Ontology Evolution and its Impact on Downstream Applications

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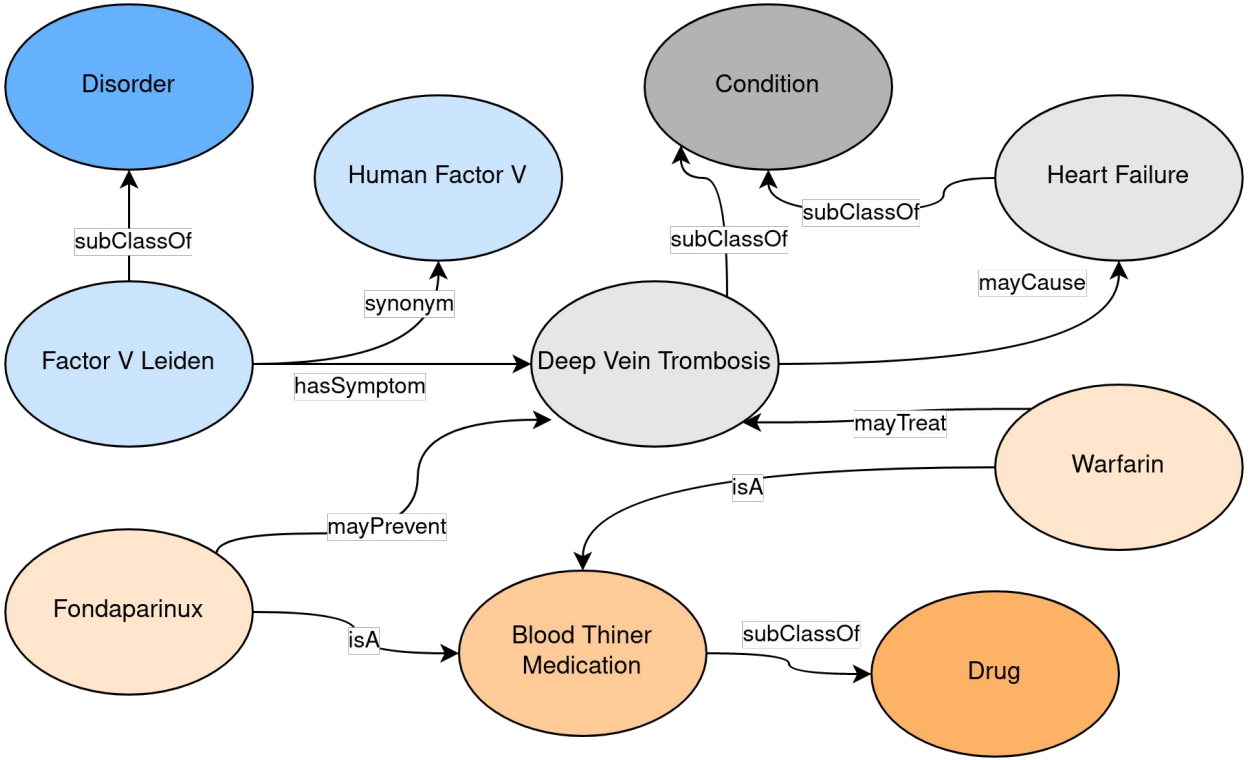
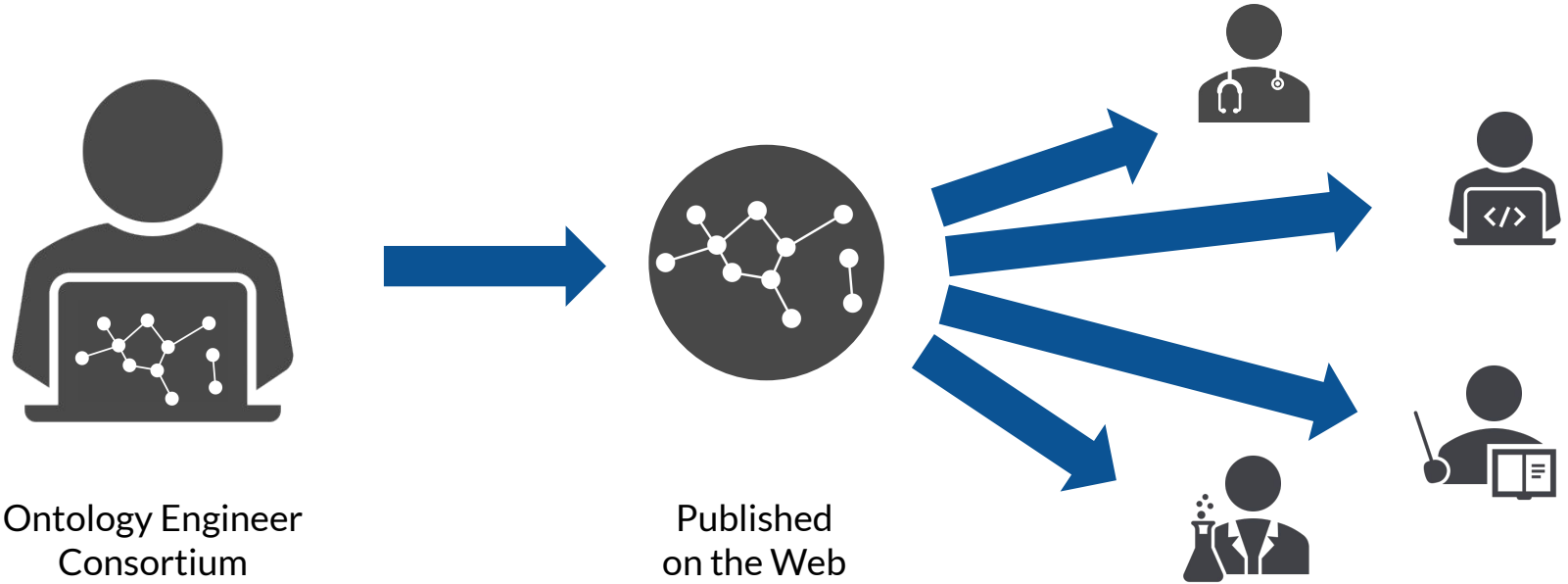
- Knowledge in Artificial Intelligence
- Discovery Lab, Elsevier

The Knowledge Evolution Problem

Modelling Domain Knowledge with Ontologies



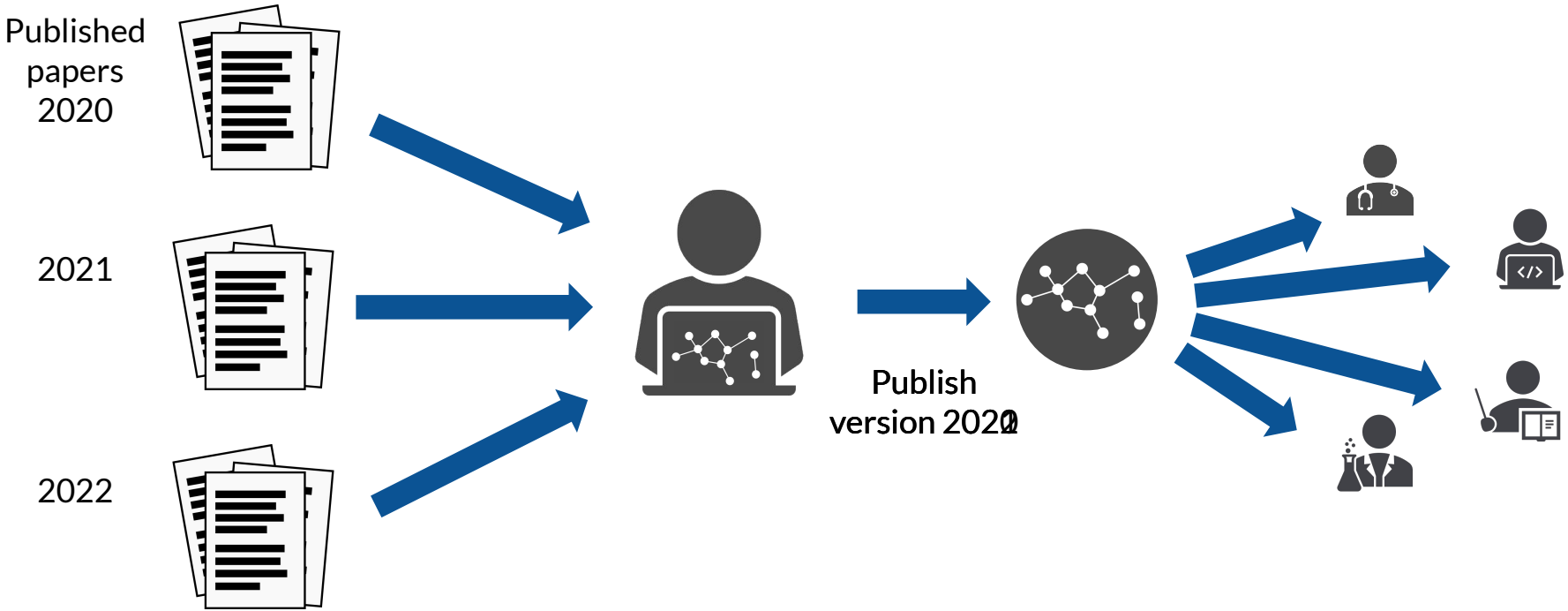
Usage of Ontologies in Applications.



