From Data to Knowledge through Grailog Visualization

(Long version: http://www.cs.unb.ca/~boley/talks/RuleMLGrailog.pdf)

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(the long version has all parts, hence gapless slide numbers):

Grailog 1.0: Graph-Logic Visualization of Ontologies and Rules
The 7th International Web Rule Symposium (RuleML 2013),
University of Washington, Seattle WA, 11-13 July 2013

The Grailog Systematics for Visual-Logic Knowledge Representation with Generalized Graphs
Faculty of Computer Science Seminar Series, University of New Brunswick, Fredericton, Canada, 26 September 2012
High Performance Computing Center Stuttgart (HLRS), Stuttgart, Germany, 14 August 2012

Grailog: Mapping Generalized Graphs to Computational Logic
Symposium on Natural/Unconventional Computing and its Philosophical Significance,
AISB/IACAP World Congress - Alan Turing 2012, 2-6 July 2012, Birmingham, UK

The Grailog User Interface for Knowledge Bases of Ontologies & Rules
OMG Technical Meeting, Ontology PSIG, Cambridge, MA, 21 June 2012

Grailog: Knowledge Representation with Extended Graphs for Extended Logics
SAP Enterprise Semantics Forum, 24 April 2012

Grailog: Towards a Knowledge Visualization Standard
BMIR Research Colloquium, Stanford, CA, 4 April 2012
PARC Research Talk, Palo Alto, CA, 29 March 2012

RuleML/Grailog: The Rule Metalogic Visualized with Generalized Graphs
PhiloWeb 2011, Thessaloniki, Greece, 5 October 2011

Grailog: Graph inscribed logic
Course about Logical Foundations of Cognitive Science, TU Vienna, Austria, 20 October -10 December 2008

Visualization of Data

- *Useful* in many areas, *needed* for big data
- Gain **knowledge insights** from **data analytics**, ideally with the entire pipeline visualized
- Statistical visualization → Logical visualization

Sample data visualization (http://wordle.net): Word cloud for frequency of words from BMIR abstract of this talk

Visualization of Data & Knowledge: Graphs Remove Entry Barrier to Logic

- From 1-dimensional *symbol-logic* knowledge **specification** to 2-dimensional *graph-logic* **visualization** in a systematic 2D syntax
  - Supports human in the loop across knowledge **elicitation**, **specification**, **validation**, and **reasoning**
- Combinable with graph transformation, (‘associative’) indexing & parallel processing for efficient **implementation** of specifications
- Move towards model-theoretic **semantics**
  - Unique names, as graph nodes, mapped directly/ injectively to elements of semantic interpretation

Grailog

Graph **i**nscribed **log**ic provides intuition for logic

Advanced cognitively motivated systematic graph standard for visual-logic data & knowledge:

Features orthogonal → easy to learn, e.g. for (Business) Analytics

Generalized-graph framework as one uniform 2D syntax for major (Semantic Web) logics:

Pick subset for each targeted knowledge base, map to/fro RuleML sublanguage, and exchange & validate it, posing queries again in Grailog

Generalized Graphs to Represent and Map Logic Languages According to Grailog 1.0 Systematics

- We have used generalized graphs for representing various logic languages, where basically:
  - Graph nodes (vertices) represent individuals, classes, etc.
  - Graph arcs (edges) represent relationships
- *Next slides:*
  What are the *principles* of this representation and what graph generalizations are required?
- *Later slides:*
  How are these graphs *mapped* (invertibly) to logic, thus specifying Grailog as a ‘GUI’ for knowledge?
- *Final slides:*
  What is the *systematics* of Grailog features?

Grailog Principles

- Graphs should make it easier for humans to read and write logic constructs via 2D state-of-the-art representation with shorthand & normal forms, from Controlled English to logic
- Graphs should be *natural extensions* (e.g. n-ary) of Directed Labeled Graphs (DLGs), often used to represent simple semantic nets, i.e. of atomic ground formulas in function-free dyadic predicate logic (cf. binary Datalog ground facts, RDF triples, the Open Graph, and the Knowledge Graph)
- Graphs should allow *stepwise refinements* for all logic constructs: Description Logic constructors, F-logic frames, general PSOA RuleML terms, etc.
- Extensions to boxes & links should be *orthogonal*

