Rules and Reasoning for Graph Data

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Creating Bridges: RDF, Property Graph and SQL

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Background: Rules and ...

- Views in databases already constitute special Rules (cf. Datalog).
- Rules can define **one-step derivations** between (graph-relational) “forms” (patterns, shapes) that specify data Inputs & Outputs: $I_{form} \rightarrow O_{form}$ “$I_{form}$ derives $O_{form}$”
  or, equivalently,
  $O_{form} \leftarrow I_{form}$ “$O_{form}$ is derived by $I_{form}$”

Here, $I_{form}$ and $O_{form}$ may contain variables:
- $I_{form}$ can be matched to data via variable bindings, adding variable-instantiated $O_{form}$ data
- $O_{form}$-unifying queries can be reduced to $I_{form}$ queries, extracting variable bindings whenever arriving at data
Background: ... and Reasoning

- Reasoning can chain Rules for **multi-step derivations**, e.g.:
  - Forward (bottom-up) Reasoning, only *adding* data
  - Backward (top-down) Reasoning, only *querying* data
  - Forward/Backward-combined (bi-directional) Reasoning

- Reasoning may
  - resolve Rule conflicts, committing to one Rule per step
  - search Rule-chain space, e.g. breadth/depth/best-first

- Ontologies can complement Rules by derived classes to type Rule variables, thus pruning the conflict sets or search space

- Graph ([SPARQL/SHACL](http://www.w3.org/TR/rdf-sparql-pellet/) and [Cypher/PGQL](http://www.pgsql.com/)...*) data forms permit enriched Reasoning via path queries, graph algorithms, etc.*
Languages for Graph Rules and Reasoning

1) Augment languages for:
   a) **Graph Databases** by **Rules and Reasoning**
   b) **Relational Rules and Reasoning** by **Graphs**

2) Examples of such languages:
   a) **N3** (augmenting **RDF** triple-store Graph Databases)
   b) **LIFE** (ψ-terms), **F-logic** (frames), **RIF** (frames), **PSOA RuleML** (psoa terms)

3) Metamodel helps **Bridging Graph and Relational Databases**
Technology for Graph Rules and Reasoning

● **Graph Foundations for Data & Knowledge** (Ontologies & Rules):
  ○ Graph Querying in SPARQL and Cypher/PGQL/...
  ○ Graph Reasoning in N3 with engines **Cwm**, **EYE**, etc.
    (cf. [W3C Notation 3 Community Group](https://www.w3.org/2005/Community/Notation3/))
  ○ Joint Replication of Labeled Property Graphs

● **Graph-Relational Bridges**: **RDB2RDF**, **PSOATransRun**, ...
  ○ Normalize F-logic frames into RDF-triple conjunctions (cf. **N3Basic**)

● **Semantics Bridges**: Ontology languages defined via Rules:
  ○ [Extending OWL 2 RL in (RIF and SPIN) Rules](https://www.w3.org/TR/owl2-rules/)
  ○ [Warded Datalog+/-](https://www.w3.org/TR/w理由-datalog/-)
  ○ [Substantiating Knowledge with EYE](https://www.w3.org/2005/Community/EYE/)
Beyond Deductive Reasoning / From Relations to Graphs

- Quantitative (probabilistic) extensions (focus: StarAI Workshops):
  - Statistical Relational Learning/AI (cf. GraRel/DOR)
- Qualitative extensions (also transferred from Relational to Graph Data):
  - Inductive (Functional and Logic) Programming (cf. AAIP Workshops)
    - Analogical Reasoning (cf. Argument from Analogy)
    - Association Rule Learning
  - Abductive Reasoning (cf. Abductive Logic Programming)
  - Relevance Logic
  - Defeasible Logic
  - Argumentation Theory