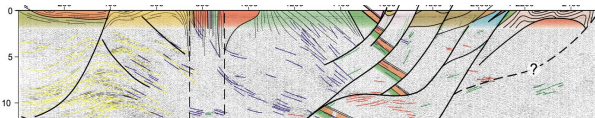
Geological map of the Central Armorican Domain at 1:1,000,000 scale ( source BRGM)



Field measurements  
(ISTO report)

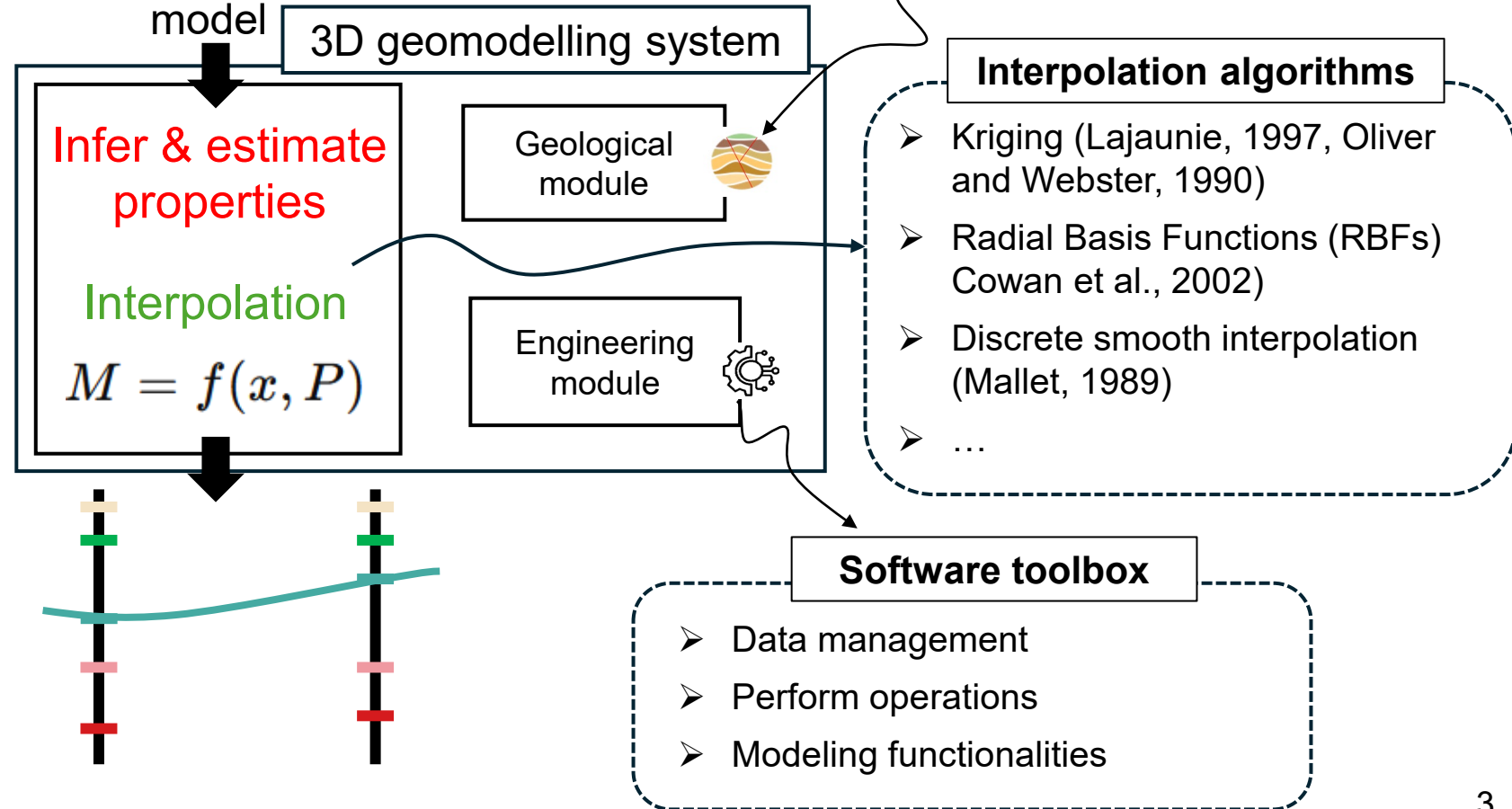


Borehole data

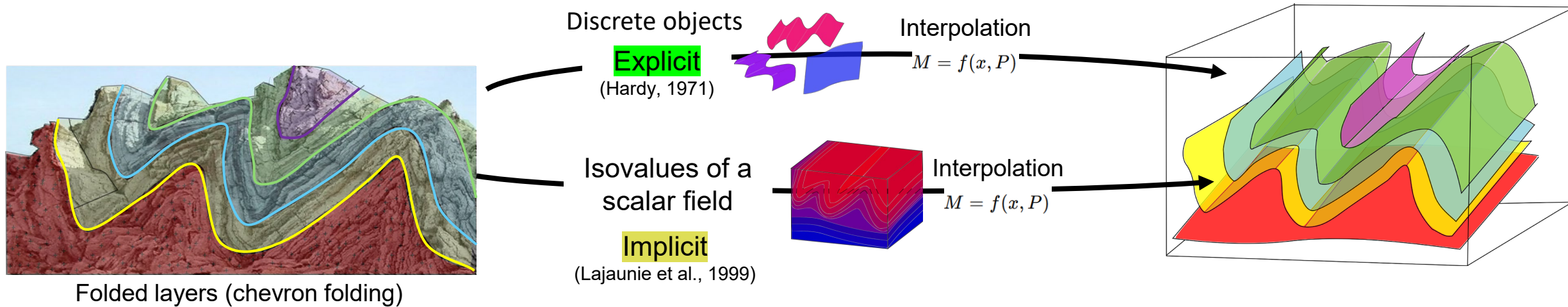


Seismic profile Armor2 interpreted (Gumiaux 2003)

Volume of inputs  
< 0.1 %  
volume of the  
model



## Geomodels: Knowledge incorporation & limitations



Folded layers (chevron folding)

### Geological aspects

- Succession of strata

---

- Continuity of surfaces (topology)

---

- Thickness (constant vs variable)

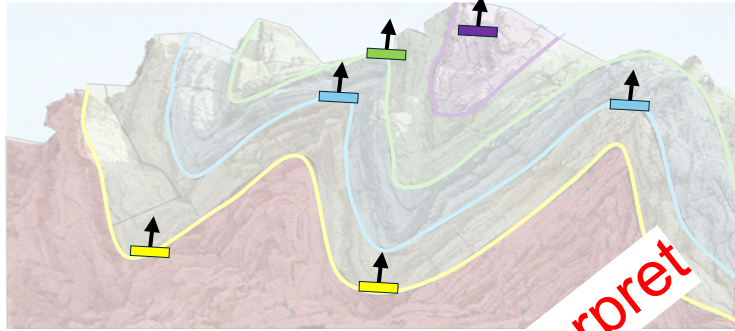
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- **Folds**

### Limitations during model construction

- Restriction in integrating geological knowledge

## Geomodels: Knowledge incorporation & limitations



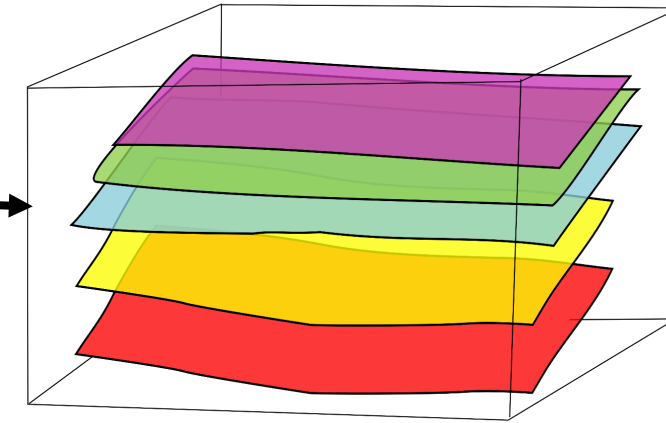
Folded layers (chevron folds)

### Geological aspects

- Successive strata
- Connectivity of surfaces (topology)
- Thickness (constant vs variable)
- **Folds**