Grailog Generalizations

- **Directed hypergraphs:** For n-ary relationships, directed relation-labeled (binary) arcs will be generalized to directed relation-labeled (n-ary) *hyperarcs*, e.g. representing relational-database tuples
- **Recursive (hierarchical) graphs:** For nested terms and formulas, modal logics, and modularization, ‘flat’ graphs will be generalized to allow other graphs as *complex nodes* to any level of ‘depth’
- **Labelnode graphs:** For allowing higher-order logics describing both instances and relations (predicates), arc *labels* will also become usable as *nodes*

Graphical Elements: Names

- Written **into** boxes (nodes):
  Unique (canonical, distinct) names

  unique

  – Unique Name Assumption (UNA)
  refined to Unique Name Specification (UNS)

- Written **onto** boxes (node labels):
  Non-unique (alternate, ‘aka’) names

  non-unique

  – Non-unique Name Assumption (NNA)
  refined to Non-unique Name Specification (NNS)

- Grailog combines UNS and NNS: xNS, with x = U or N

Instances: Individual Constants with Unique Name Specifications

General:	Graph (node)	$\xrightarrow{\text{mapping}}$	Logic
	$\boxed{\textit{unique}}$		*unique*
Examples:	Graph		Logic
	$\boxed{\text{Warren Buffett}}$		Warren Buffett
	$\boxed{\text{General Electric}}$		General Electric
	$\boxed{\text{US\\$ 3 000 000 000}}$		US$ 3 000 000 000

Instances: Individual Constants with Non-unique Name Specifications

General: Graph (node) $\xrightarrow{\text{mapping}}$ Logic (vertical bar for non-uniqueness)

non-unique

|*non-unique*

Examples: Graph Logic

WB

|WB

GE

|GE

US$ 3B

|US$ 3B

Graphical Elements: Hatching Patterns

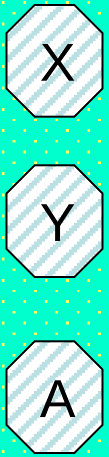
- No hatching (boxes): Constant
- Hatching (elementary boxes): Variable

Parameters: Individual Variables

General: Graph (*hatched* node) Logic (*italics* font, POSL uses "?" prefix)

variable

Examples: Graph Logic



X

Y

A

Predicates: Binary Relations (1)

General: Graph (*labeled* arc) Logic

$\boxed{inst_1} \xrightarrow{\textbf{binrel}} \boxed{inst_2}$

$binrel(inst_1, inst_2)$

Example: Graph Logic

$\boxed{\text{Warren Buffett}} \xrightarrow{\text{Trust}} \boxed{\text{General Electric}}$

Trust(Warren Buffett,
General Electric
)

Predicates: Binary Relations (2)

General: Graph (*labeled* arc) Logic

$binrel(var_1, var_2)$

Example: Graph Logic

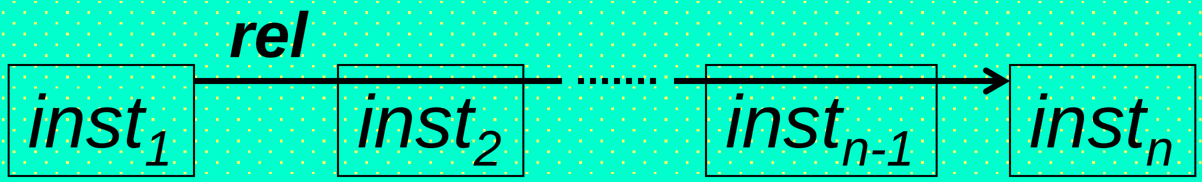
Trust(X,Y)

Graphical Elements: Arrows (1)

- Labeled arrows (directed links) for arcs and hyperarcs (where hyperarcs ‘cut through’ nodes intermediate between first and last)

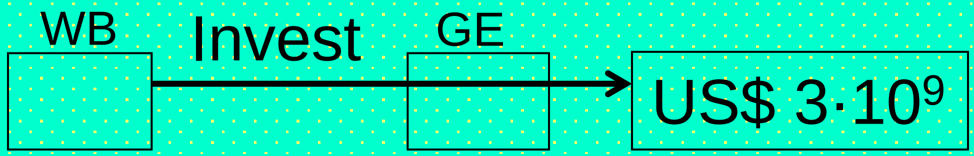
Predicates: n-ary Relations (n>1)

General: Graph (*hyper*arc) Logic



$rel(inst_1, inst_2, \ldots, inst_{n-1}, inst_n)$

Example: (n=3) Graph Logic



Invest(|WB,
|GE,
US$ $3 \cdot 10^9$)

Implicit Conjunction of Formula Graphs: Co-Occurrence on Graph Top-Level

General: Graph (*m* hyperarcs) Logic

$inst_{1,1}$ $\mathbf{rel_1}$ $inst_{1,2}$ .... $inst_{1,n^1}$

...

