ENGAGE.EU - Data Science in Action

Combining Semantic Web and Machine Learning Techniques for Data Analysis Systems

Anna Breit (SWC), Laura Waltersdorfer (TU), Fajar J. Ekaputra (WU), **Marta Sabou (WU),** Andreas Ekelhart (Uni Wien), Andreea Iana (UMannheim), Heiko Paulheim (UMannheim), Jan Portisch (UMannheim), Artem Revenko (SWC), Annette ten Teije (VUA'dam), Frank van Harmelen (VUA'dam)

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STAND: JUNI 2018

This talk would not have been possible without the SemSys TEAM

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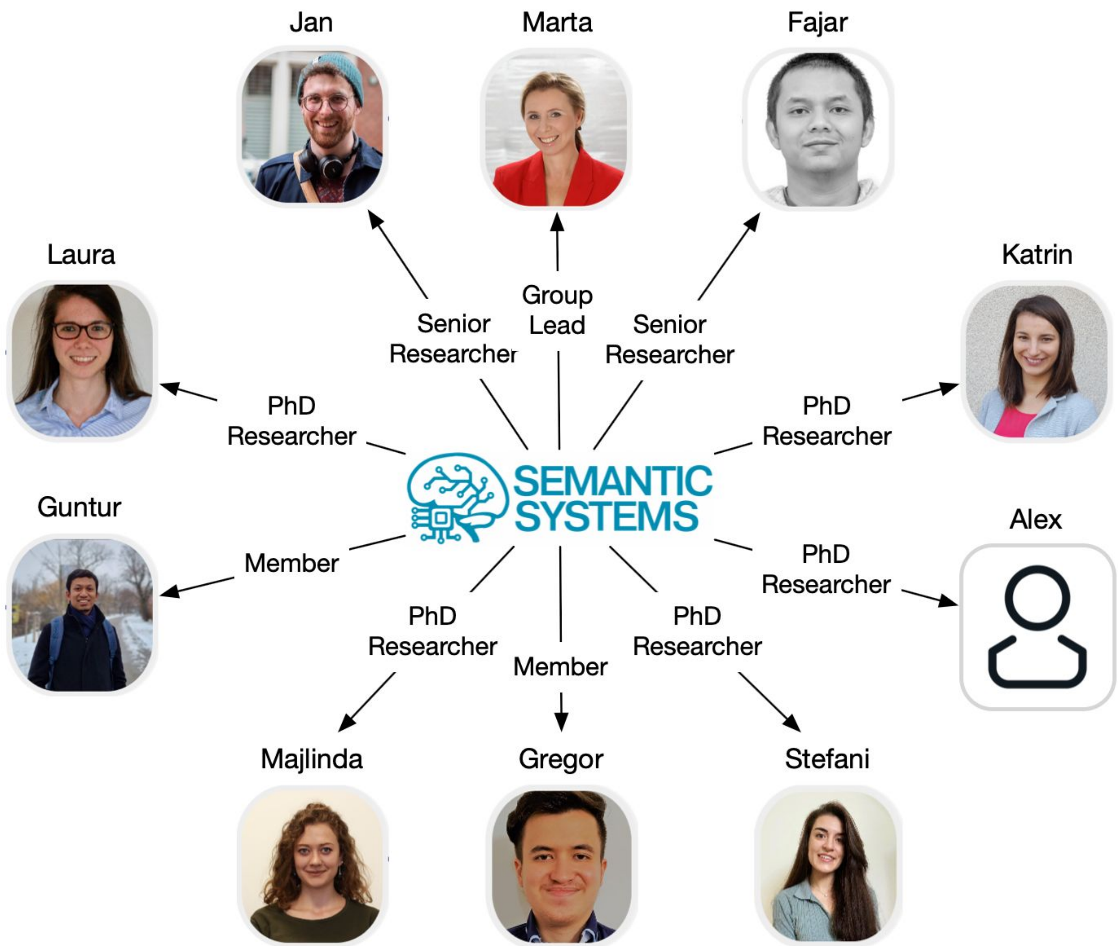

Summary of my talk

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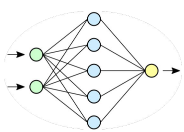
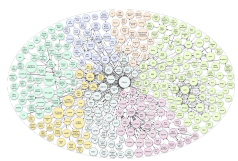
Creating intelligent applications that valorise complex domain data such as in the **scientific, technical, and legal domain** often calls for solutions that **combine sub-symbolic and symbolic AI** methods.

Part I (Preliminaries):



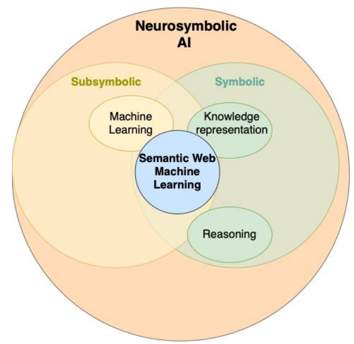
Sub-symbolic AI



Symbolic AI

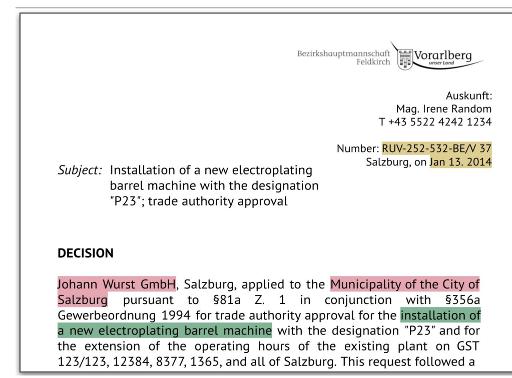
Neuro-Symbolic AI Techniques

Part II (Macro):



Systematic Study of SW and ML systems (SWeML) (a sub-family of neuro-symbolic systems)

Part III (Micro):



Bezirkshauptmannschaft Feldkirch Vorarlberg

Auskunft:
Mag. Irene Random
T +43 5522 4242 1234

Number: RUV-252-532-BE/V 37
Salzburg, on Jan 13. 2014

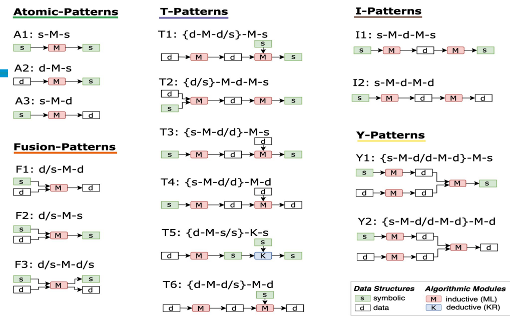
Subject: Installation of a new electroplating barrel machine with the designation "P23"; trade authority approval

DECISION

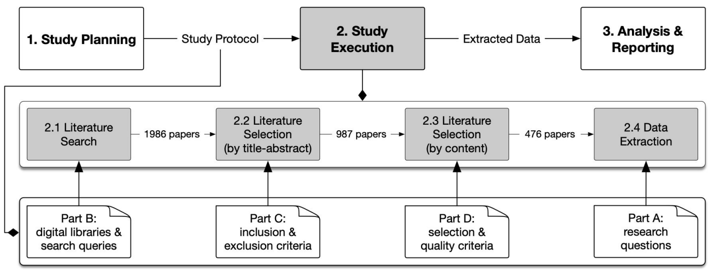
Johann Wurst GmbH, Salzburg, applied to the Municipality of the City of Salzburg pursuant to §81a Z. 1 in conjunction with §356a Gewerbeordnung 1994 for trade authority approval for the installation of a new electroplating barrel machine with the designation "P23" and for the extension of the operating hours of the existing plant on GST 123/123, 12384, 8377, 1365, and all of Salzburg. This request followed a

SWeML approach for information extraction in the legal domain

What you will learn in this talk

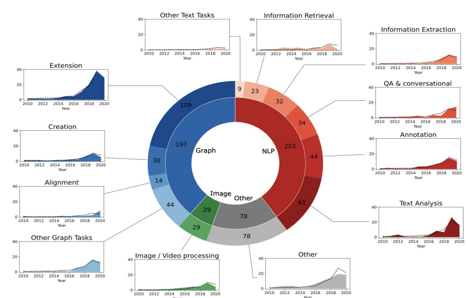


New techniques combine **symbolic** (Semantic Web) **and sub-symbolic** (Machine Learning) **AI** methods in various ways to solve complex (data science) tasks.



Systematic Literature Review is a valuable research method.

Beyond "Data Science" - applications that valorise complex domain data, with an example from the legal domain.



Preliminaries: Semantic Web (Symbolic AI)

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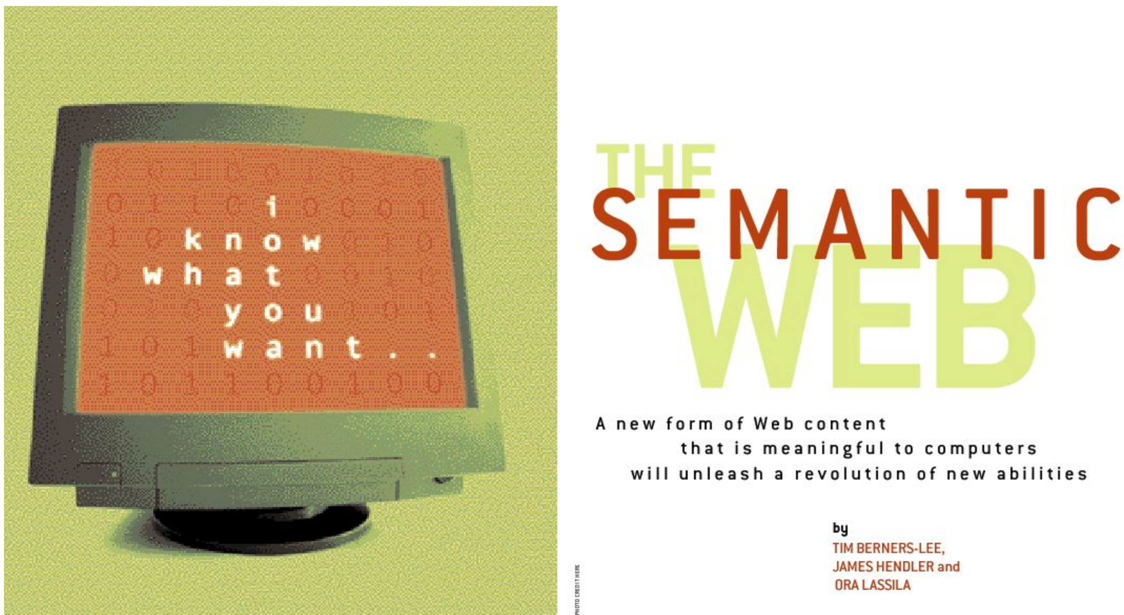
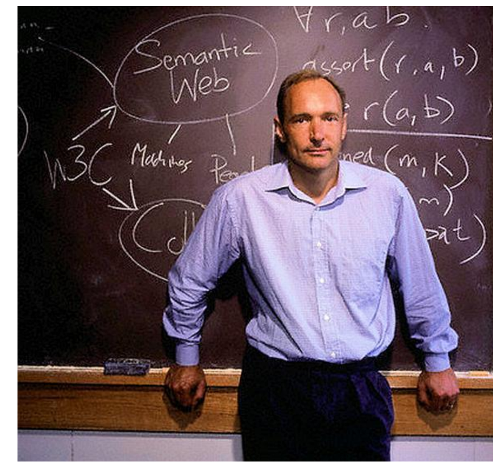
STAND: JUNI 2018

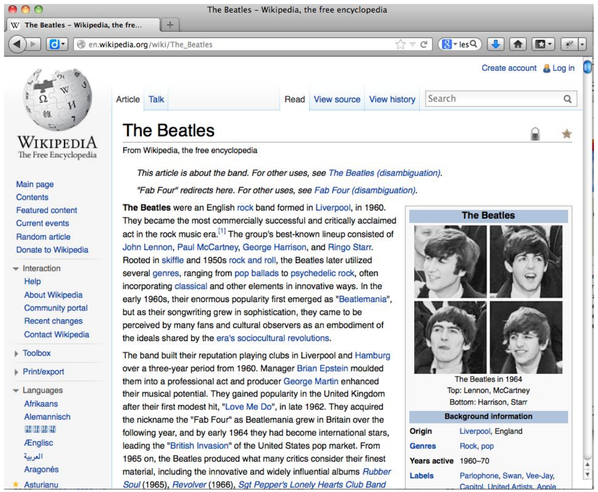
Symbolic AI – The Semantic Web

Scientific American, May 2001:





Symbolic AI – DBpedia


The Beatles – Wikipedia, the free encyclopedia

en.wikipedia.org/wiki/The_Beatles

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  - Ænglisc
  - العربية
  - Aragonés
  - Asturianu

The Beatles

From Wikipedia, the free encyclopedia

This article is about the band. For other uses, see The Beatles (disambiguation).