Ontology Engineer
Consortium

Published
on the Web

Knowledge and Ontologies Evolve



Formal Setting

Treatment recommendation: Warfarin

$\text{impact}_f(O_i, O_j)$

R_i $\longrightarrow$ R_j

$\Delta_{i,j}$

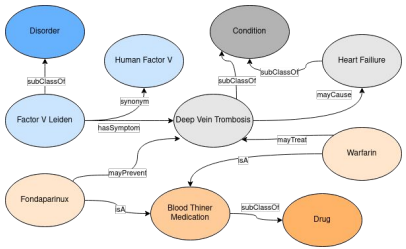
$f(O_i)$

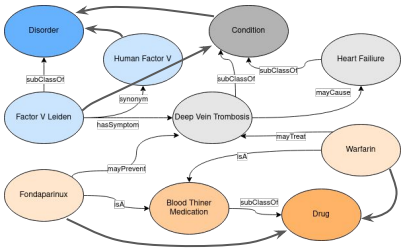
$\delta_{i,j}$

O_i $\longrightarrow$ O_j

$\text{changes}(O_i, O_j)$

Treatment recommendation: Warfarin or Fondaparinux





The Knowledge Evolution Problem

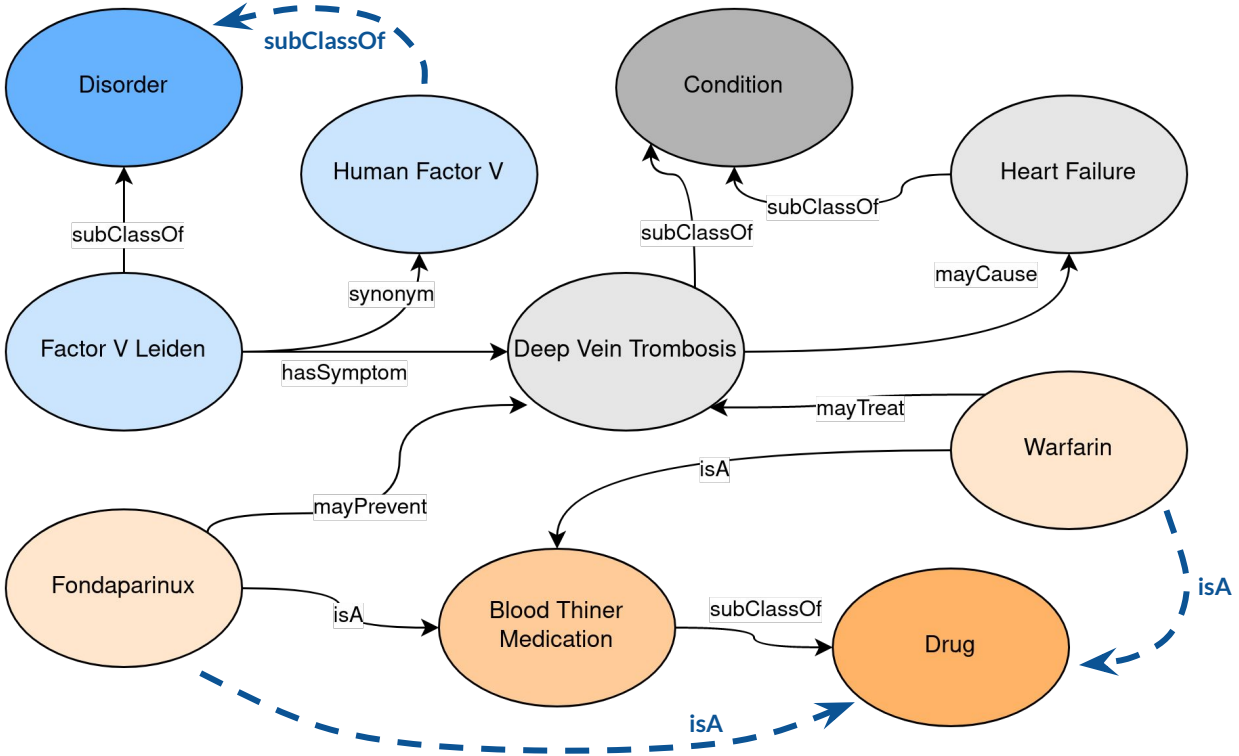
How can we capture the impact on the materialisation?

How do ontology engineers understand the impact of ontology changes?

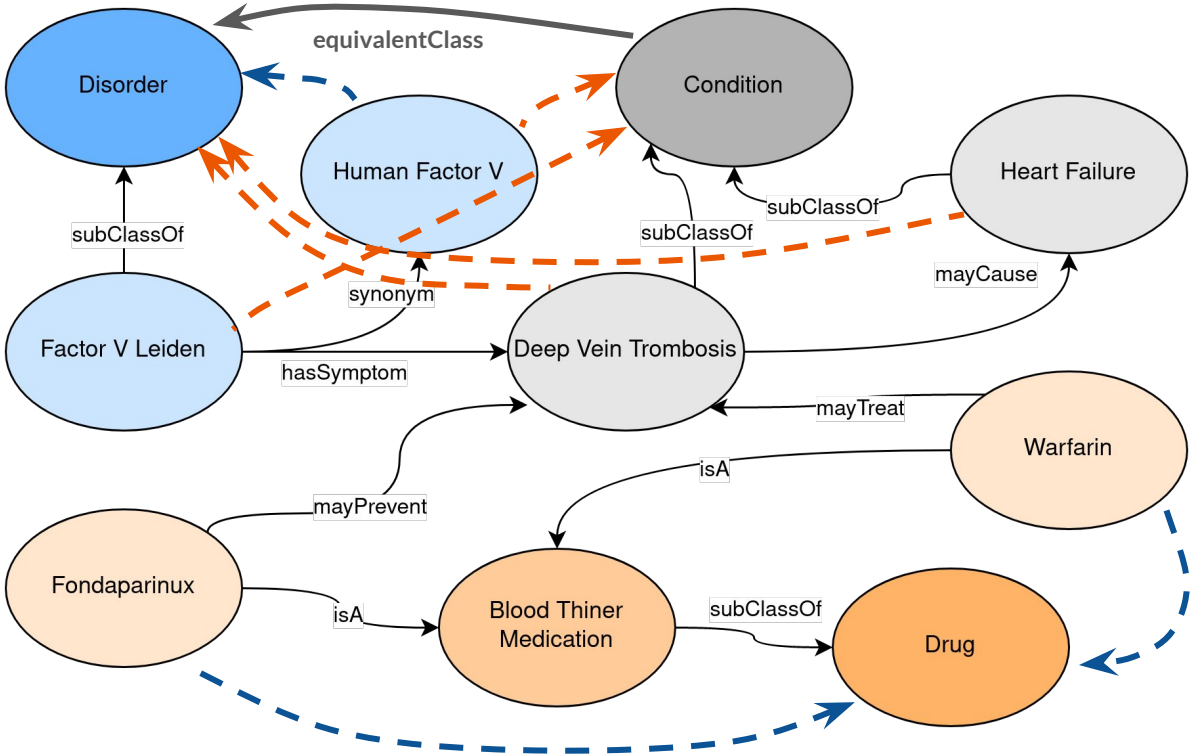
Do ontology management frameworks match the need in practice?

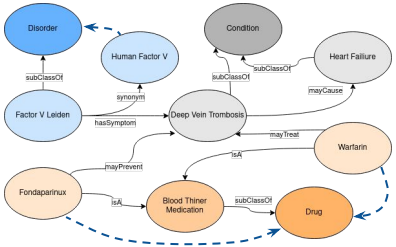
Quantify:
How can we **capture the impact** of ontology changes on the materialisation?

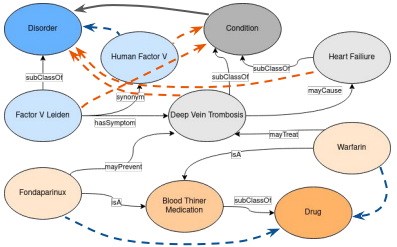
What is materialisation?

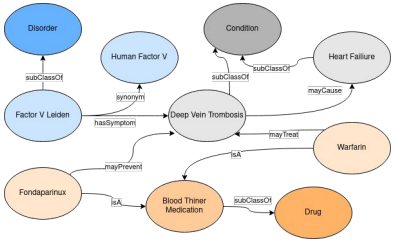


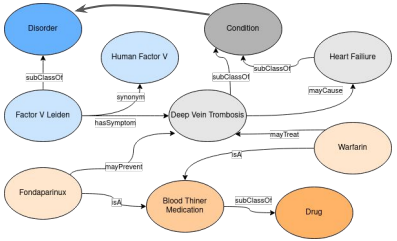
Unexpected Consequences of Changes









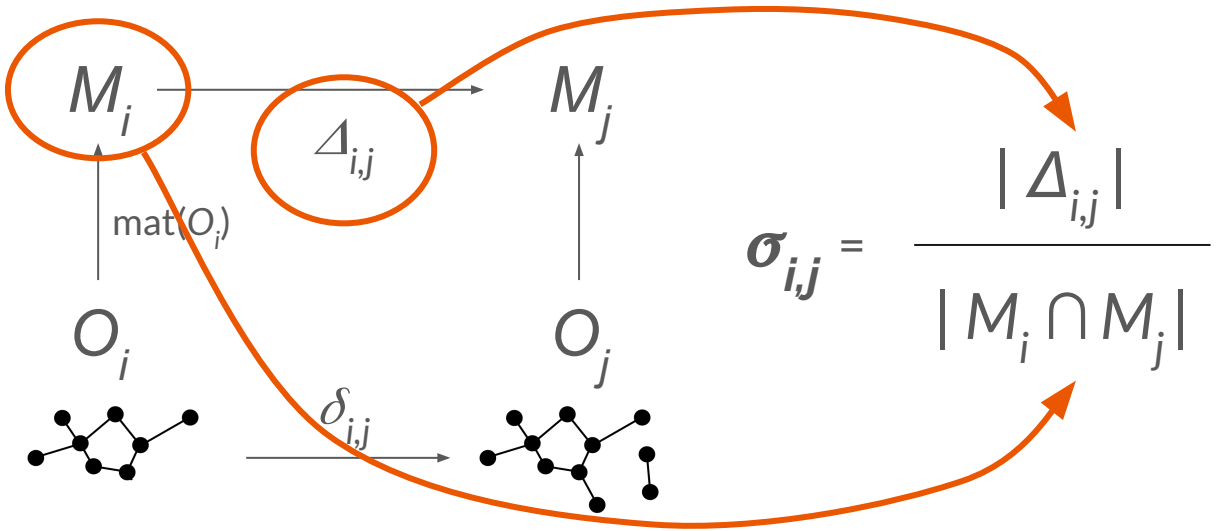


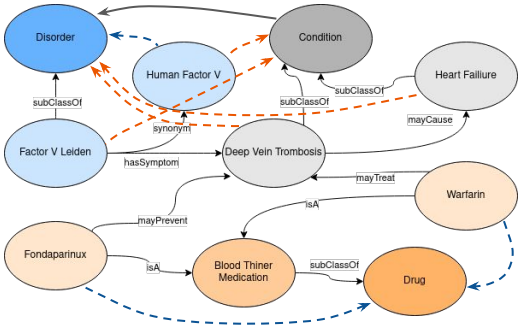
Formal Setting

impact$_{\text{mat}}(O_i, O_j)$

$$\begin{tikzcd}
M_i \arrow[r, "\Delta_{i,j}"'] & M_j \\
O_i \arrow[u, "\text{mat}(O_i)"'] \arrow[r, "\delta_{i,j}"] & O_j \arrow[u]
\end{tikzcd}$$