Interpolation

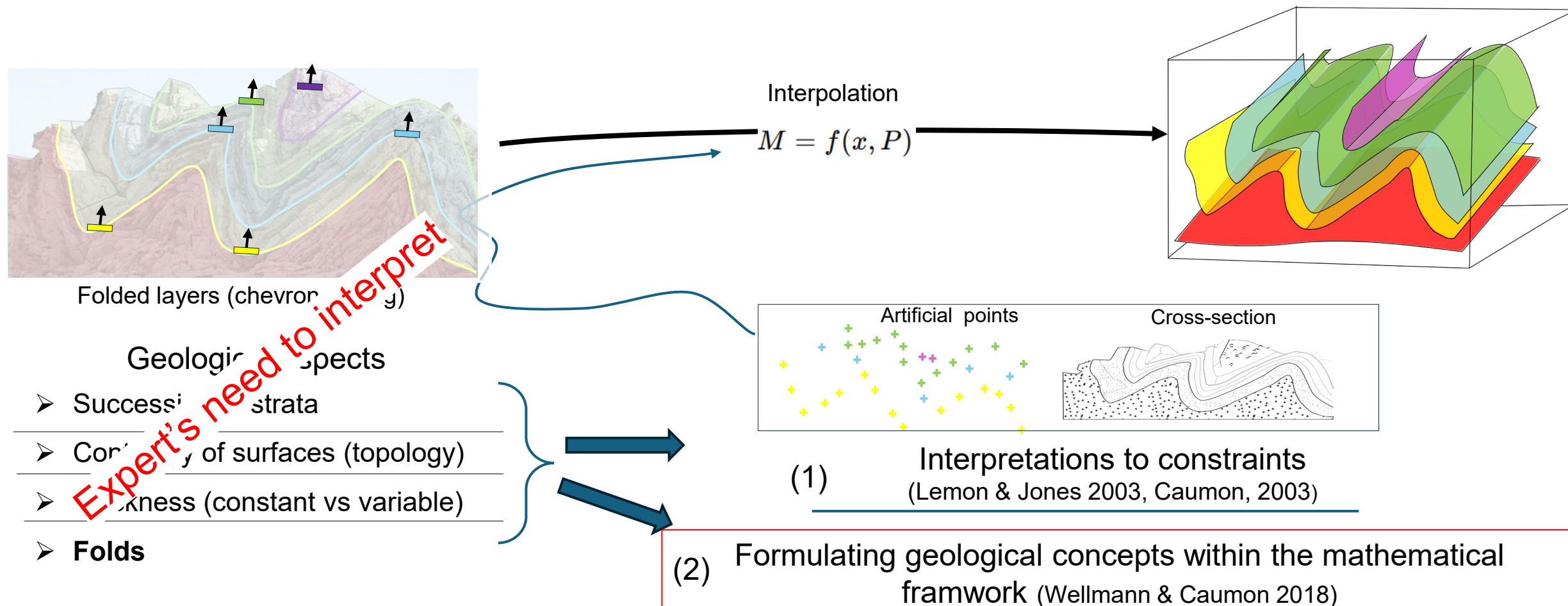
$$M = f(x, P)$$



### Limitations during model construction

- Restriction in integrating geological knowledge
- Expert centric (subjectivity, bias, loss of history)

## Geomodels: Knowledge incorporation & limitations

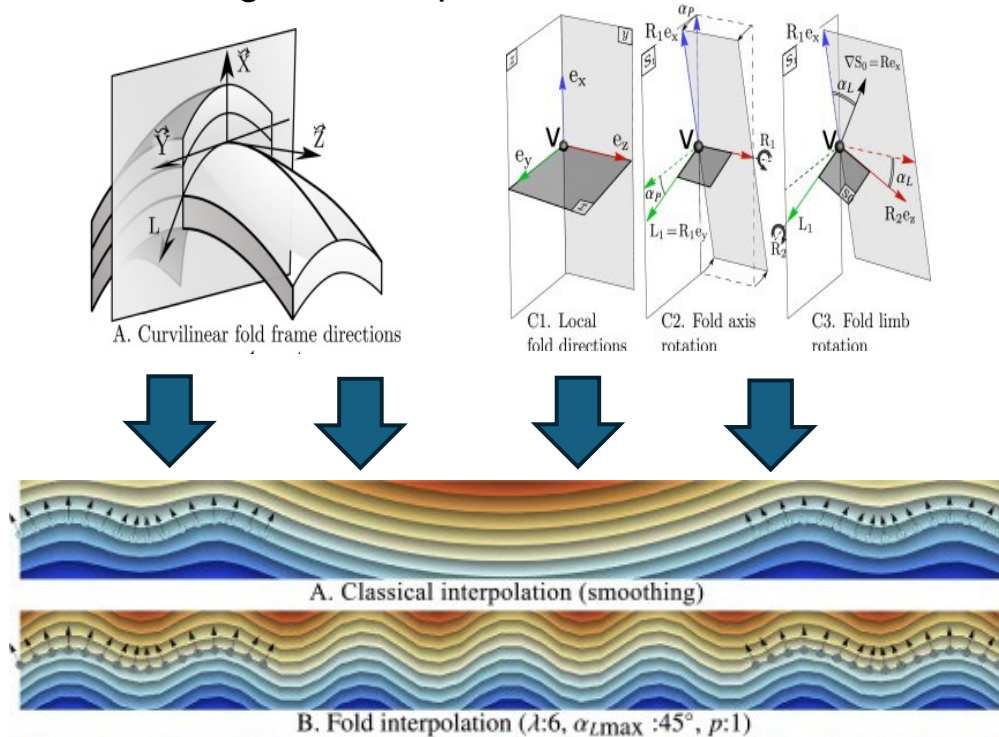


### Limitations during model construction

- Restriction in integrating geological knowledge
- Expert centric (subjectivity, bias, loss of history)
- Loss of the semantic content

## Geomodels: Knowledge incorporation & limitations

Extraction of structure's properties and convert them to geometric parameters (Laurent et al., 2016)



Interpolation with fold geometry constraints  
(wavelength, amplitude and tightness)

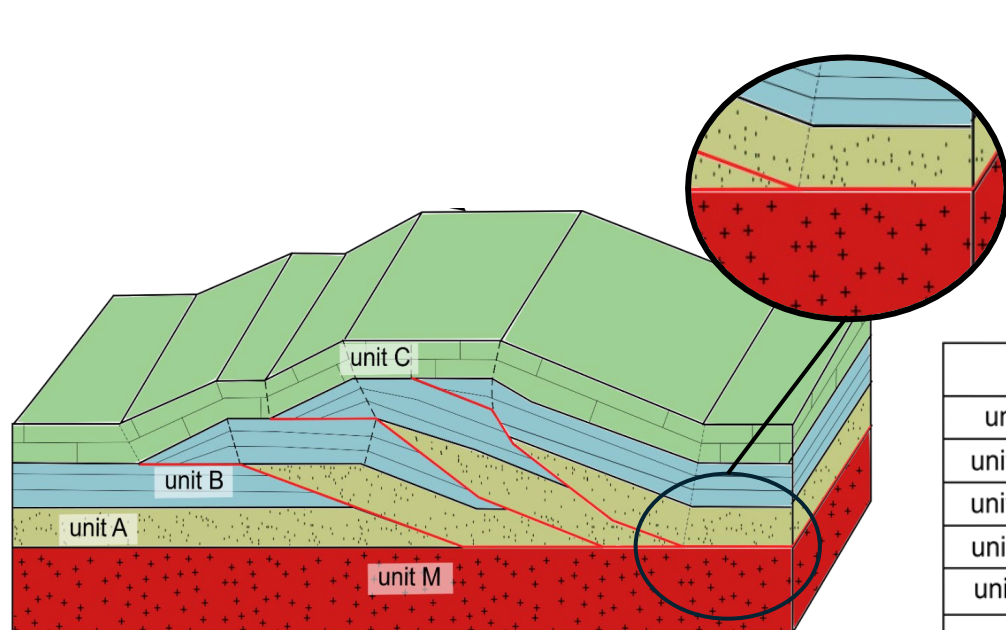
### Limitations during model construction

- Restriction in integrating geological knowledge
- Expert centric (subjectivity, bias, loss of history)
- Loss of the semantic content
- Focus on knowledge mathematically formulable
- Dependency on data
- Global parametrization

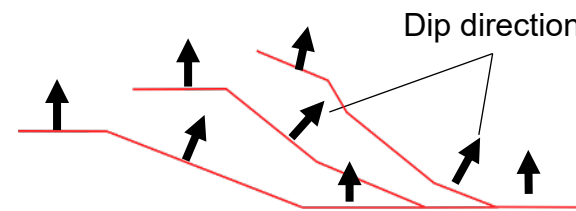
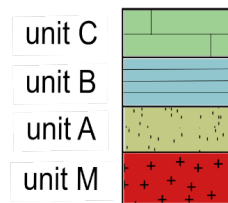
Literature :

- A 3D modeling approach to complex faults with multi-source data (Wu et al., 2015)
- Generating variable shapes of salt geobodies from seismic images and prior geological knowledge (Clausolles et al., 2019)
- Realistic modelling of faults in LoopStructural 1.0 (Grose et al., 2021)
- Inversion of geological maps for fault geometry (Grose et al., 2021)
- Spatial agents for geological surface modelling (De Kemp et al., 2021)
- Finite Difference Implicit Structural Modeling of Geological Structures (Irakarama et al., 2021)
- ...

