Neuro-Symbolic Knowledge Representation and Reasoning

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ESSAI 2024 Athens

MANCHESTER 1824
The University of Manchester

Preamble

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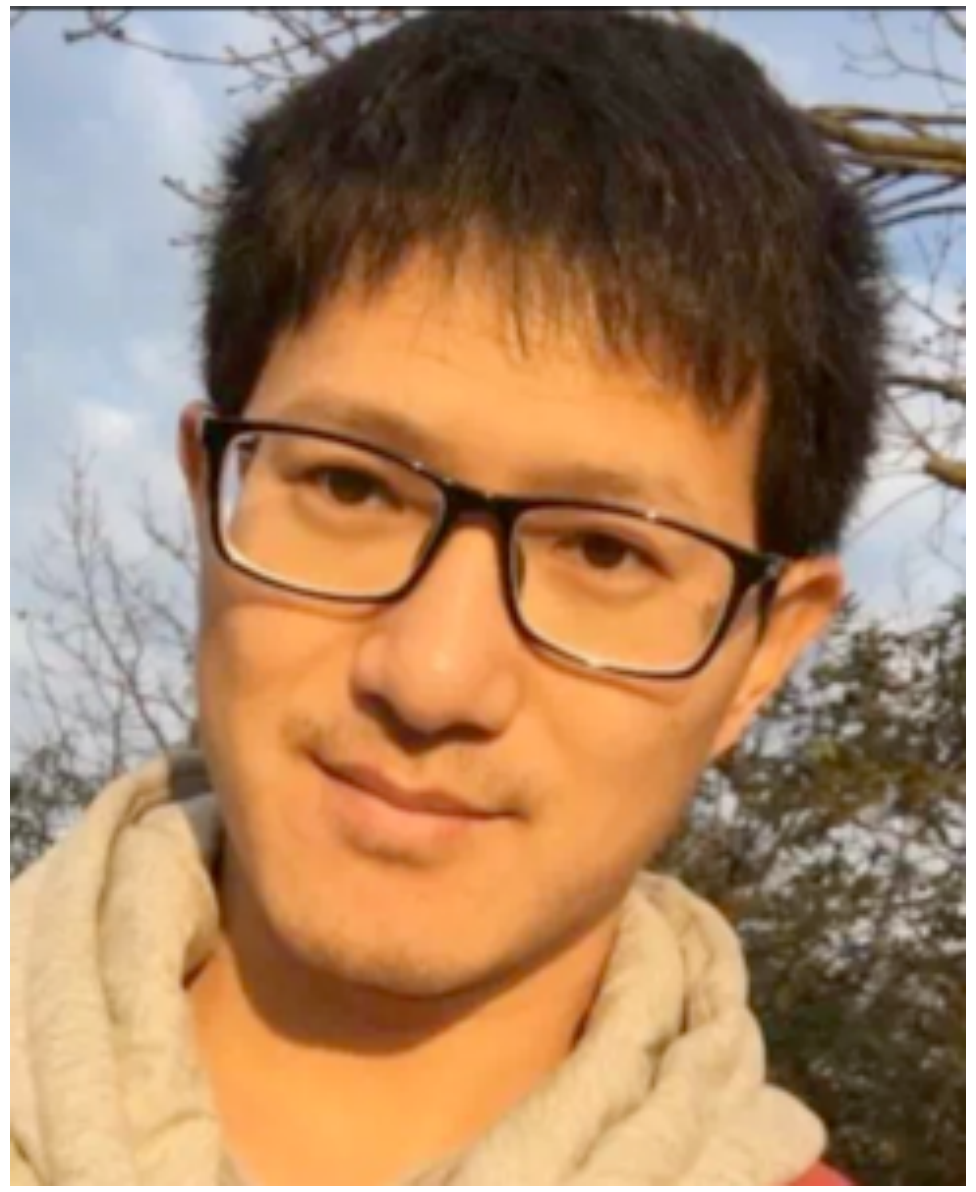
This course is



- introductory
- aimed at general computer scientist

- taught by
  - Jiaoyan Chen - days 3-5
  - Uli Sattler - days 1-2

- explores combination/integration/collaboration of
  - neural &
  - symbolic
    - approaches to knowledge representation, reasoning, ML, …

This course

- is rather intensive
  - 5 * 90mins
  - no coursework, example classes, exercises
- requires a lot of attention
  - please ask if something is unclear…
- is selective
  - we cannot cover all approaches/applications/views

Overview of this course

Day	Topic	Concepts	Technologies
1	Knowledge Graphs	parsing/serialisation, queries, schemas, validation & reasoning	RDF(S), SPARQL, SHACL,
2	Ontologies	Facts & background knowledge, entailments, reasoning & materialisation	OWL, OWL API, Owlready, Protégé
3	Knowledge Graph Embeddings	Classis Es, literal-aware Es, variants, evaluation	TransE, TransR
4	Ontology Embeddings	Geometric embeddings, literal-aware OEs, soundness & completeness	ELEm, BoxEL, Box^2EL, OWL2Vec*, HiT
5	Applications & Outlook	Preprocessing, materialisation, evaluation	DeepOnto, mOWL

Motivation

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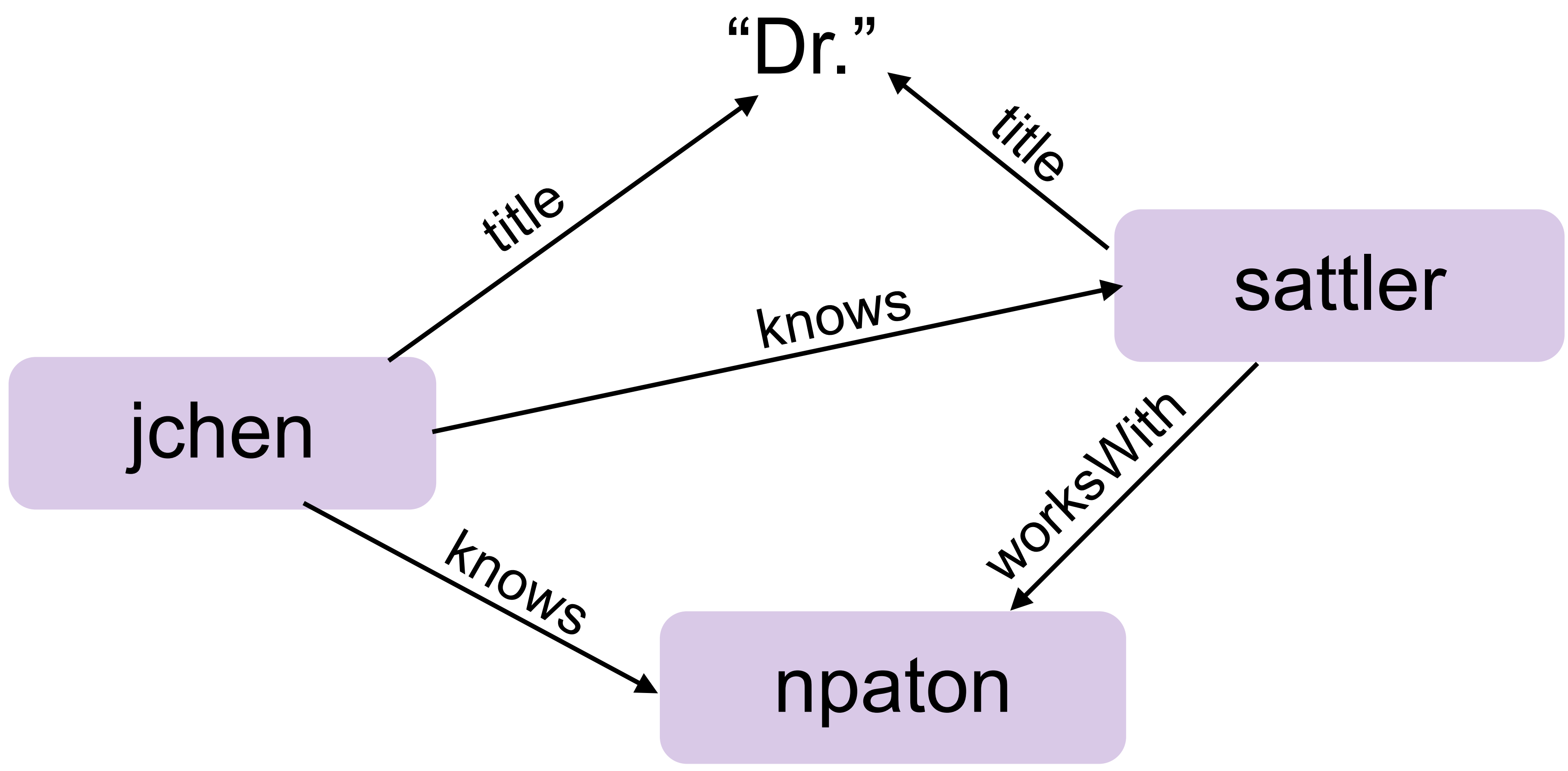
How do we store/access data?

	name	company	address
2	Aleshia Tomkiewicz	Alan D Rosenburg Cpa Pc	14 Taylor St, St.
3	Evan Zigomalas	Cap Gemini America	5 Binney St, Abb
4	France Andrade	Elliott, John W Esq	8 Moor Place, Ea
5	Ulysses Mcwalters	Mcmahan, Ben L	505 Exeter Rd, H
6	Tyisha Veness	Champagne Room	5396 Forth Stre
7	Eric Rampy	Thompson, Michael C Esq	9472 Lind St, De
8	Marg Grasmick	Wrangle Hill Auto Auct & Slvg	7457 Cowl St #7
9	Laquita Hisaw	In Communications Inc	20 Gloucester P
10	Lura Manzella	Bizerba Usa Inc	929 Augustine S
11	Yuette Klapec	Max Video	45 Bradfield St #
12	Fernanda Writer	K & R Associates Inc	620 Northampto

- in **relational** database
  - ✓ manipulation via SQL
  - ✓ very fast access
  - ✓ highly optimised DBMSs
  - ✓ proven technology, well understood properties
  - ✓ with ACID guarantees
  - requires *schema,* certain *normal forms, joins*
  - tricky for
    - sharing/spontaneous usage
    - many many-to-many relations
    - navigational/path queries

How do we store/access data?

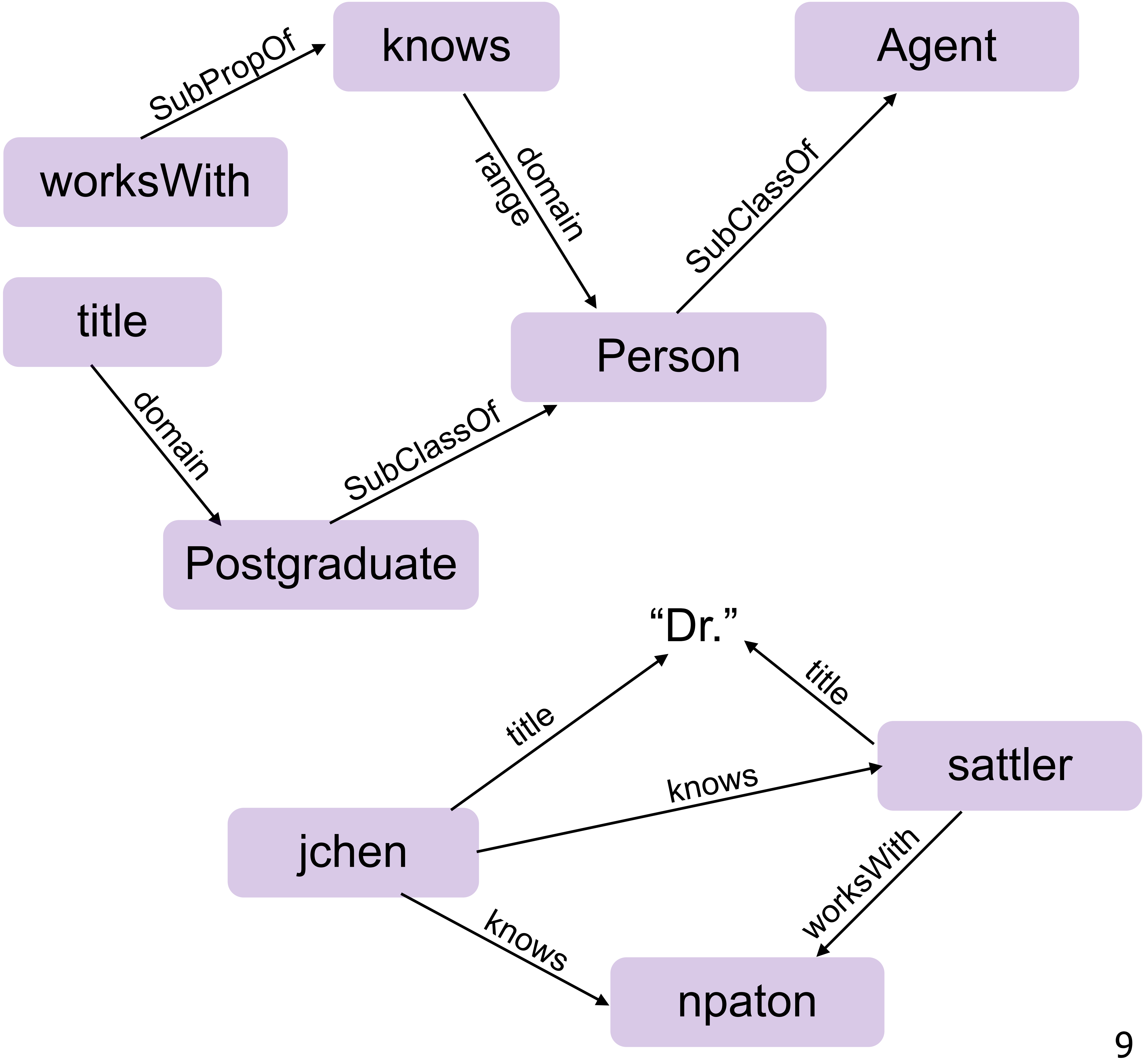


- as **graphs**/in **graph** database
  - for **objects** and their **relations**
  - manipulation:
    - programmatically
    - via query languages
  - relatively new, but powerful DBMSs available
    - often built 'on top' of RDMSs
  - doesn't require *schema or normal forms* or *joins*
  - suitable for
    - data with many many-to-many relations
    - navigational/path queries
    - sharing/integrating data

Data Graph or Knowledge Graph?

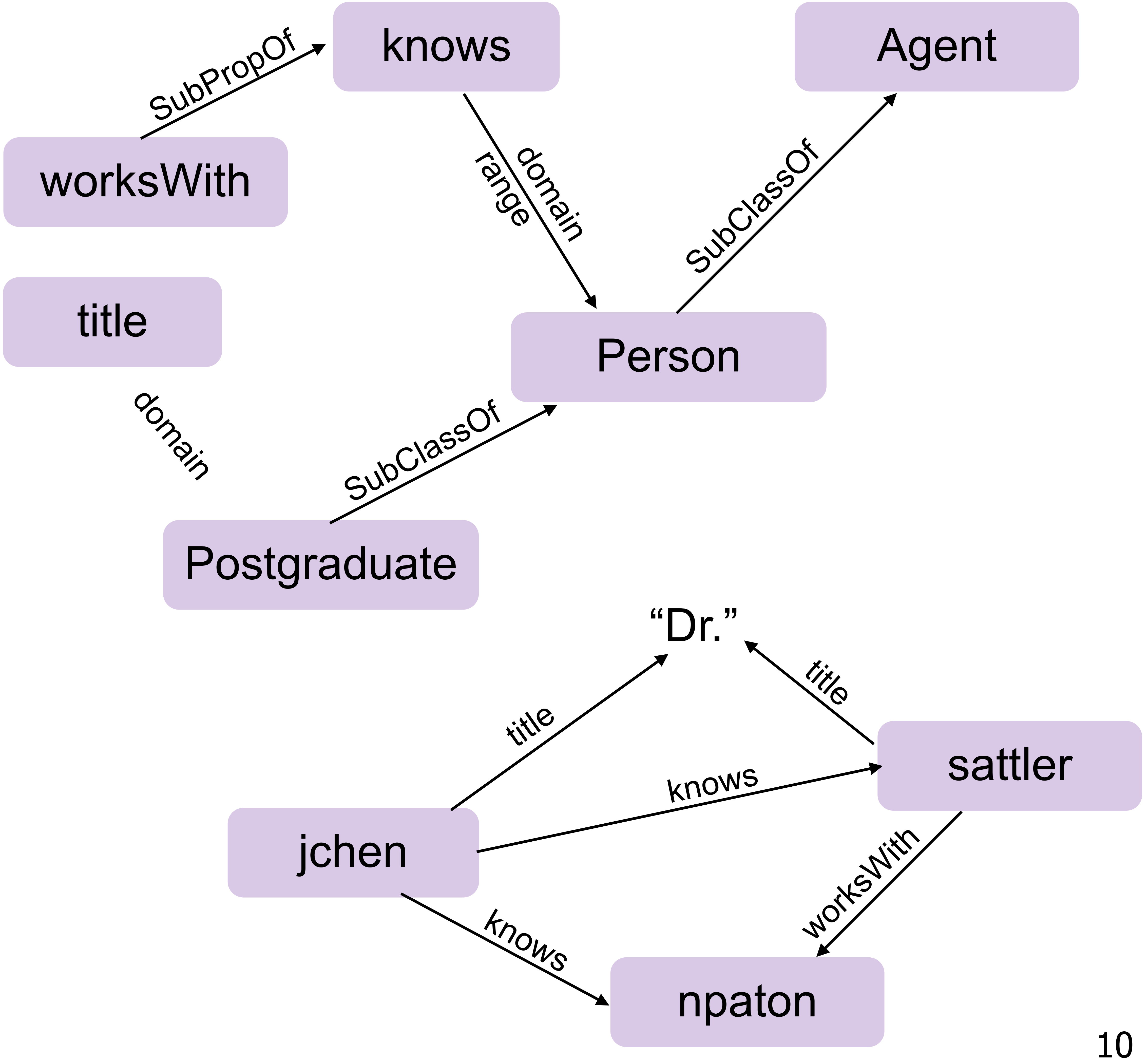
- objects + relations = knowledge?
  - context
  - meaning
  - understanding

- data: factual, about individuals
- knowledge: conceptual, about
  - concepts
  - their relations