Size-based Impact $\sigma_{i,j}$

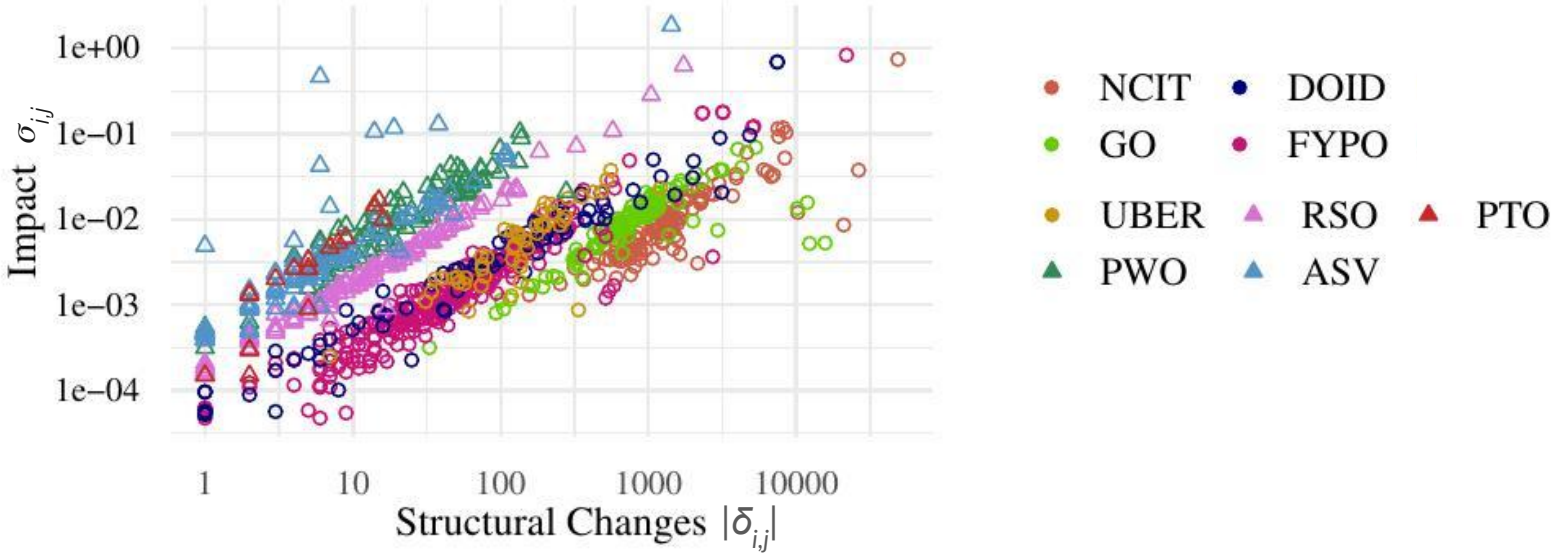




$\sigma = 1.33$

Pernisch et al. (2021). Beware of the hierarchy - An analysis of ontology evolution and the materialisation impact for biomedical ontologies. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2021.100658.

Size-based Impact $\sigma_{i,j} = \frac{|\Delta_{i,j}|}{|M_i \cap M_j|}$



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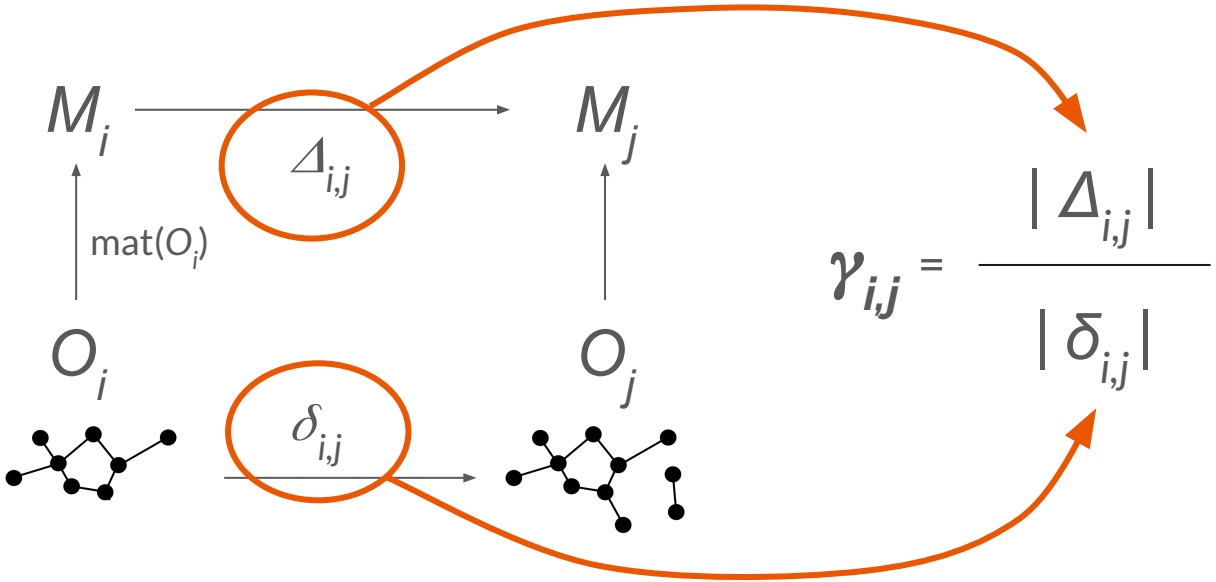
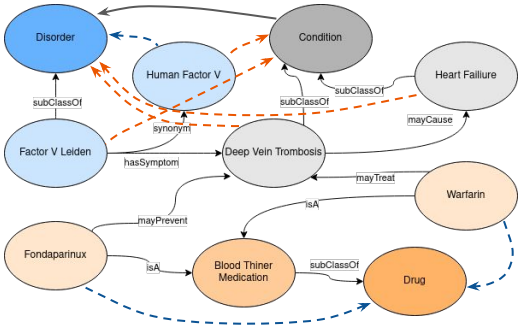
Change-based Impact $\gamma_{i,j}$





$\gamma = 4$

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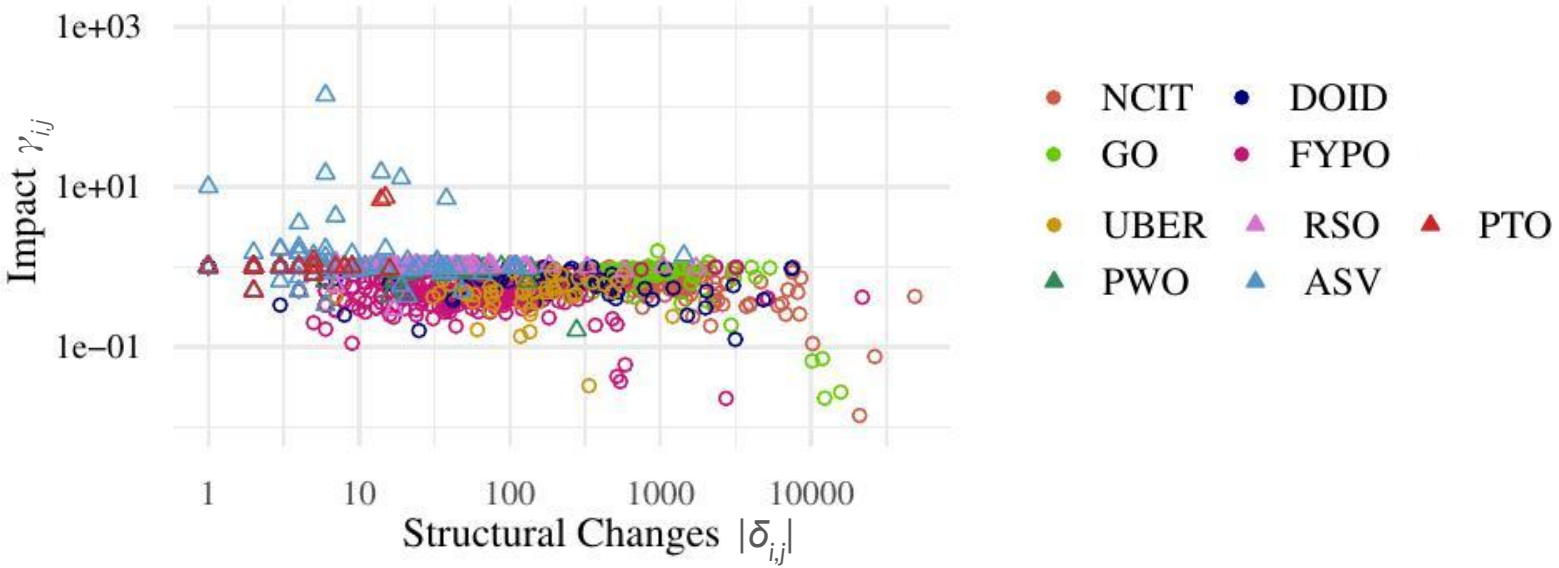
Change-based Impact $\gamma_{i,j} = \frac{|\Delta_{i,j}|}{|\delta_{i,j}|}$



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We defined materialisation impact measures at **macroscopic** scale.