## Geomodels: Knowledge incorporation & limitations



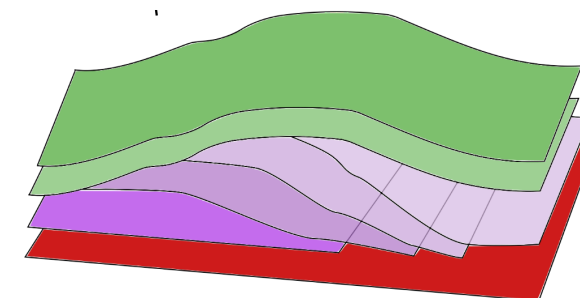
Duplex structure with folds, thrusts and flat ramps



original model

Formation	Surf type
unit C	Erod
unit AB4	Onlap
unit AB3	Onlap
unit AB2	Onlap
unit AB1	Onlap
unit M	Erod

Alternative model (no faults)



Institutions database



Stored in

### Limitations after model construction

- Knowledge sharing and querying
- Geomodels updating and reproducing

### Limitations during model construction

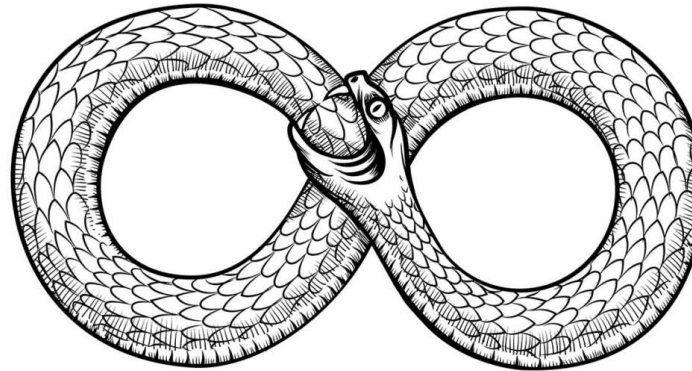
- Restriction in integrating geological knowledge
- Expert centric (subjectivity, bias, loss of history)
- Loss of the semantic content
- Focus on knowledge mathematically formulable
- Dependency on data
- Global parametrization

Geomodeller's hurdles

Institution's hurdles

Problem statement & proposed solution

# Interpretation



# Knowledge

PhD part 1

Formal interpretation

A **generic formalism** for the interpretation as a **distinct entity**

Tracing explicitly the **decision history**

Knowledge formalization

Introduction of knowledge in an **explicit** and **structured** way without loss of semantics

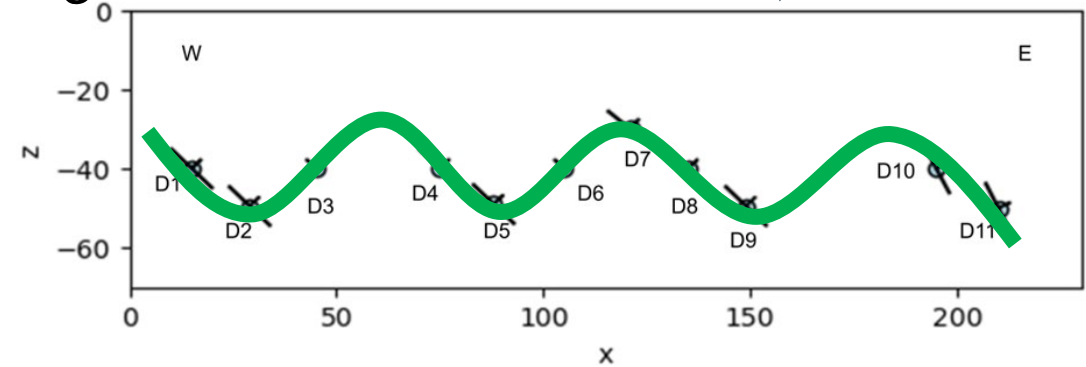
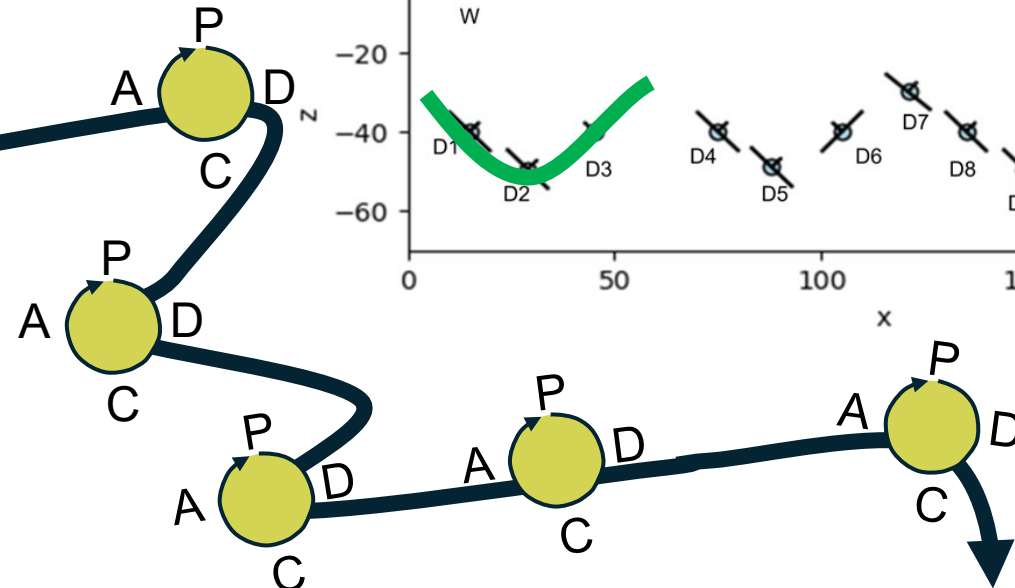
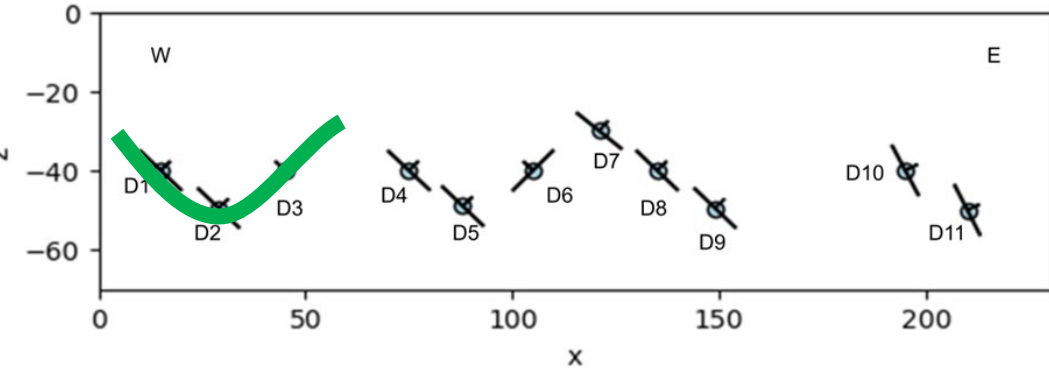
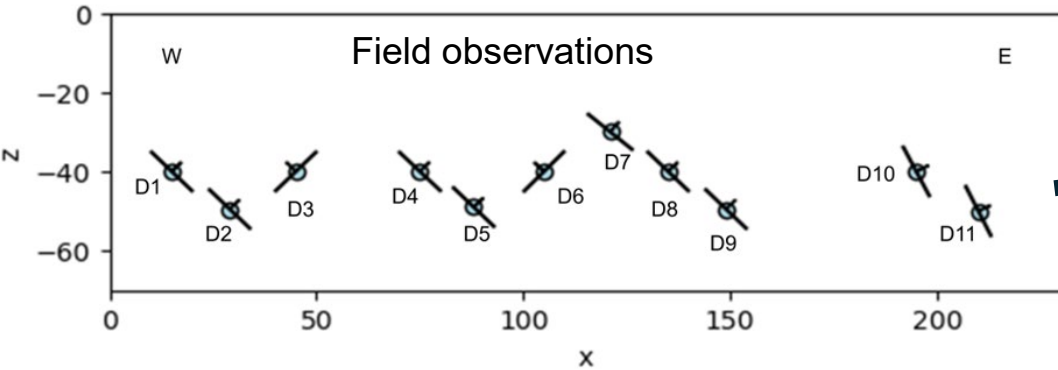
Making knowledge in the geomodel **independent** of its 3D geometric rendering