"Fab Four" redirects here. For other uses, see Fab Four (disambiguation).

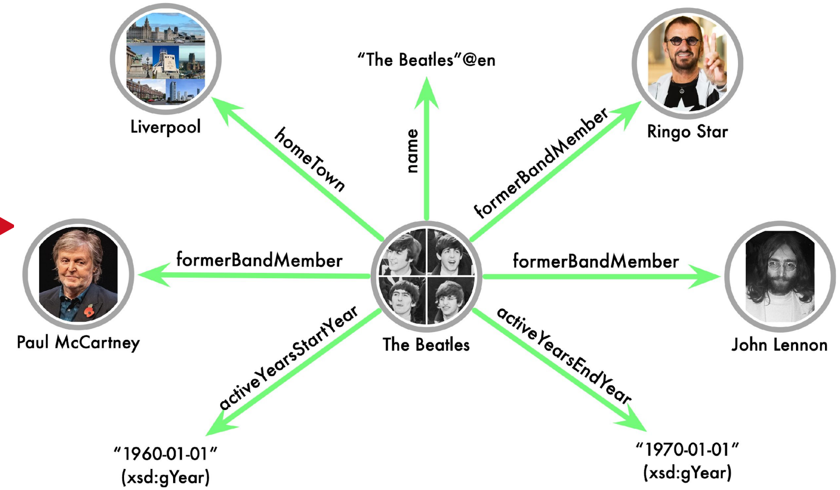
The Beatles were an English rock band formed in Liverpool, in 1960. They became the most commercially successful and critically acclaimed act in the rock music era.[1] The group's best-known lineup consisted of John Lennon, Paul McCartney, George Harrison, and Ringo Starr. Rooted in skiffle and 1950s rock and roll, the Beatles later utilized several genres, ranging from pop ballads to psychedelic rock, often incorporating classical and other elements in innovative ways. In the early 1960s, their enormous popularity first emerged as "Beatlemania", but as their songwriting grew in sophistication, they came to be perceived by many fans and cultural observers as an embodiment of the ideals shared by the era's sociocultural revolutions.

The band built their reputation playing clubs in Liverpool and Hamburg over a three-year period from 1960. Manager Brian Epstein moulded them into a professional act and producer George Martin enhanced their musical potential. They gained popularity in the United Kingdom after their first modest hit, "Love Me Do", in late 1962. They acquired the nickname the "Fab Four" as Beatlemania grew in Britain over the following year, and by early 1964 they had become international stars, leading the "British Invasion" of the United States pop market. From 1965 on, the Beatles produced what many critics consider their finest material, including the innovative and widely influential albums *Rubber Soul* (1965), *Revolver* (1966), *Sgt Pepper's Lonely Hearts Club Band*

The Beatles

The Beatles in 1964
Top: Lennon, McCartney
Bottom: Harrison, Starr

Background information	
Origin	Liverpool, England
Genres	Rock, pop
Years active	1960–70
Labels	Parlophone, Swan, Vee-Jay, Capitol, United Artists, Apple



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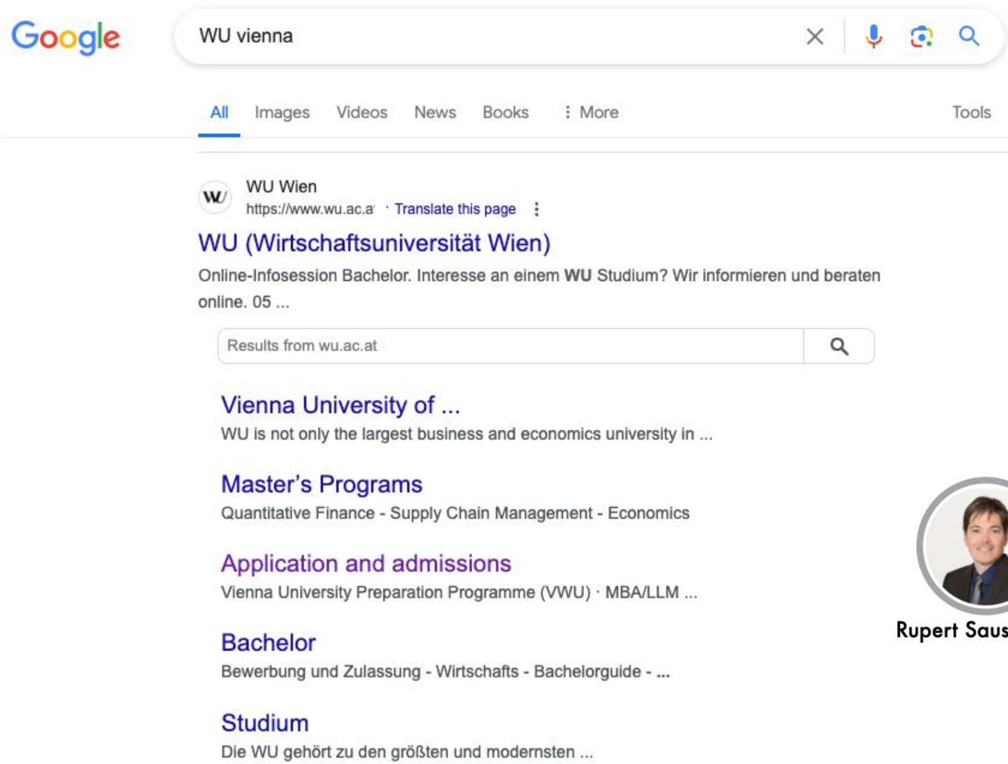
The Free Encyclopedia

DBpedia

Symbolic AI – Knowledge Graphs on the Web

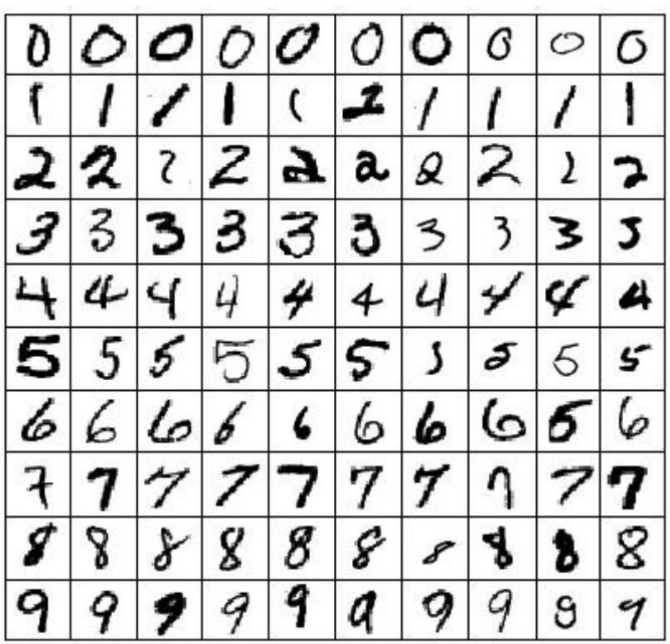


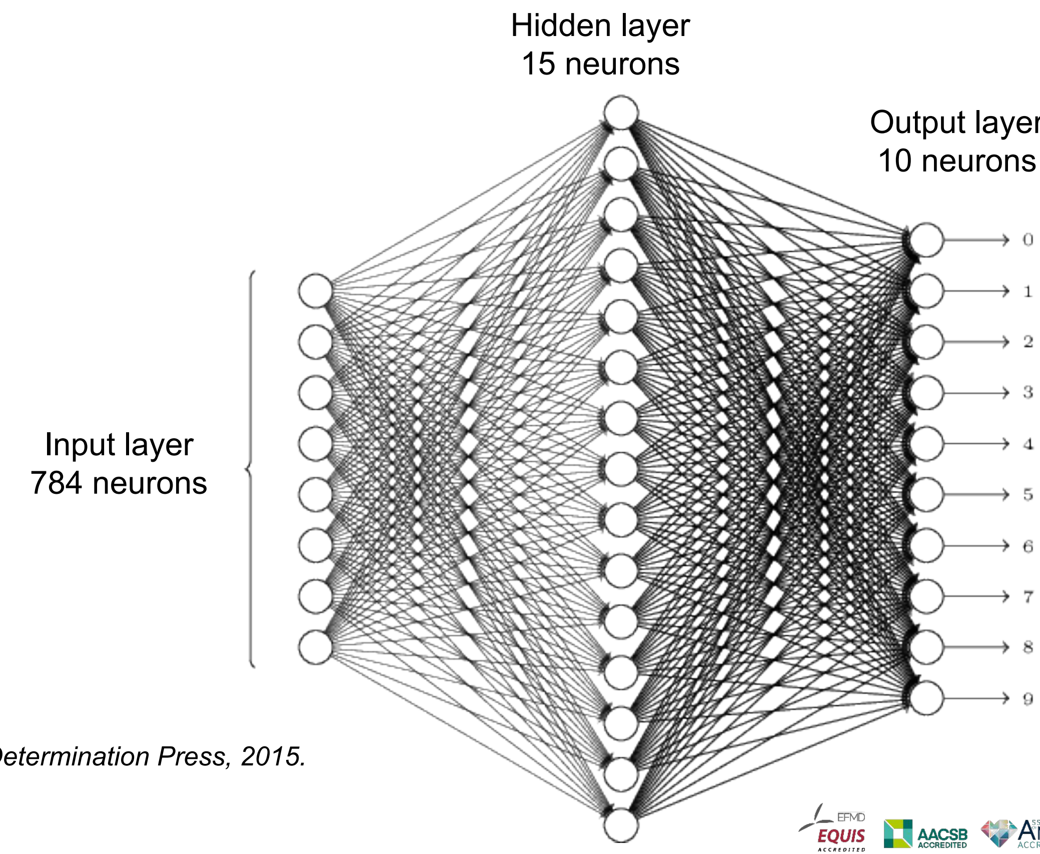
Preliminaries: Machine Learning (sub-symbolic AI)

STAND: JUNI 2018

Sub-Symbolic AI – Neural Networks

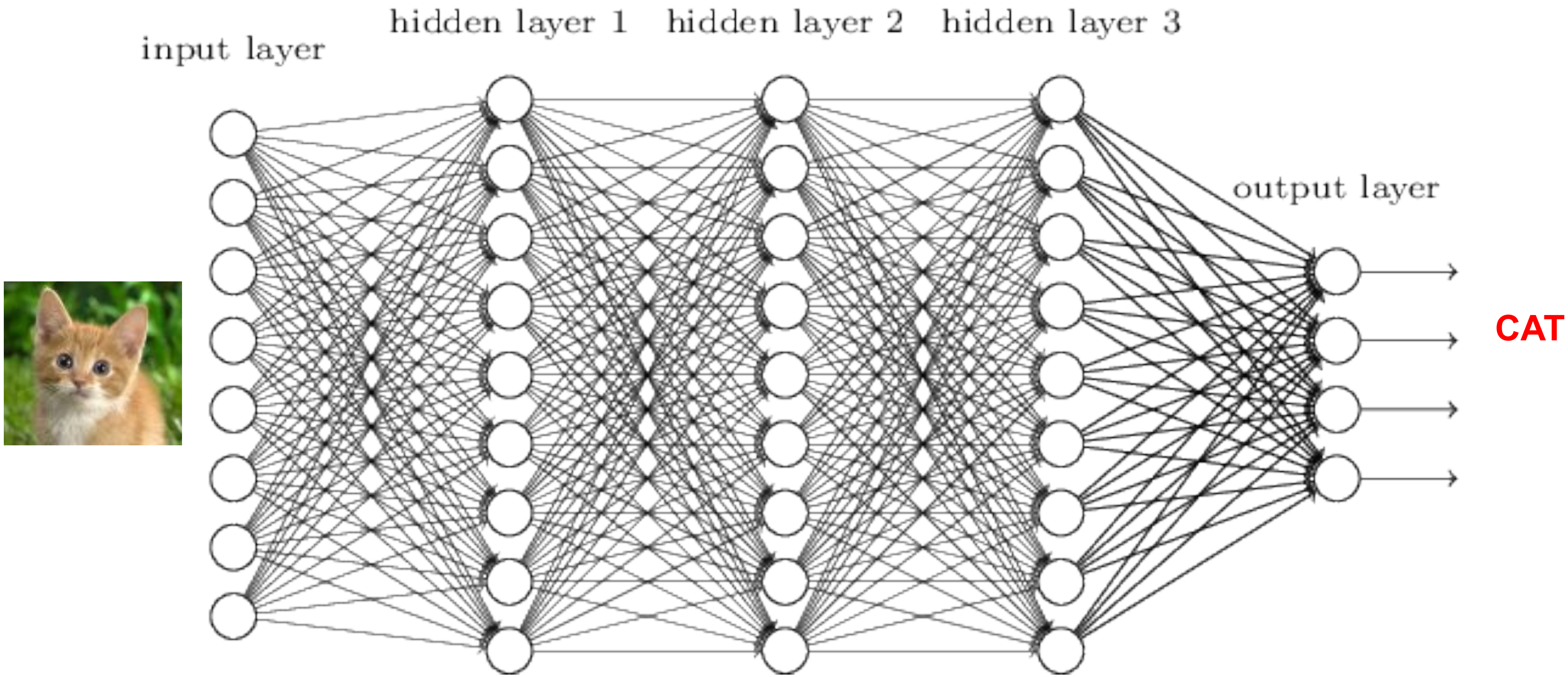
AI systems that learn patterns from large amounts of data