The Knowledge Evolution Problem

How can we capture the impact on the materialisation?

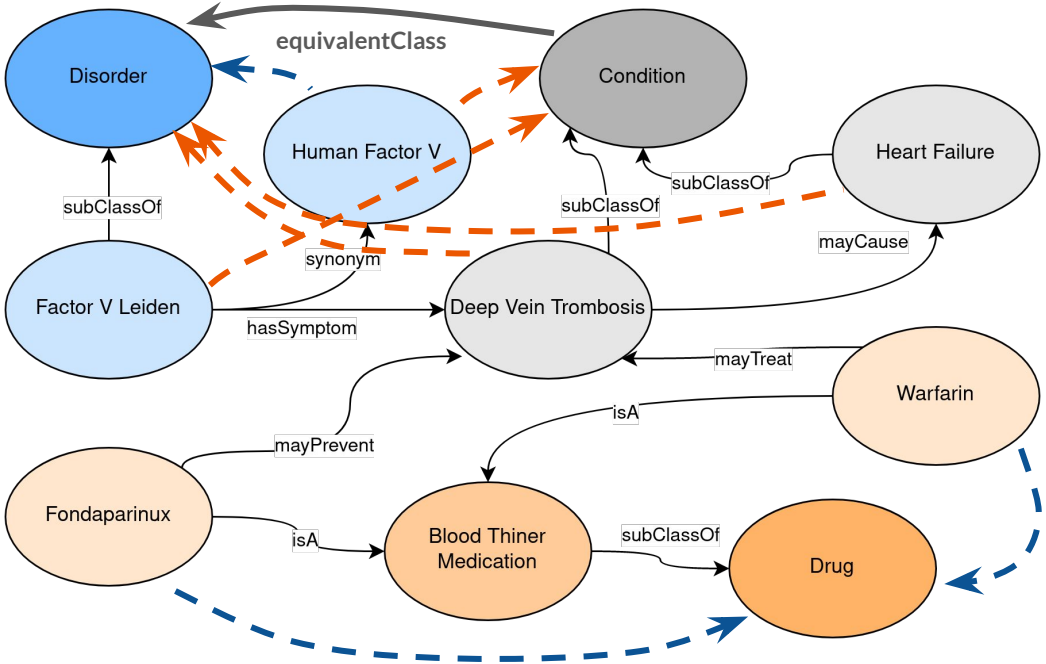
Change-based impact
Size-based impact

How do ontology engineers understand the impact of ontology changes?

Do ontology management frameworks match the need in practice?

Analyse:
How do ontology engineers **understand the impact** of ontology evolution on the materialisation?

Can measures help engineers while applying changes?



Size-based impact

$\sigma = 1.33$

Change-based impact

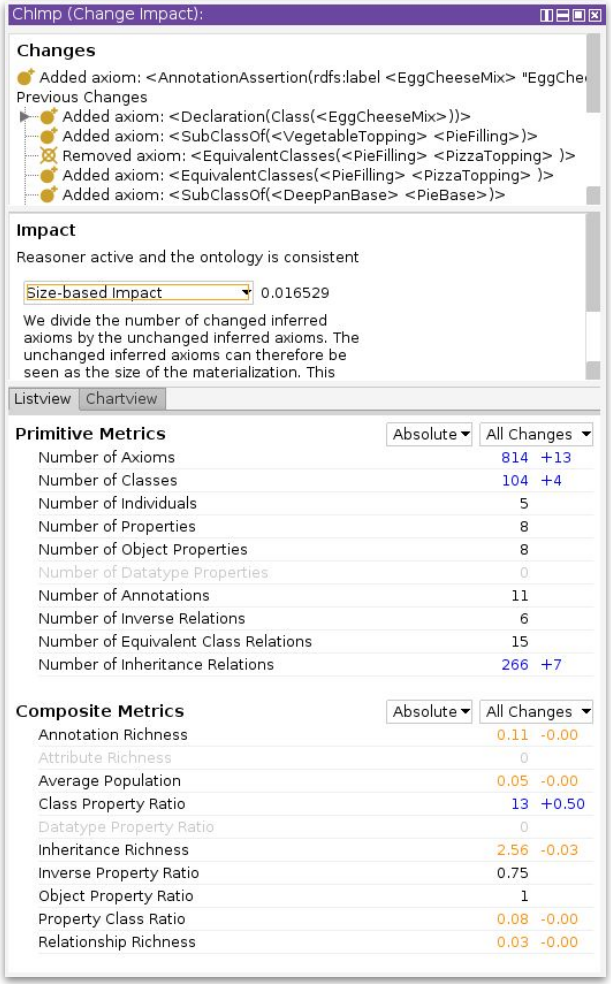
$\gamma = 4$

Implementation of Materialisation Impact

- Requirements elicitation through online questionnaire
- Identified 10 requirements:
  - List of changes
  - Consistency
  - Measures and their change
  - Export functionality
  - Usage of colors

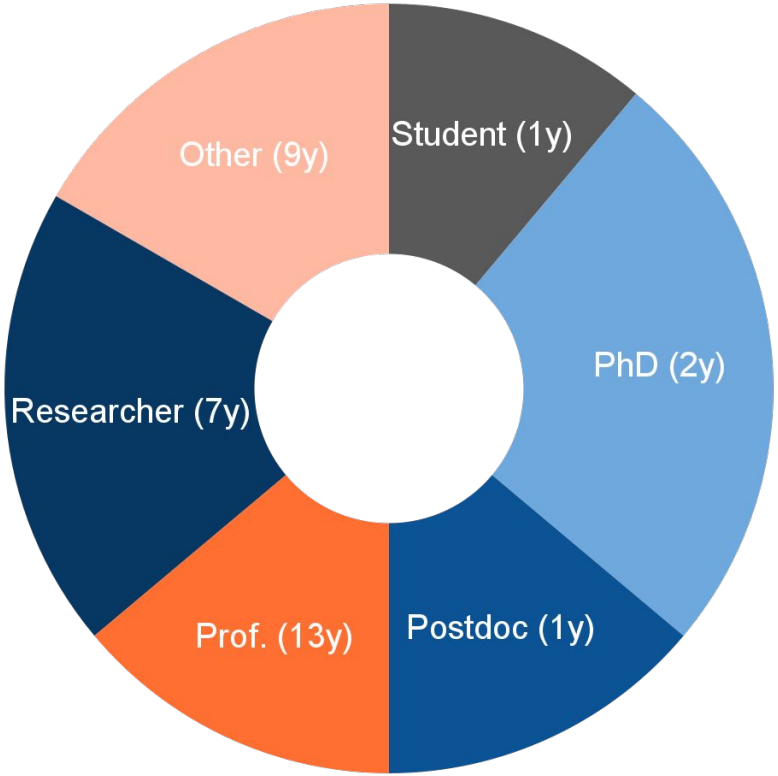
Pernisch et al. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2022.100715.

Implementation of Materialisation Impact



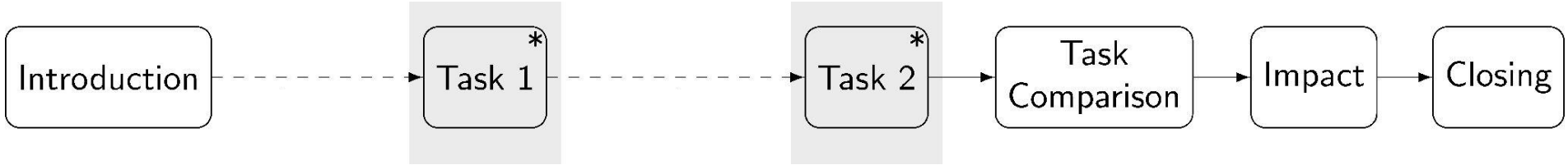
User Study

- Pizza ontology and 2 tasks to apply changes, one task with and the other without ChImp
- 36 Participants performed tasks locally on their own machine while following an online questionnaire



Pernisch et al. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2022.100715.