PhD part 2

Semantics in geomodels

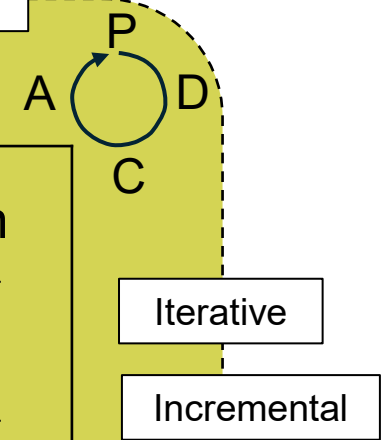
Post-doc

Theory: Analyzing the interpretation process

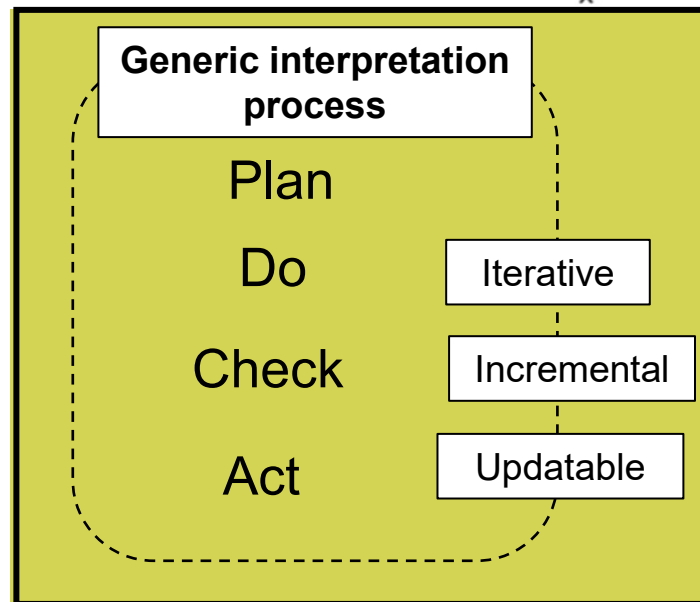
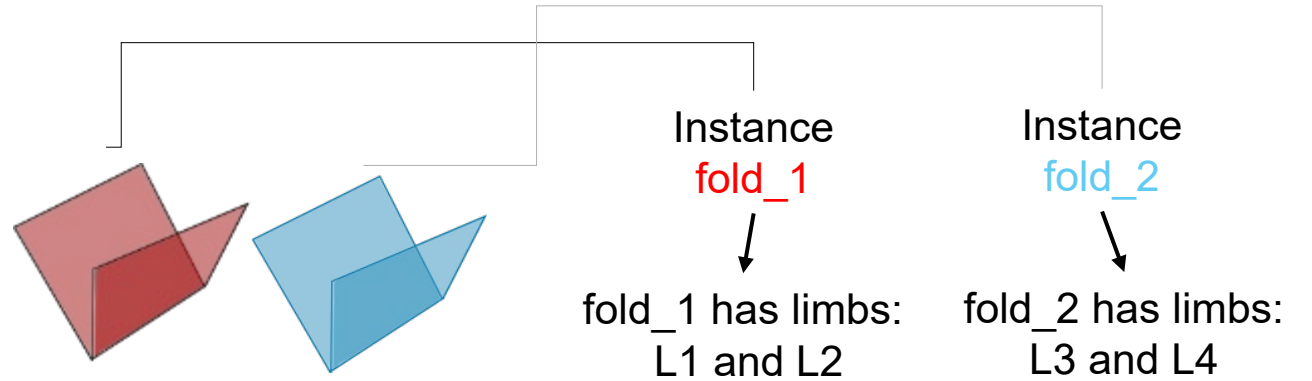
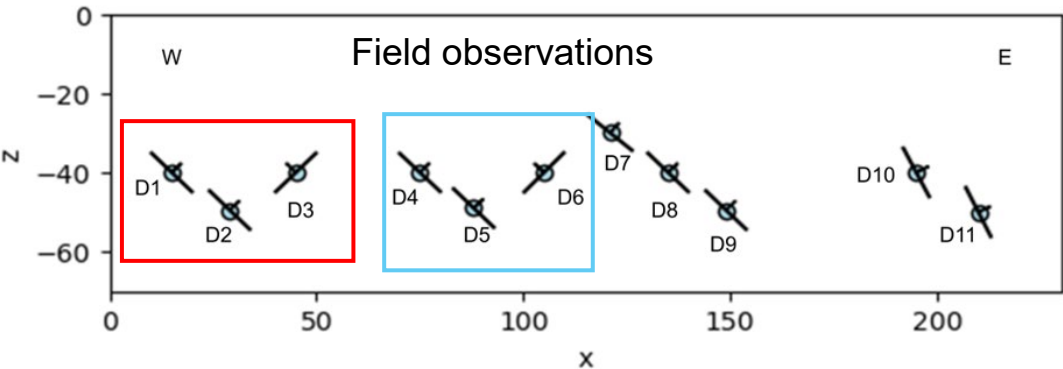


Generic interpretation process

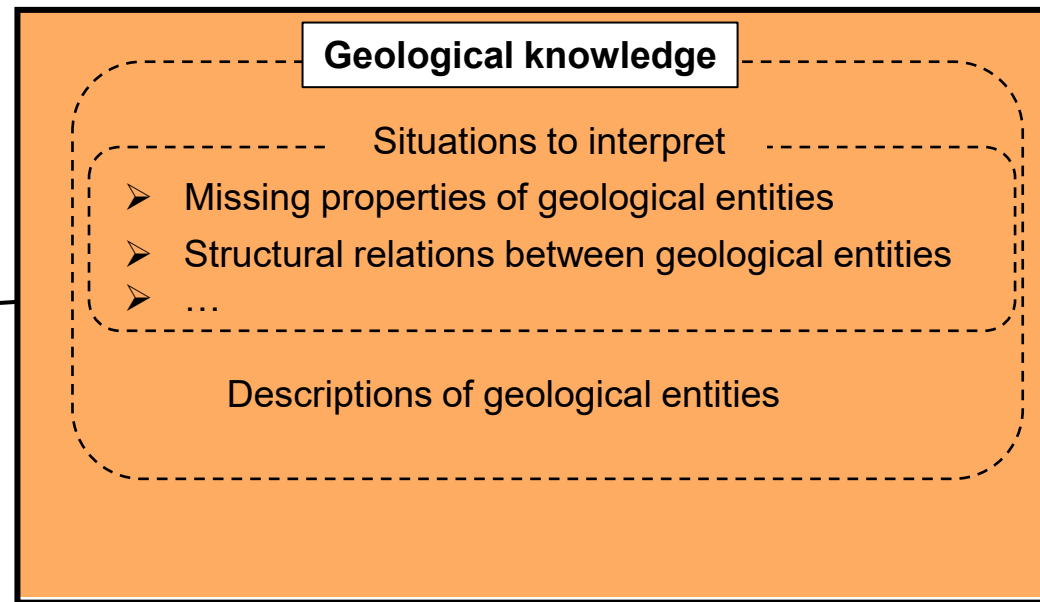
Interpretative Tasks	
Interrogate information Select situation to interpret	Plan
Choose hypothesis Estimating and Assigning values	Do
Evaluate the hypothesis	Check
Decide about the hypothesis Update initial understanding	Act



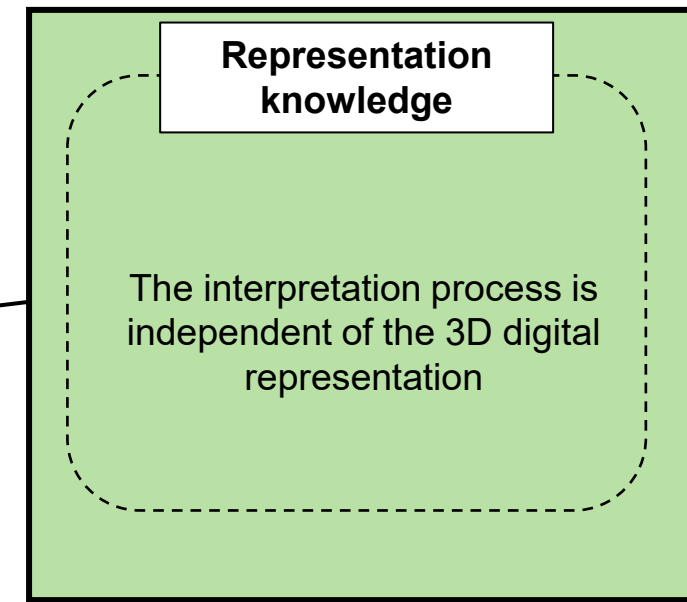
## Theory: Required knowledge



Operational system



Knowledge model (MOGI)