Source: M. Nielsen: "Neural Networks and Deep Learning", Determination Press, 2015.
http://neuralnetworksanddeeplearning.com/index.html

Sub-Symbolic AI – Deep Learning Networks



Source: M. Nielsen: Neural Networks and Deep Learning
http://neuralnetworksanddeeplearning.com/index.html

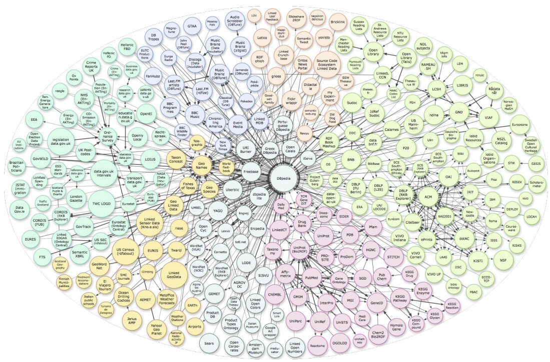
Sub-Symbolic AI –
Large Language Models (LLMs)

- LLMs ***are*** Deep Learning systems

- **LLMs** largely represent a class of Deep Learning architectures called transformer networks*
  - *Transformer model* is a neural network that learns context and meaning by tracking relationships in sequential data

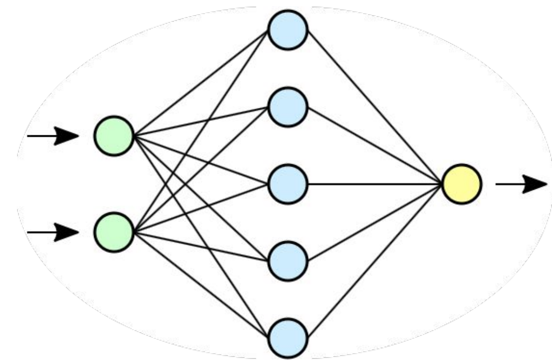
The Rise of Neurosymbolic AI

Symbolic AI



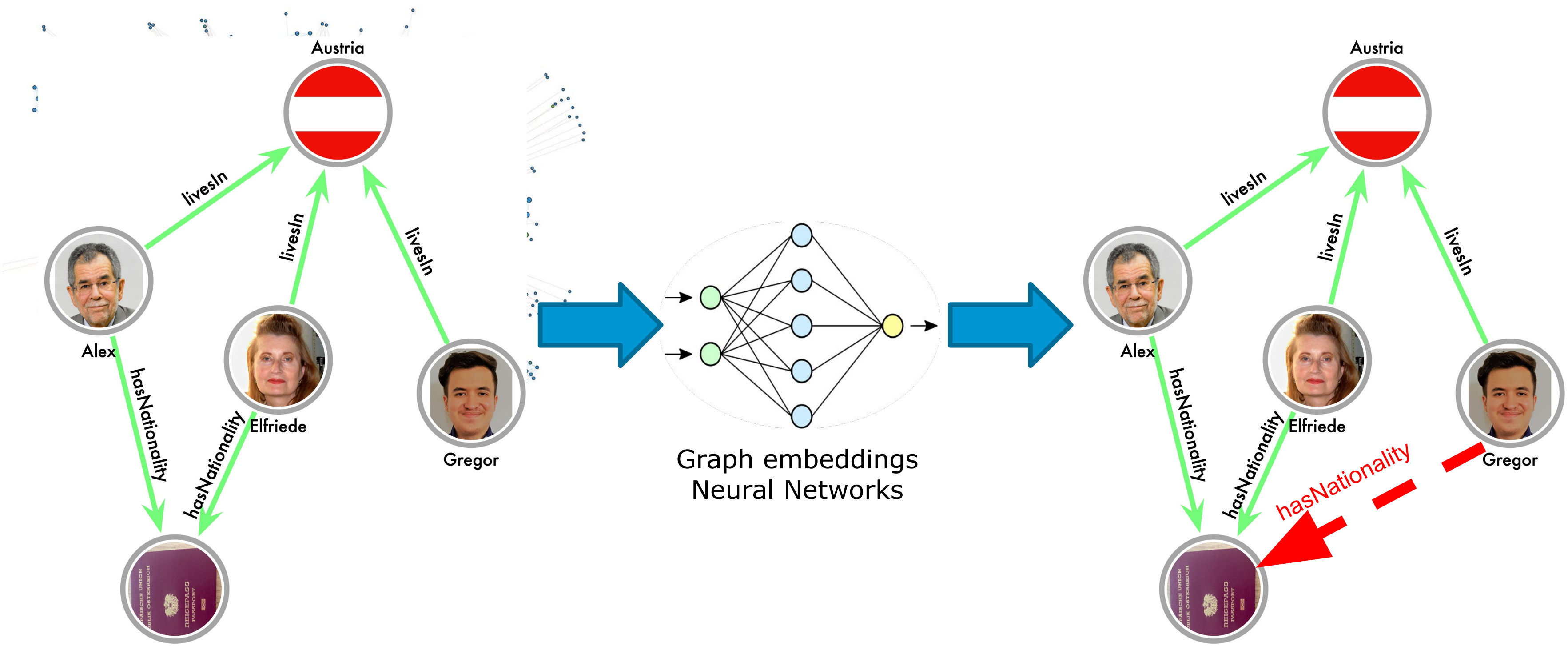
+ symbolic knowledge
+ explainability
- vulnerable to noisy data
- Knowledge acquisition bottleneck

Sub-symbolic AI

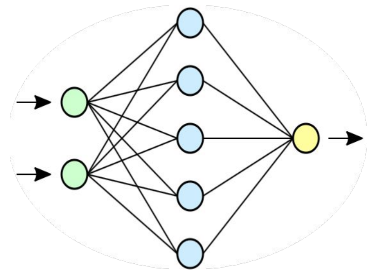


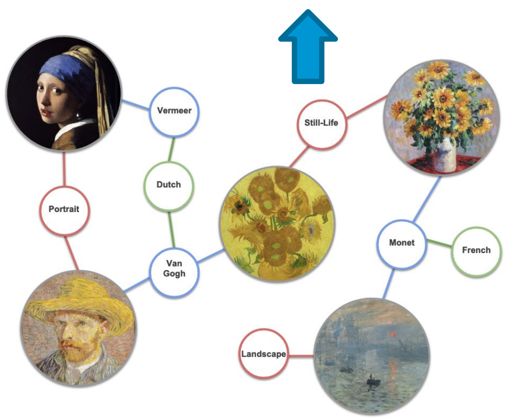
+ knowledge from sparse data
+ broad applicability
- Intransparency
- Often lots of training data required

Neuro-Symbolic AI – KG Completion with Neural Network



Neuro-Symbolic AI – Improving Neural Networks with KG





Classification:

- Type: Still-life
- School: Dutch
- Author: van Gogh

Accuracy improvement

+ 7.3%

Image Retrieval:

- “Still-life with flowers from Dutch school”

+ 37.24%

Garcia, N., Renoust, B., & Nakashima, Y. Context-aware embeddings for automatic art analysis. Int. Conf. on Multimedia Retrieval, 2019.

QUESTIONS?

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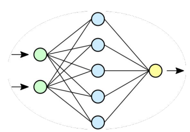
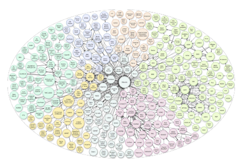


Sub-symbolic AI



Symbolic AI

Neuro-Symbolic AI Techniques

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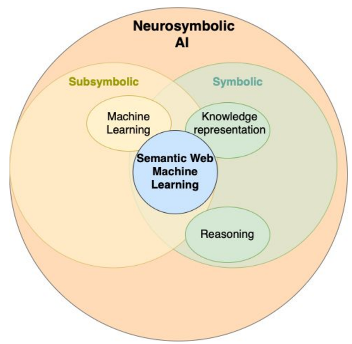

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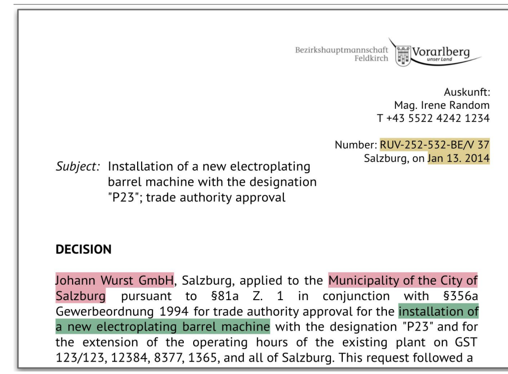

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SWeML approach for information extraction in the legal domain

Combining Machine Learning and Semantic Web: A Systematic Mapping Study (ACM Computing Surveys‘2023)

Anna Breit (SWC), Laura Waltersdorfer (TU), **Fajar J. Ekaputra (WU), Marta Sabou (WU),** Andreas Ekelhart (Uni Wien), Andreea Iana (UMannheim), Heiko Paulheim (UMannheim), Jan Portisch (UMannheim), Artem Revenko (SWC), Annette ten Teije (VUA’dam), Frank van Harmelen (VUA’dam)

Context: The Rise of Neurosymbolic AI

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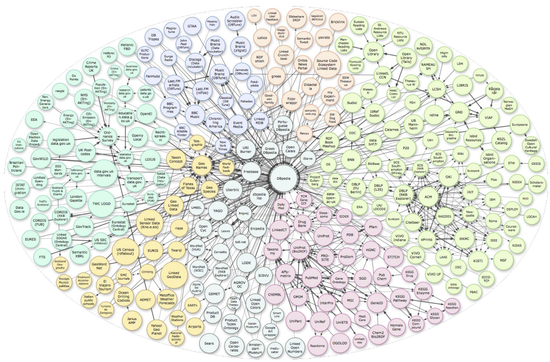
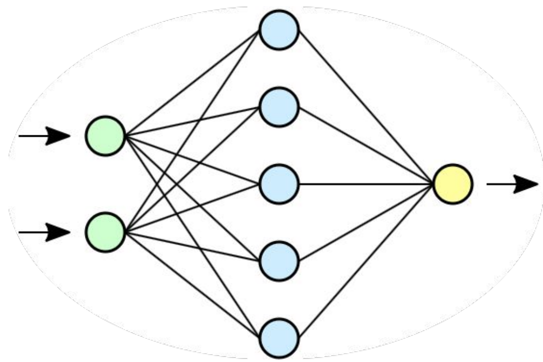
Symbolic AI



- + symbolic knowledge
- + explainability
- - vulnerable to noisy data
- - Knowledge acquisition bottleneck

Subsymbolic AI



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- - Intransparency
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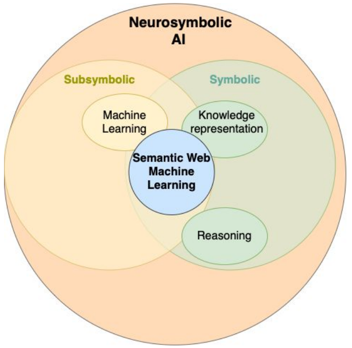
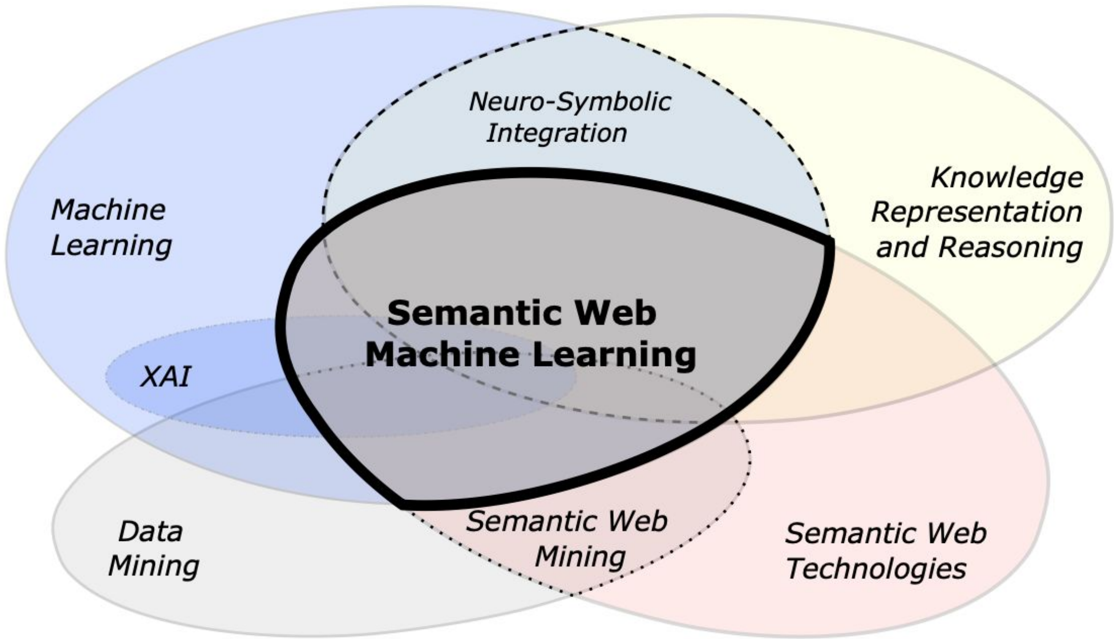
Semantic Web Machine Learning Systems



Our scope, subset/related area to neurosymbolic AI

→ Dynamic and impactful research area, yet **systematic knowledge missing** in terms of characteristics and system architectures

Semantic Web Machine Learning (Sytems) SWeML(S)



Semantic Web Machine Learning (**SWeML**) Systems combine Semantic Web Technologies and an inductive model.