Within-subject Study Design

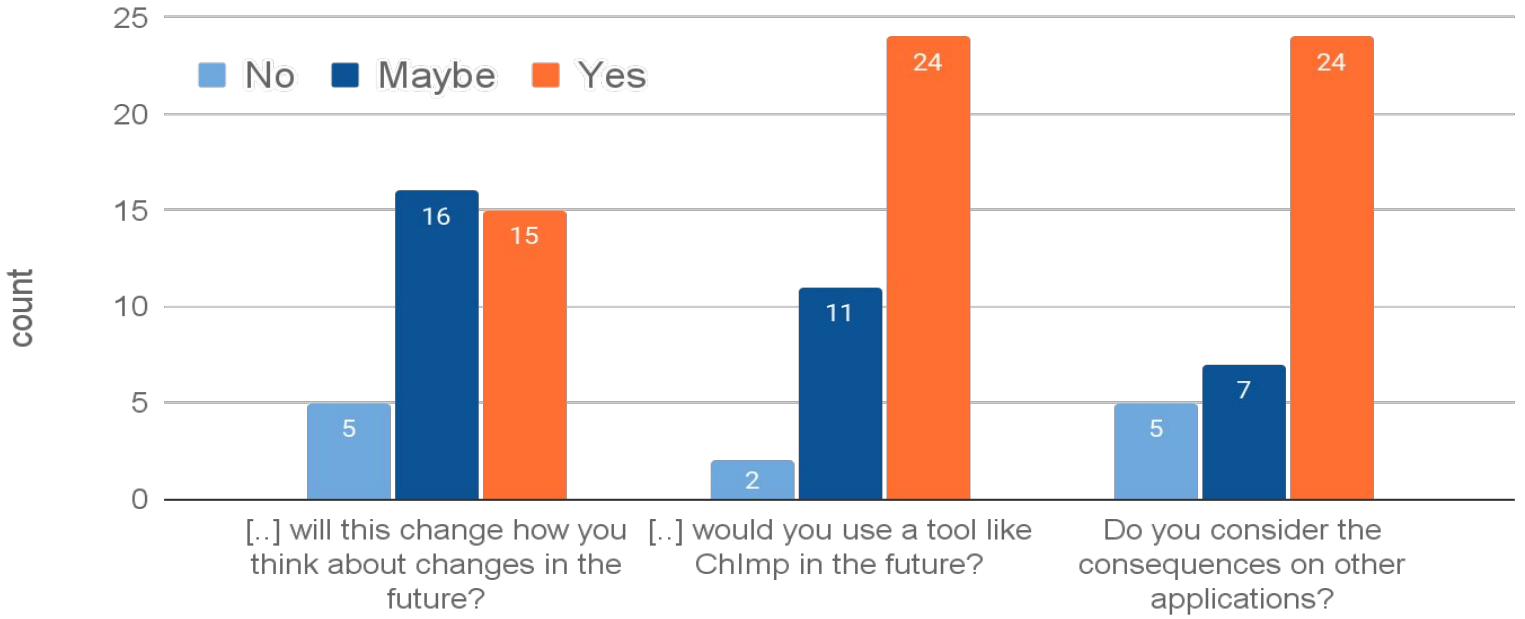


Participant Numbers

	Recorded	Used	G1	G2	G3	G4
Task 1	53	36	5	13	7	11
Task 2	37	25	4	7	6	8

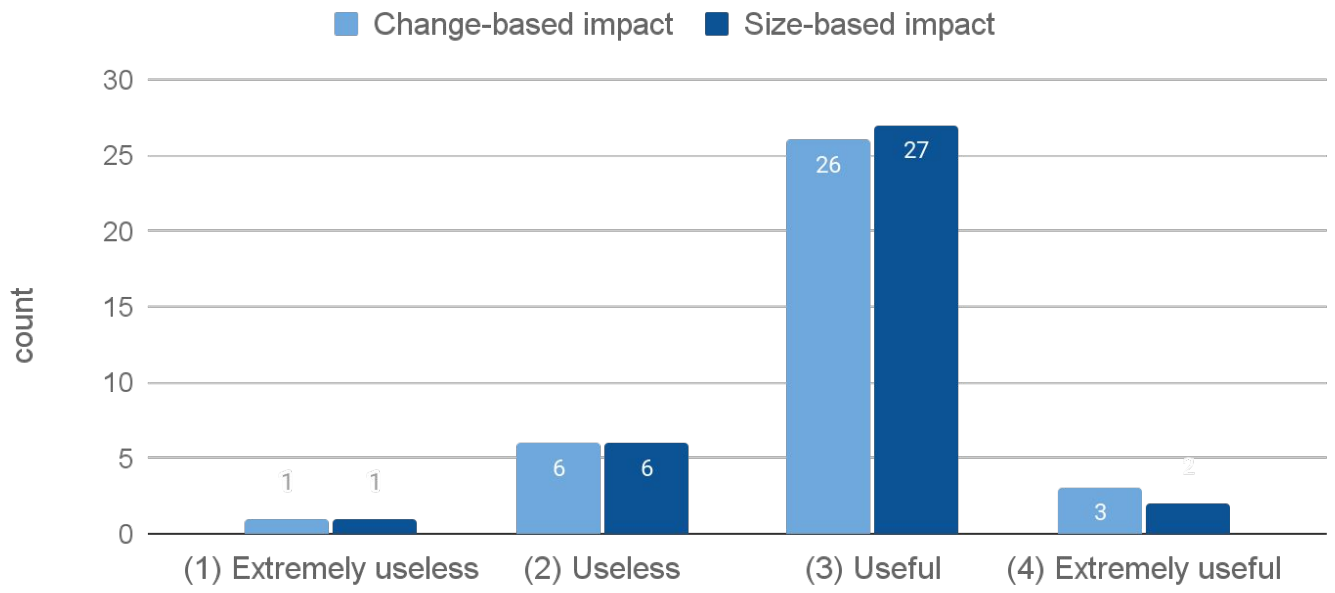
Pernisch et al. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2022.100715.

Is ChImp helpful in thinking about consequences?



Pernisch et al. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2022.100715.

Are the materialization impact measures useful for ontology engineers?



Pernisch et al. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*. https://doi.org/10.1016/j.websem.2022.100715.

ChImp is a **useful tool** to communicate the impact of changes on the ontology and materialisation.

The Knowledge Evolution Problem

How can we capture the impact on the materialisation?

Change-based impact
Size-based impact

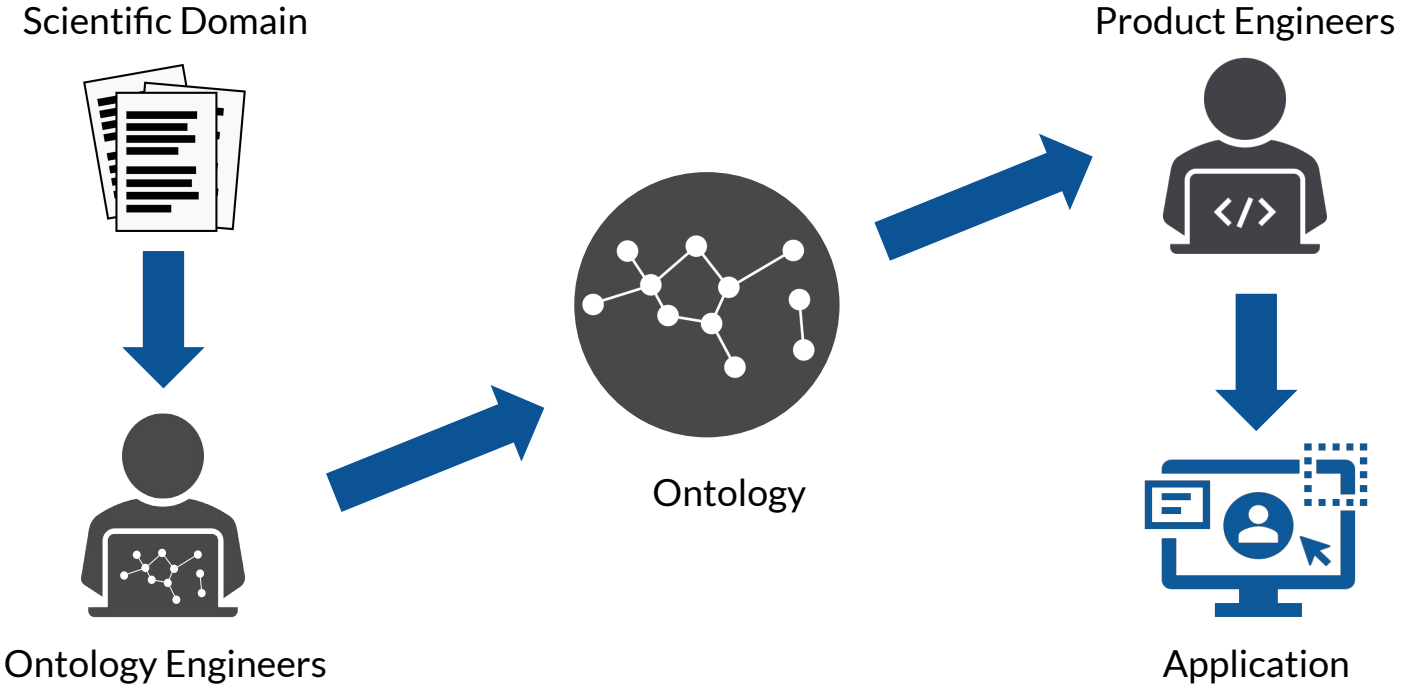
How do ontology engineers understand the impact of ontology changes?

ChImp plugin and measures were useful

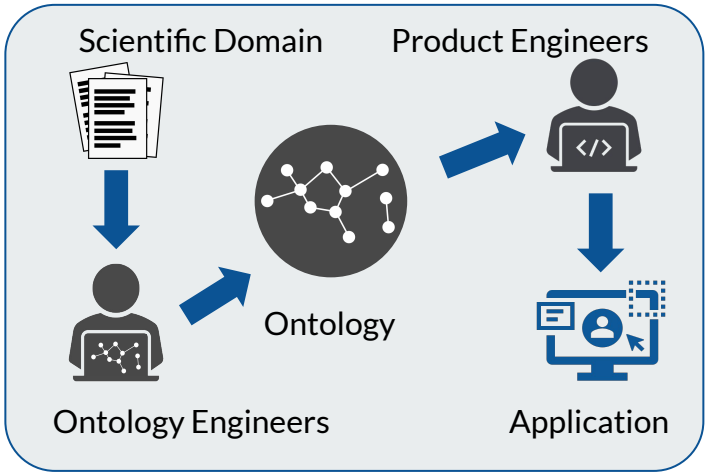
Do ontology management frameworks match the need in practice?

Manage:
Do ontology management frameworks match the **need in practice**?