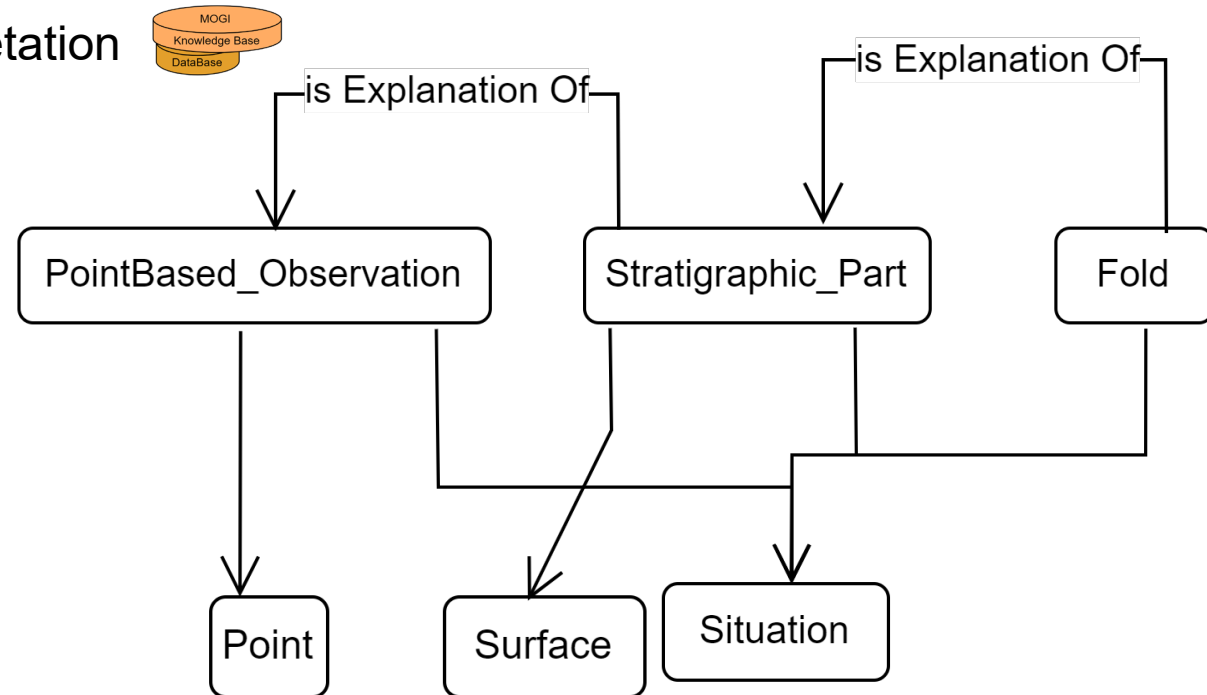
Results: Knowledge model

## MOGI Minimal Ontology for Geological Interpretation

● owl:Thing

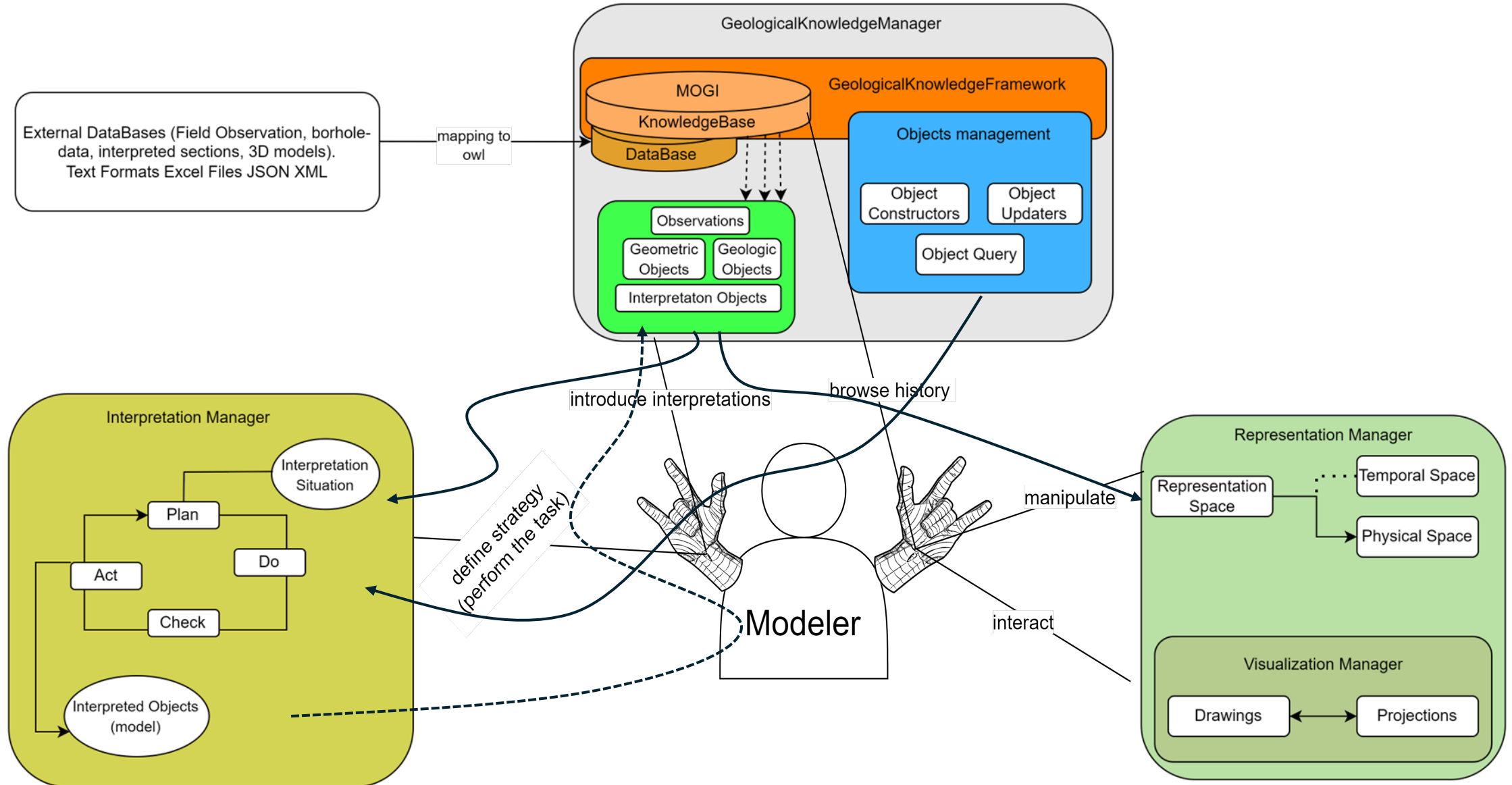
▼ ● Geological Concept

▼ ● Observation

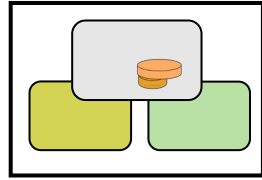
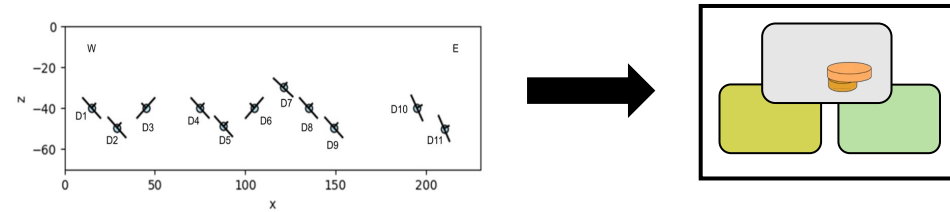


- Observations and geological entities
- Situations and relations between explaining and candidate entities
- Geological concepts are related but independent from representational concepts

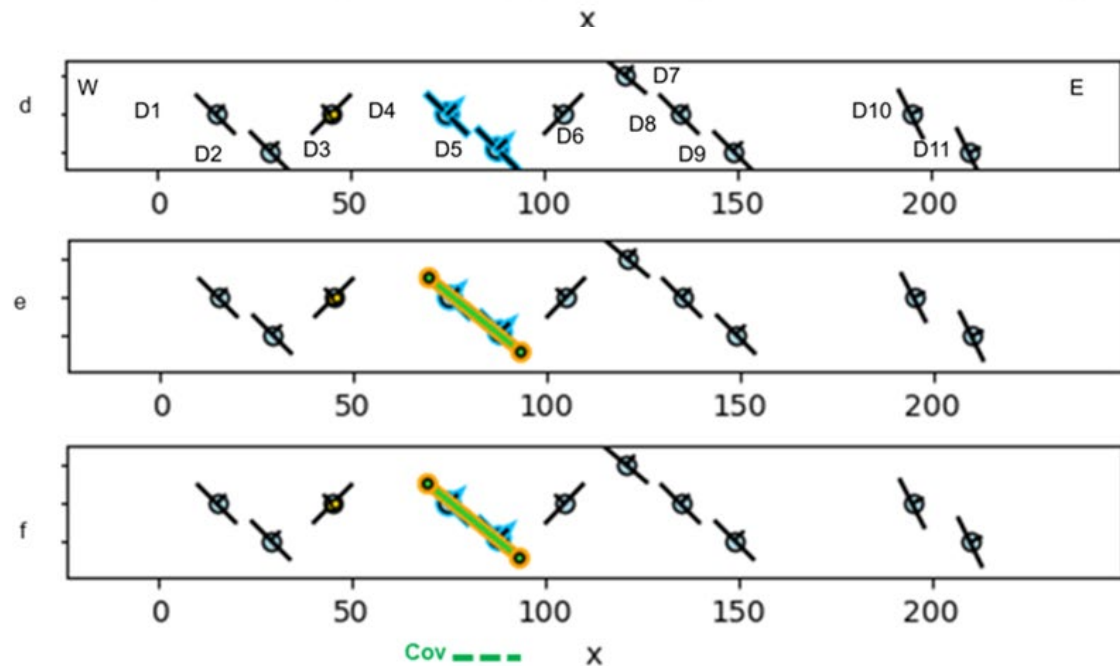
## Results: Operational system's components