They describe a system which makes use of a *Semantic Web knowledge structure* as well as a *machine learning sub-system* in order to solve a specific task.

Motivation:
Keeping up with trends in the field unfeasible

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***RQ:** What is the state of the art and trends related to systems that combine SW and ML components?*

Related Work:
focused on broader or narrower areas, rarely systematic

Ref.	Authors	Venue	Type	Year	Paper selection
[5]	Besold et al.	Neuro-Symbolic AI: The State of the Art	NeSy	2021	custom
[35]	von Rueden et al.	IEEE Transactions on Knowledge and Data Engineering	NeSy	2021	custom
[33, 34]	van Bekkum et al., van Harmelen et ten Teije	Applied Intelligence, J. of Web Engineering	NeSy	2019, 2021	custom
[16]	Hitzler et al.	Semantic Web	NeSy	2020	custom (vision paper)
[28]	Sarker et al.	arXiv	NeSy	2021	survey papers collected from NeurIPS, ICML, AAAI, ICLR, IJCAI
[29]	Seeliger et al.	SEMEX ISWC	XAI SWeMLS	2019	systematic literature review: *(Q1)* "deep learning" OR "data mining"; *(Q2)* "explanation*" OR "interpret*" OR "transparen*"; *(Q3)* "Semantic Web" OR "ontolog*" OR "background knowledge" OR "knowledge graph*"
[8]	D'Amato	Semantic Web	SW SWeMLS	2020	custom

Contribution:
Trends landscape through systematic mapping study

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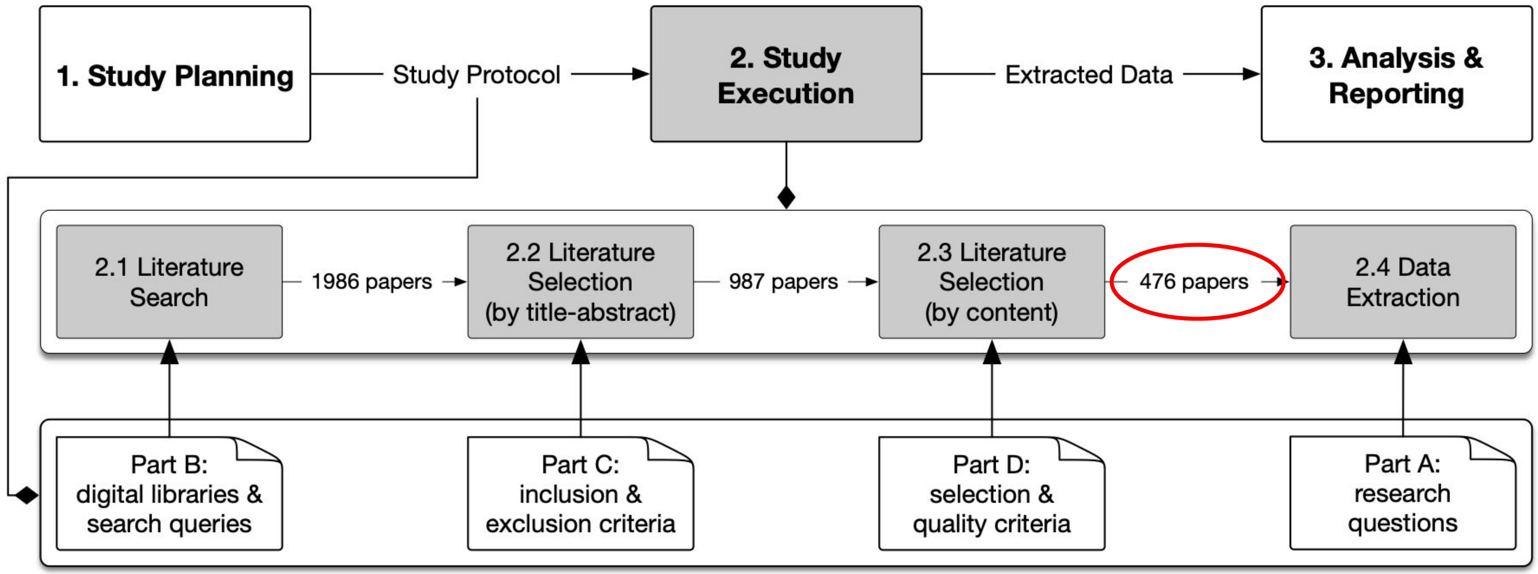
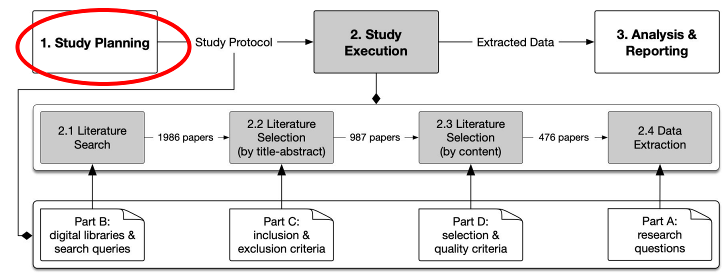
Methodology - Systematic Mapping Study [1]



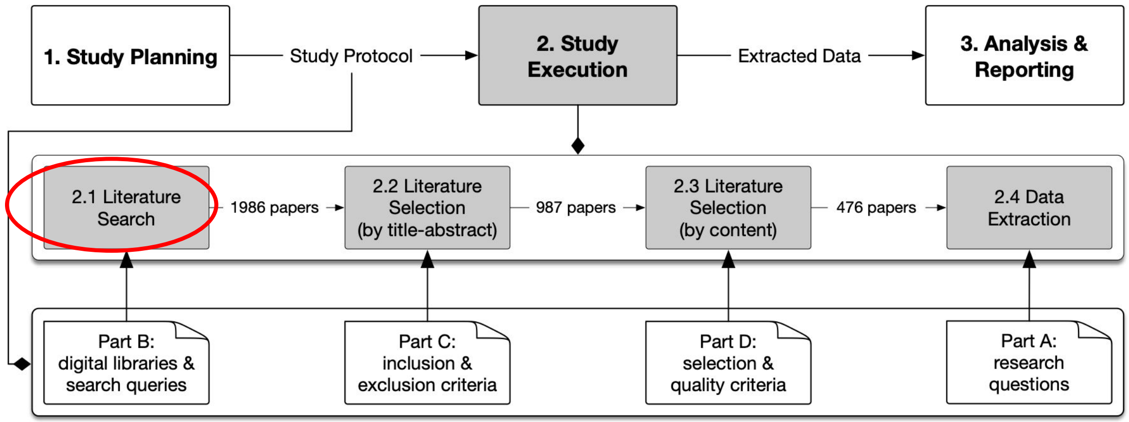
[1] Kitchenham B, Charters S, et al. Guidelines for performing systematic literature reviews in software engineering version 2.3. Engineering. 2007;45(4ve):1051

Methodology - Systematic Mapping Study

- **RQ1 Bibliographic characteristics**
  - Temporal and geographic distribution, keywords
- **RQ2 System Architecture.**
  - What processing patterns are used in terms of inputs/outputs and the order of processing units?
- **RQ3 Application Areas.**
  - tasks solved (e.g., text analysis), application domains (e.g., life sciences)
- **RQ4 Characteristics of the ML Module.**
  - typer of ML models (e.g., SVM), components (e.g., attention), training
- **RQ5 Characteristics of the SW Module.**
  - types, size, formalisation of SW structure (e.g., taxonomy); use of KR
- **RQ6 Maturity, Transparency and Auditability.**
  - system maturity and transparency (e.g., sharing source code, details of infrastructure, and evaluation setup); provenance-capturing



Methodology - Systematic Mapping Study



Sub-Query	Used Search Keywords
Q1 (SW module)	knowledge graph, linked data, semantic web, ontolog*, RDF, OWL, SPARQL, SHACL
Q2 (ML module)	deep learning, neural network, embedding, representation learning, feature learning, language model, language representation model, rule mining, rule learning, rule induction, genetic programming, genetic algorithm, kernel method
Q3 (System)	Natural Language Processing, Computer Vision, Information Retrieval, Data Mining, Information Integration, Knowledge Management, Pattern Recognition, Speech Recognition

Query Date: October 2020

Research Team: 10 participants

QUESTIONS?

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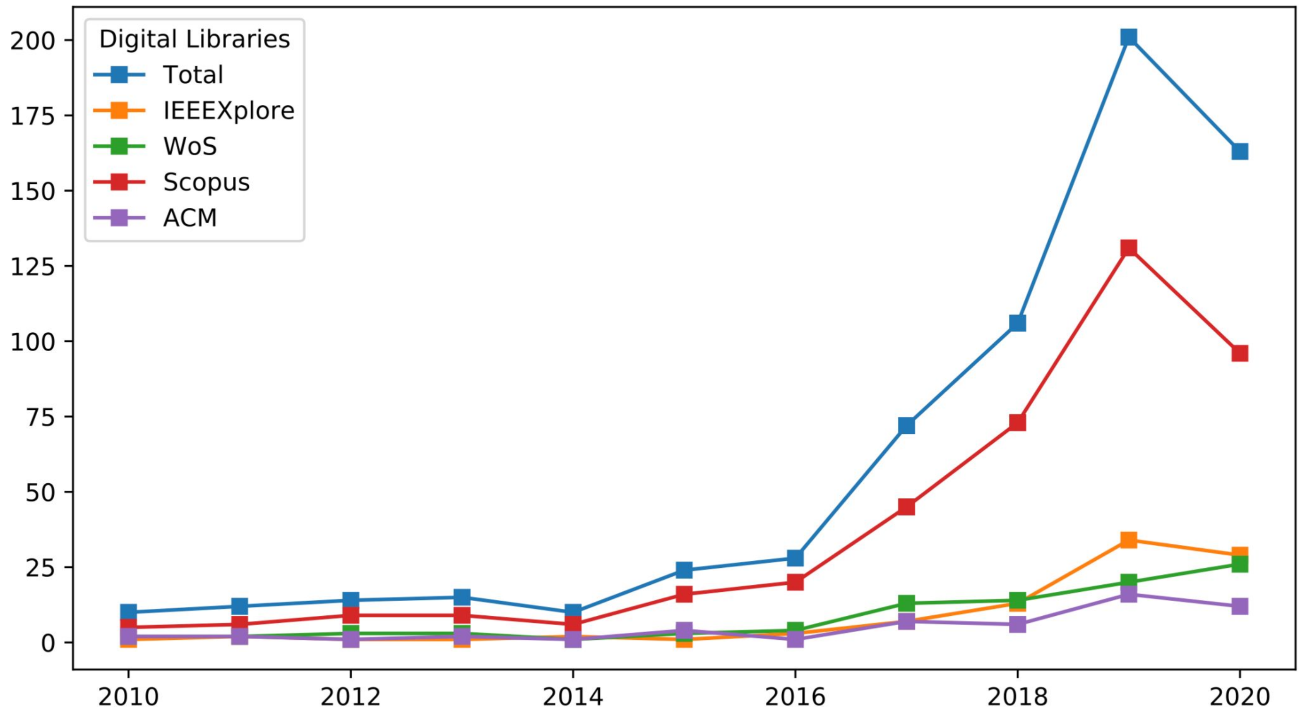
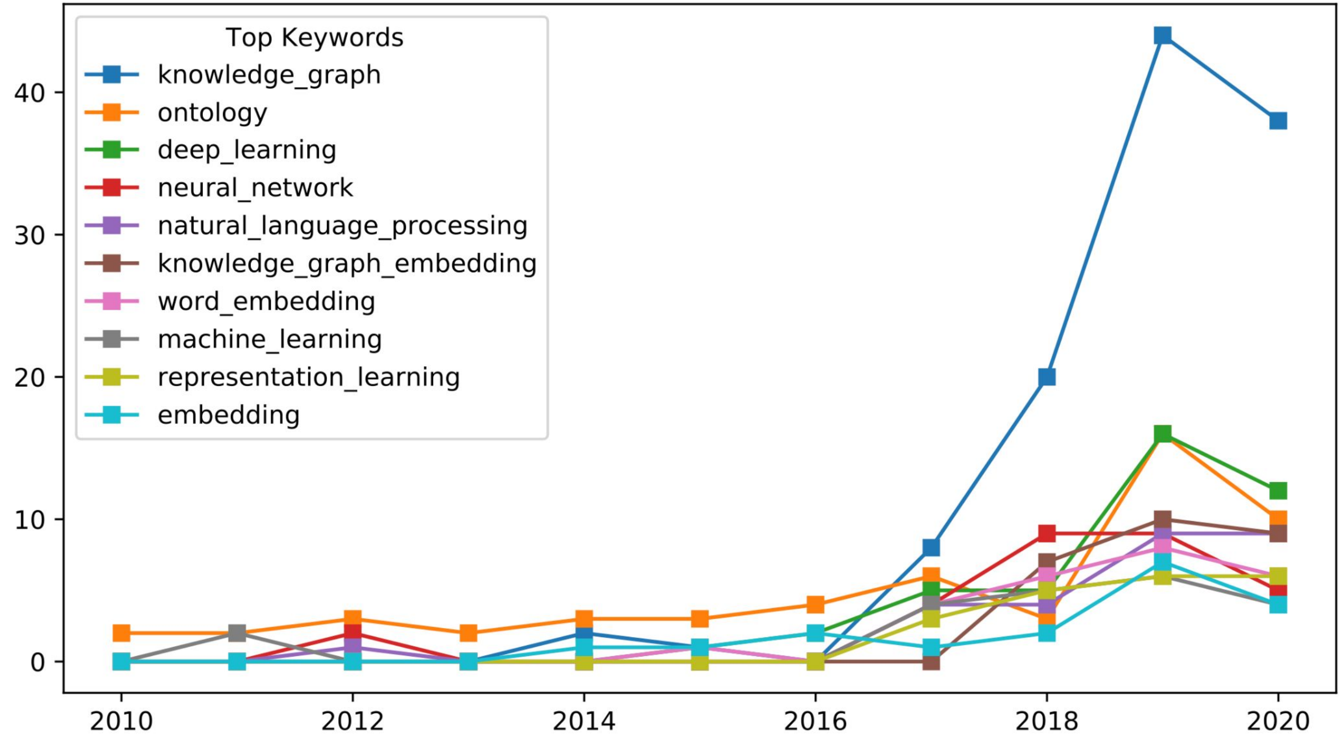
RQ1 - Bibliographic characteristics