Knowledge Representation & Reasoning

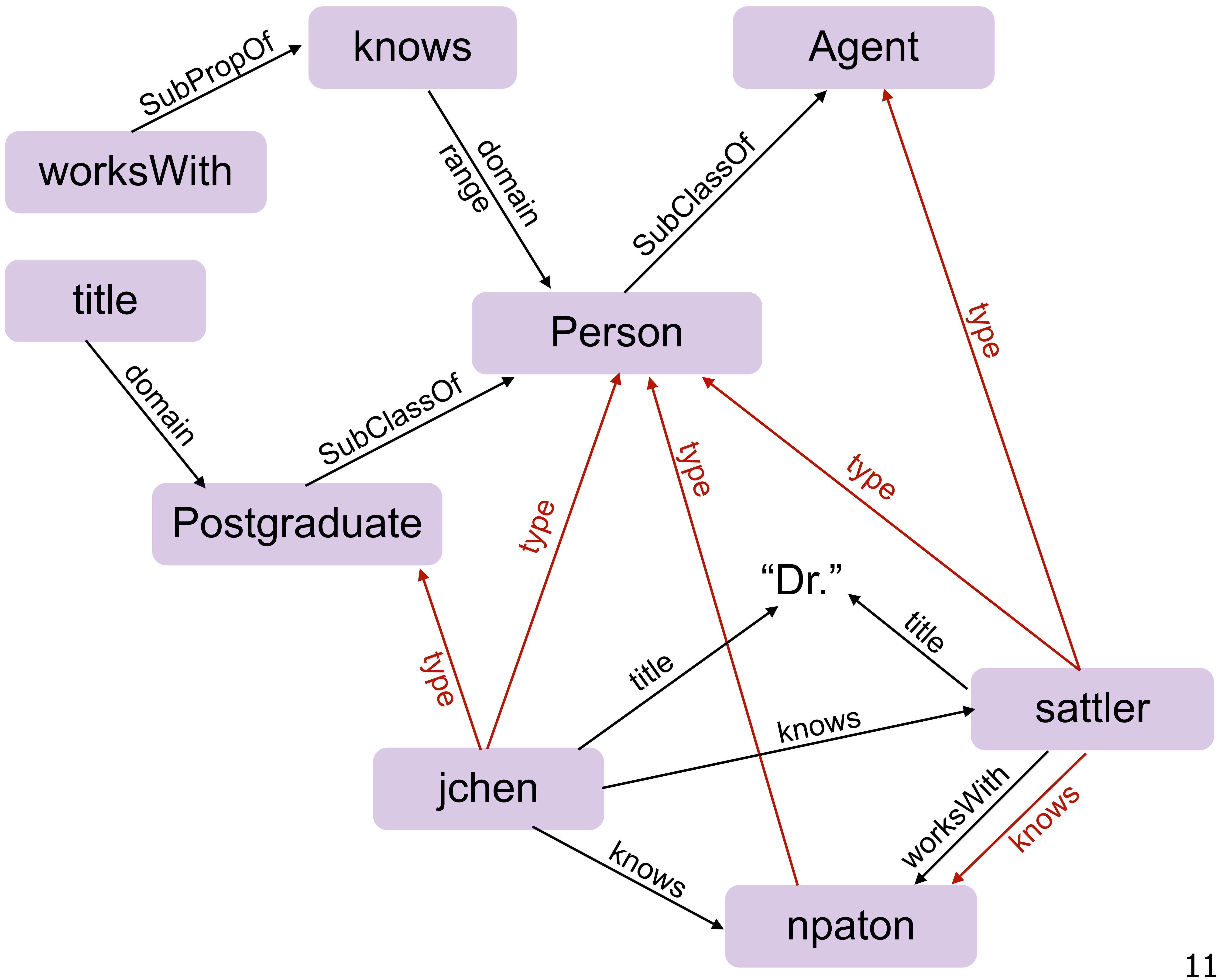
- store/access knowledge
  - factual, about individuals
  - conceptual
    - relevant concepts
    - their relations
      - hierachical/logical
      - domain dependent
- *reason* about it
  - draw conclusions from the explicitly stated knowledge



via well-understood *algorithms* implemented in powerful *reasoners*

Reasoning

- draw conclusions from the explicitly stated knowledge
- E.g.,
  - jchen is of type Person
  - sattler is of type Person
  - sattler knows npaton
  - npaton is of type Person
  - jchen is of type Postgraduate
  - sattler is of type Agent
  - …



KR&R and *symbolic* AI

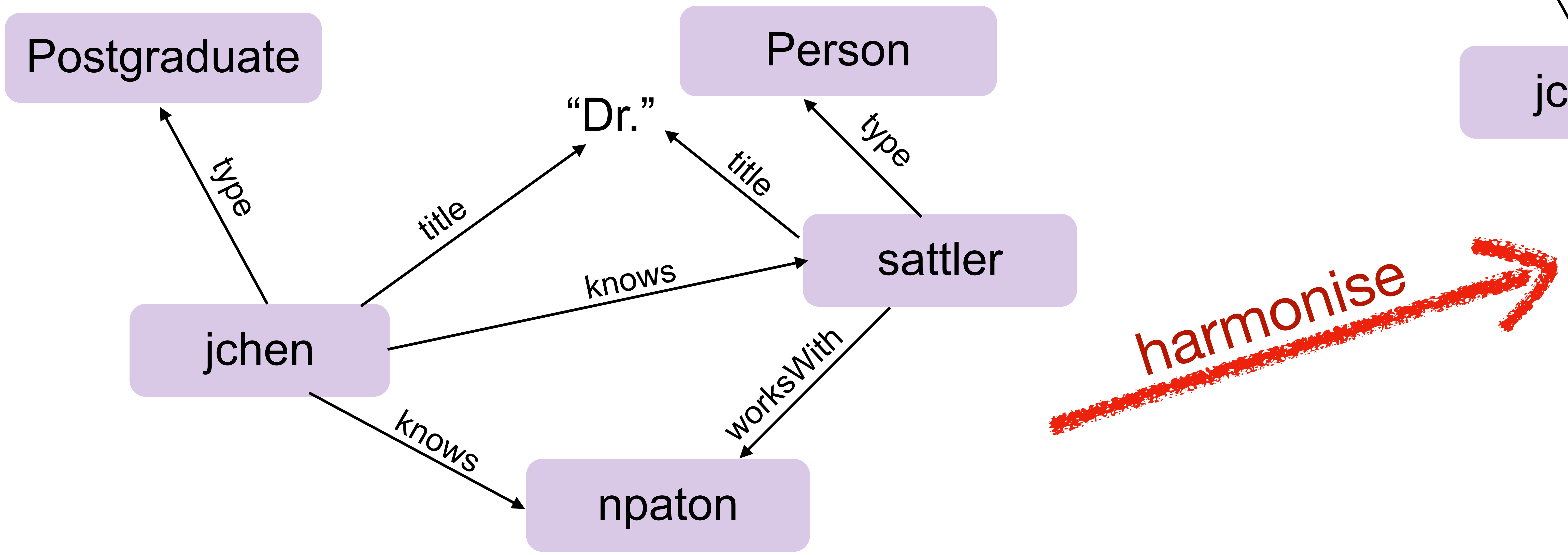
- in KR&R, we use *symbols* for
  - concepts
    - eg Person, Postgraduate, …
  - relations
    - eg title, knows
  - individuals
  - …and build *intelligent* systems to deal with these
- where does our knowledge (graph) come from?
  - domain experts, database, …
- what do we do with our knowledge?
  - use them to *harmonise KGs*

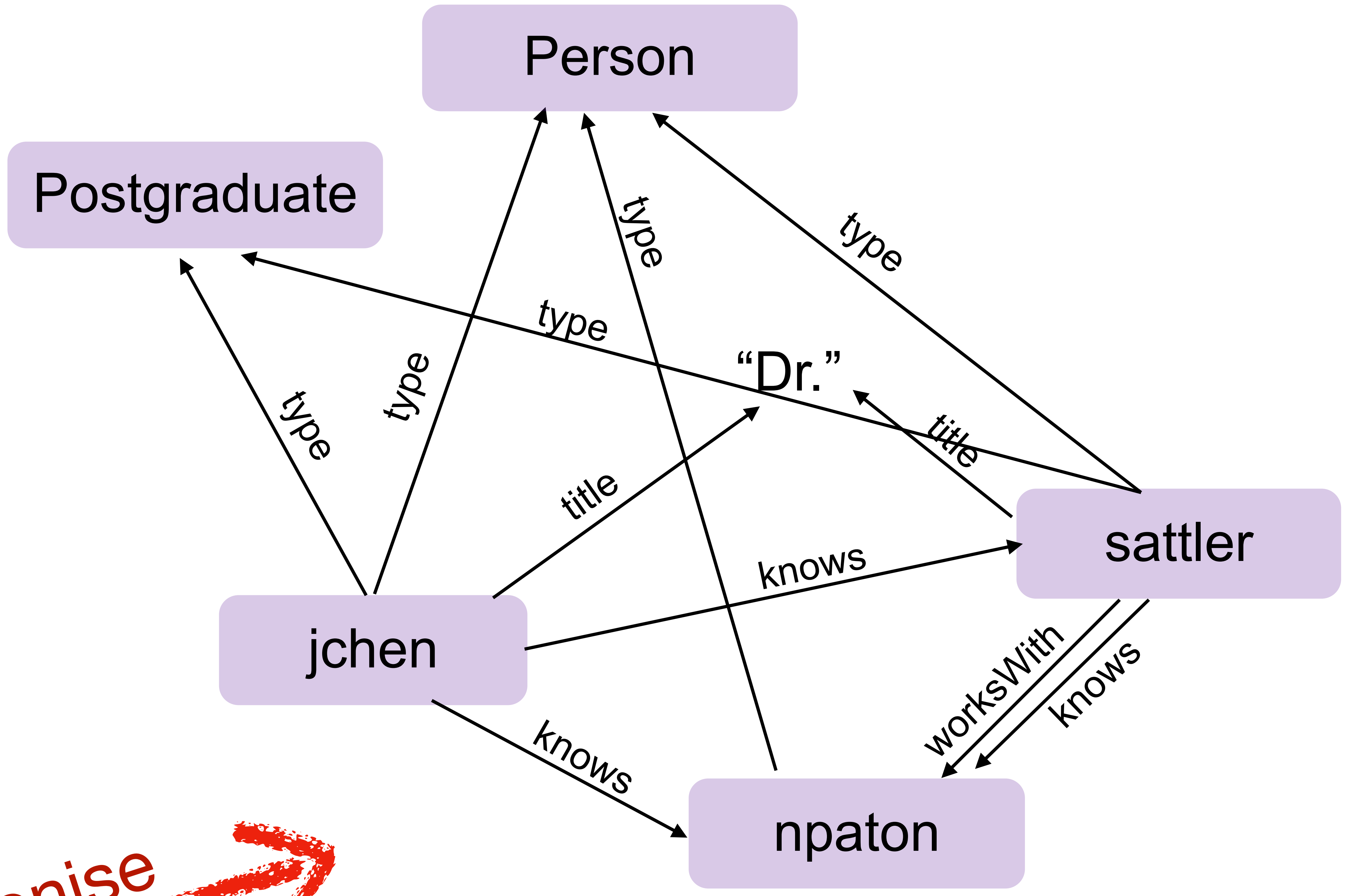
capable of reasoning

add inferred types & links

Harmonise KGs to…

- make explicit knowledge explicit
- reflect background knowledge
  - no need to guess/*predict links*
- increase *regularity* in KG
  - ➡ improve *machine learnability*





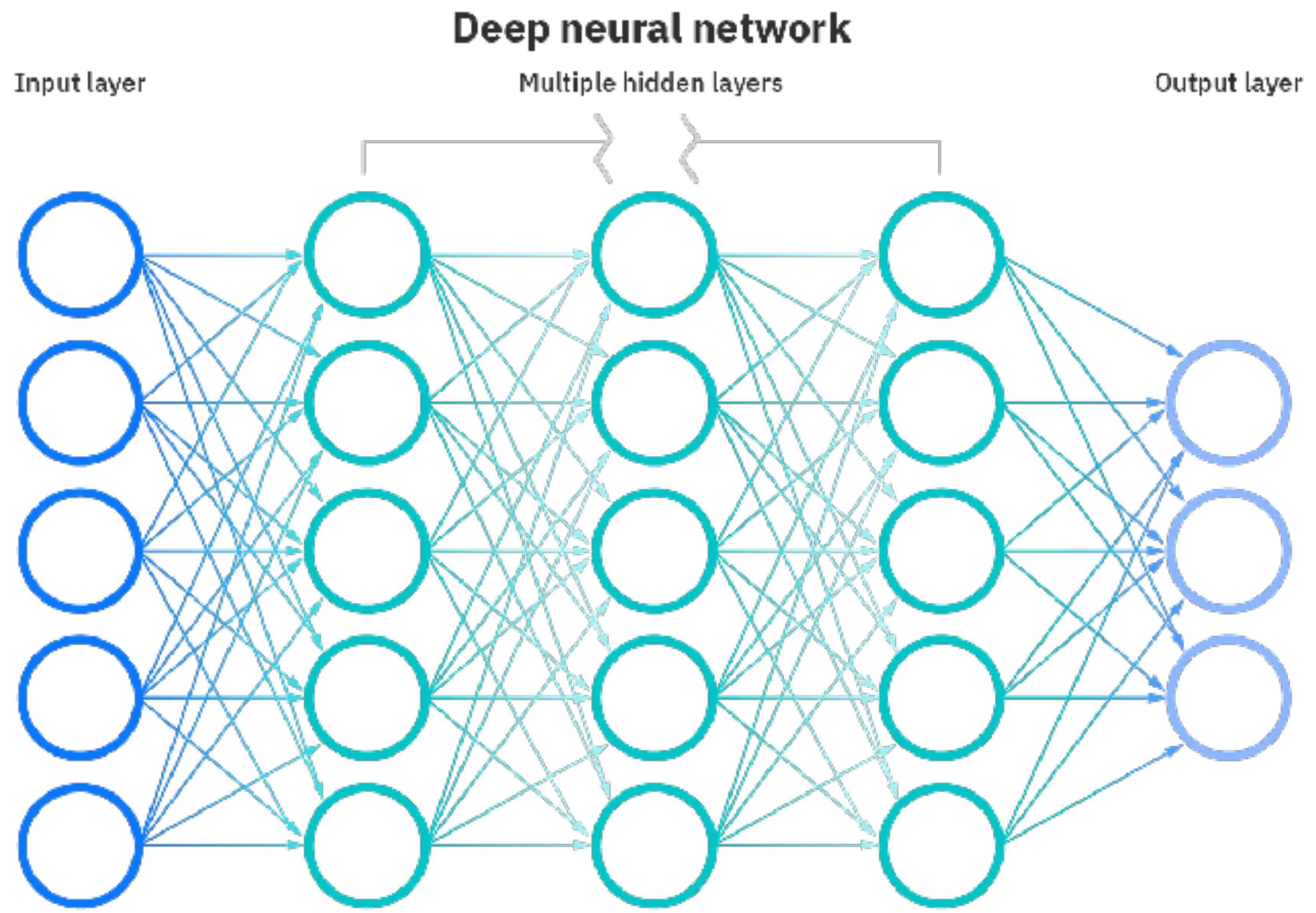
Sub-symbolic AI — Machine Learning

In sub-symbolic AI, we

- build/train *a model*
  - artificial/deep/graph neural networks
  - statistical methods
  - …

  to spot/learn regularities/patterns from data

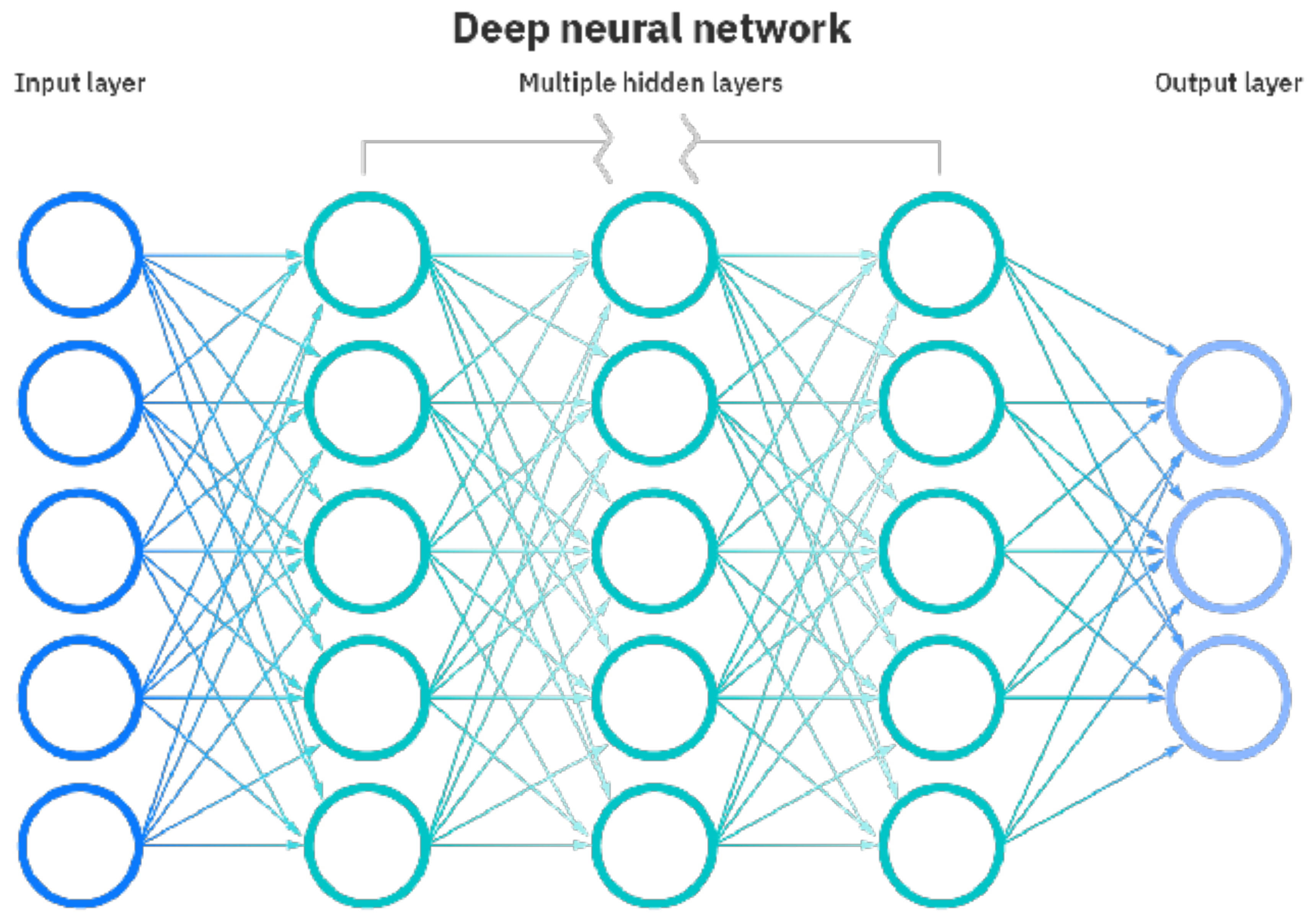
- don't need to
  - formulate explicit rules
  - identify the right terms/symbols
- get amazing results/performance



Sub-symbolic AI — Machine Learning

In sub-symbolic AI, we

- need huge amounts of data for training
  - costly
  - not always available
- bias in training data goes into model
- find it hard to analyse behaviour
  - other than testing it
  - independent on data



Neuro-symbolic KR&R

combines approaches

- neural/sub-symbolic and
- symbolic

- symbolic ⇒ sub-symbolic
  - inject *background knowledge* into ML models
  - informed embeddings

- sub-symbolic ⇒ symbolic
  - learn rules from data
  - learn facts
  - learn how to reason

Today:

- Knowledge Graphs
  - RDF
  - factual and conceptual knowledge
- Querying of and Reasoning with KGs
  - SPARQL
  - RDFS
  - SHACL
  - Materialisation of reasoning results