$inst_{m,1}$ $\mathbf{rel_m}$ $inst_{m,2}$ .... $inst_{m,n^m}$

$rel_1(inst_{1,1}, inst_{1,2}, \ldots, inst_{1,n^1}) \wedge$

$\ldots \wedge$

$rel_m(inst_{m,1}, inst_{m,2}, \ldots, inst_{m,n^m})$

Example: Graph (2 hyperarcs) Logic

WB Invest GE US$ $3 \cdot 10^9$

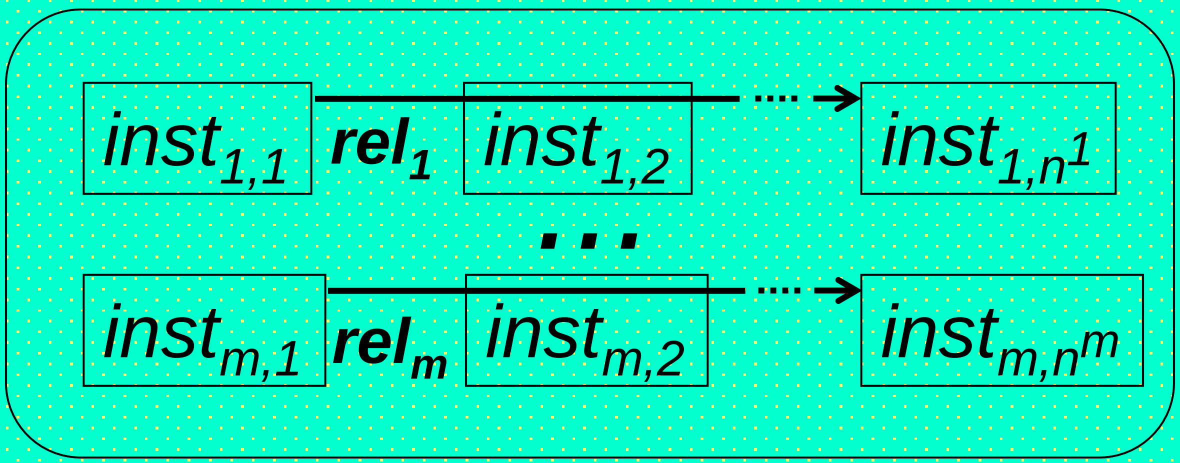
JS Invest VW US$ $2 \cdot 10^4$

Invest(|WB, |GE, US$ $3 \cdot 10^9$) $\wedge$

Invest(|JS, |VW, US$ $2 \cdot 10^4$)

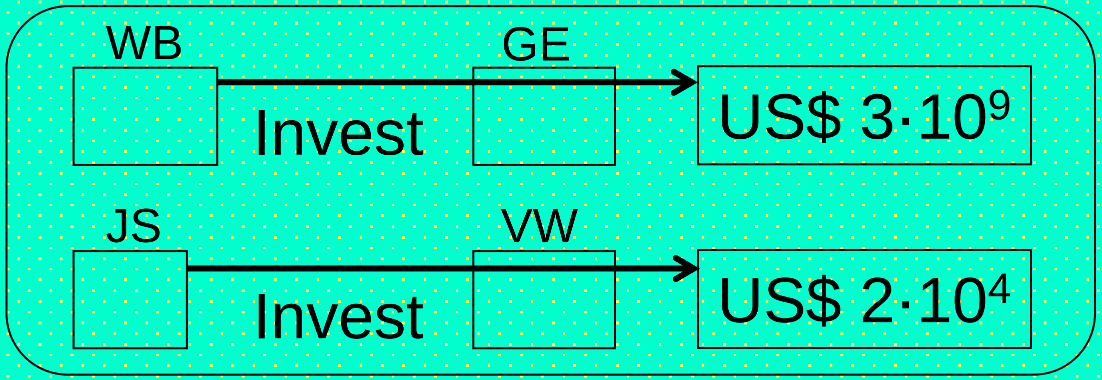
Explicit Conjunction of Formula Graphs: Co-Occurrence in (parallel-processing) And Node

General: Graph (*solid*+*linear*) Logic



$(rel_1(inst_{1,1}, inst_{1,2}, \ldots, inst_{1,n^1}) \wedge \ldots \wedge rel_m(inst_{m,1}, inst_{m,2}, \ldots, inst_{m,n^m}))$