Ontology evolution within organisations

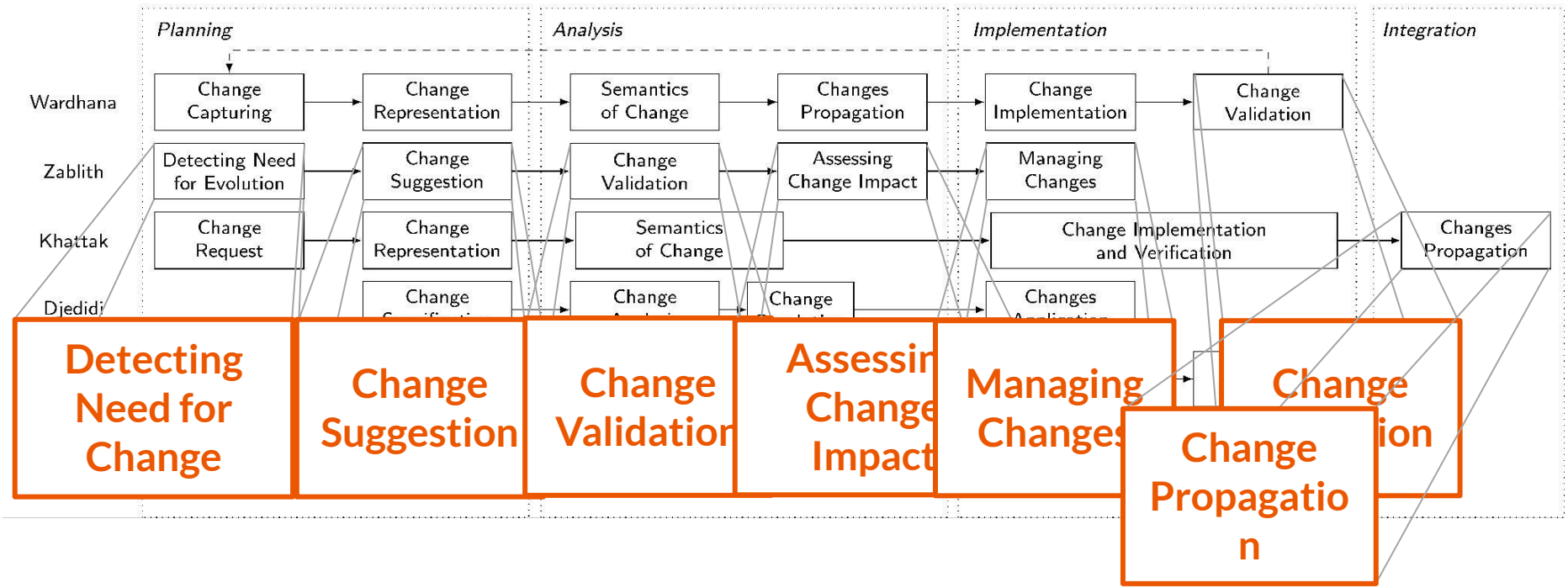


Investigation of Theoretical Frameworks



- What are **known requirements** for the process of ontology evolution?
- Do these requirements encompass what the **process is in practice**? Do we need more requirements?
- How do state-of-the-art ontology evolution frameworks **comply** to these requirements?
- Can we **unify** state-of-the-art frameworks and bridge the gap between practice and theory?

Ontology Evolution Framework



Zablith, F., Antoniou, G., d'Aquin, M., Flouris, G., Kondylakis, H., Motta, E., ... & Sabou, M. (2015). *Ontology evolution: a process-centric survey*. The knowledge engineering review, 30(1), 45-75.

Requirements for Ontology Evolution

R1 Ontology evolution facilitates **identification of change** requirements from several sources.

- **R1.1** End-user behaviour
- **R1.2** Domain

R2 Ontology evolution has to enable the **handling** of the given ontology **changes**.

- **R2.1** Formal specification
- **R2.2** Task separation
- **R2.3** Validation after impl.

R3 Ontology evolution ensures the **consistency** of the changed **ontology** and dependent artefacts.

- **R3.1** Choice of resolution
- **R3.2** Minimize impact
- **R3.3** Impact notification before imp.

Example: SciBite

Suggesting Changes

Validating Changes

Assessing Impact

Managing and Applying Changes

Propagating and Publishing Changes

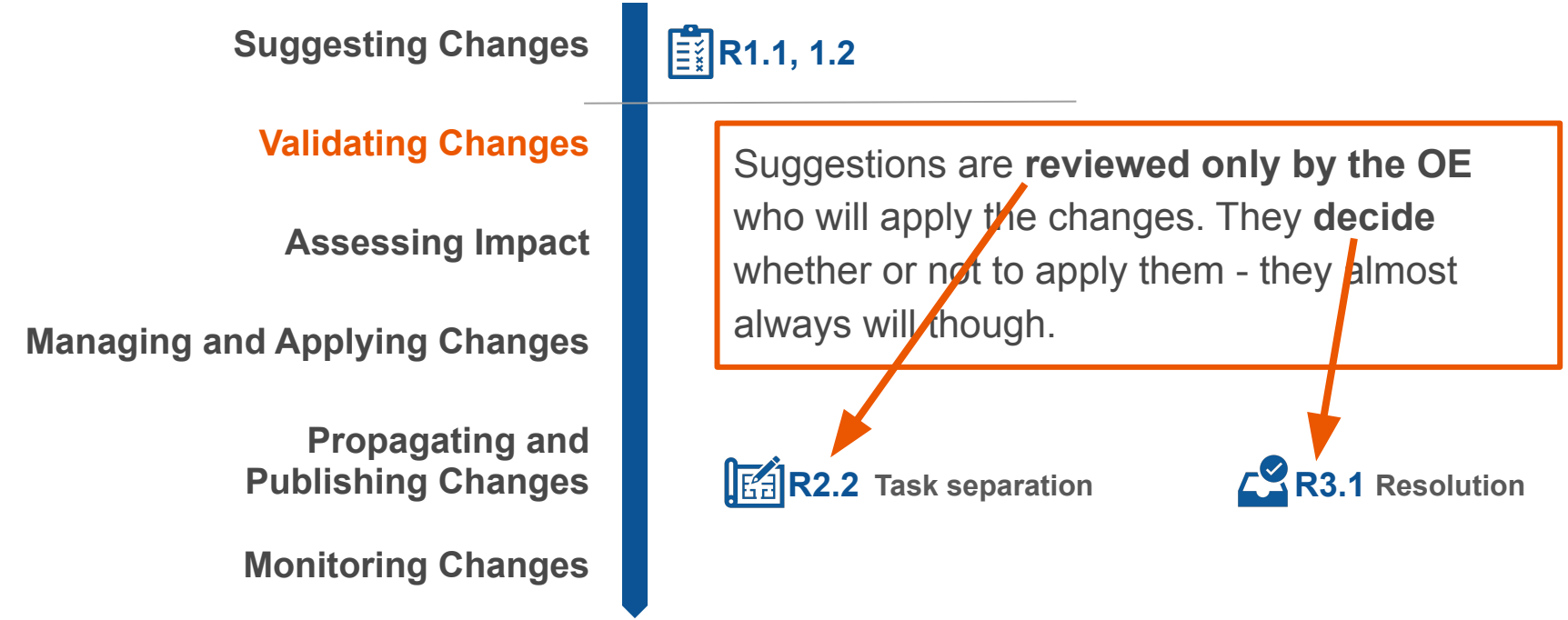
Monitoring Changes

Suggestions come from **external** and **internal customers**. Also from the **OEs**. These are logged in a **Git ticket** for the next update for that ontology.