Number of papers per year/digital library

Fast increase in interest after 2016

RQ1 - Bibliographic characteristics



Main keywords over time
(author given keywords or TF-IDF from abstract/title)

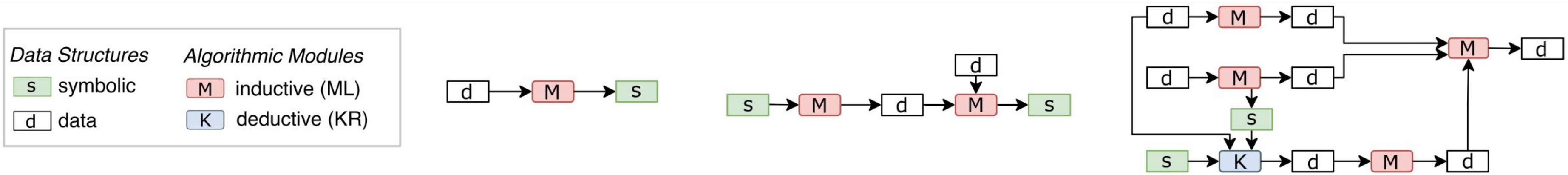
Knowledge Graphs and Deep Learning as a catalyst for SWeML development.

RQ2 - System Architectures
Boxology notation

We relied on the boxology of system design patterns by van Harmelen [1] which includes:

- data structures:
  - symbolic, data
- algorithmic modules:
  - ML models, reasoning engines (KR)
- system architecture in terms of data flow and sequence of algorithmic modules

Main benefit: allows organising (mapping) a large space of complex systems.



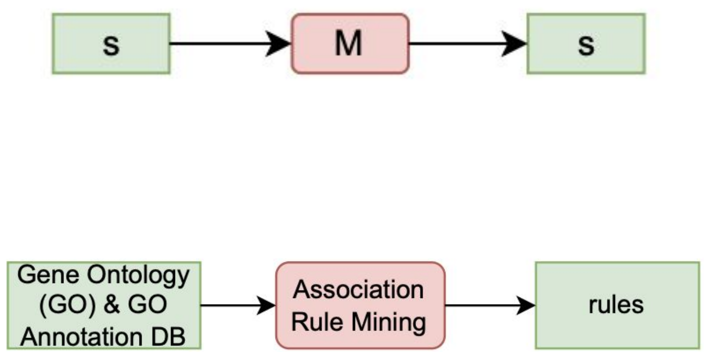
[1] F. van Harmelen, A. ten Teije, A boxology of design patterns for hybrid learning and reasoning systems, J. of Web Engineering 18 (2019) 97–124. arXiv:1905.12389.

RQ2 - System Architectures
Example systems for patterns

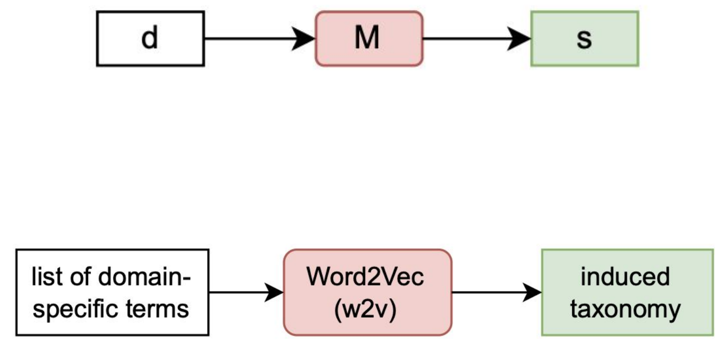
Abstract Pattern

System (Pattern Instance)

A1: s-M-s



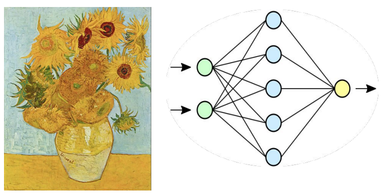
A2: d-M-s



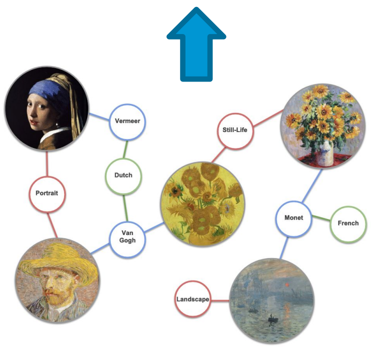
Agapito G, Cannataro M, Guzzi PH, et al. Using GO-WAR for mining cross-ontology weighted association rules. Computer Methods and Programs in Biomedicine. 2015;120(2):113–122.

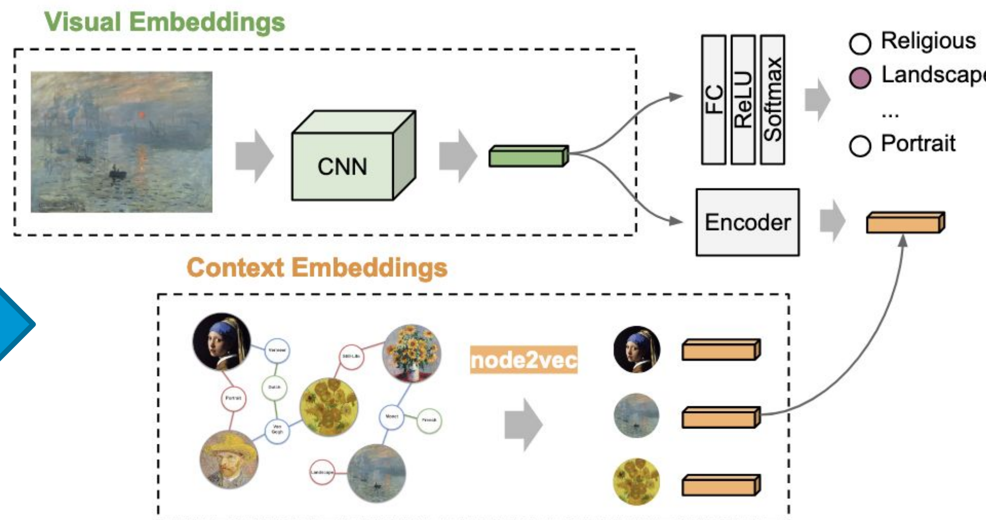
Zafar B, Cochez M, Qamar U. Using Distributional Semantics for Automatic Taxonomy Induction. In: Int. Conf. on Frontiers of Information Technology (FIT); 2016.

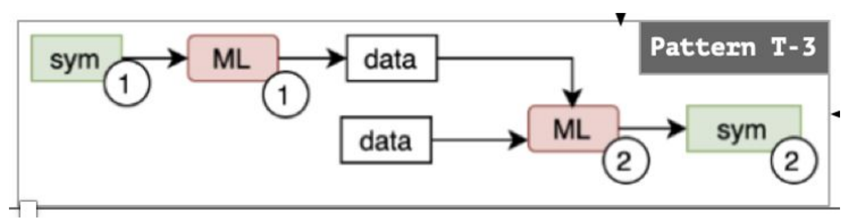
RQ2 - System Architectures
Example systems for patterns