## Results: Application on synthetic data



- Plan:
  - Selection of inputs → random selection
  - Querying inputs and listing their possible explaining objects
- Do:
  - Selection of the interpretation hypothesis → random selection (Stratigraphic\_Part)
  - Assigning parameters (mean value of spatial coordinates)
- Check:
  - Evaluating the hypothesis → strict alliance with criteria (conform)
- Act:
  - Updating the knowledge base with the new accepted interpretation



Plan

Do

Check  
Act

## Results: Application on synthetic data

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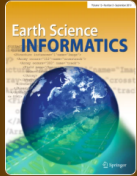
Home > Earth Science Informatics > Article

### A knowledge-driven modeling formalism for automatic structural interpretation

Methodology | Published: 20 December 2024  
Volume 18, article number 84, (2025) [Cite this article](#)

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Imadeddine Laouici [✉](#), Gautier Laurent, Christelle Loiselet & Yannick Branquet

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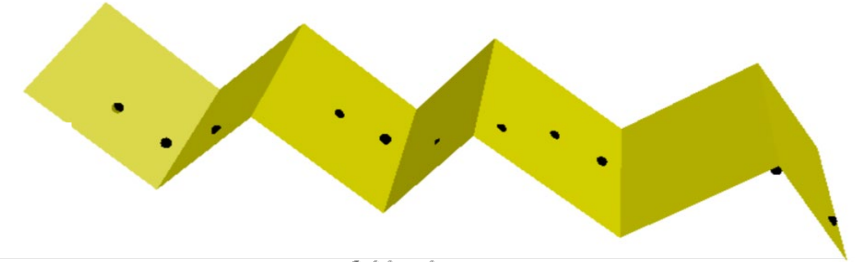


Paper

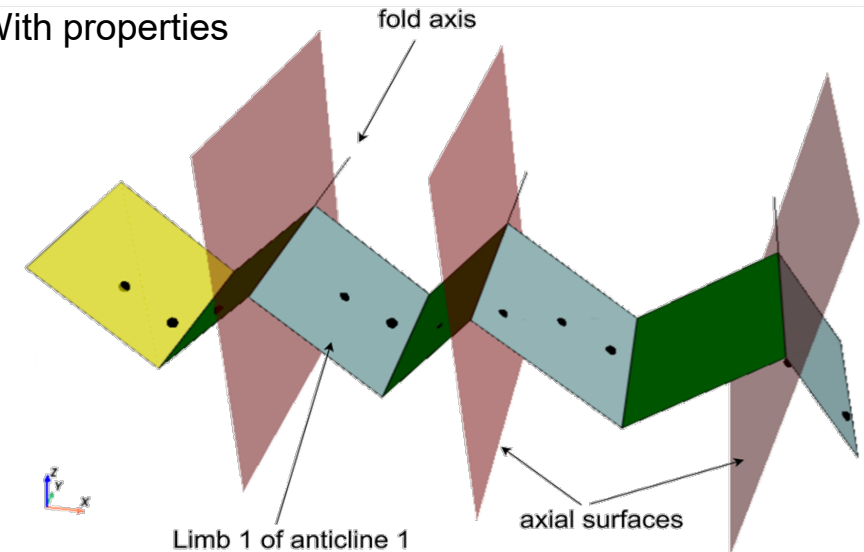


Repository of the script  
10k lines of code

### General view

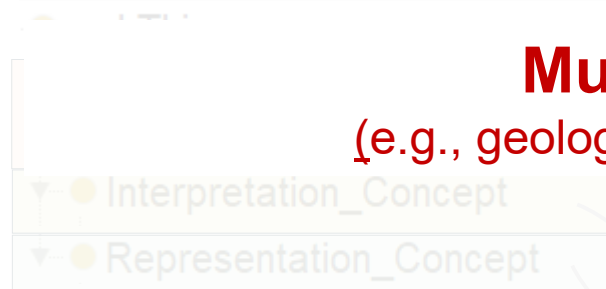


### With properties



- ✓ Preservation of the semantics of the described objects
  - ✓ Automation of various interpretative tasks
  - ✓ In depth interaction with the interpretation process
- ✓ Preservation of the interpretation history and the decisions made

Motivation



Minimal Or Interp

### Multidisciplinarity

(e.g., geology, knowledge representation)

- Types of geological entities, their geological relations and characteristics (mechanical, lithological ...etc)
- Geological principles, laws, and rules.

- Relations between interpretations and geomodels

### Knowledge modeling at different levels

(i.e., modeling models)

and their knowledge

te to als

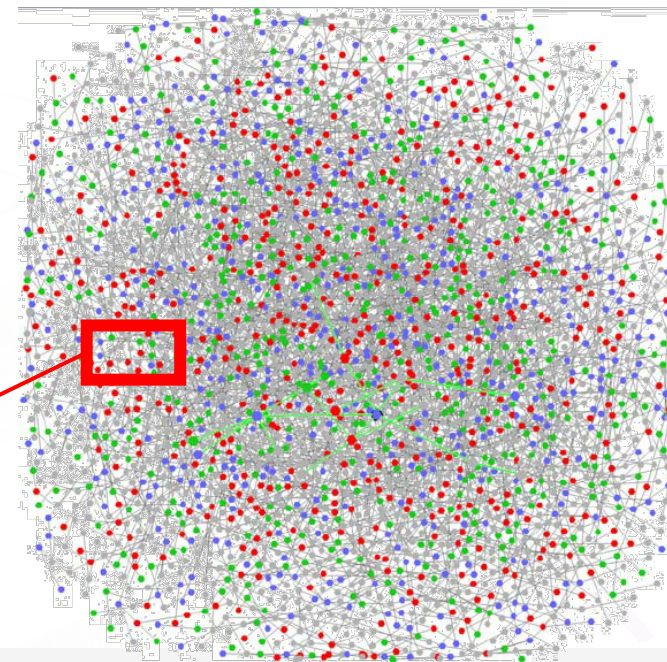
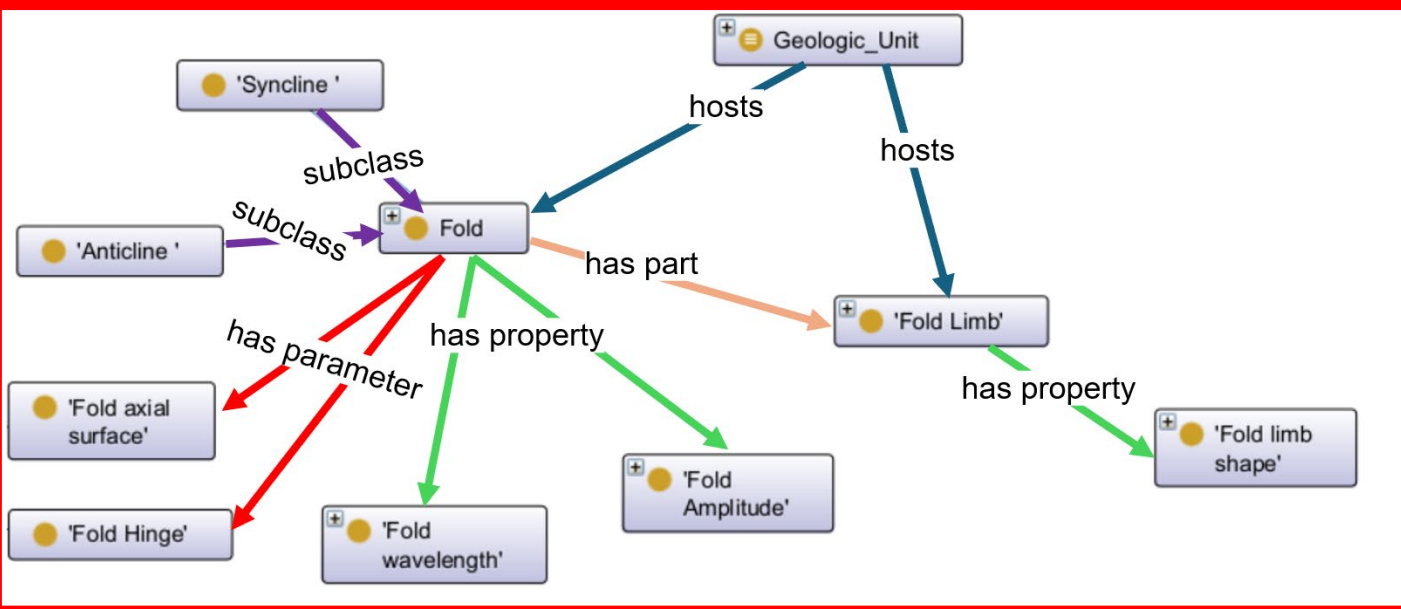
- Relations between models

