Rules and Reasoning for Graph Data

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Creating Bridges: RDF, Property Graph and SQL

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Background: Rules and ...

- Rules can define **one-step derivations** between (graph-relational) "forms" (patterns, shapes) that specify data **I**nputs & **O**utputs:
  Iform ⟹ *Oform* "*Iform* derives *Oform*"
  or, equivalently,
  Oform ⟸ *Iform* "*Oform* is derived by *Iform*"
  Here, *Iform* and *Oform* may contain variables:
  - *Iform* can be matched to data via variable bindings, adding variable-instantiated *Oform* data
  - *Oform*-unifying queries can be reduced to *Iform* 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 and Cypher/PGQL/...) 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)
  - 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
  - Substantiating Knowledge with EYE
  - RDF Triple Stores vs. Labeled Property Graphs: What's the Difference? (A Comparison: Semantics)

Beyond Deductive Reasoning / From Relations to Graphs

- Quantitative (probabilistic) extensions (focus: StarAI Workshops):
  - Statistical *Rel*ational Learning/AI (cf. **Gra***Rel*DOR)
- Qualitative extensions (also combined, and from Relational to Graph Data):
  - **I**nductive (**F**unctional and **L**ogic) **P**rogramming (cf. AAIP Workshops)
    - Analogical Reasoning (cf. Argument from Analogy)
    - Association Rule Learning
  - Abductive Reasoning (cf. Abductive Logic Programming)
  - Relevance Logic
  - Defeasible Logic
  - Argumentation Theory