Classification:
Type: Still-life
School: Dutch
Author: vanGogh

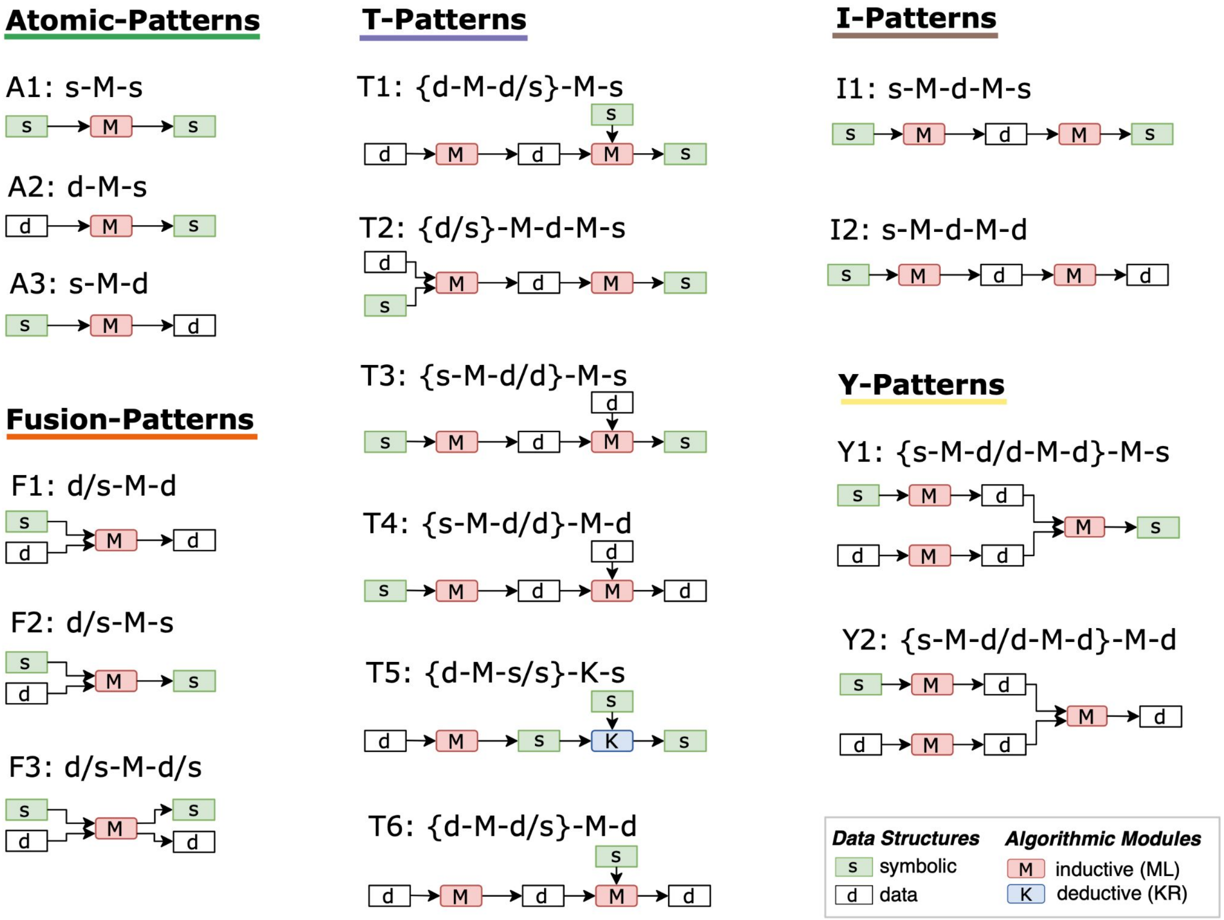






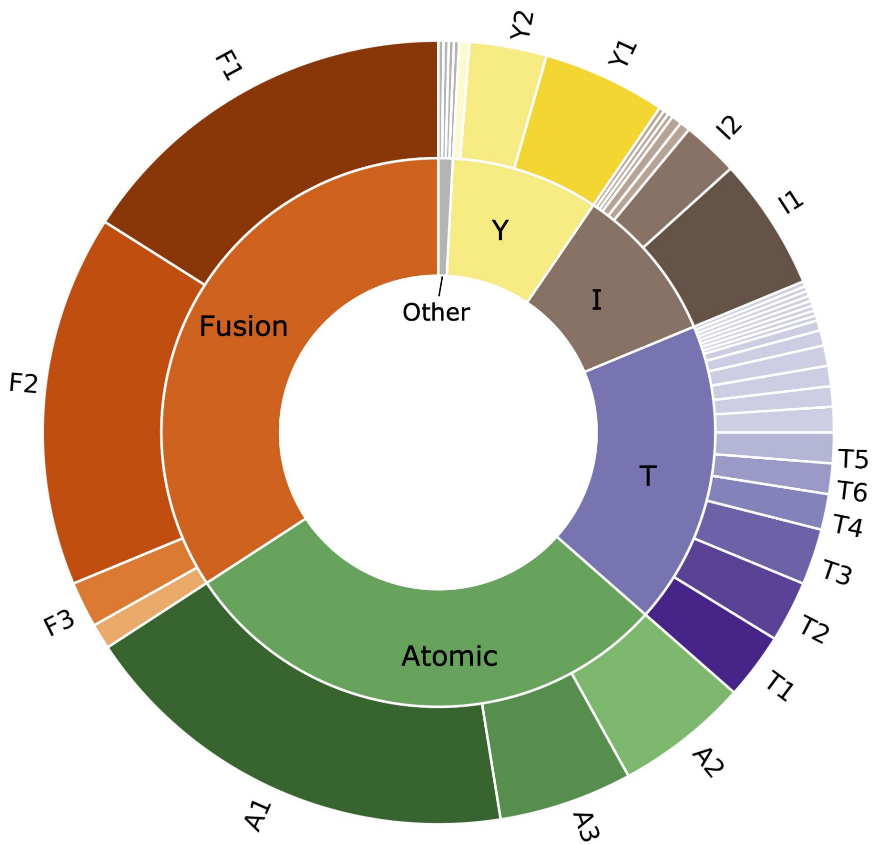
Garcia, N., Renoust, B., & Nakashima, Y. Context-aware embeddings for automatic art analysis. Int. Conf. on Multimedia Retrieval, 2019.

RQ2 - System Architectures
(some) Patterns and their typology



41 patterns were discovered in the data

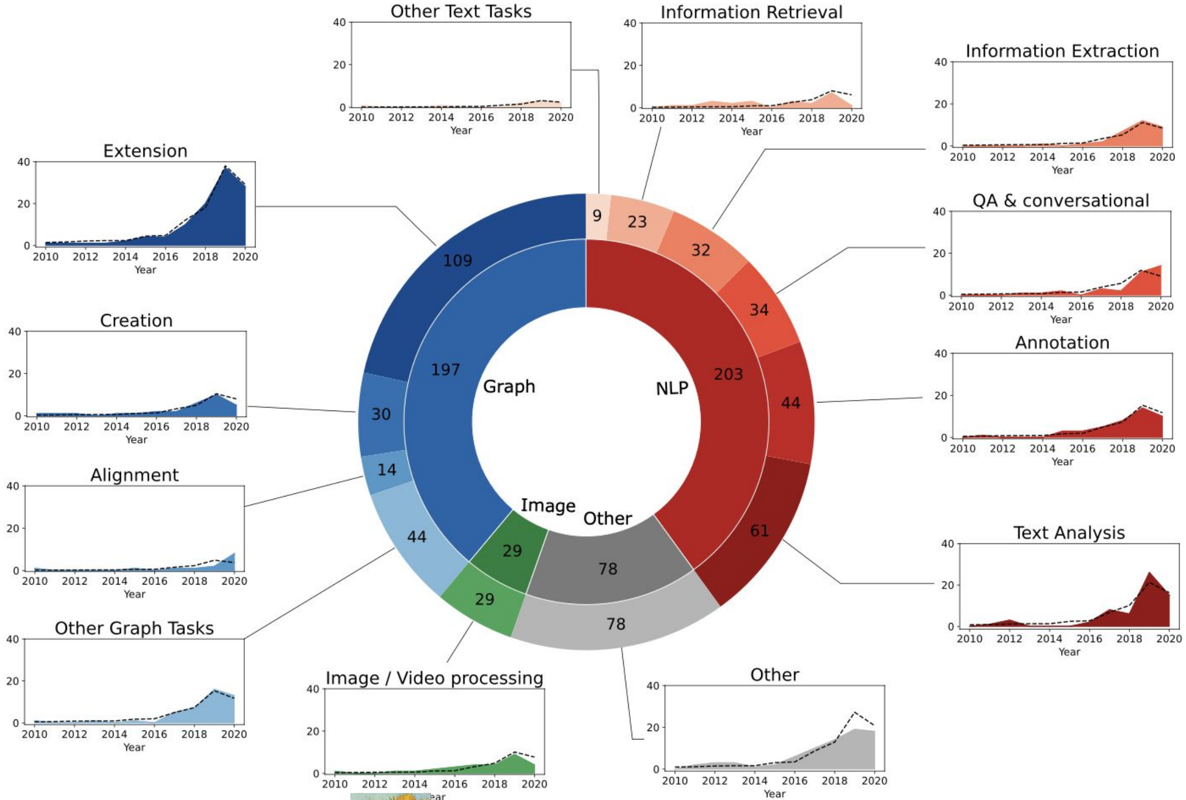
RQ2 - System Architectures Patterns and their frequency



63% of systems use simple patterns

- A1 (s-M-s) - link prediction on KG; rule learning

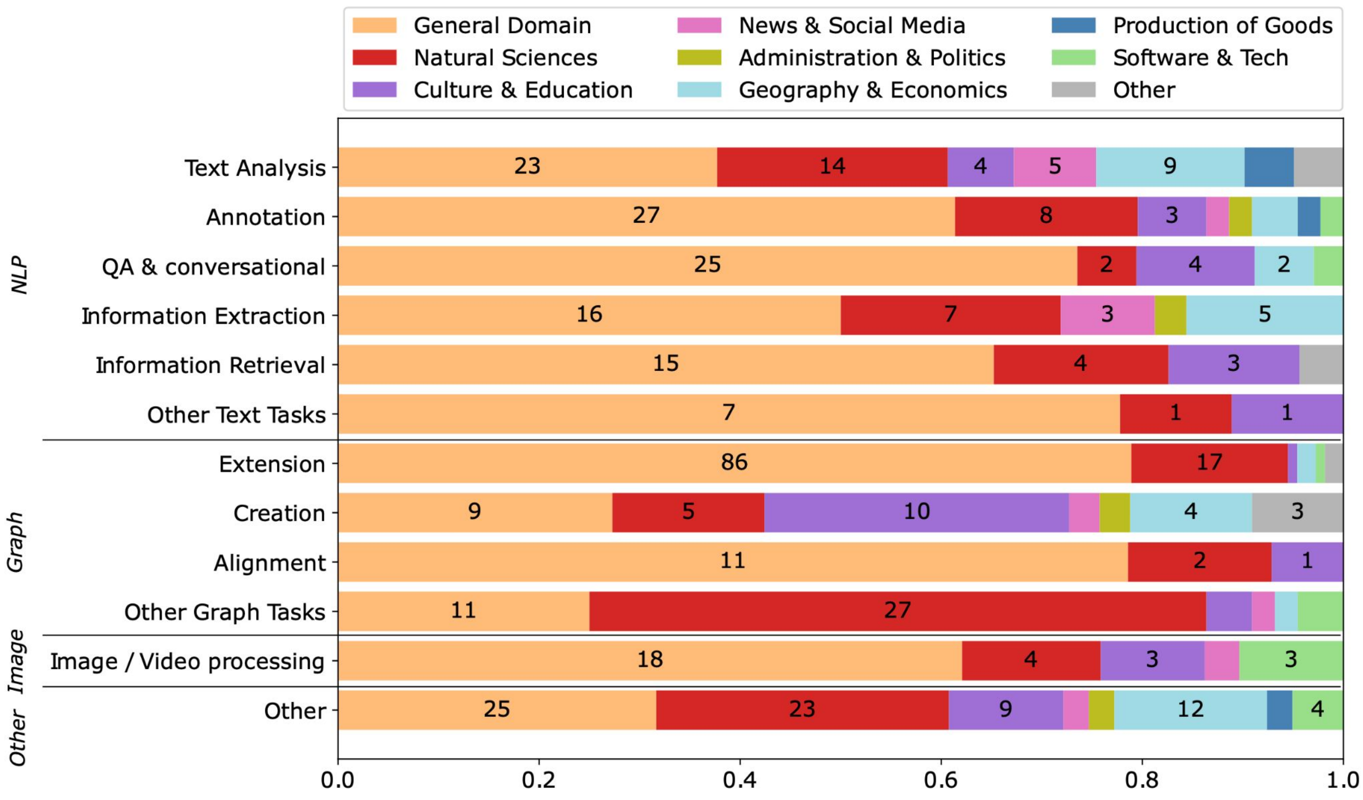
RQ3: Application Areas
Distribution of papers per targeted tasks



Graph and NLP tasks most frequent

Trending tasks:
- graph alignment
- text analysis
- QA and conversational agents

RQ3: Application Areas
Normalised distribution of domain per tasks



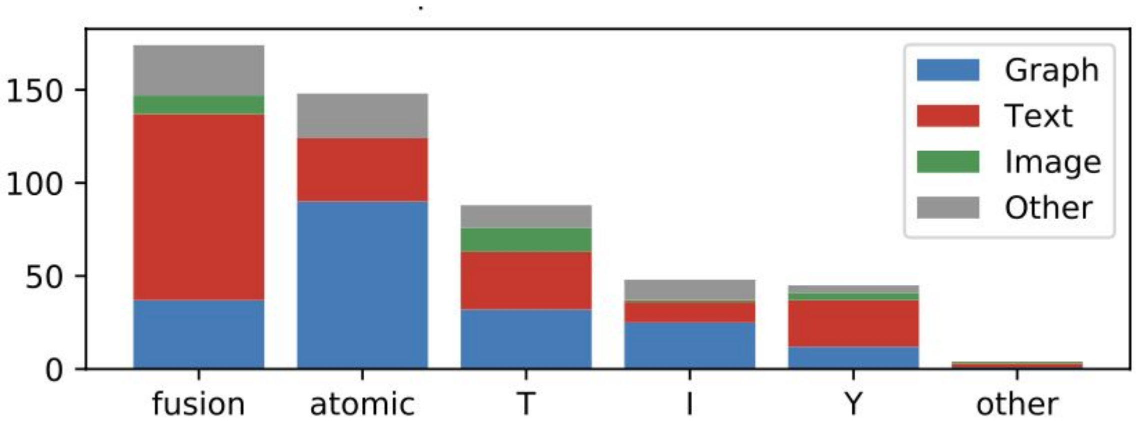
SWeMLs versatile across domains and tasks

NLP tasks mostly in General Domain

Graph tasks (creation and other) have more focus on specialised domains

Most frequent application domains: "Natural Sciences" & "Culture and Education"