### Need for better knowledge formalization (ontologies !!)

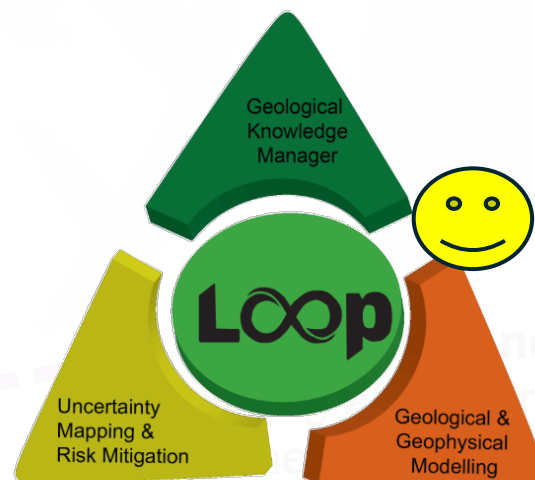
Flow modeling & simulation



## Ontologies



Subset from the  
GeoScience Ontology  
(Brodaric & Richards, 2020)



## Ontology metrics:

## Metrics

Axiom	121 478
Logical axiom count	16 491
Declaration axioms count	6 893
Class count	6 700
Object property count	178
Data property count	1
Individual count	1 042
Annotation Property count	61

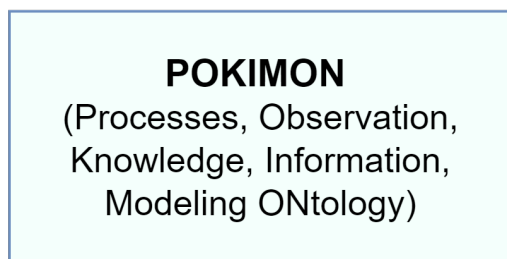
## Class axioms

SubClassOf	7 500
EquivalentClasses	74

## Ontologies

## Application level

## Proposed ontology



## Domain level

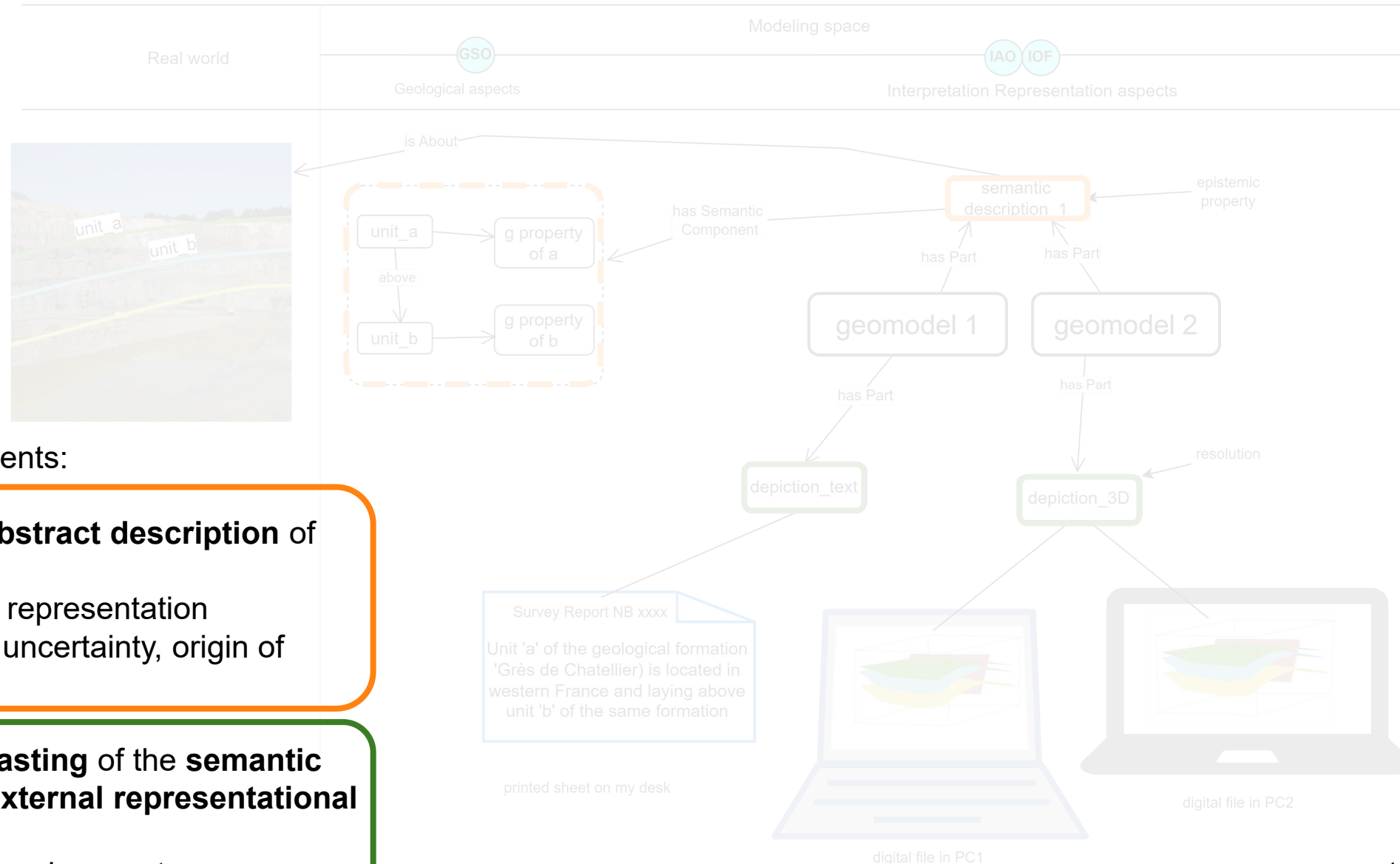
## Specifications for the ontology

- Geological entities (objects, structures)
- Geological principles, laws, and rules.

- Geomodels, their characteristics, and their relations to interpretation
- Interpretation processes

- Representational entities

## Proposed ontology: Definition &amp; main entities



The geomodel:

- **Copyable entity** → represented in different physical artefacts



The geomodel has two components:

- **Semantic Content Entity** : **abstract description** of geological entities.

- Modeled → ontological representation
- Attributes → epistemic uncertainty, origin of information...

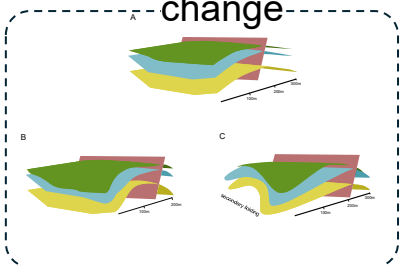
- **Depiction Content Entity** : **casting** of the **semantic component** into a specific **external representational paradigm**

- Attributes → resolution, colors ...etc.

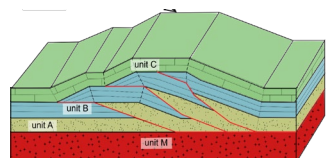
## Proposed model: Application

## uses cases

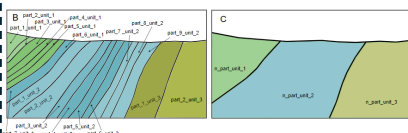
## When geomodels change



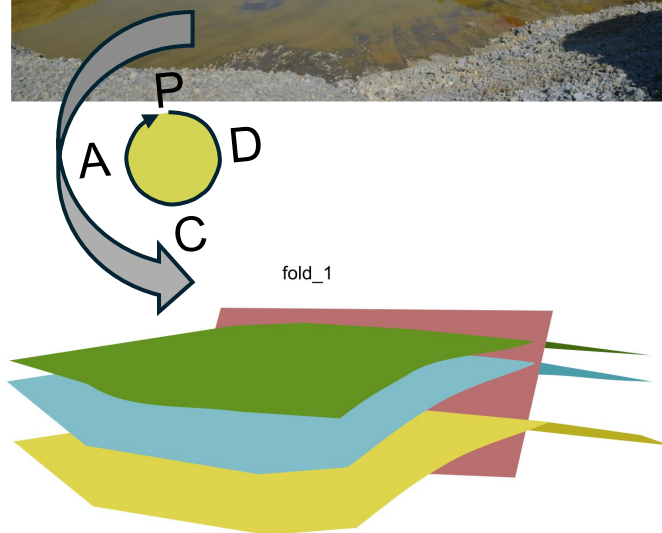
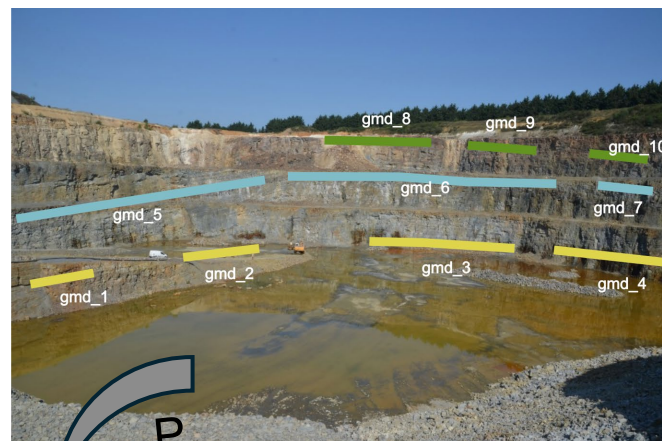
## Modeling geomodels relations