Day 1
Knowledge Graphs

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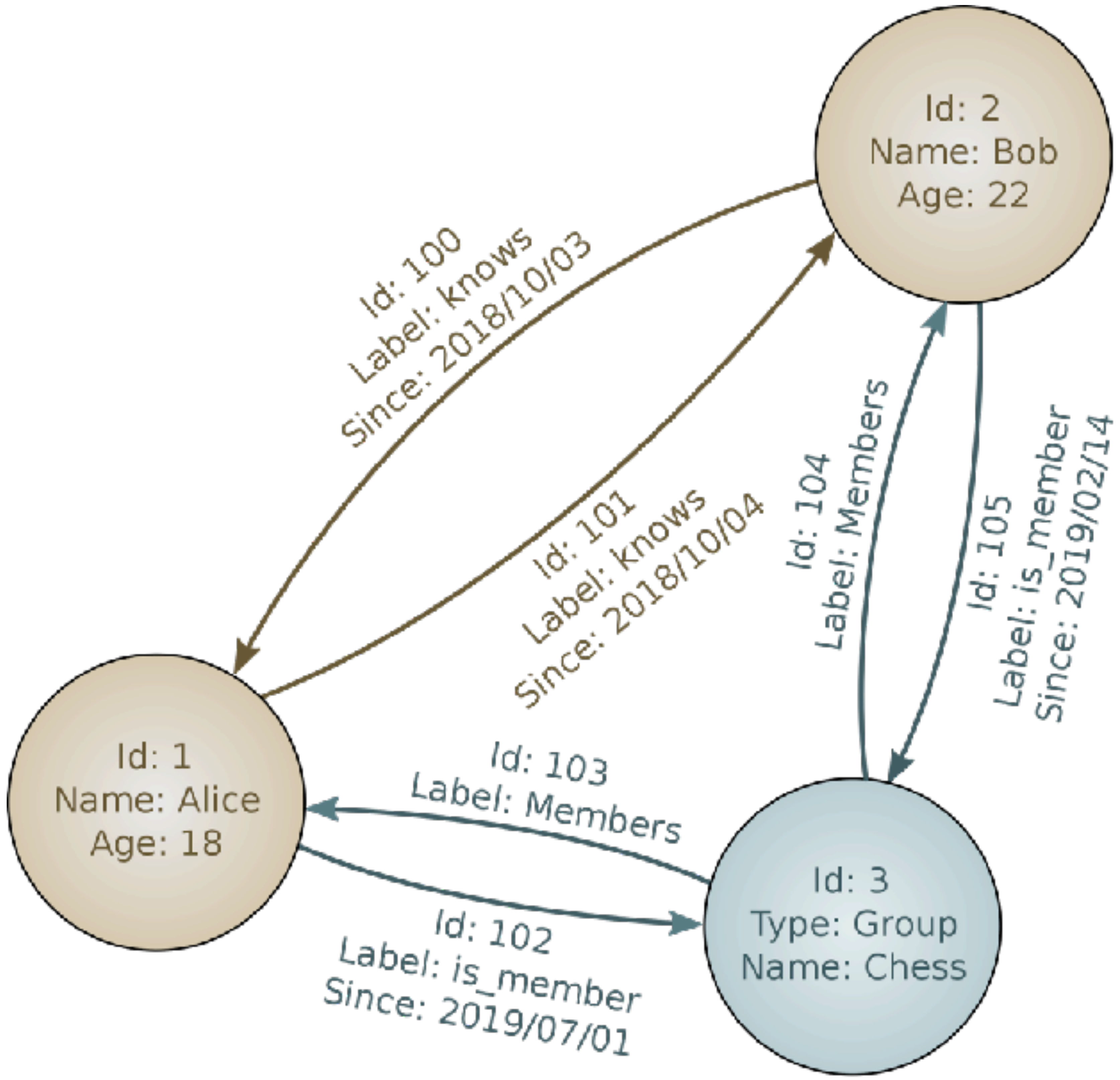
(Knowledge) Graphs

come in different shapes

- Google KG
  - both GDB and content
- Neo4J
- Amazon Neptune
- Arango
- RDF
  - a W3C standard for KGs
- …

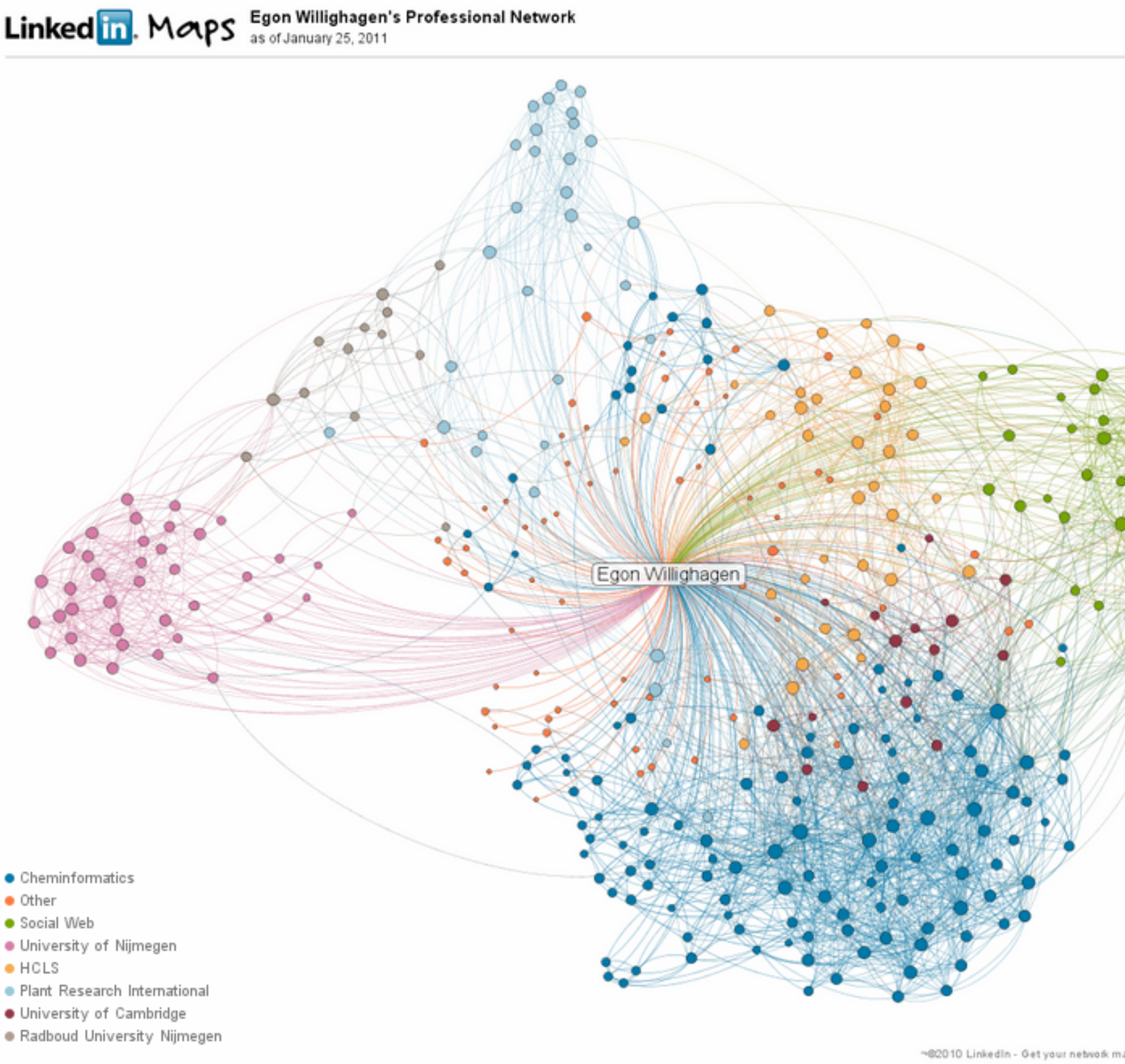


- nodes
- edges - between nodes
- labels - on edges and nodes

(Knowledge) Graphs

are everywhere

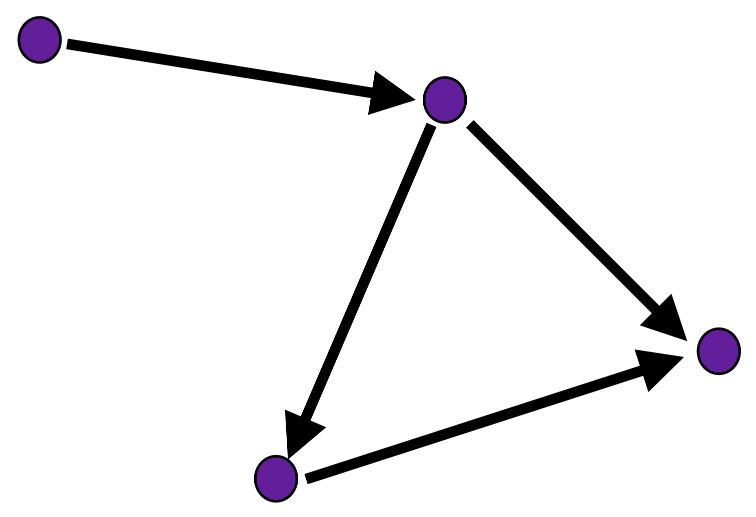
- “knows” on people
  - social networks
- “isRelatedTo” in genealogy
- “interactsWith” on proteins
  - bio-chemistry
- “educatedAt” etc in Wikidata
- …



Graph Basics

- A graph G = (V,E) is a pair with
  - V a set of vertices (also called) nodes, and
  - $E \subseteq V \times V$ a set of edges

- Variants:
  - (in)finite graphs: V is a (in)finite set
  - (un)directed graphs: E (is) is not a symmetric relation
    - i.e., if G is undirected, then $(x,y) \in E$ implies $(y,x) \in E$.
  - node/edge labelled graphs: a label set S, labelling function(s)
    - $L: V \rightarrow S$ (node labels)
    - $L: E \rightarrow S$ (edge labels)



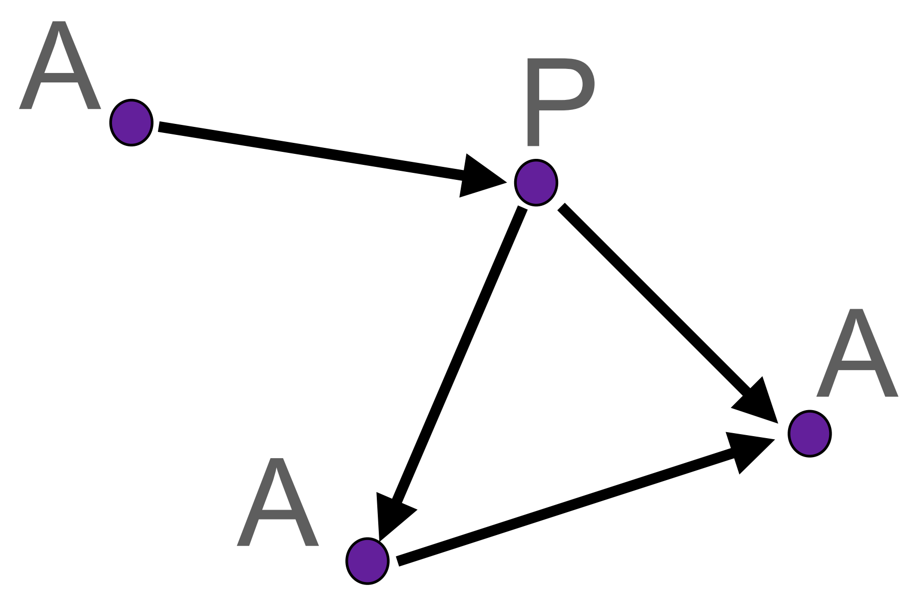
Example:

G = ({a,b,c,d},
 {(a,b), (b,c), (b,d), (c,d)})

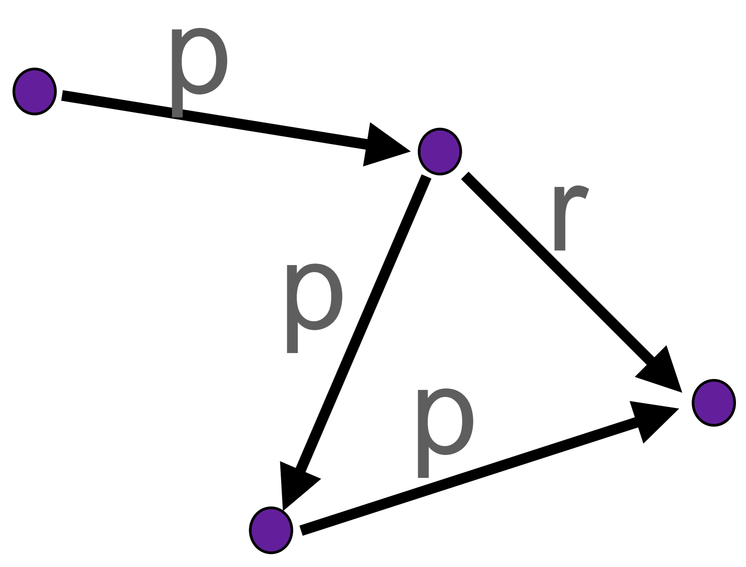
- where are a,….,d in this graph's picture?

Graph Basics (2)

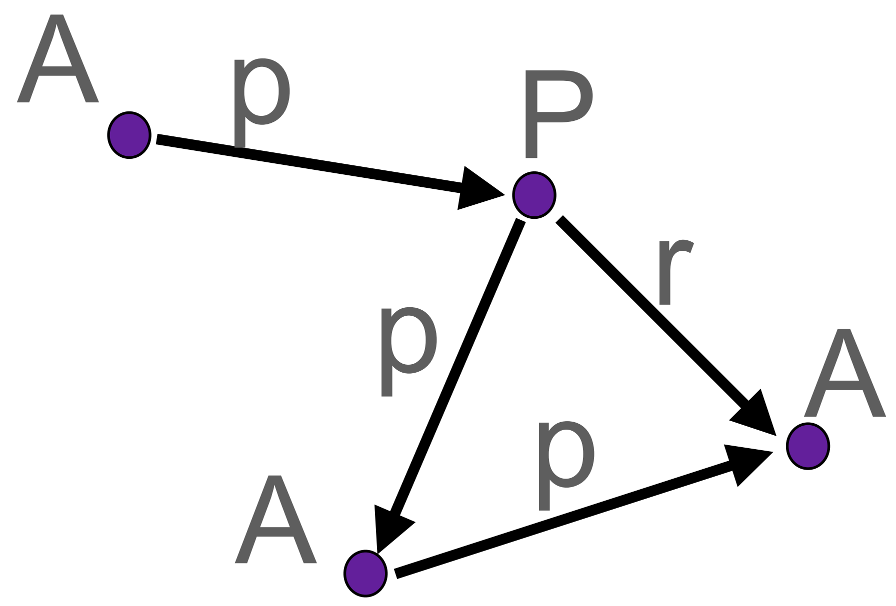
- Example: node-labelled graph
  - L: V $\rightarrow$ {A,P}



- Example: edge-labelled graph
  - L: E $\rightarrow$ {p,r,s}



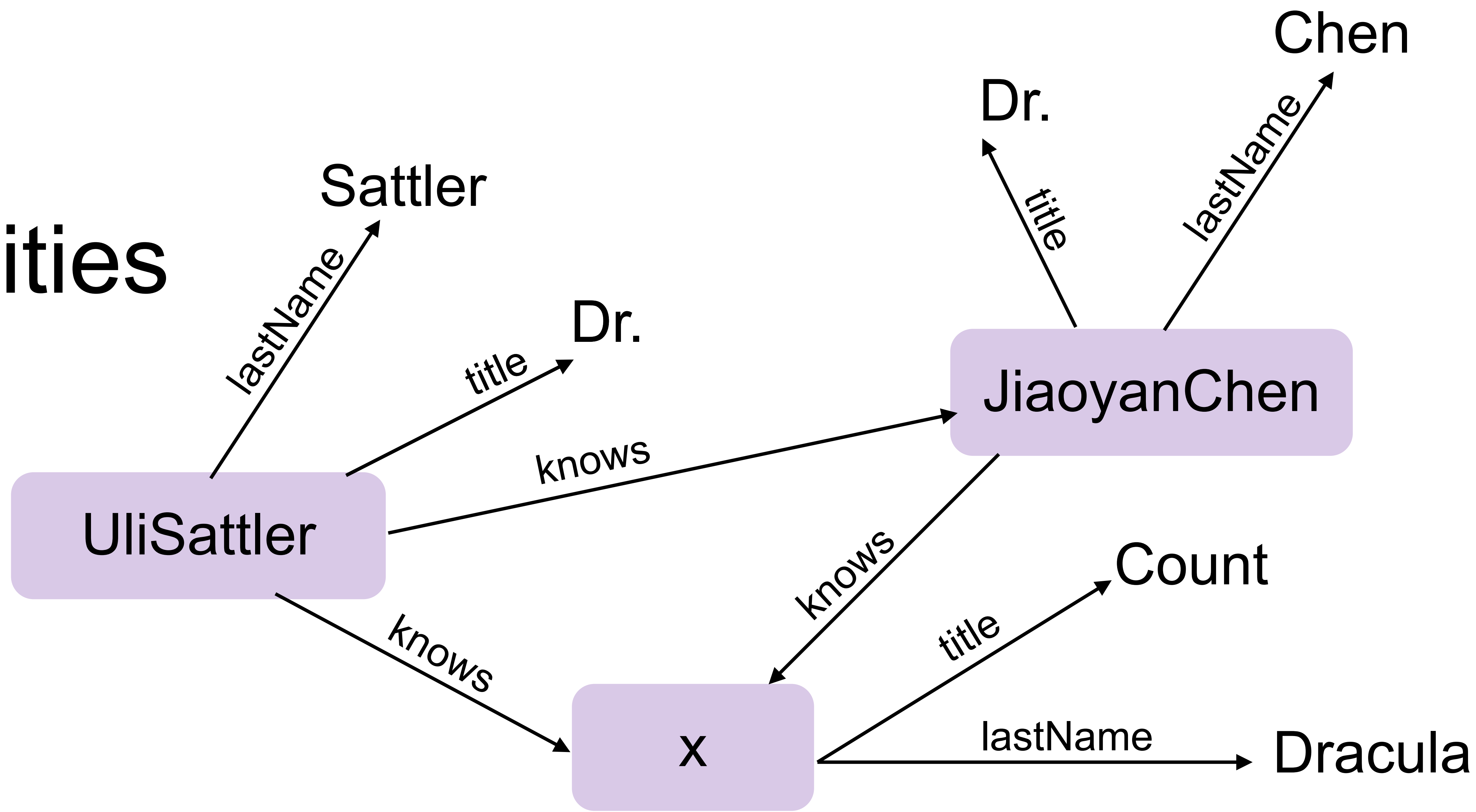
- Example: node-and-edge-labelled graph
  - L: V $\rightarrow$ {A,P}
  - L: E $\rightarrow$ {p,r,s}



Knowledge Graph

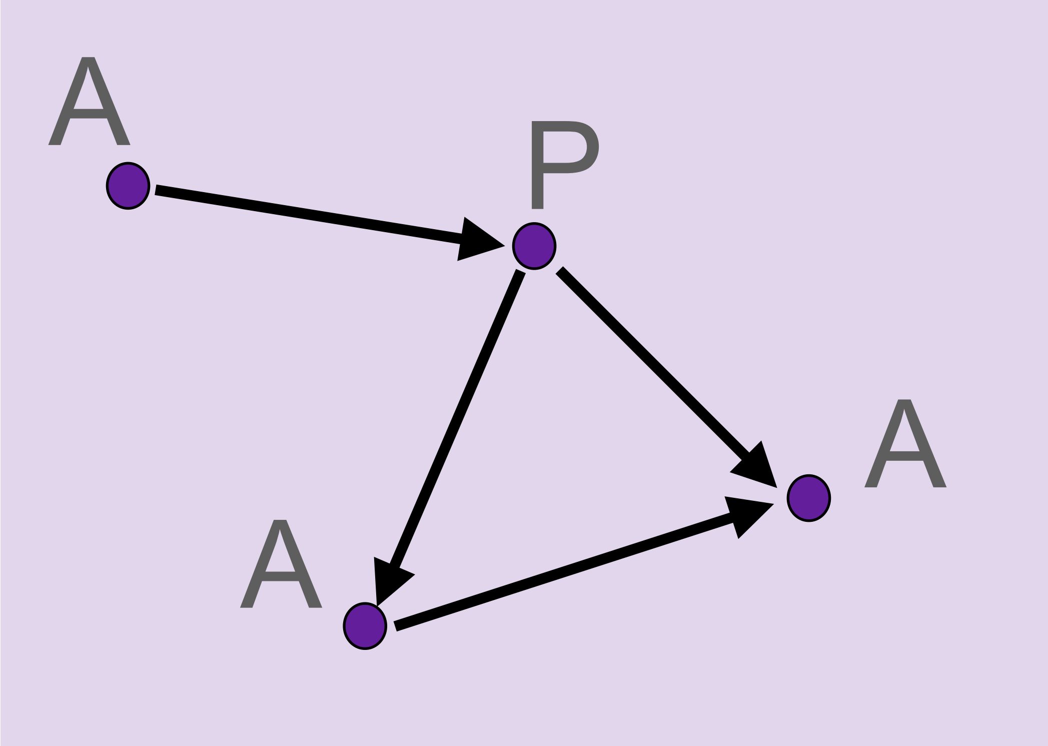
- Nodes ~ entities
  - possibly with *attributes* for *features* of nodes
- Edges ~ relations between entities
  - edge labels to describe kind