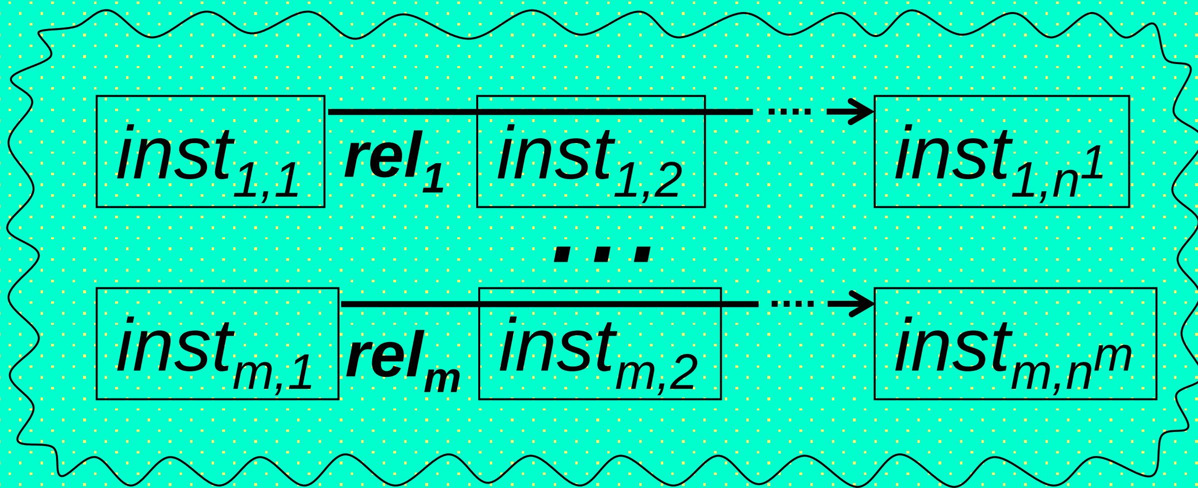
Example: Graph Logic



(Invest(|WB, |GE, US$ $3 \cdot 10^9$) $\wedge$ Invest(|JS, |VW, US$ $2 \cdot 10^4$))

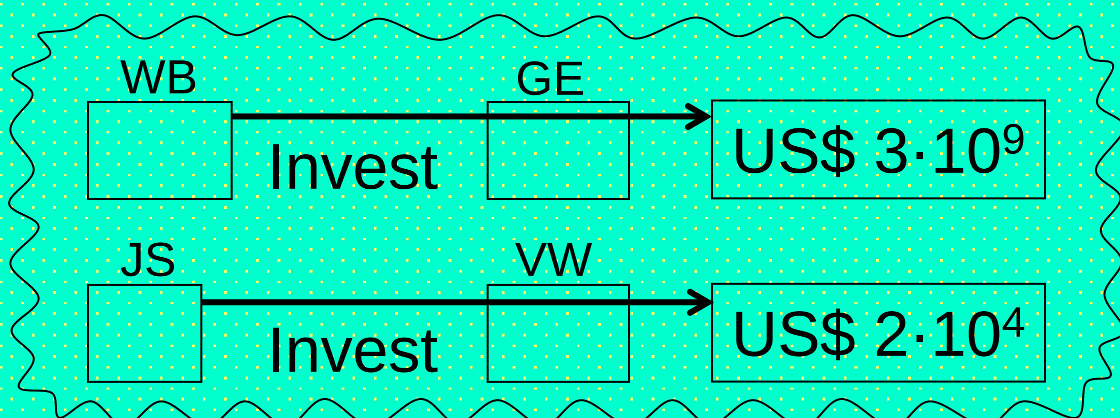
Disjunction of Formula Graphs: Co-Occurrence in Or Node

General: Graph (*solid*+*wavy*) Logic



$(rel_1(inst_{1,1}, inst_{1,2}, \ldots, inst_{1,n^1}) \vee \ldots \vee rel_m(inst_{m,1}, inst_{m,2}, \ldots, inst_{m,n^m}))$