	Formation	Surf type
unit C	unit C	Erod
unit B	unit AB4	Onlap
unit A	unit AB3	Onlap
unit M	unit AB2	Onlap
	unit AB1	Erod
	unit M	



## Modeling the interpretation process



## Implementation

http://www.POKIMON (http://www.POKIMON)

active ontology × Entities × Individuals by class × Individual Hierarchy Tab × DL Query × OntoGraf ×

Ontology header: ⌵ ⌴ ⌶ ⌷ **Ontology metrics:** ⌵ ⌴ ⌶ ⌷

Ontology IRI	http://www.POKIMON	Metrics	
Ontology Version IRI	e.g. http://www.POKIMON	Axiom	608
		Logical axiom count	339
		Declaration axioms count	254
		Class count	186
		Object property count	65
		Data property count	3
		Individual count	0
		Annotation Property count	2

Annotations +



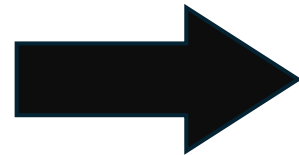
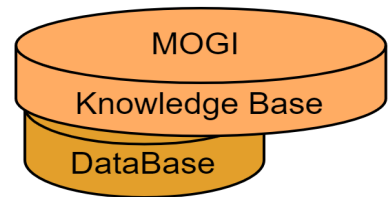
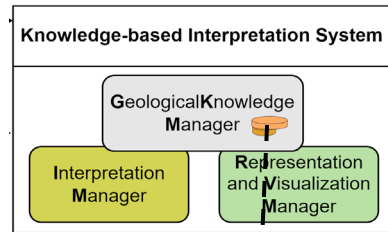
Paper 2: POKIMON: an ontology for geological interpretation in 3D geo-modelling  
(in preparation for submission)

Motivation

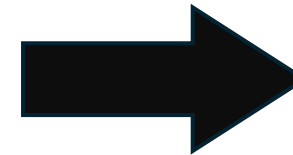
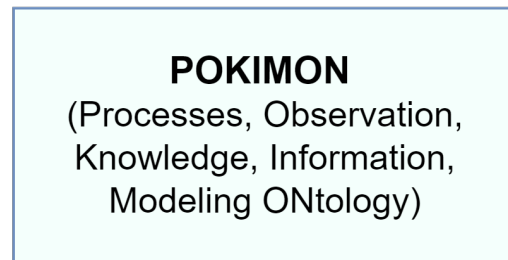
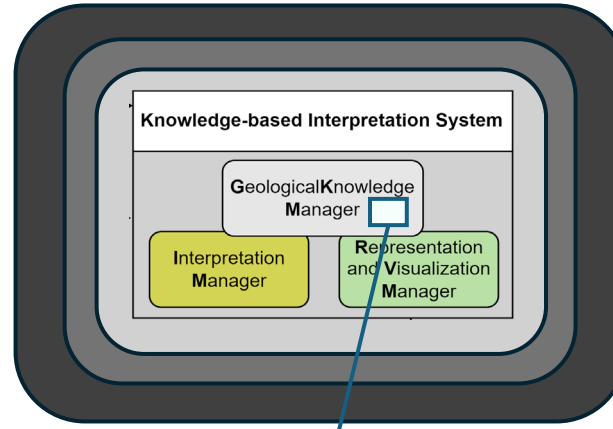
State of the art

Next .....?

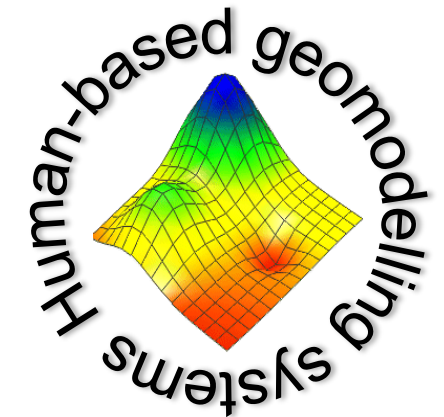
Prototype v0



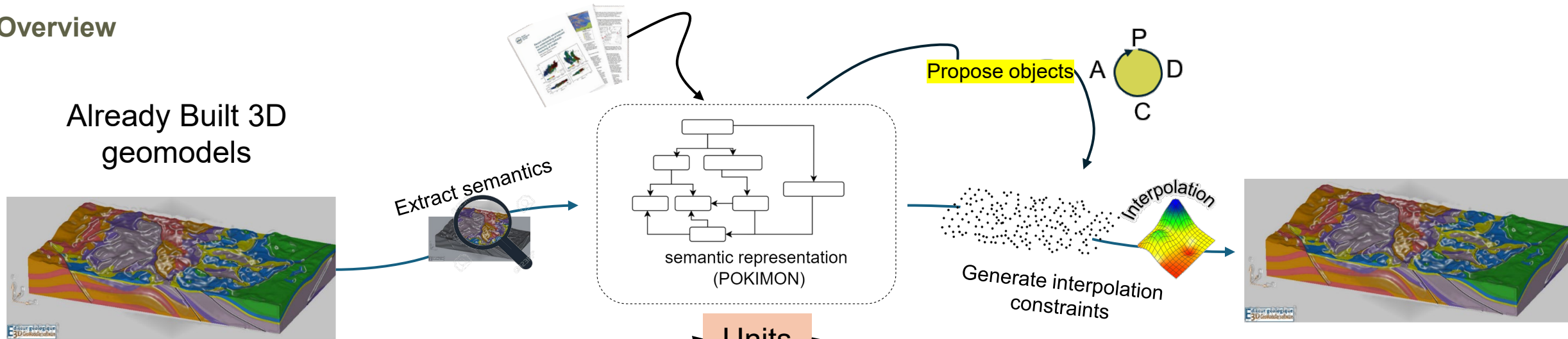
Prototype v1.0



Deployment within geomodelling systems ?!



## Overview



Units

Stratigraphic column (pile)

Intrusive bodies

Stratigraphic column (pile)

Boundaries

interfaces

interfaces

Folds

Blocks (tectonic units)

Fault interfaces

Faults

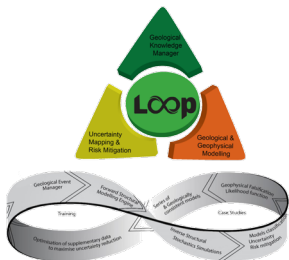
Fault interfaces



# THANK YOU FOR THE ATTENTION

Imadeddine LAOUICI

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Presentation at the 3D Geological modeling Conference Fremantle, Apr 9, 2025

- Abel, M., Gastal, E.S.L., Michelin, C.R.L., Maggi, L.G., Firmkes, B.E., Pachas, F.E.H., Alvarenga, R. dos S., 2019. A Knowledge Organization System for Image Classification and Retrieval in Petroleum Exploration Domain, in: Almeida, J.P.A., Bax, M., Berardi, R., Baião, F. (Eds.), Proceedings of the XII Seminar on Ontology Research in Brazil and III Doctoral and Masters Consortium on Ontologies, Porto Alegre, Brazil, September 2nd-5th, 2019, CEUR Workshop Proceedings. CEUR-WS.org.
- Brodaric, B., Richard, S.M., 2020. The GeoScience Ontology 2020, IN030-07.
- Caumon, G., Collon-Drouaillet, P., Le Carlier de Veslud, C., Viseur, S., Sausse, J., 2009. Surface-Based 3D Modeling of Geological Structures. *Math Geosci* 41, 927–945. <https://doi.org/10.1007/s11004-009-9244-2>
- Ceusters, W., Smith, B., 2015. Aboutness: Towards Foundations for the Information Artifact Ontology, in: Proceedings of the Sixth International Conference on Biomedical Ontology (ICBO). CEUR vol. 1515, pp. 1–5.
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