- Great for
  - many-to-many relations
  - cyclic relations
  - path queries



Graph Basics: **External** Representation

- Pictures are a bad external representations for graphs



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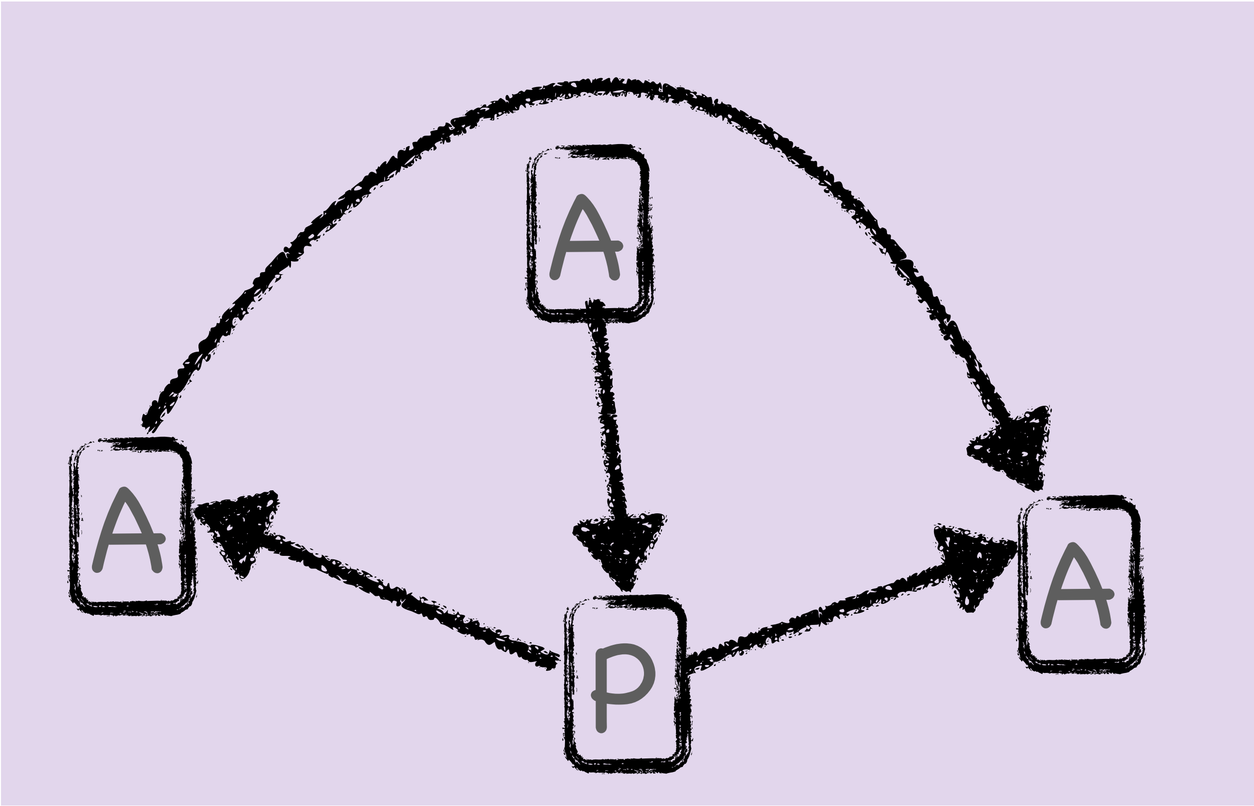


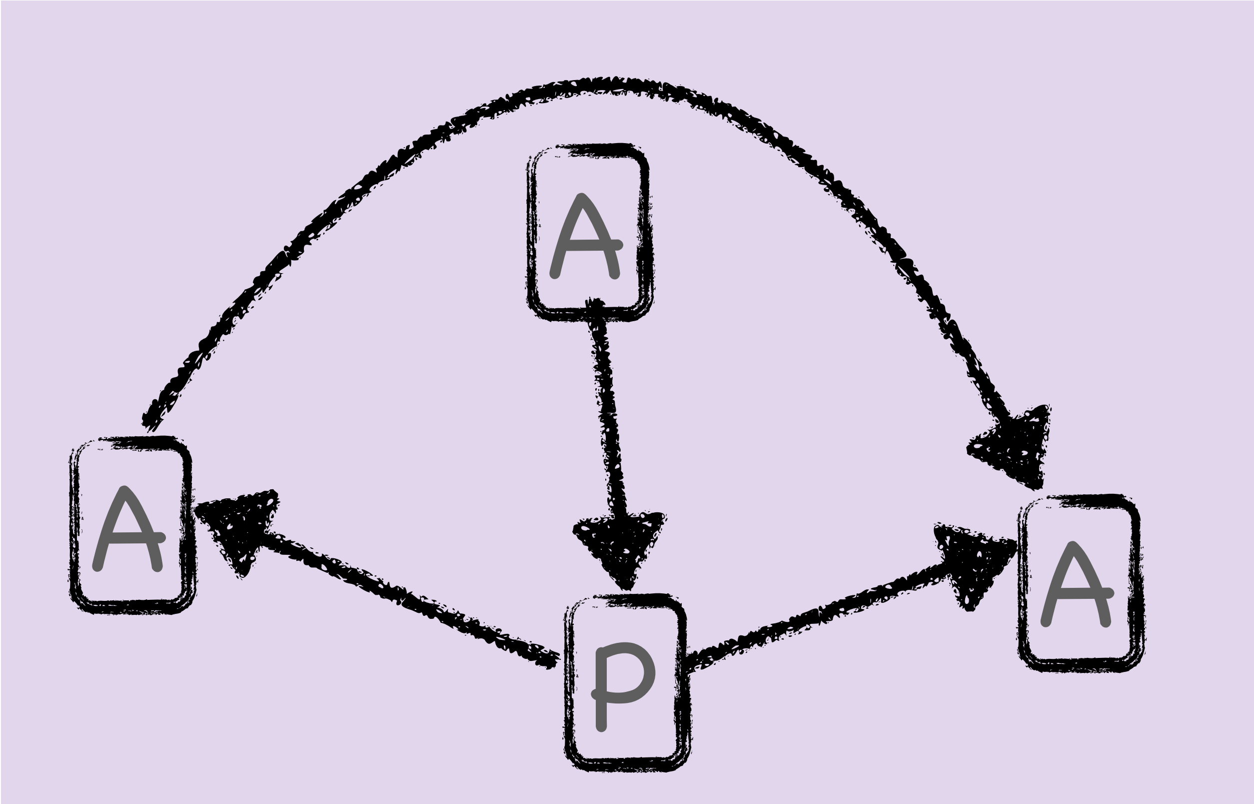
= =

G = ({a,b,c,d},
{(a,b), (b,c), (b,d), (b,c)},
L: V ⟶ {A,P}
L: a ↦ A, b ↦ P, c ↦ A, d ↦A)

= …

Graph Basics: External Representation

- Pictures are a bad **external representations** for graphs
  - capture loads of irrelevant information
    - colour
    - location, geometry,
    - shapes, strokes, …
  - what if labels are more complex/structured?
  - how do we *parse* a picture into an **internal representation**?
    - what is a *good* internal representation?



Day 1: RDF
a graph-shaped data model

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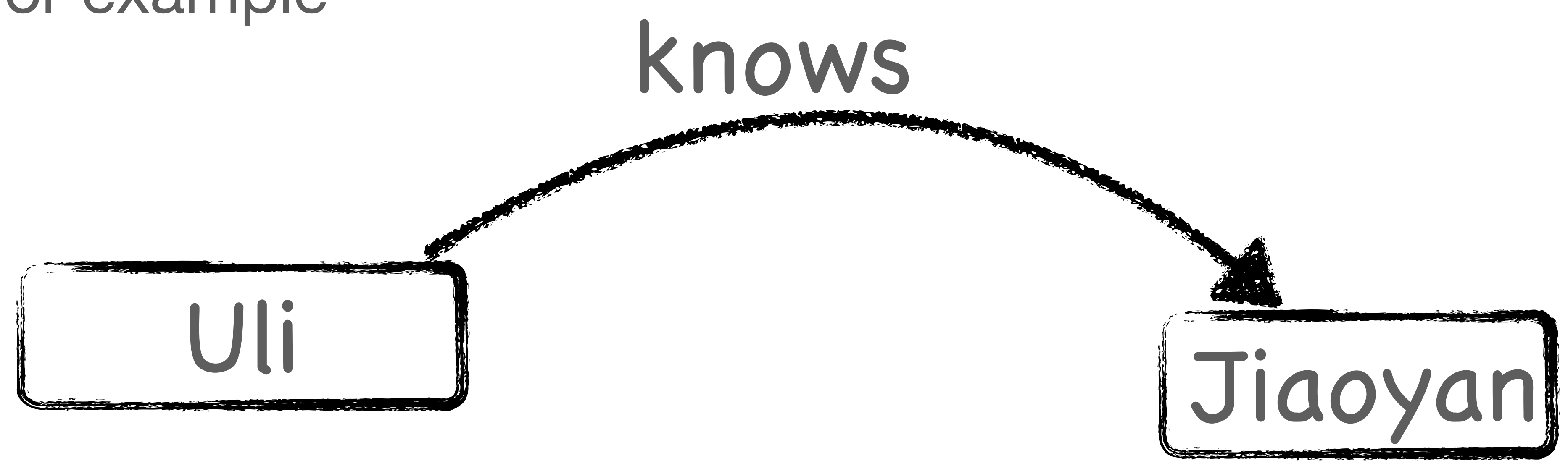
A Graph Formalism: RDF…why?

- RDF is an
  - *independent* data model
  - standardised by W3C
  - supported by various of the about GBDMSs
- other graph formalisms/data models are available, eg
  - Neo4J
  - GraphDB
  - MongoDB

A Graph Formalism: RDF

- **R**esource **D**escription **F**ramework
- a **graph-based** data structure formalism
- a W3C standard for the representation of **graphs**
- comes with various syntaxes for External Representation
- is based on **triples** *(subject, predicate, object)*

For example

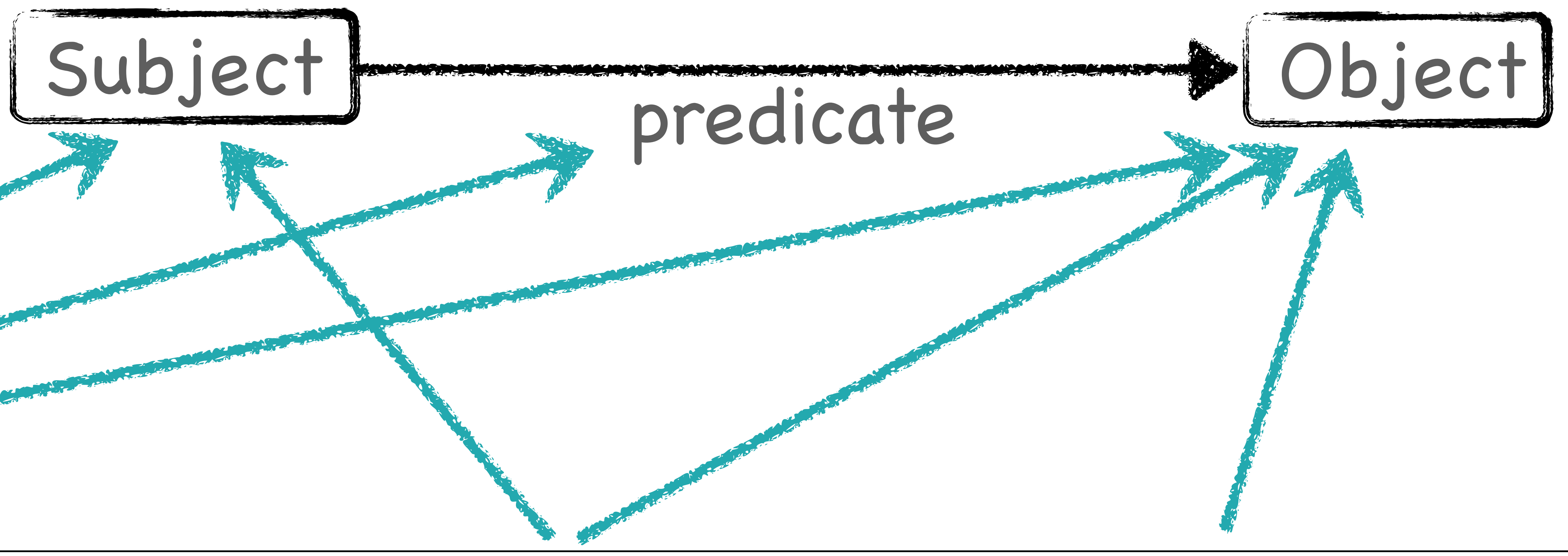


RDF: basics

U: URIs (for *resources*), incl. rdf:type
B: Blank nodes
L: Literals

- an RDF **graph G** is a **set** of **triples** $\{(s_i, p_i, o_i) \mid 1 \leq i \leq n\}$

- where each
  - $s_i \in U \cup B$
  - $p_i \in U$
  - $o_i \in U \cup B \cup L$



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a graph ???

{(ex:jchen, foaf:knows, ex:sattler),
(ex:jchen, rdf:type, foaf:Person),
(ex:jchen, rdf:type, foaf:Agent),
(ex:sattler, foaf:title, “Dr.”),
(ex:sattler, foaf:lastName, “Sattler”),
(ex:jchen, foaf:title, “Dr.”),
(ex:sattler, foaf:knows, ex:npaton),
(ex:jchen, foaf:knows, ex:npaton) }

abbreviate: ex: for http://www.cs.man.ac.uk/
foaf: for http://xmlns.com/foaf/0.1/

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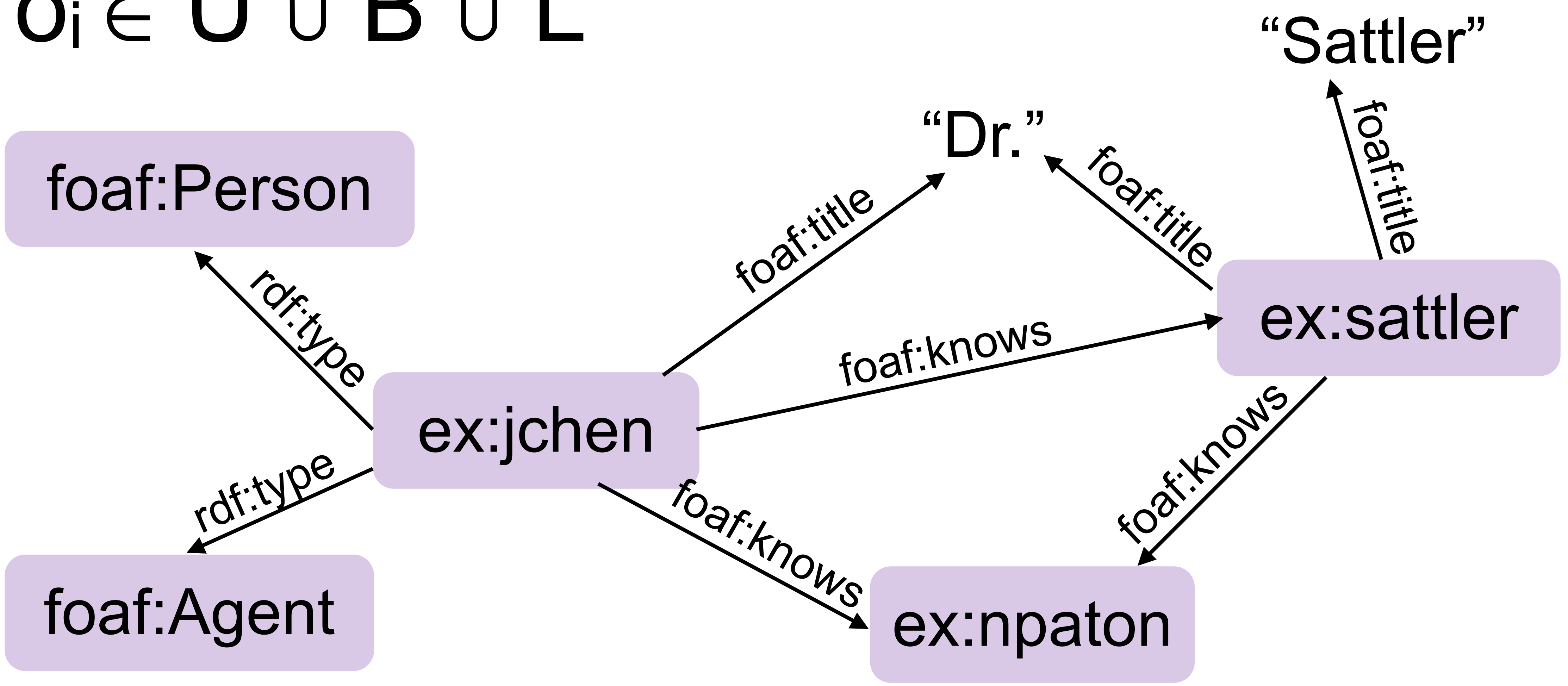
a graph !!!