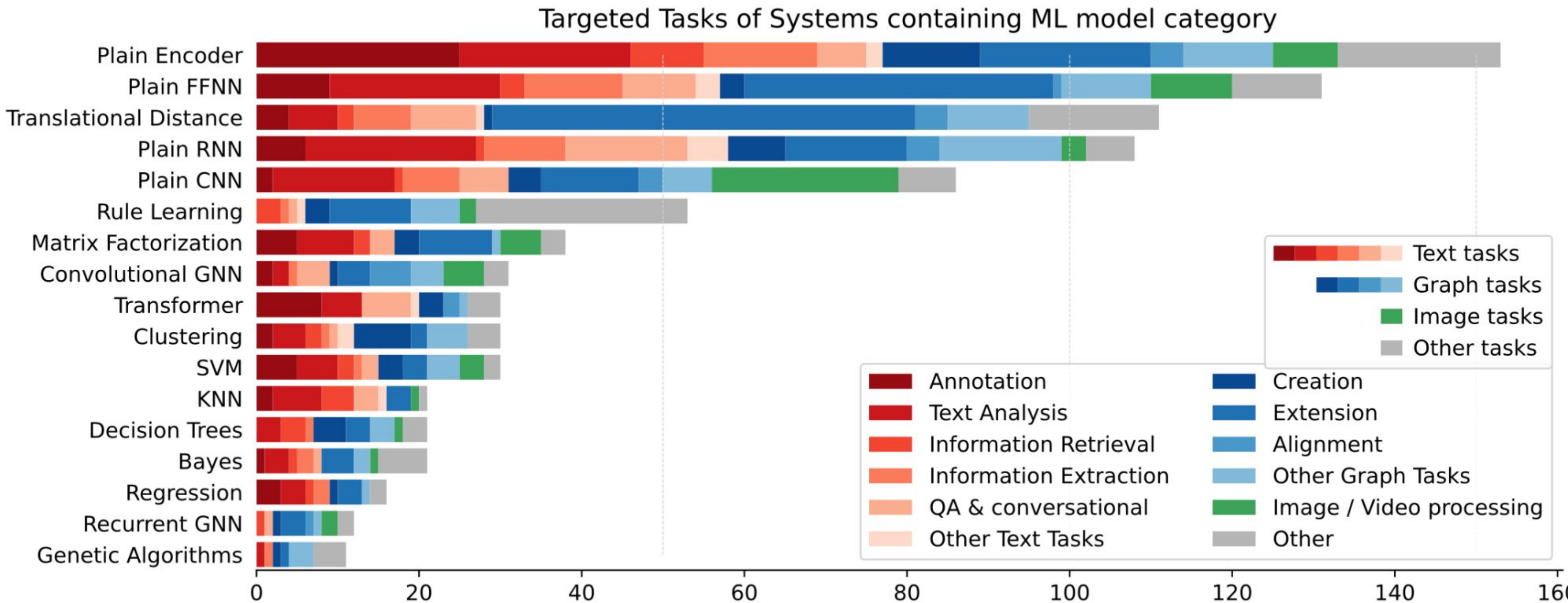
RQ3: Application Areas
Pattern types used for tasks



Some pattern types tend to be used more frequently for certain task categories (fusion for Text, atomic for graph)

=> Can we derive best practices of recommending patterns for AI engineers depending on the task/domain they address?

RQ4: Characteristics of the ML Module
Relations between ML categories and tasks

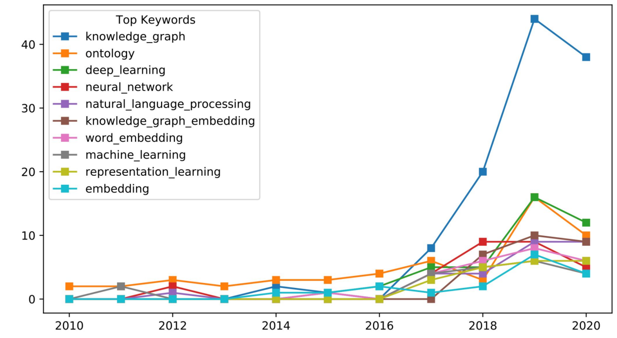


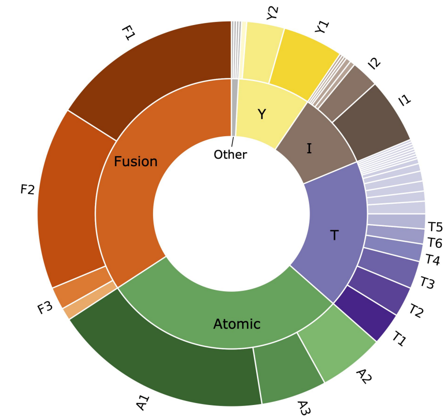
- NLP tasks freq.solved with Plain Encoders, Transformer models and kNN
- Graph tasks often solved with Graph DL model categories (Translational Distance models, Convolutional GNNs) and Rule Learning.
- Image tasks are addressed particularly with CNN algorithms.

=> Can we derive best practices of recommending ML models for AI engineers depending on task?

Key conclusions

- Multi-disciplinary, high-impact, rapidly developing field.
- Deep Learning is a key catalyst for SWeML systems.
- Large Knowledge Graphs are on the rise.
- High diversity of system patterns.
- Low system maturity and auditability.
- High diversity in reporting SWeMLS requires a more uniform classification scheme.





QUESTIONS?

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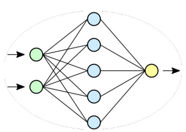
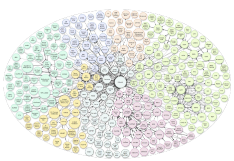
Summary of my talk

Creating intelligent applications that valorise complex domain data such as in the **scientific, technical, and legal domain** often calls for solutions that **combine sub-symbolic and symbolic AI** methods.

Part I (Preliminaries):



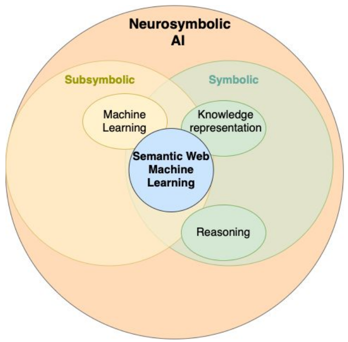
Sub-symbolic AI



Symbolic AI

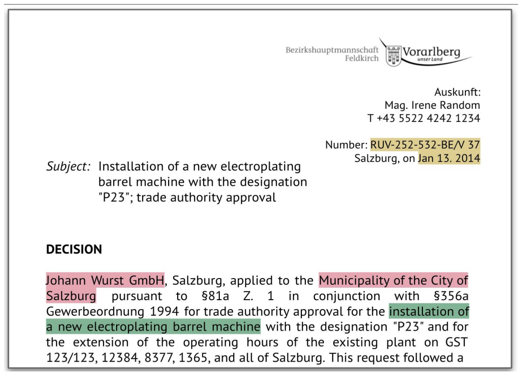
Neuro-Symbolic AI Techniques

Part II (Macro):



Systematic Study of SW and ML systems (SWeML) (a sub-family of neuro-symbolic systems)

Part III (Micro):



Bezirkshauptmannschaft Feldkirch Vorarlberg

Auskunft:
Mag. Irene Random
T +43 5522 4242 1234

Number: RUV-252-532-BE/V 37
Salzburg, on Jan 13. 2014

Subject: Installation of a new electroplating barrel machine with the designation "P23"; trade authority approval

DECISION

Johann Wurst GmbH, Salzburg, applied to the Municipality of the City of Salzburg pursuant to §81a Z. 1 in conjunction with §356a Gewerbeordnung 1994 for trade authority approval for the installation of a new electroplating barrel machine with the designation "P23" and for the extension of the operating hours of the existing plant on GST 123/123, 12384, 8377, 1365, and all of Salzburg. This request followed a

SWeML approach for information extraction in the legal domain

Combining SW and ML for Auditable Legal Key Element Extraction (ESWC‘23)

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

OBARIS

Anna Breit (SWC), Laura Waltersdorfer (TU), **Fajar J. Ekaputra (WU),**
Sotiris Karampatakis (SWC), Tomasz Miksa (TU), Gregor Käfer (TU)

eswc23

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Combining SW and ML for Auditable Legal Key Element Extraction

Key Element Extraction from Legal Permits

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Reference Nr	RUV-252-532-BE/V 37
Issuing Date	13.01.2014
Operator	Johann Wurst GmbH, GLN 123456
Issuing Authority	Magistrate of the City of Salzburg
Object Type	Operating Site
Processing Type	Extension Notice
Procedure Type	Simplified Procedure

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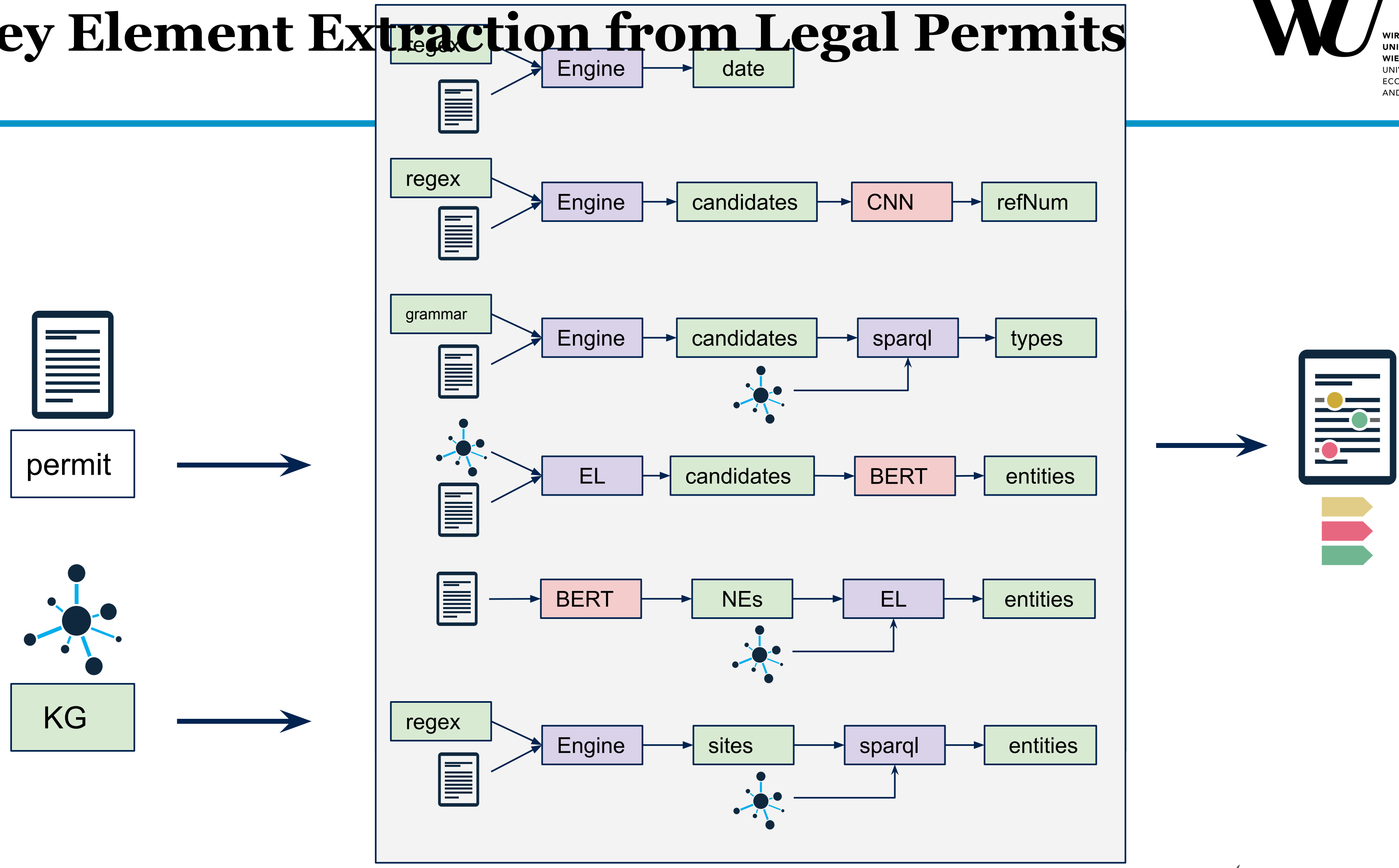
Key Element Extraction from Legal Permits



Combining SW and ML for Auditable Legal Key Element Extraction

Domain and Language

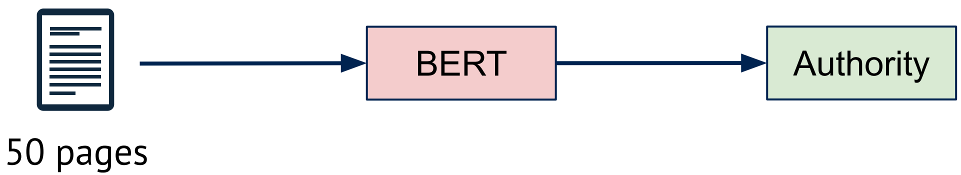
Half a

~~One~~ simple sentence from an Austrian legal permit….