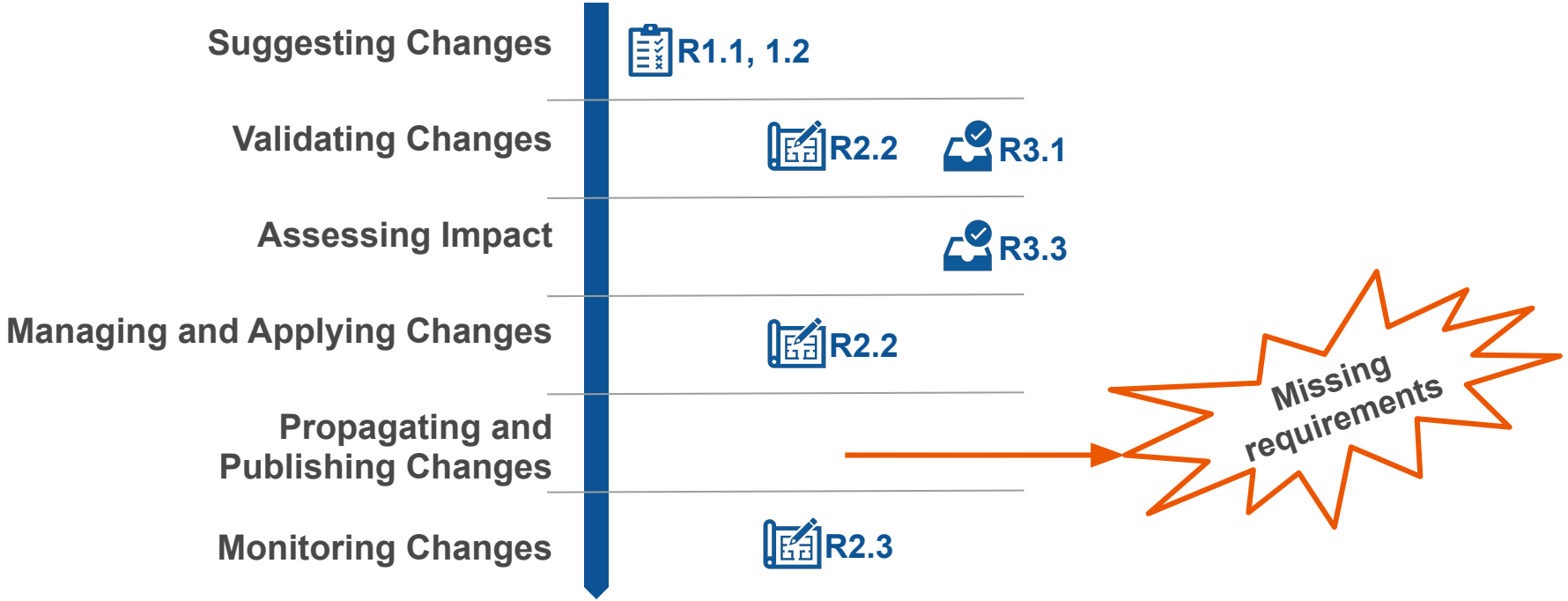
R1.1 End-user behaviour

1.2 Domain

Example: SciBite



Example: SciBite

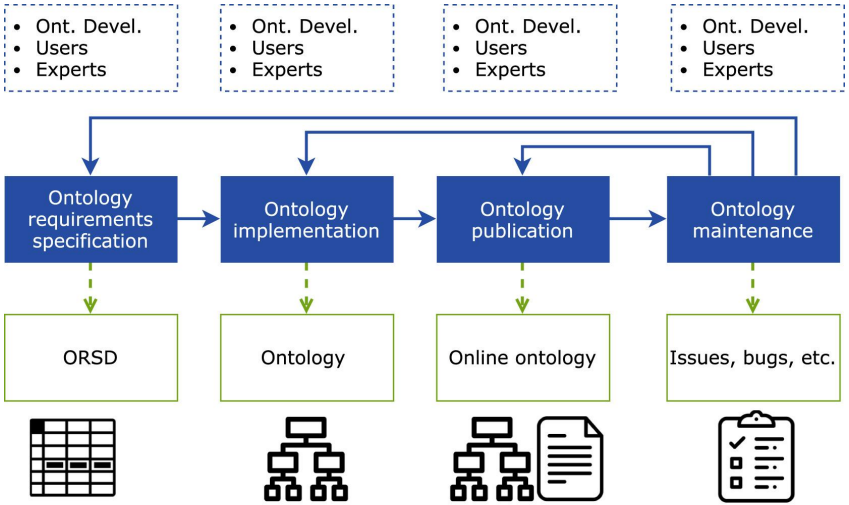


Ontology Engineering

R4

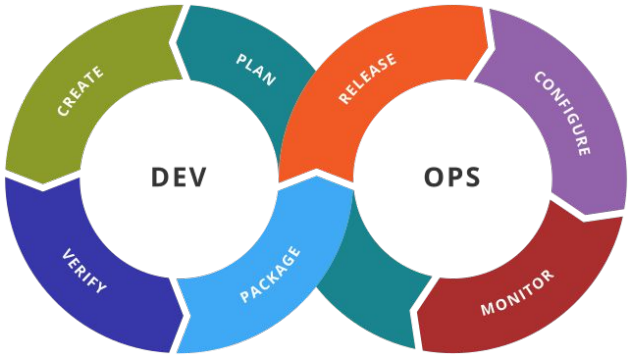
Ontology evolution **focuses on its application** and usage throughout the process.

- **R4.1** While defining changes
- **R4.2** Validation before
- **R4.3** Verification after



M. Poveda-Villalón, A. Fernández-Izquierdo, M. Fernández-López, and R. García-Castro. 2022. LOT: An industrial oriented ontology engineering framework. Engineering Applications of Artificial Intelligence 111 (May 2022), 104755.

Continuous Development and Operations



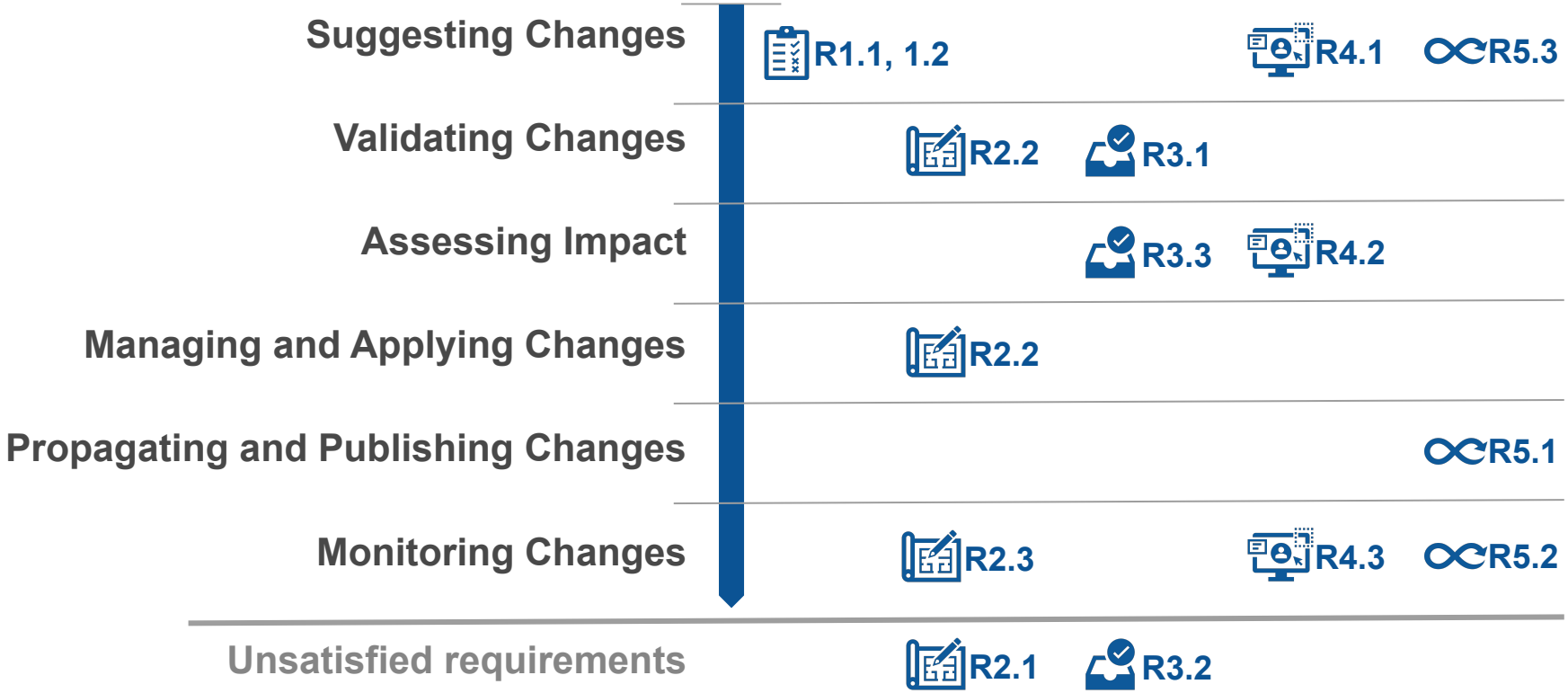
∞R5

Ontology evolution is a **collaborative** endeavour between development and operations.

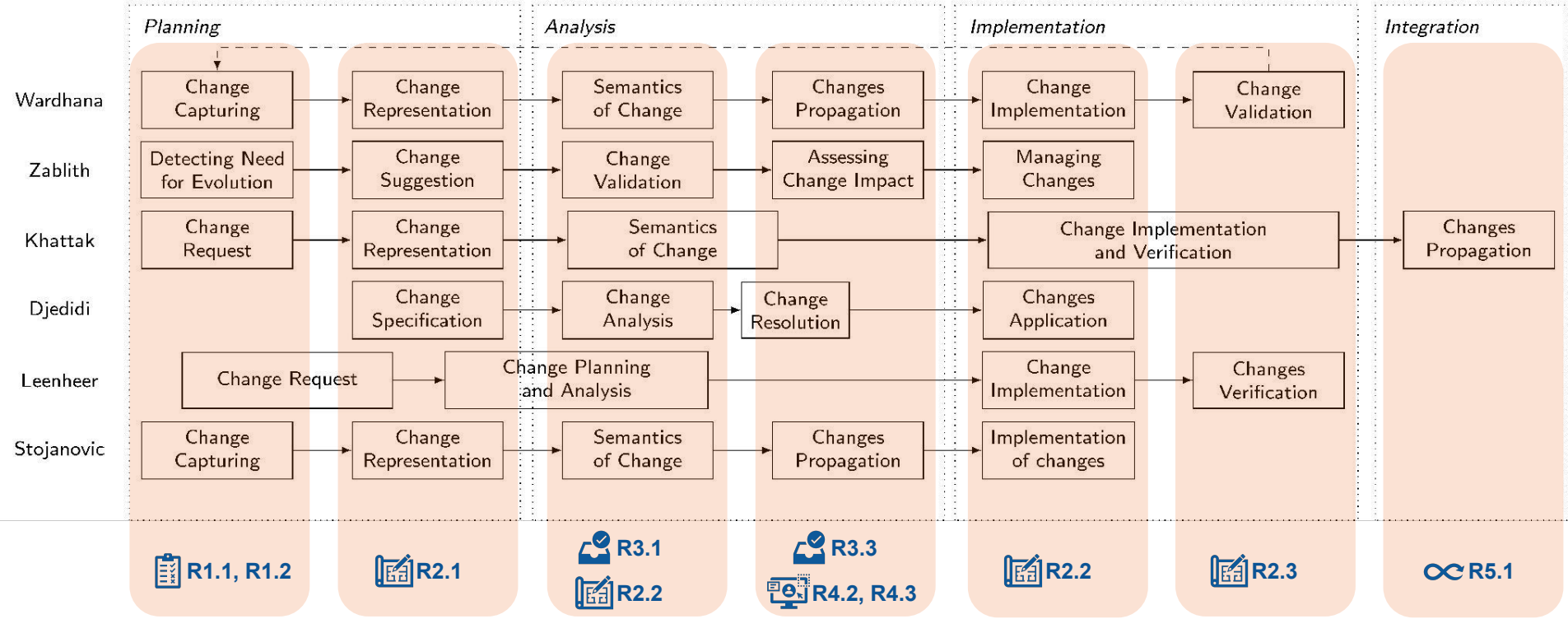
- ∞R5.1 Propagation
- ∞R5.2 Monitoring
- ∞R5.3 Cycle

P. Arentoft Nielsen, T. J. Winkler, and J. Nørbjerg. 2017. Closing the IT Development-operations Gap: The DevOps Knowledge Sharing Framework. In Joint Proceedings of the BIR 2017 pre-BIR Forum, Workshops and Doctoral Consortium. CEUR.