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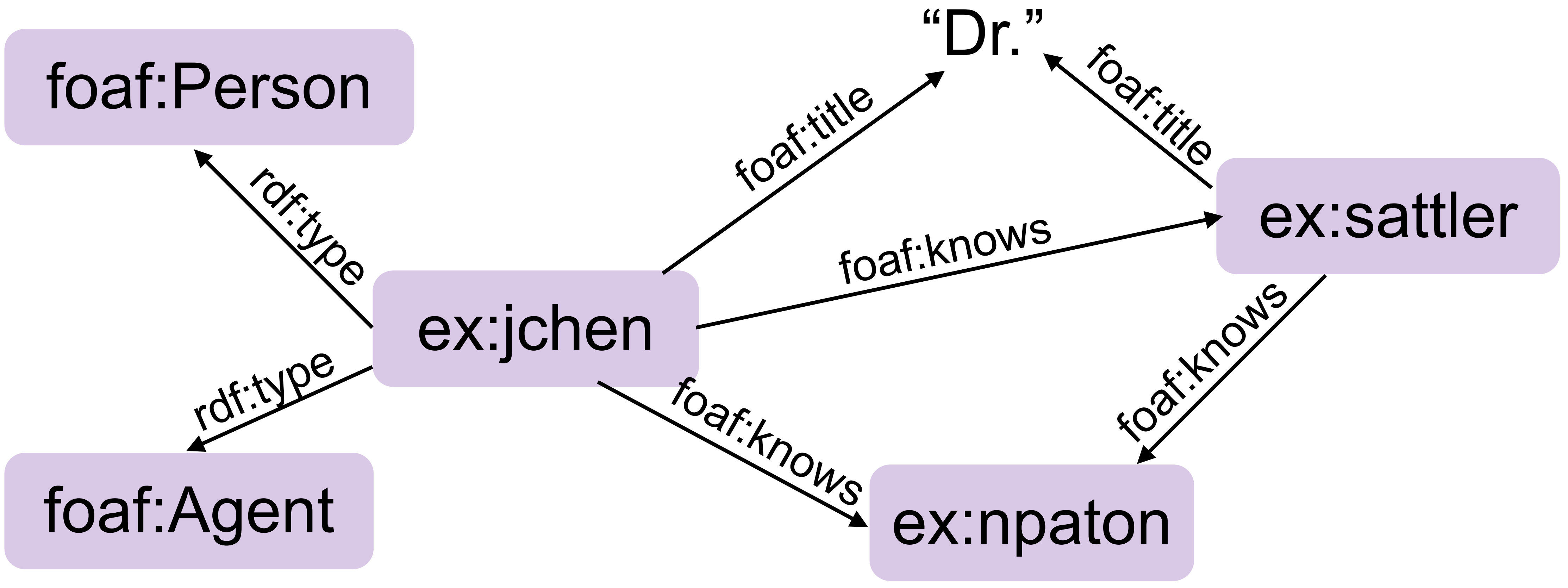
RDF syntaxes



- "serialisation formats"
  - for ExtRep of RDF graphs
    - graphs are IntReps!
- there are several:
  - **Turtle**
  - N-Triples
  - JSON-LD
  - N3
  - RDF/XML
  - …

~~{(ex:jchen, foaf:knows, ex:sattler),
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RDF syntaxes

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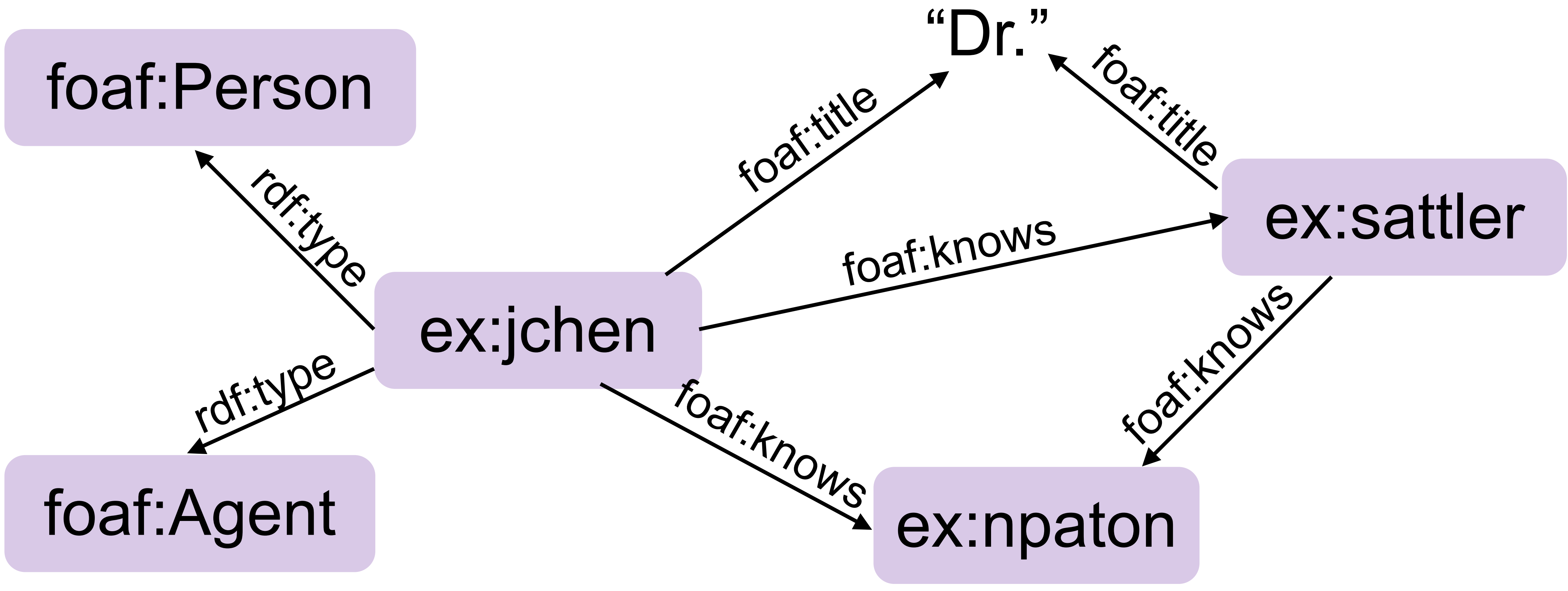

7 triples in **Turtle**:

```
@prefix rdf:   <http://www.w3.org/
1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ex:   <http://www.cs.man.ac.uk/> .

ex:sattler
  foaf:title  "Dr." ;
  foaf:lastName  “Sattler" ;
  foaf:knows ex:jchen ;
  rdf:type foaf:Person ;
ex:jchen
 foaf:title  "Dr." ;
 foaf:knows ex:npaton ;
 foaf:knows ex:sattler ;
.
```

{(ex:jchen, foaf:knows, ex:sattler),
(ex:jchen, rdf:type, foaf:Person),
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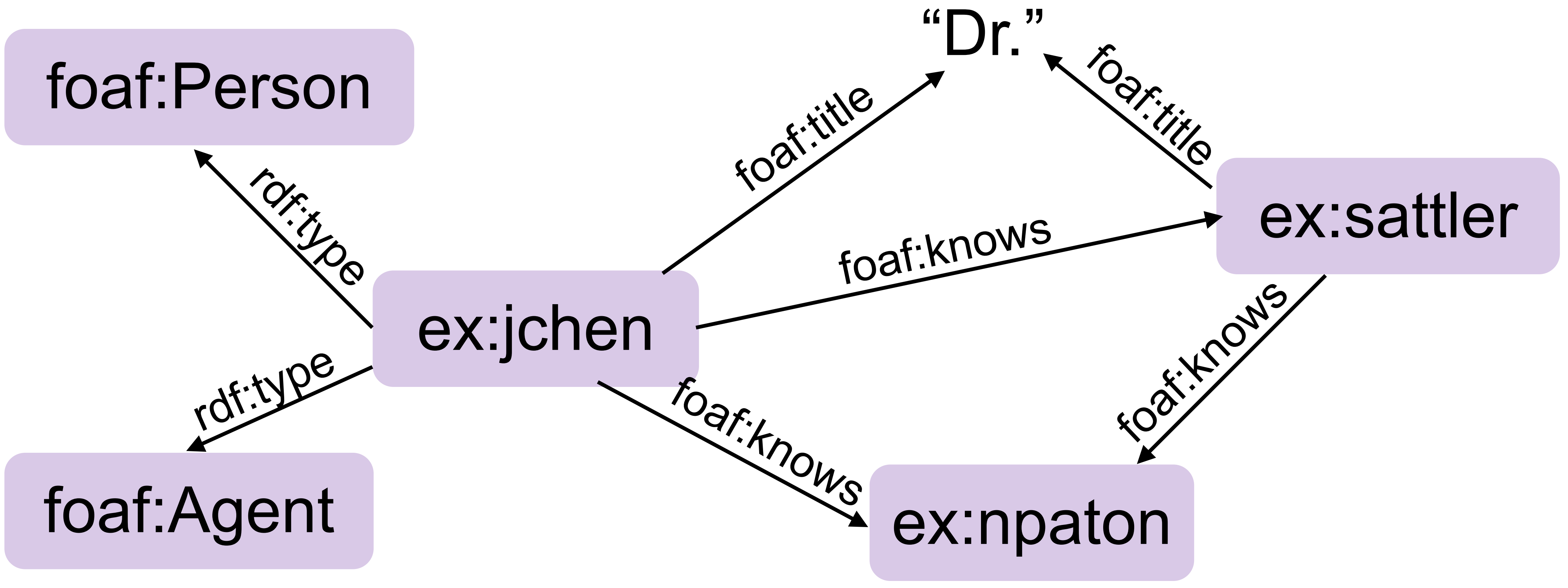
RDF syntaxes



- "serialisation formats"
  – for ExtRep of RDF graphs
    – graphs are IntReps!
- there are several:
  –Turtle
  –N-Triples
  –**JSON-LD**
  –N3
  –RDF/XML
  –…

Triples in **JSON-LD**:

```
{"@context": {
   "Person": "http://xmlns.com/foaf/0.1/Person",
   "title": "http://xmlns.com/foaf/0.1/title",
   "lastName": "http://xmlns.com/foaf/0.1/lastName",
   "knows": "http://xmlns.com/foaf/0.1/knows"
 }, "@graph": [{
    "@id": "http://www.cs.man.ac.uk/sattler",
    "@type": "Person" ,
    "title": "Dr." ,
    "lastName": "Sattler",
    "knows": "http://www.cs.man.ac.uk/npaton"
        }, {
    "@id": "http://www.cs.man.ac.uk/jchen",
    "@type": "Person" ,
    "title": "Dr." ,
    "lastName": "Chen",
    "knows": ["http://www.cs.man.ac.uk/npaton",
                  "http://www.cs.man.ac.uk/sattler"]}
]}
```

~~{(ex:jchen, foaf:knows, ex:sattler),
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(ex:sattler, foaf:title, "Dr."),
(ex:jchen, foaf:title, "Dr."),
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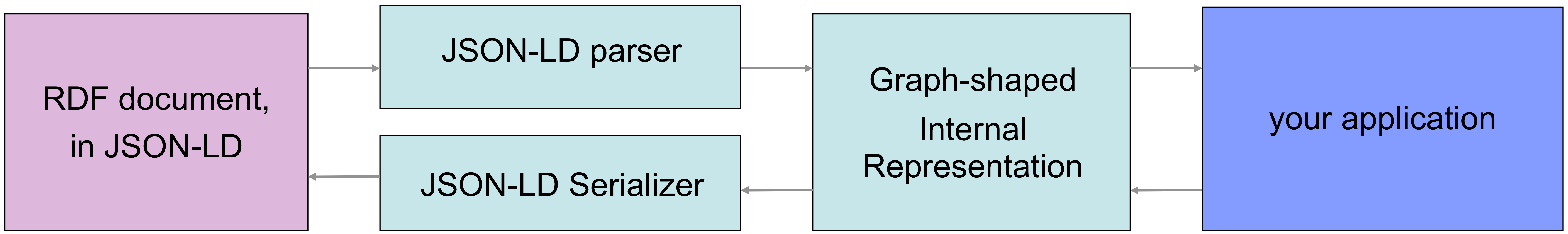
Parsing/serialising RDF graphs



- See eg https://json-ld.org/
- See eg https://github.com/RDFLib/rdflib
  - for Python parsers/serialisers/libraries
  - for RDF/XML, N3, NTriples, N-Quads, Turtle, …
  - with support for SPARQL for querying

Day 1: SPARQL

a query language for RDF

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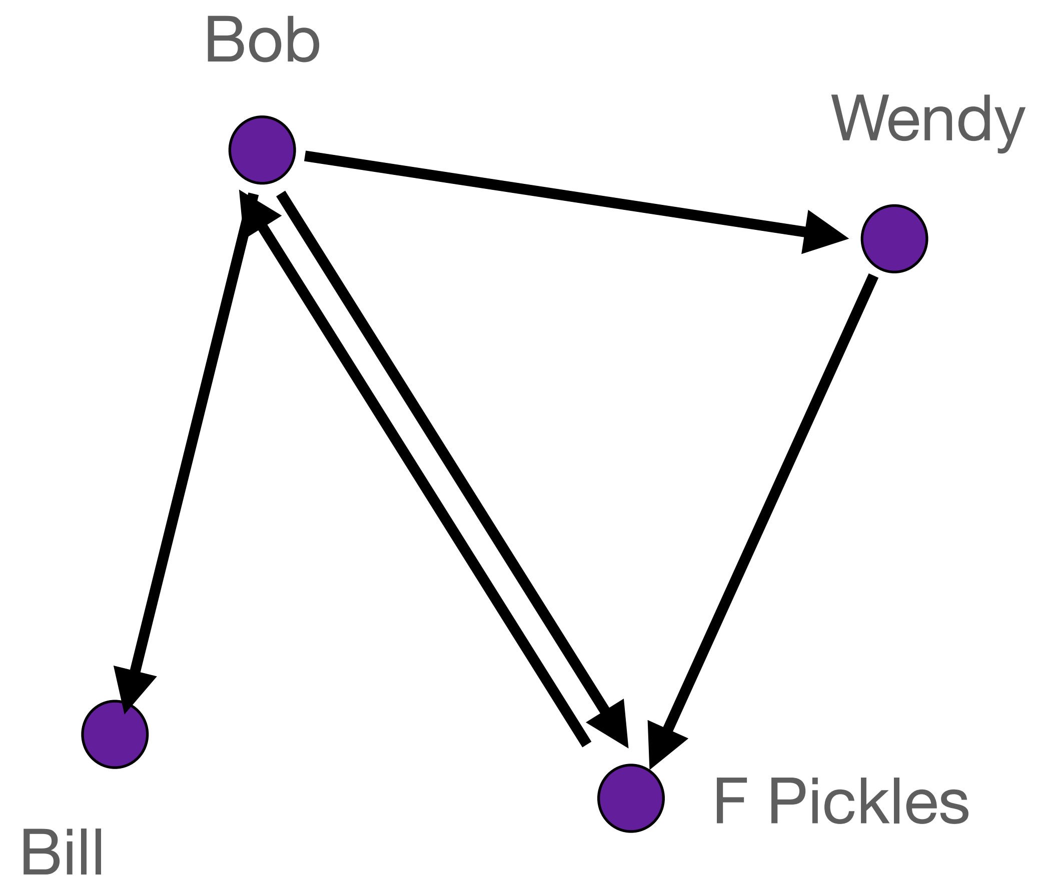
SPARQL

- We have
  - a data structure/internal representation: graphs!
  - schema languages (later: RDF, SHACL)
    - plus various external representions (Turtle, N3, N-triples, JSON-LD,..)
- For manipulating RDF graphs: you can use
  - libraries for your favourite programming language:
    - rdflib in Python
    - Jena, RDF4J, CommonsRDF, … in Java
    - …
  - a query language
    - SPARQL, a W3C standardised QL
    - Cypher, supported by Neo4j
      - http://neo4j.com/developer/cypher/
      - has “graph structural” features like “shortest path”
      - lacks “regular path” queries

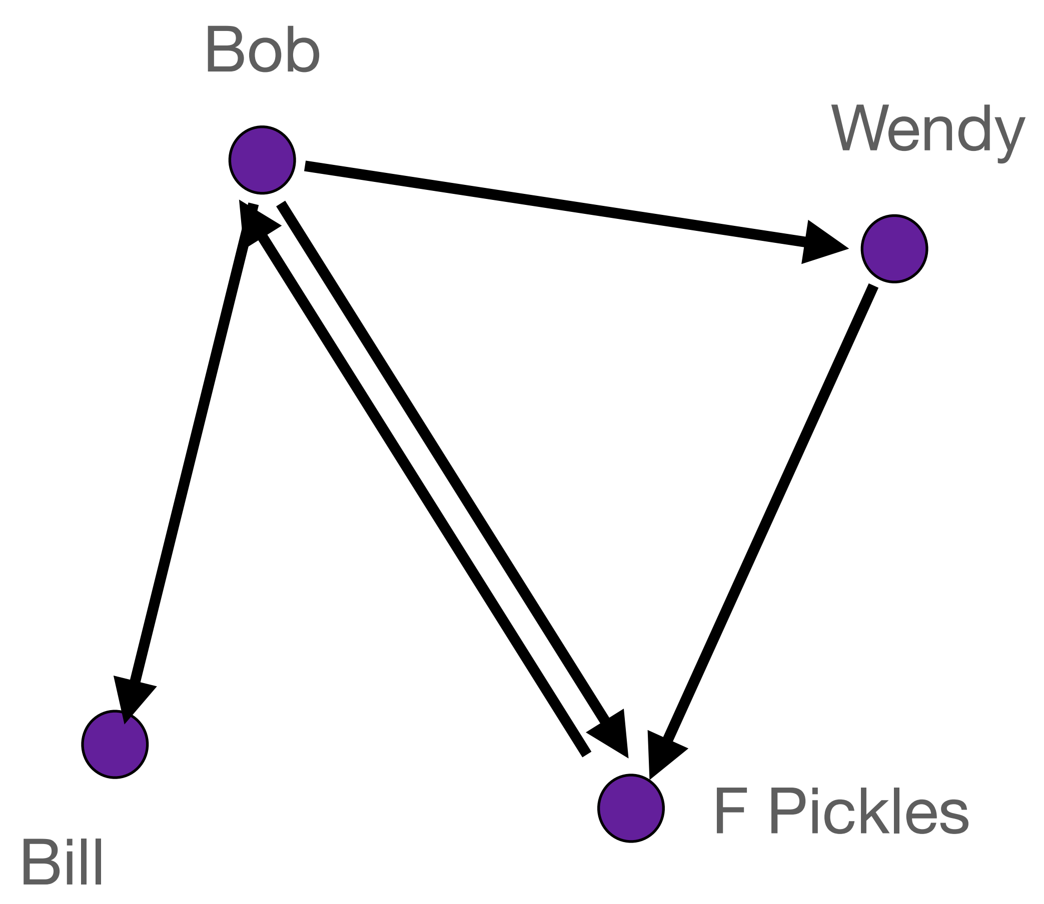
SPARQL: Basic Graph Patterns



- are at the core of SPARQL queries:
  - a *BGP* is a list/set of *triple patterns*
    - e.g., →
    - with abbreviations for shared subjects or predicates
    - separated by .
  - a *triple pattern* is a triple where *variables* can be used as subject, predicate, or object
    - e.g., {?x rdf:type foaf:Person}

```
ex:bobthebuilder
        foaf:firstName "Bob";
        foaf:lastName "Builder";
        foaf:knows ex:Wendy .
```

SPARQL: Clauses (1)



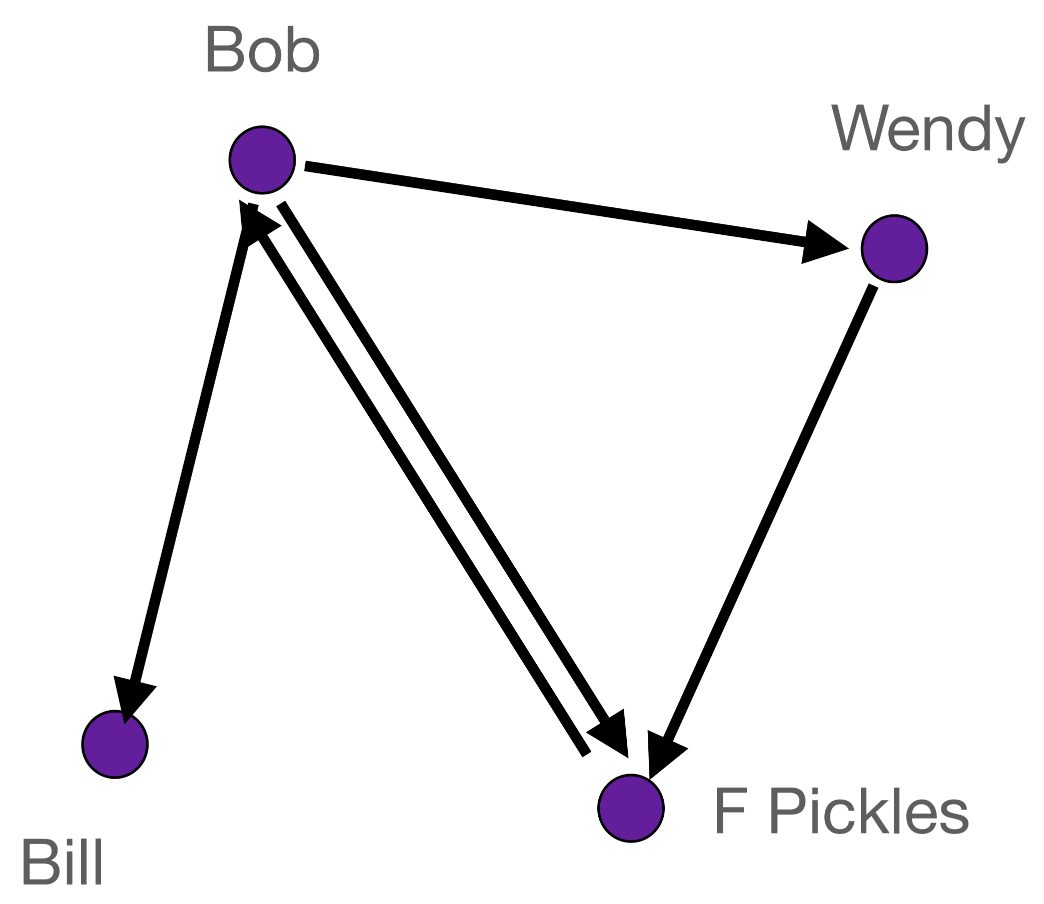
- We combine a BGP with a **query type**
  - ASK
    - e.g., ASK WHERE {ex:sattler rdf:type foaf:Person}
    - returns true or false (only)
  - SELECT
    - e.g., SELECT ?p WHERE {?p rdf:type foaf:Person}
    - very much like SQL SELECT
  - Careful:
    - ASK returns a Boolean (not an RDF graph!)
    - SELECT returns a table (not an RDF graph!)
    - SPARQL is *not* closed over graphs!
      - unusual: compare to SQL or XQuery!