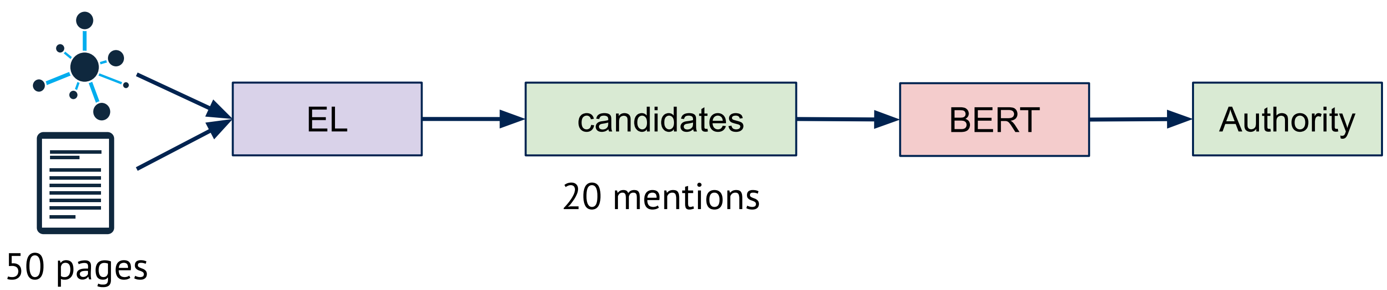
Der Landeshauptmann von Tirol als zuständige Abfallbehörde gemäß § 38 Abs. 6 Abfallwirtschaftsgesetz 2002 – AWG 2002, BGBl. I Nr. 102/2002, zuletzt geändert durch BGBl. I Nr. 193/2013, entscheidet über den Antrag der XXX GmbH & Co OG, vertreten durch die Geschäftsführer Albert YYY und Martin ZZZ, Oberdorf 20, 2301 Groß-Enzersdorf, vom 01.01.2014, eingelangt am 04.05.2014, ergänzt mit Eingaben vom 19.8.2014 (OZl. 123), vom 23.09.2014 (Beilage zur OZl. 234), vom 28.09.2014 (OZl. 345 und OZl. 456), vom 02.10.2014 (OZl. 567), vom 10.11.2014 (OZl. 678), vom 21.11.2014 (ABF-2-21/1/1-2014), vom 22.11.2014 (OZl. 8 und 9), vom 13.12.2014 (OZl. 26), vom 20.12.2014 (OZl. 45), sowie durch die Projektskonkretisierungen im Zuge der mündlichen Verhandlung am 24.12.2014 (OZl. 62) und eingeschränkt mit Eingabe vom 31.12.2014 (OZl. 69), gemäß den §§ 37 Abs. 1, 38 Abs. 1 und 1a und 43 Abs. 1 und 2 AWG 2002 unter Anwendung der Gewerbeordnung 1994 – GewO 1994, BGBl. Nr. 194/1994, zuletzt geändert durch BGBl. I Nr. 81/2015, des ArbeitnehmerInnenschutzgesetzes – ASchG, BGBl. Nr. 450/1994, zuletzt geändert durch BGBl. I Nr. 60/2015, des Immissionsschutzgesetzes-Luft – IG-L, BGBl. I Nr. 115/1997, zuletzt geändert durch BGBl. I Nr. 77/2010, des Wasserrechtsgesetzes 1951 – WRG 1959, BGBl. Nr. 2015/1959, zuletzt geändert durch BGBl. I Nr. 54/2014, wie folgt:

Combining SW and ML for Auditable Legal Key Element Extraction

Generate Candidates



vs



Infuse Background Knowledge

[...] The plant in question has been approved based on **§37 Article 3 sub-section 2 of AWG 2002** [...]

Legal permit

6. Abschnitt
Behandlungsanlagen

Genehmigungs- und Anzeigepflicht für ortsfeste Behandlungsanlagen

§ 37. (1) Die Errichtung, der Betrieb und die wesentliche Änderung von ortsfesten Behandlungsanlagen bedarf der Genehmigung der Behörde. Die Genehmigungspflicht gilt auch für ein Sanierungskonzept gemäß § 57 Abs. 4.

(2) Der Genehmigungspflicht gemäß Abs. 1 unterliegen nicht

stationary plant

incineration plant

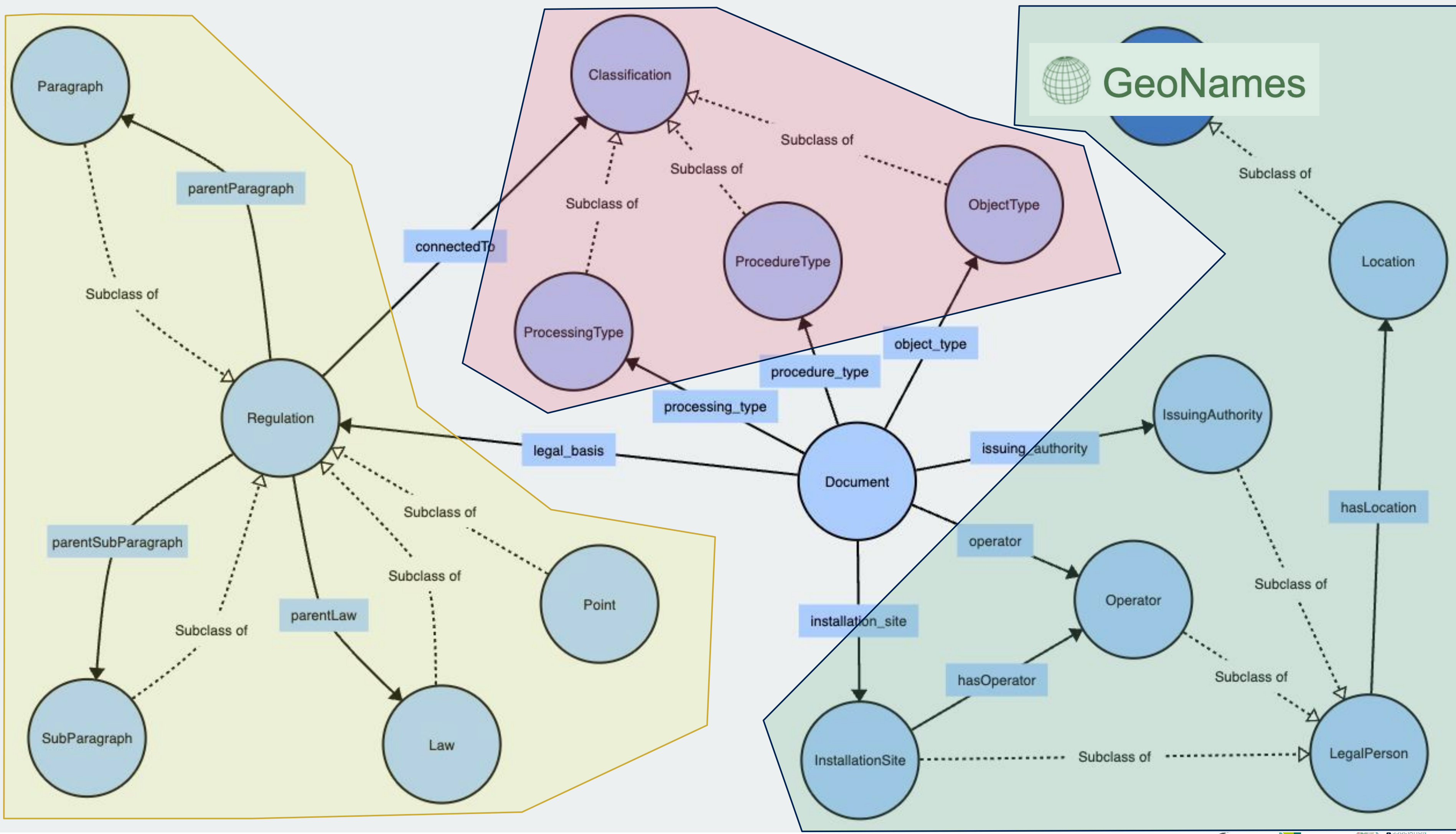
simplified legal procedure

einsetzen.

(3) Folgende Behandlungsanlagen – sofern es sich nicht um IPPC-Behandlungsanlagen oder Seveso-Betriebe handelt – und Änderungen einer Behandlungsanlage sind nach dem vereinfachten Verfahren (§ 50) zu genehmigen:

1. Deponien, in denen ausschließlich Bodenaushub- und Abraummaterial, welches durch Ausheben oder Abräumen von im Wesentlichen natürlich gewachsenem Boden oder Untergrund anfällt, abgelagert werden, sofern das Gesamtvolumen der Deponie unter 100 000 m^3 liegt;
2. Verbrennungs- oder Mitverbrennungsanlagen zur thermischen Verwertung für nicht gefährliche Abfälle mit einer thermischen Leistung bis zu 2,8 Megawatt;

AWG 2002



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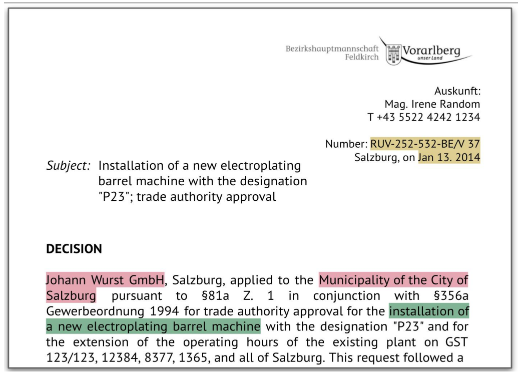
Key conclusions

Part III (Micro):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SWeML approach for information extraction in the legal domain

- Solving a challenging use case using a SW + ML system
- **ML:** Deal with complex input
- **KG:** Reduce complexity of (sub) problems
- Auditing: Traceability of suggestions & System monitoring

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Creating intelligent applications that valorise complex domain data such as in the **scientific, technical, and legal domain** often calls for solutions that **combine sub-symbolic and symbolic AI** methods.

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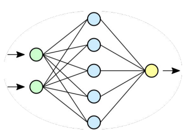
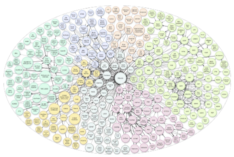


Sub-symbolic AI



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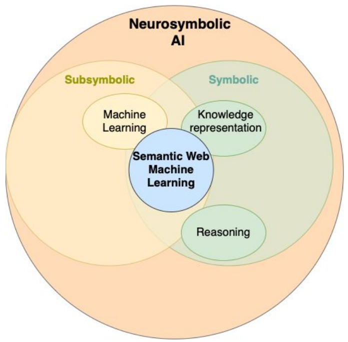

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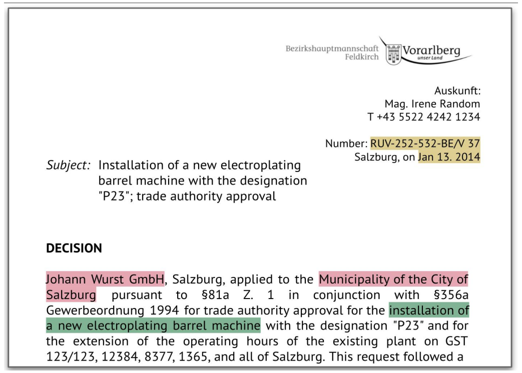

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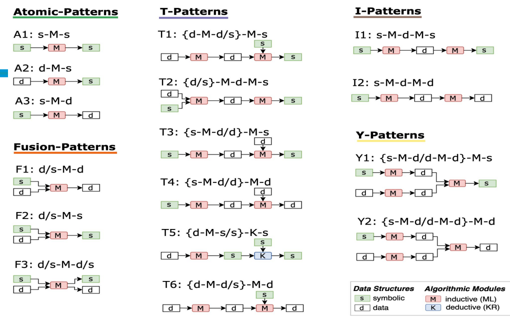
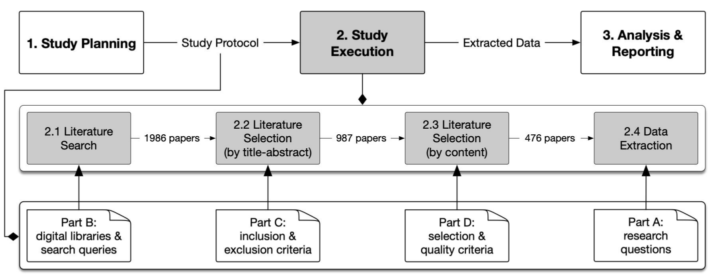
What (I hope) you learned in this talk

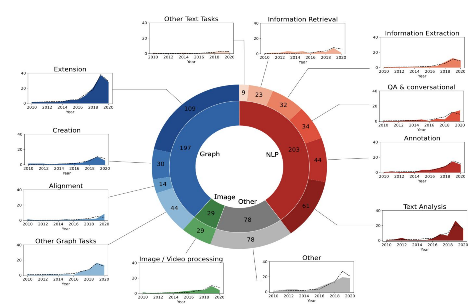


New techniques combine **symbolic** (Semantic Web) **and sub-symbolic** (Machine Learning) **AI** methods in various ways to solve complex (data science) tasks.



Systematic Literature Review is a valuable research method.

Beyond "Data Science" - applications that valorise complex domain data, with an example from the legal domain.



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- Start October 2024
- Budget (5y):
  - ~20M EUR FWF Funding
  - >30M EUR Total Budget
- Coordinator:
  - JKU Linz (Sepp Hochreiter)
- Partners:
  - WU Wien
  - TU Wien
  - TU Graz
  - ISTA
  - AAU Klagenfurt