Requirement Mapping to Case Studies



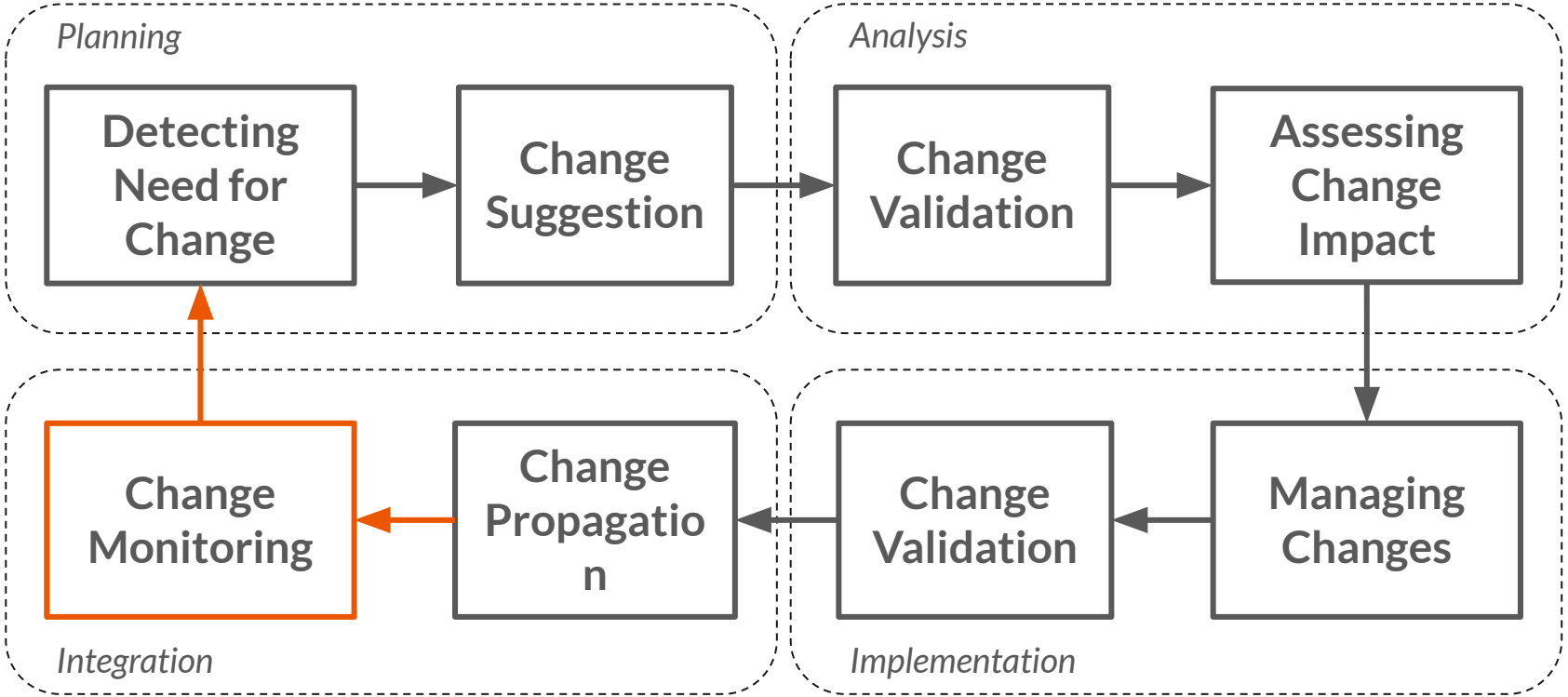
Comparison of Frameworks



Comparison to Requirements

	Case Study	Stojanovic	Leenheer	Djedidi	Khattak	Zablith	Wardhana
R1 **1.1, 1.2**	✓ ✓, ✓	✓ ✓, ✓	✓ ✗, ✗	✗ ✗, ✗	✓ ✗, ✗	✓ ✓, ✓	✓ ✓, ✓
R2 **2.1, 2.2, 2.3**	✓ ✗, ✓, ✓	✓ ✓, ✓, ✗	✓ ✓, ✓, ✓	✓ ✓, ✓, ✗	✓ ✓, ✓, ✓	✓ ✓, ✓, ✗	✓ ✓, ✓, ✓
R3 **3.1, 3.2, 3.3**	✓ ✓, ✗, ✓	✓ ✗, ✗, ✓	(✓) ✗, ✗, ✗	(✓) ✓, ✓, ✗	(✓) ✗, ✓, ✗	✓ ✗, ✓, ✓	✓ ✗, ✓, ✓
R4 **4.1, 4.2, 4.3**	✓ ✓, ✓, ✓	(✓) ✓, ✓, ✗	✗ ✗, ✓, ✗	✗ ✗, ✓, ✗	✗ ✗, ✓, ✗	✗ ✗, ✓, ✗	✗ ✗, ✓, ✗
R5 **5.1, 5.2, 5.3**	✓ ✓, ✓, ✓	✗ ✗, ✗, ✗	✗ ✗, ✗, ✗	✗ ✗, ✗	✗ ✓, ✗	✗ ✗, ✗	✗ ✗, ✗, (✓)

Requirement-based Evolution Framework for Ontologies



We **identified a gap** between theoretical frameworks and ontology evolution in practice.

The Knowledge Evolution Problem

How can we capture the impact on the materialisation?

Change-based impact
Size-based impact

How do ontology engineers understand the impact of ontology changes?

ChImp plugin and measures were useful

Do ontology management frameworks match the need in practice?

Gap between theory and practice

Open Challenges

Change impact and its analysis on other applications

Change ownership

Communication between engineers and product owners

Handling of change impact

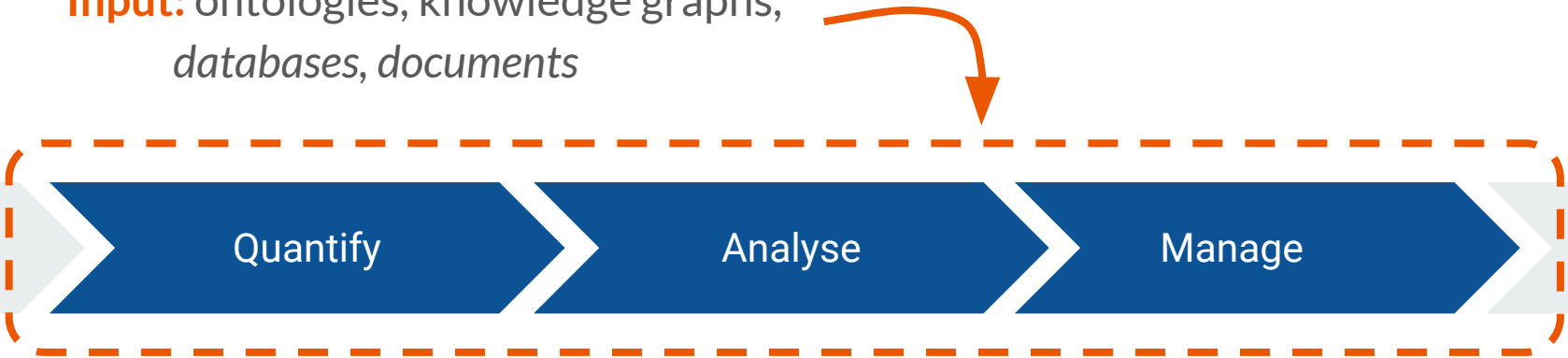
Extending the existing framework

Tool support and availability

Extend of process automation

Knowledge Evolution, and their Impact on Downstream Applications

Input: ontologies, knowledge graphs,
databases, documents



Applications: reasoning, embeddings,
stream reasoning, machine learning

Conclusion:
Analytical and empirical study of ontology evolution and methodology for managing it.

Questions?

impact
ontology
study
metrics
protégé
web
user
survey
consequences
semantics
research
severity
science
reasoner
investigate
design
data
implementation
evaluation
execution
mock-up
difference
users
engineer
world
axioms
semantic
informative
reasoning
usefulness
self-assessment
www
important
inform
property
superclass
subclass
owl
completed
methodology
understand
individual
communication
contrast
commented
removeaxiom
inconsistent
ontologyid
mappings
department
parts
entailment
piebase
veganbase
logical
interpretation
multiple
hierarchy

Thank you for your attention.

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Vrije Universiteit Amsterdam, Netherlands

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email: r.pernisch@vu.nl

References

Pernisch, R., Dell'Aglio, D., & Bernstein, A. (2021). Beware of the hierarchy—An analysis of ontology evolution and the materialisation impact for biomedical ontologies. *Journal of Web Semantics*, *70*, 100658.

Pernisch, R., Dell'Aglio, D., Serbak, M., Gonçalves, R. S., & Bernstein, A. (2022). Visualising the effects of ontology changes and studying their understanding with ChImp. *Journal of Web Semantics*, *74*, 100715.

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Wardhana, H., Ashari, A., & Kartika, A. (2018). Review of ontology evolution process. *International Journal of Computer Applications*, *45*, 26-33.

Khattak, A. M., Latif, K., Lee, S., & Lee, Y. K. (2009). Ontology evolution: A survey and future challenges. In *U-and E-Service, Science and Technology: International Conference, UNESST 2009, Held as Part of the Future Generation Information Technology Conference, FGIT 2009, Jeju Island, Korea, December 10-12, 2009. Proceedings* (pp. 68-75). Springer Berlin Heidelberg.

Djedidi, R., & Aufaure, M. A. (2009). Ontology Change Management. In *I-SEMANTICS* (pp. 611-621).

De Leenheer, P., & Mens, T. (2008). Ontology evolution: State of the art and future directions. *Ontology management: semantic web, semantic web services, and business applications*, 131-176.

Stojanovic, L. (2004). Methods and tools for ontology evolution.

Ongoing and Future Work

Quantify	Analyse	Manage
Survey of ontology and KG measures and their usage in research.	Analysis of concept changes in a robot environment.	Visualisations for ontology change summarisation.
Impact of changes on ML applications.		Extension of existing management frameworks.

Embeddings

Quantify → Analyse → Manage

How can we capture the impact on embeddings?

Link prediction performance change, Embedding Resemblance Indicator.

Analysis of synthetic changes and their impact on embeddings.

Change in link prediction performance very small, ERI captures the change in embedding structure.

Compute embeddings incrementally to minimize the impact of changes?

MaCLKGE: performance of link prediction same as recalculations.

Pernisch et al. (2021). Toward Measuring the Resemblance of Embedding Models for Evolving Ontologies. *Proceedings of the 11th Knowledge Capture Conference*. https://doi.org/10.1145/3460210.3493540.


R1


R2


R2.2


R2.3


R3


R3.1


R3.3


R4


R4.3


R5


R5.3