SPARQL Clauses (2)

- There are two query types that return graphs:
  - CONSTRUCT
    - e.g., CONSTRUCT {?p rdf:type :Befriended}
WHERE {?p foaf:knows ?q}
    - like XQuery element and attribute constructors
  - DESCRIBE
    - e.g., DESCRIBE ?p WHERE {?p rdf:type foaf:Person}
    - implementation dependent!
    - returns a“description”
      - as a graph
      - whatever the service deems helpful!
      - similar to querying system tables in SQL

Examples: Data

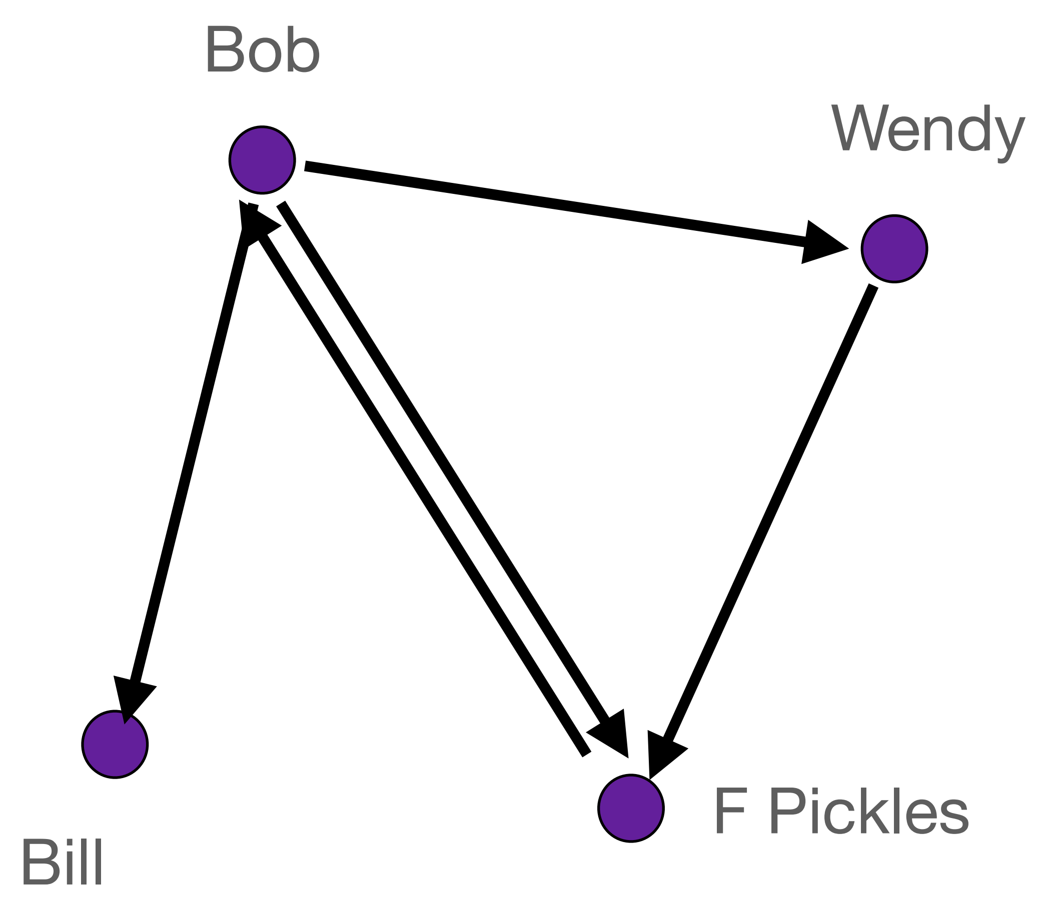
```
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ex:   <http://www.cs.man.ac.uk/> .

ex:bobthebuilder
        foaf:firstName "Bob";
        foaf:lastName "Builder";
        foaf:knows ex:wendy ;
        foaf:knows ex:farmerpickles;
        foaf:knows ex:billbibs.
ex:wendy
        foaf:firstName "wendy";
        foaf:knows ex:farmerpickles.

ex:farmerpickles
        foaf:firstName "Farmer";
        foaf:lastName "Pickles";
        foaf:knows ex:bobthebuilder.

ex:billbibs
        foaf:firstName "Bill";
        foaf:lastName "Bibby".
```



Example: Count Friends!

How many friends does Bob Builder have?

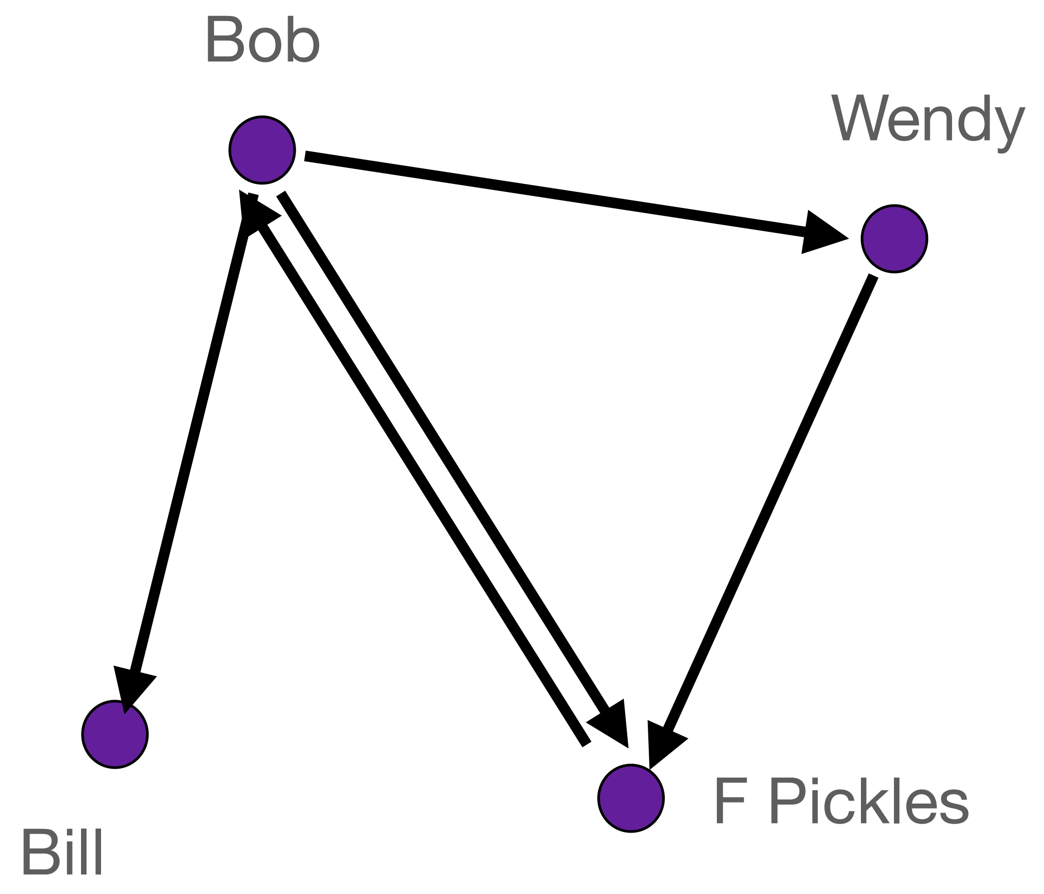
```
SELECT DISTINCT COUNT(?friend)
WHERE {ex:bobthebuilder
              foaf:firstName "Bob";
              foaf:lastName "Builder";
              foaf:knows ?friend };
```



Quite similar to a SQL query:

```
SELECT COUNT(DISTINCT k.Whom)
FROM Persons P, knows k
WHERE ( P.PersonID = k.Who AND
            P.FirstName = "Bob" AND
            P.LastName = "Builder" );
```

Example: Find Friends' Friends?



Give me Bob Builder's friends' friends' names?

```
SELECT ?first, ?last
WHERE {ex:bobthebuilder
                foaf:firstName "Bob";
                foaf:lastName "Builder";
                foaf:knows ?x.
          ?x foaf:knows ?y.
          ?y foaf:firstName ?first;
              foaf:lastName ?last}
```

As a SQL query:

```
SELECT P3.FirstName , P3.LastName
FROM knows k1, knows k2, Persons P1, Persons P3
WHERE (  k1.whom = k2.who AND
         P1.PersonID = k1.Who AND
         P3.PersonID = k2.Whom AND
         P1.FirstName = "Bob" AND
         P1.LastName = "Builder" );
```

Friends network?

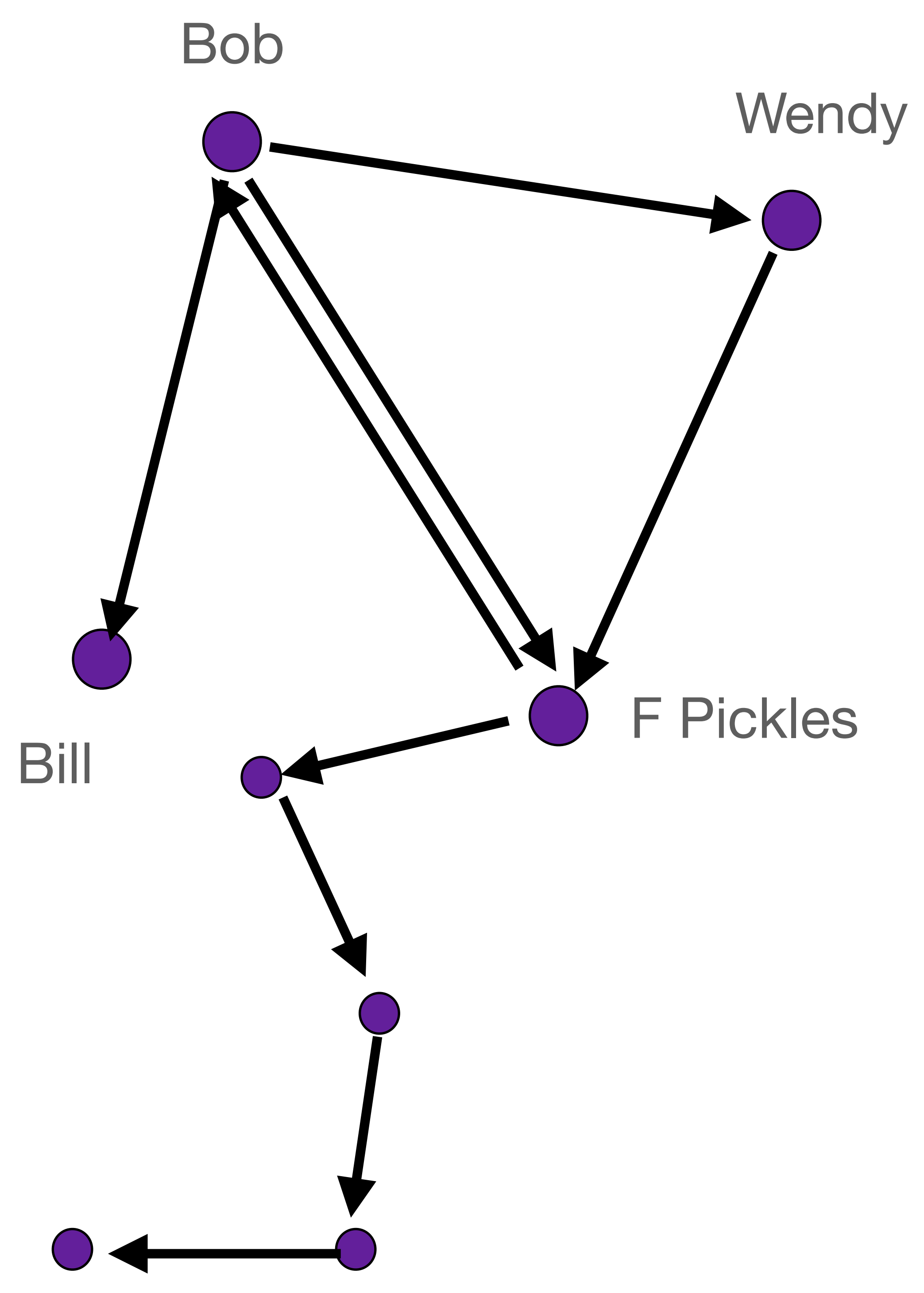
Give me everybody in Bob Builder's friends' friends…?

```
SELECT ?first, ?last
WHERE {ex:bobthebuilder
                 foaf:firstName "Bob";
                 foaf:lastName "Builder";
                 foaf:knows+ ?friend.
          ?friend foaf:firstName ?first;
                     foaf:lastName ?last}
```

a path query !!!!

works regardless of path length

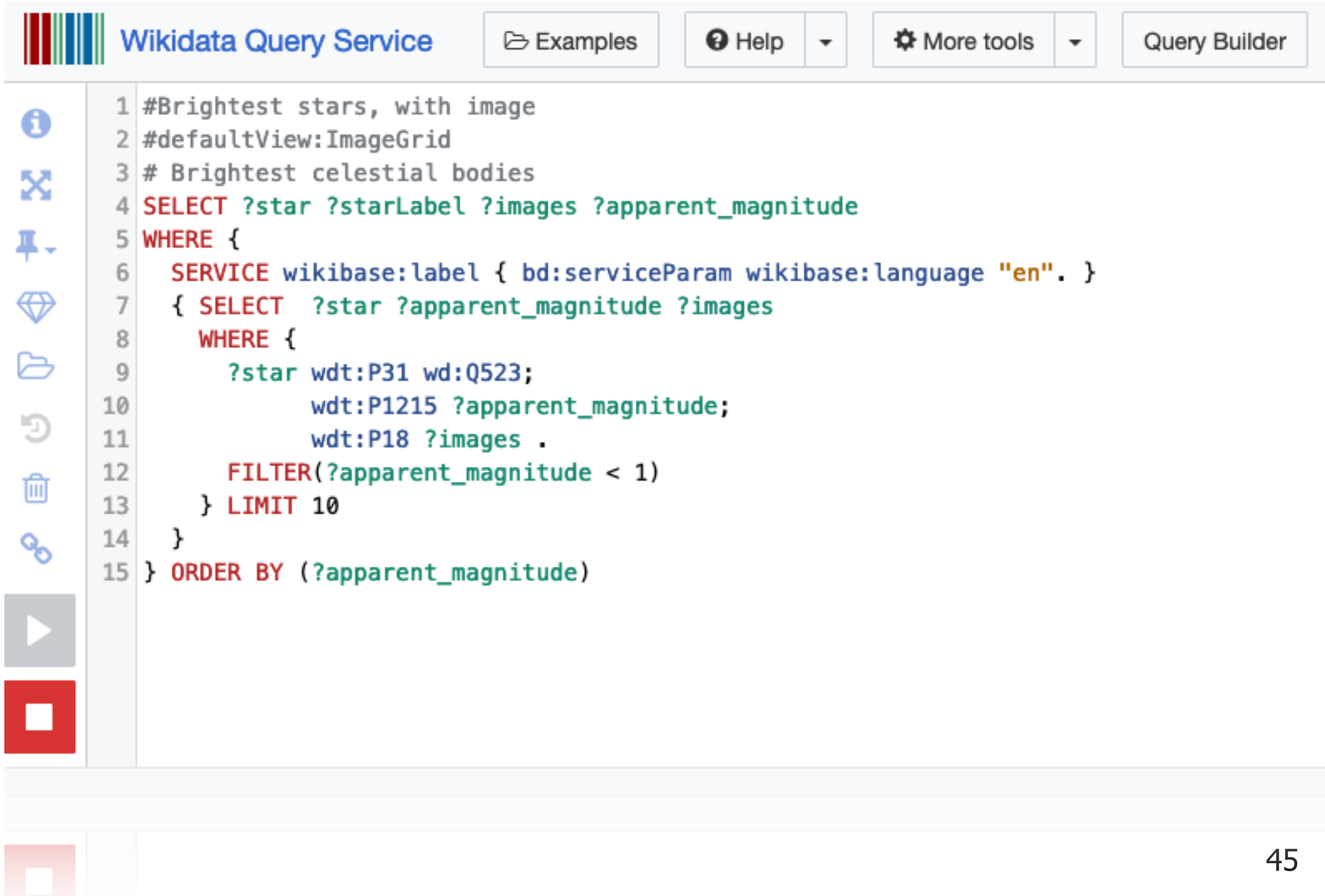
works without cycle detection



SPARQL supports
full regular expressions
in path queries!

Working with RDF graphs through SPARQL endpoints

- by hand
  - eg Wikidata
- programmatically
  - eg through REST APIs



Day 1: RDFS

a schema language for RDF

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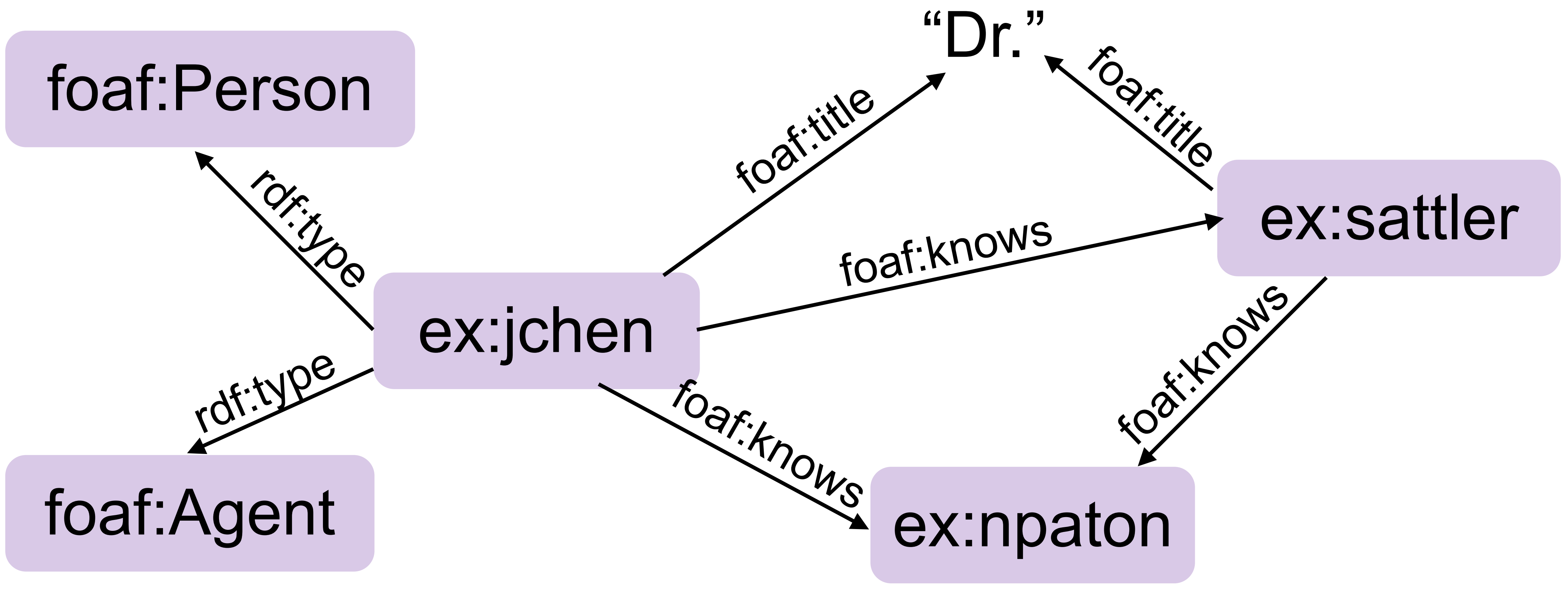
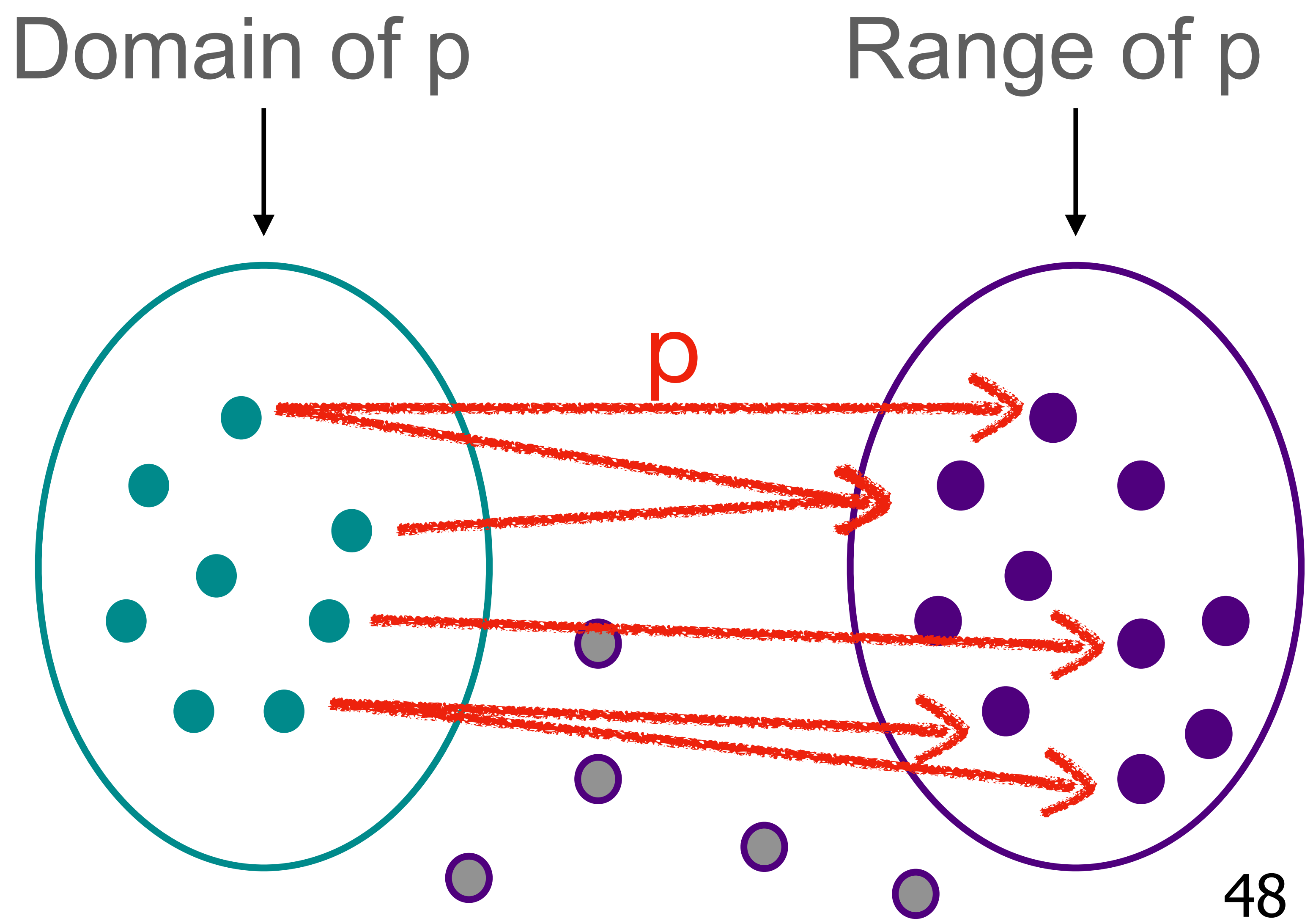
RDF

- in RDF, we can state *factual* knowledge:
  - how 2 nodes relate
    - e.g. (ex:sattler, foaf:knows, foaf:npaton)
  - how a node relates to a literal
    - e.g. (ex:jchen, foaf:title, “Dr.”)
  - what type a node has via rdf:**type**
    - e.g. (ex:sattler, rdf:type, foaf:Person)
- but we can’t say anything about
  - classes
    - e.g., foaf:Person implies foaf:Agent
  - properties
    - e.g., worksWith implies knows



RDFS: a schema language for RDF

- in RDFS, we can state *conceptual knowledge:*
  - rdfs:**subClassOf**
    - e.g. (foaf:Person, rdfs:subClassOf, foaf:Agent)
    - (ex:Woman, rdfs:subClassOf, foaf:Person)
  - rdfs:**subPropertyOf**
    - e.g. (ex:worksWith, rdfs:subPropertyOf, foaf:knows)
  - rdfs:**domain**
    - e.g. (ex:hasChild, rdfs:domain, foaf:Person)
(foaf:currentProject, rdfs:domain, foaf:Person)
  - rdfs:**range**
    - e.g. (ex:hasChild, rdfs:range, foaf:Person)
(foaf:currentProject, rdfs:range, foaf:Project)



Reasoning: Default Values++

- RDFS does **not** *describe/constrain structure*
  - that is, unlike in other schema languages,
    - in RDFS, we don't describe what *has to be the case*

      we don't write *integrity constraints*
    - RDFS can't be used to "validate" documents/graphs
- RDFS allows us to provide *extra information*
  - …a bit like default values!
  - …rather than requesting information, we infer it!

Reasoning: Default Values++

- RDFS does **not** *describe/constrain structure*
- RDFS allows us to provide *extra information*

Facts

```
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ex:   <http://www.cs.man.ac.uk/> .

ex:sattler
  foaf:title  "Dr." ;
  foaf:knows ex:jiaoyanchen ;
  foaf:knows
   [
    foaf:title "Count";
    foaf:lastName "Dracula"
  ] .
```

\+

extra information

```
@prefix rdfs:   <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
foaf:knows rdfs:domain foaf:Person.
foaf:knows rdfs:range foaf:Person.
foaf:person rdfs:subClassOf foaf:Agent.
```

=>

inferences

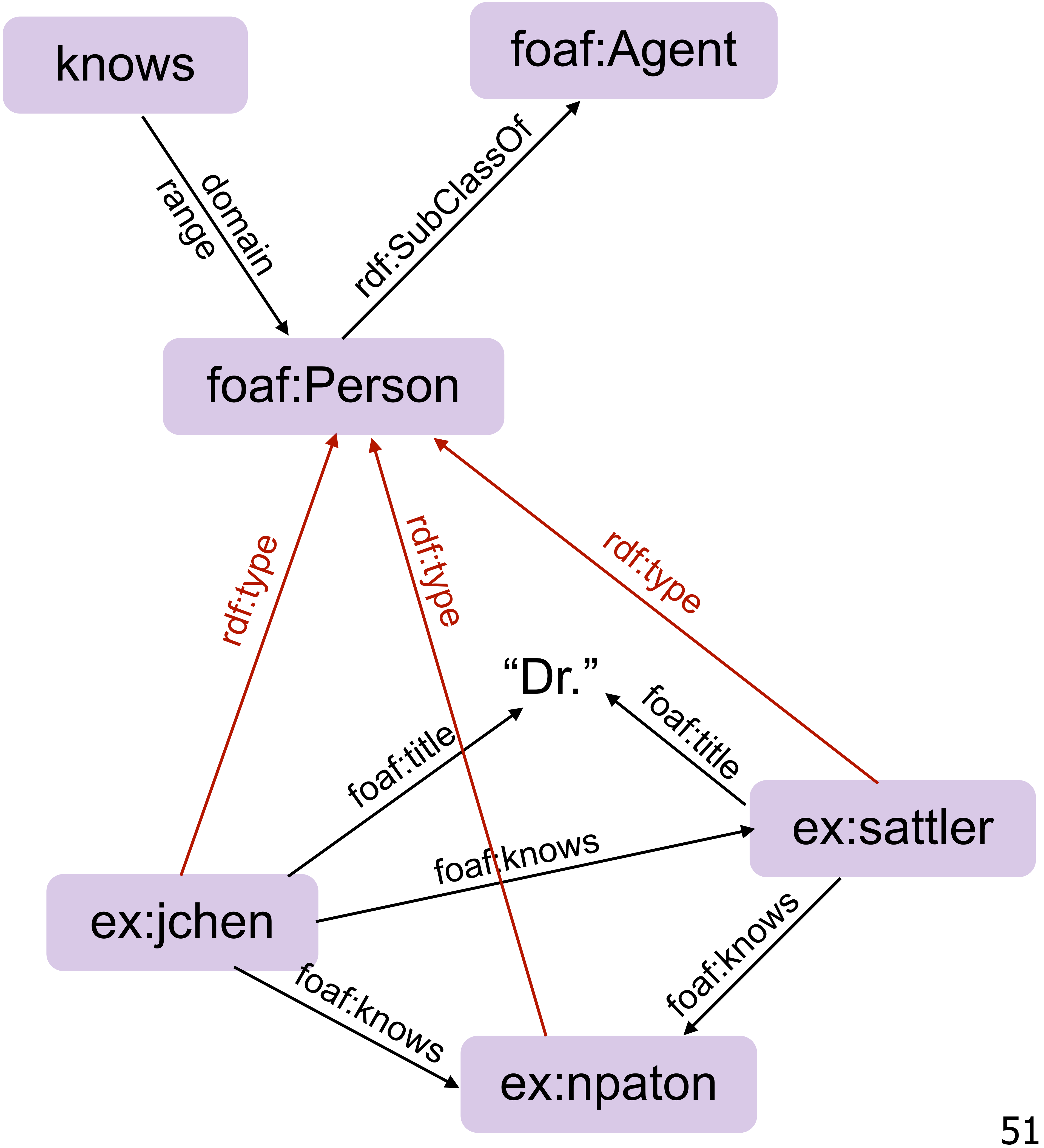
```
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ex:   <http://www.cs.man.ac.uk/> .

ex:sattler rdf:type foaf:Person.
ex:sattler rdf:type foaf:Agent.
ex:jiaoyanchen rdf:type foaf:Person.
ex:jiaoyanchen rdf:type foaf:Agent.
```

Reasoning: Default Values++

- RDFS does **not** *describe/constrain structure*
- RDFS allows us to provide *extra information*

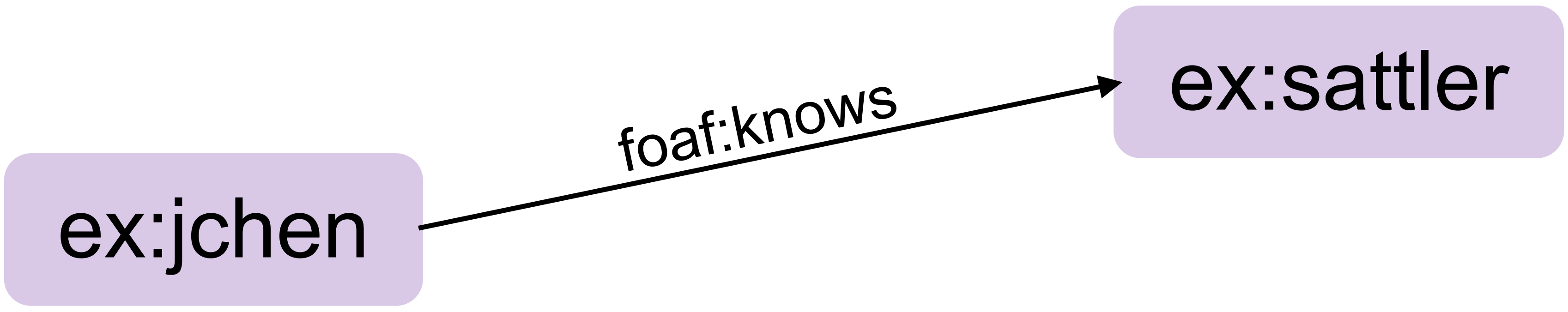
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
foaf:knows rdfs:domain foaf:Person.
foaf:knows rdfs:range foaf:Person.
foaf:Person rdfs:subClassOf foaf:Agent



What do schemas usually do again?

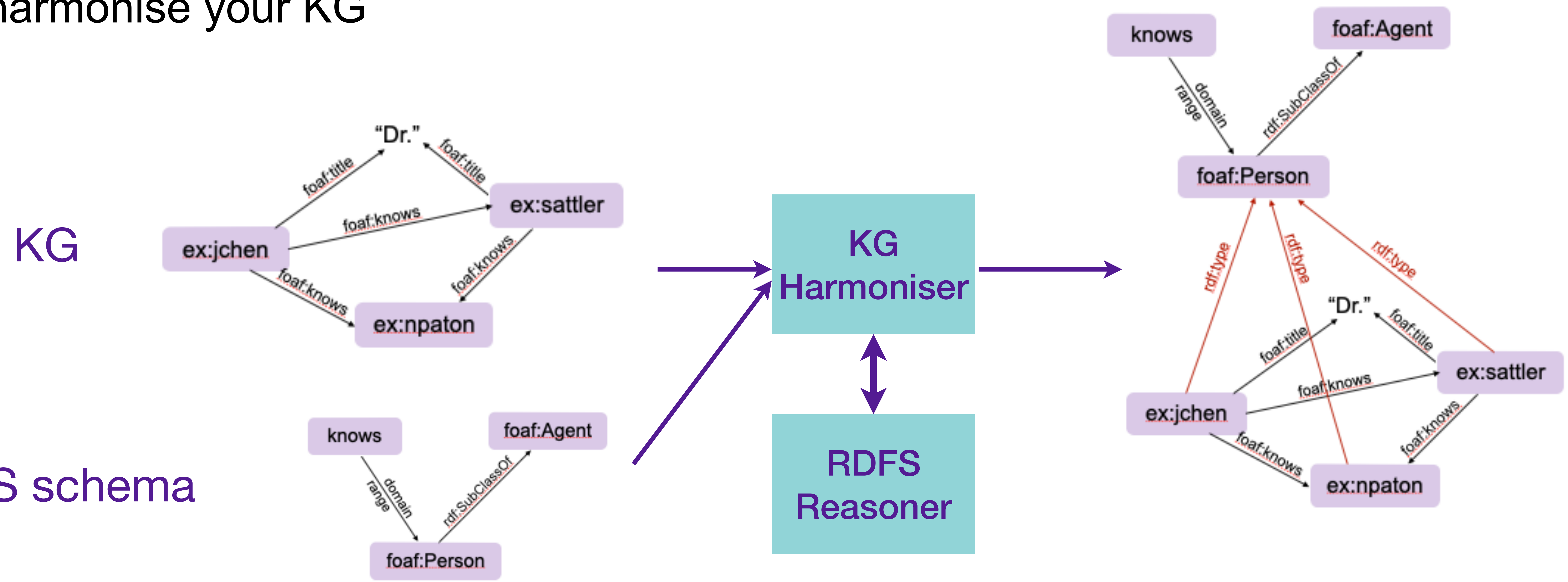
- In other schema languages, we usually **describe** ExtReps:
  - what’s allowed
  - what’s required
  - what’s assumed
    - default values
  - what’s expected
  - what’s forbidden (e.g., in Schematron)
- In RDFS, we can only state
  - what’s assumed/known, and thus
  - what can be inferred
    - here: ex:jchen rdf:type foaf:Person.
      ex:sattler rdf:type foaf:Person.

foaf:knows rdfs:domain foaf:Person.
foaf:knows rdfs:range foaf:Person



SPARQL, RDFS, and Reasoning

- Inferences can be *materialised*
  - add reasoning results to your KG
    - make background knowledge *explicit* in KG
    - harmonise your KG



SPARQL, RDFS, and Reasoning

- SPARQL queries are sensitive to RDF(S) inference
  - the way XPath is sensitive to default values!
  - also sensitive to more expressive language inferences
    - like OWL - tomorrow!
- Inference has a cost
  - results may be surprising
  - query answering may be (!) computationally expensive!

Solves all problems?

- No!
  - RDFS can’t express complex conceptual knowledge
    - see OWL tomorrow
  - we need to decide *which* additional information to make explicit in KG
    - too much: KG size may increase dramatically
    - too little: missing knowledge
- No validation!
  - this is a formalism specific quirk
  - there is SHACL

Day 1: SHACL

another schema language for RDF

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SHACL: another schema language for RDF

- in SHACL, we have *shapes*
  - to describe constraints on nodes and edges:
  - eg in our KG, each Person has to have a first name or a last name

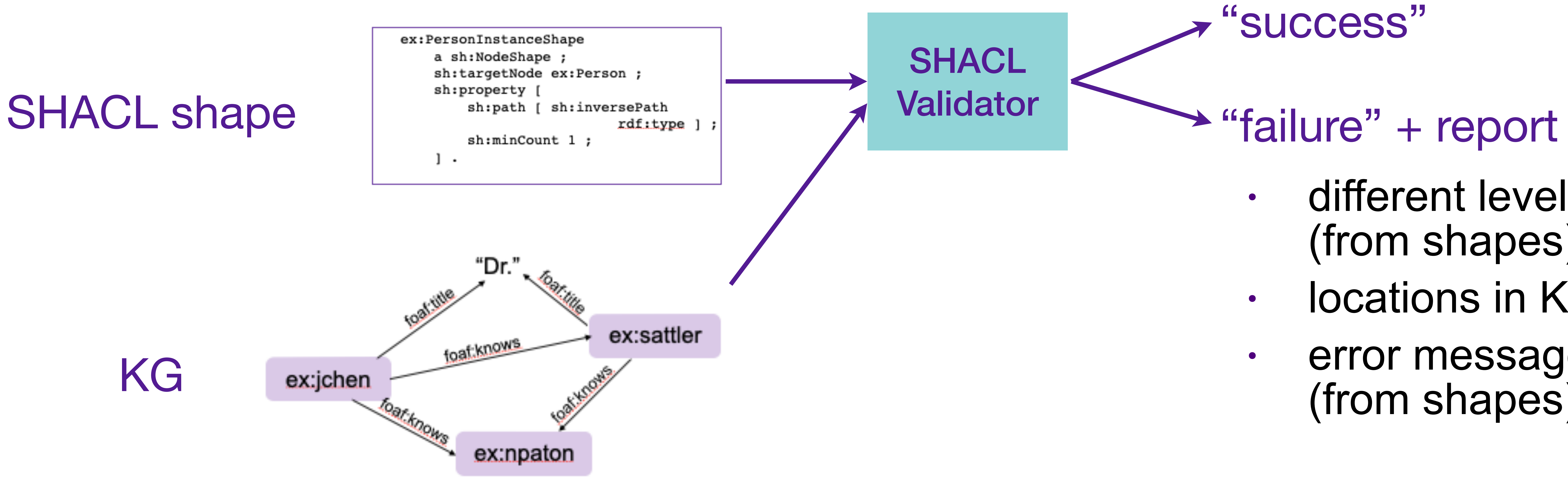
```
ex:PersonInstanceShape
    a sh:NodeShape ;
    sh:targetNode ex:Person ;
    sh:property [
        sh:path [ sh:alternativePath
                (foaf:firstName
                 foaf:lastName)] ;
        sh:minCount 1 ;
    ] .
```

- eg our KG must have at least 1 instance of Person

```
ex:PersonInstanceShape
    a sh:NodeShape ;
    sh:targetNode ex:Person ;
    sh:property [
        sh:path [ sh:inversePath
                          rdf:type ] ;
        sh:minCount 1 ;
    ] .
```

SHACL: validation

- given a KG and shapes, we can ask a *validator* to test whether KG satisfies constraints in shapes:



- different levels of severity (from shapes)
- locations in KG
- error messages (from shapes)

Day 1: RDFS & SHACL

an interesting relation

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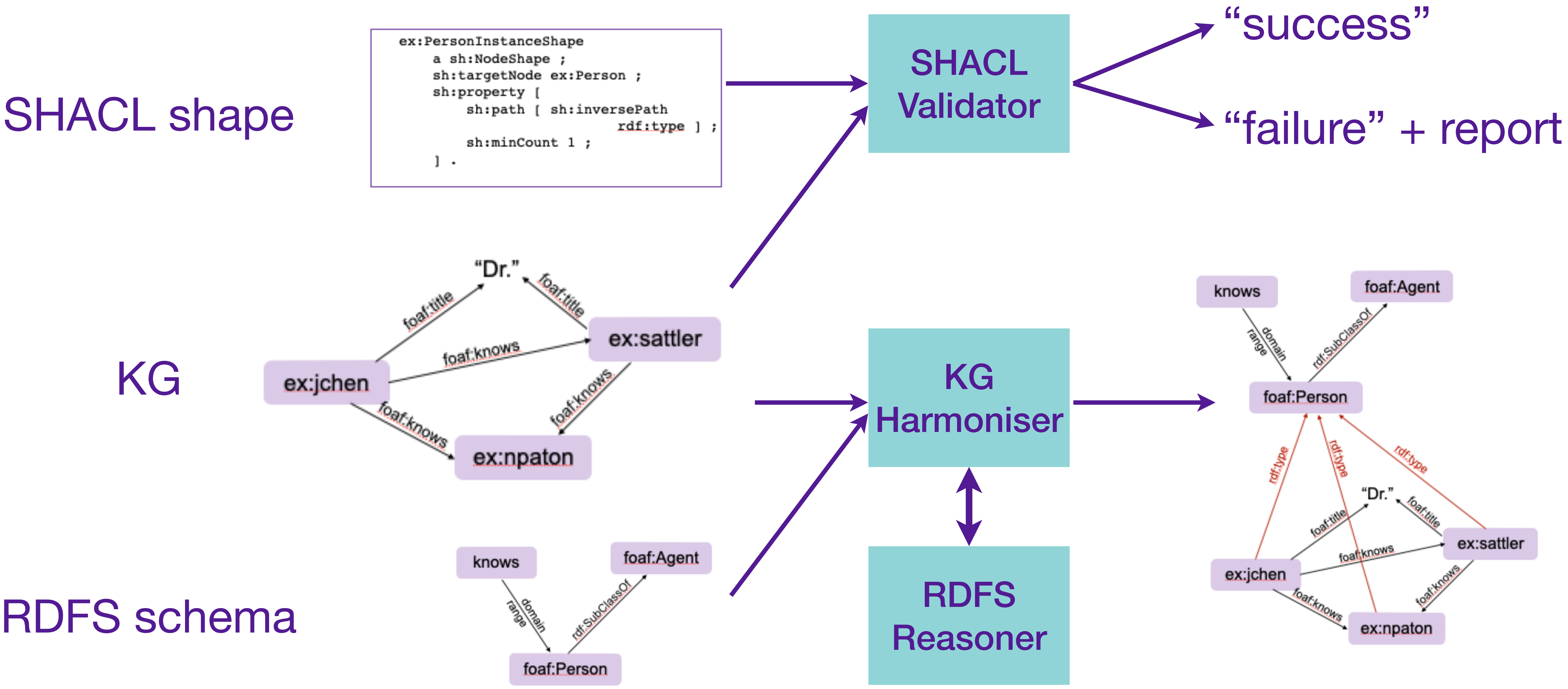
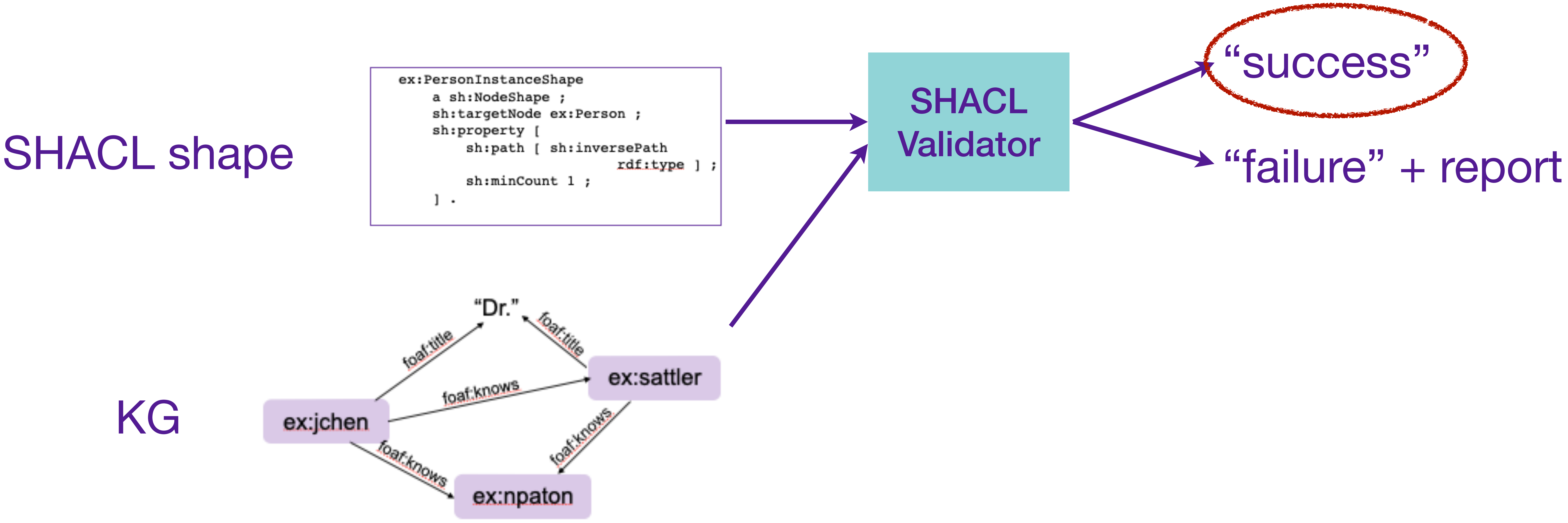
Validation and Reasoning…

- can affect each other:



Validation and Reasoning…

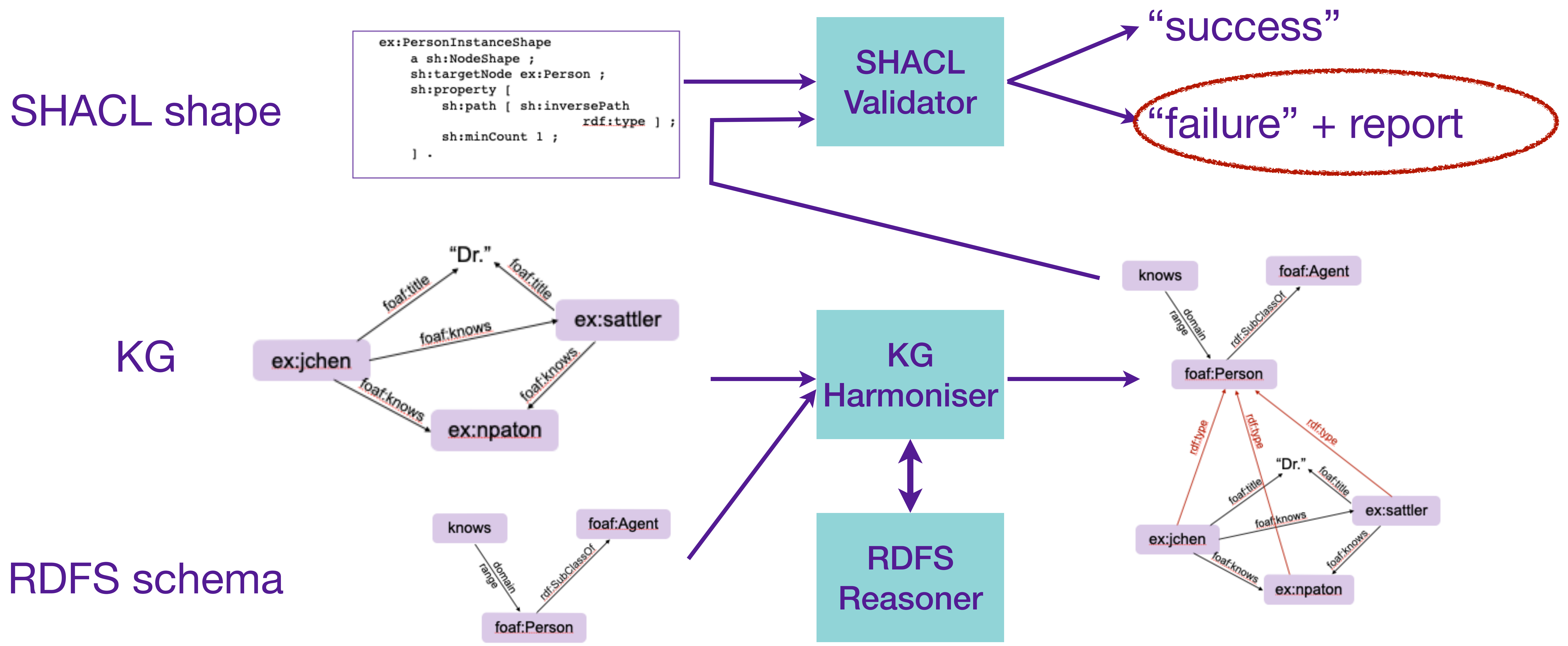
- can affect each other: it may be that



Validation and Reasoning…

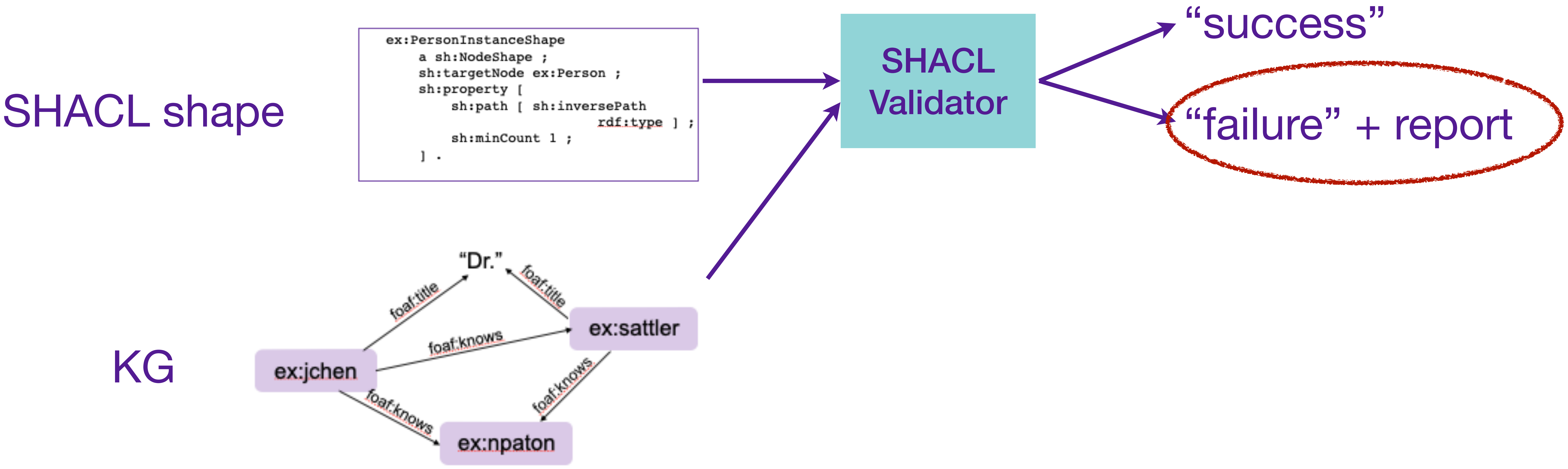
“each Person must have a name”

- can affect each other: it may be that but



Validation and Reasoning…

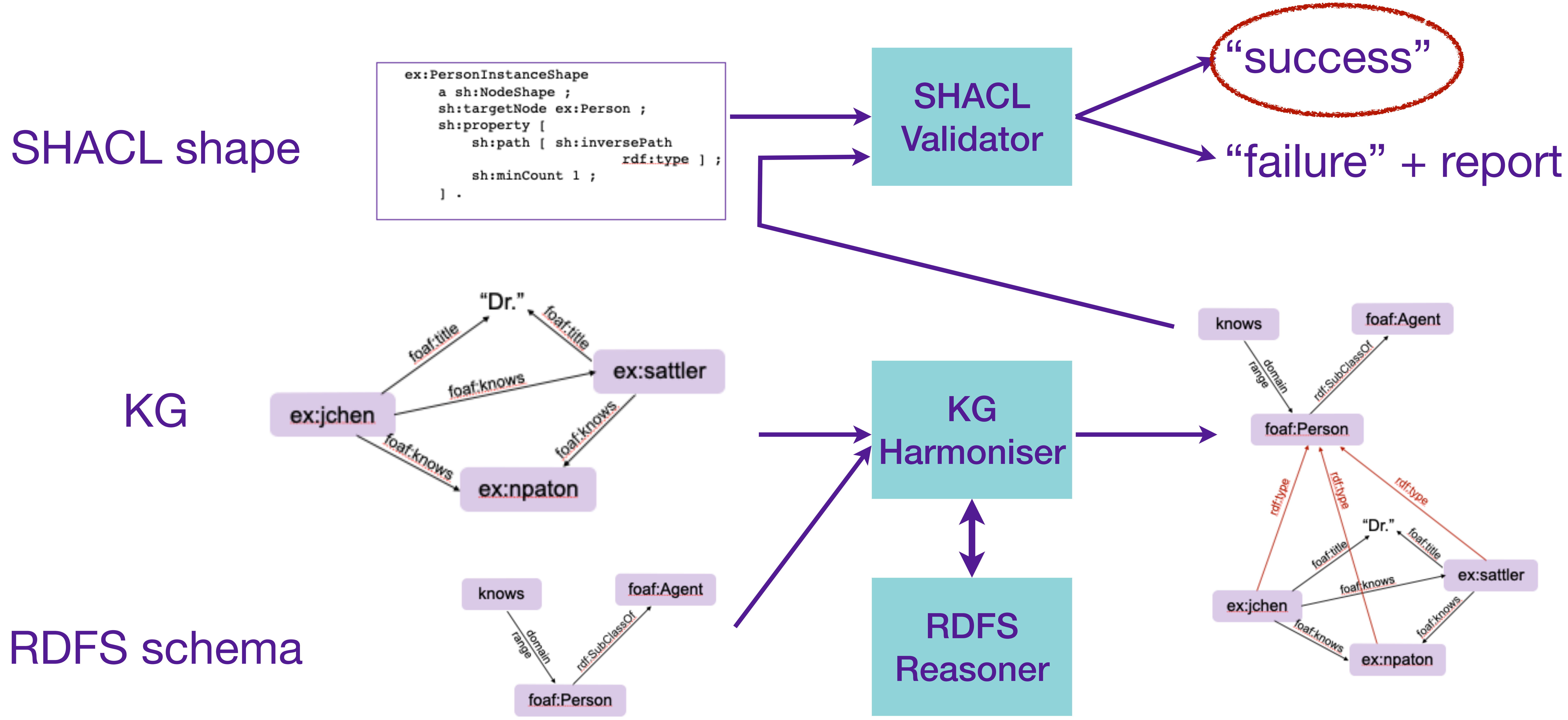
- can affect each other: it may also be that



Validation and Reasoning…

"our KG must have at least 1 instance of Person"

- can affect each other: it may be that but



Summary of today

- KGs can contain *factual* and *conceptual knowledge*
  - eg in RDF and RDFS
- *Reasoning* makes *implicit* knowledge *explicit*
- *Materialisation* of reasoning results can
  - *harmonise* a factual knowledge graph
  - prevent us from validating *invalid* documents
  - ensure that *implicitly* valid documents are validated

Any questions?

The End of Today’s session

Tomorrow: more on reasoning & OWL

Polyglott persistence

- How can we **vary?**
  - Same core data model, same implementation
    - but different domain models
  - Same core data model, same domain model
    - different implementations, e.g., SQLite vs. MySQL
  - Same shape of core data model, same conceptual model
    - different formalisms!
      - Usually, but not always, implies different implementations
      - e.g. JSON and XML
- We can be **explicitly** or **implicitly** poly-
  - If we **encode** another data model into our home model
    - We are still poly-
    - But only implicitly so
    - Key Cost: Ad hoc implementation
  - If we split our domain model across multiple formalisms/implementations

Key point

- Understand your **domain**
  - What are you trying to represent and manipulate
- Understand your use case
  - including (frequent, relevant) queries, error sources,…
- Understand the **fit** between domain and data model(s)
  - To see where there are sufficiently good fits
- Understand your infrastructure

Question 1

Consider again the Conceptual Model you started to work on last week: can you

- finish/improve/extend it?
- add adjectives?
- add examples?

- – format
- – formalism
- – core data model
- – data model
- – database
- – external repr.
- – …

- – domain model
- – schema
- – schema language
- – application
- – system
- – internal repr.
- – …

- – robust
- – extensible
- – scalable
- – self-describing
- – valid
- – expressive
- – verbose
- – …

Question 2

Consider a format for a reporting system for health & safety incidents, as exemplified by the printed example document:

- sketch a system for
  - gathering this data
  - reporting it monthly
- which kind of schema(s) would you use to describe it?
  - why?
- does this format make good use of XML's

Title Text

Good Bye!

- We hope you have learned a lot!
- It was a pleasure to work with you!
- Speak to us about projects
  - taster/MRes
  - MSc
- Enjoy the rest of your programme
  - COMP62421 query processing
  - COMP62342 rich modelling, inference
    semantic web, symbolic AI