Example: Graph Logic

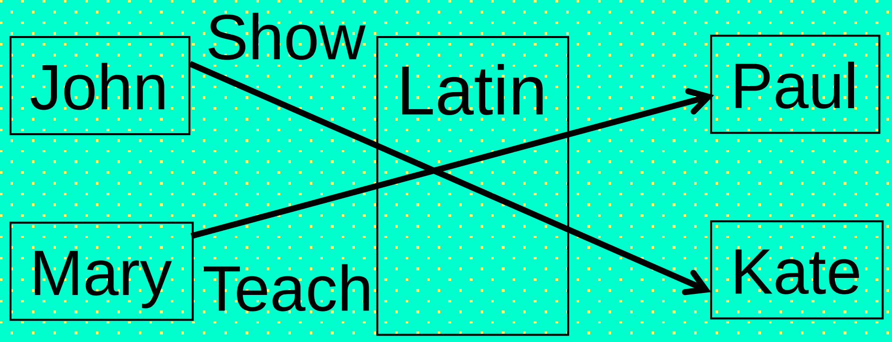


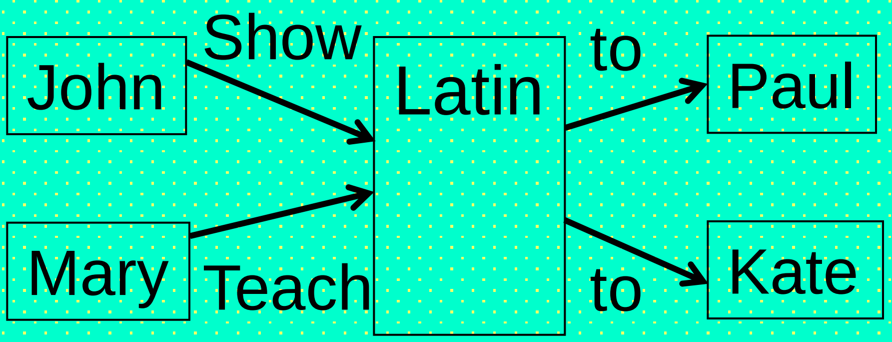
(Invest(|WB, |GE, US$ $3 \cdot 10^9$) $\vee$ Invest(|JS, |VW, US$ $2 \cdot 10^4$))

From Hyperarc Crossings to Node Copies as a Normalization Sequence (1)

Hypergraph (2 hyperarcs, crossing inside a node)

DLG (4 arcs, do <u>not</u> specify to whom Latin is shown or taught)





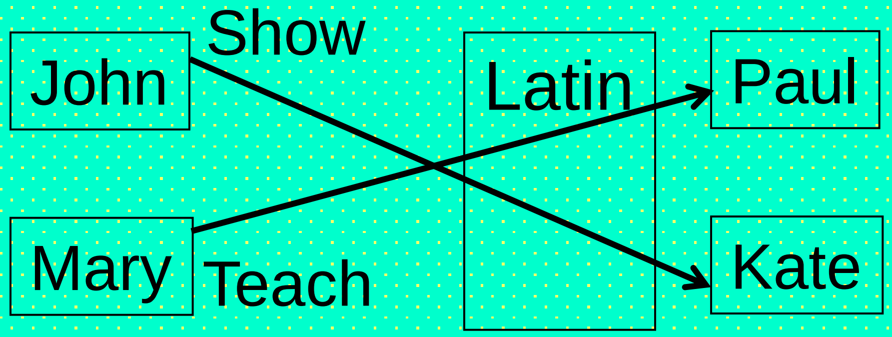
Symbolic Controlled English

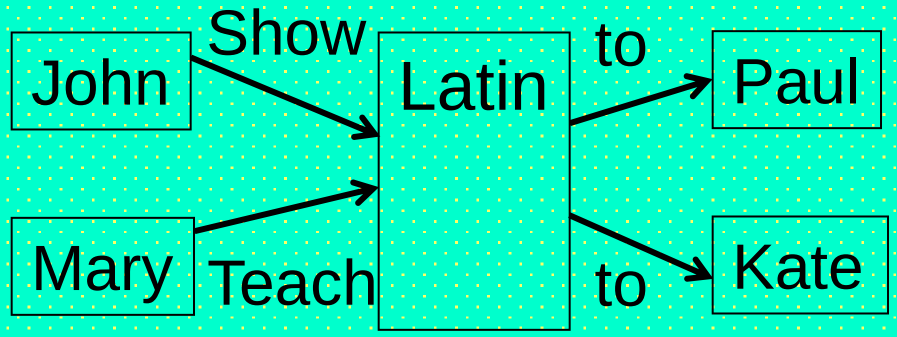
"John shows Latin to Kate.
Mary teaches Latin to Paul."

From Hyperarc Crossings to Node Copies as a Normalization Sequence (1*)

Hypergraph (2 hyperarcs, crossing outside nodes)

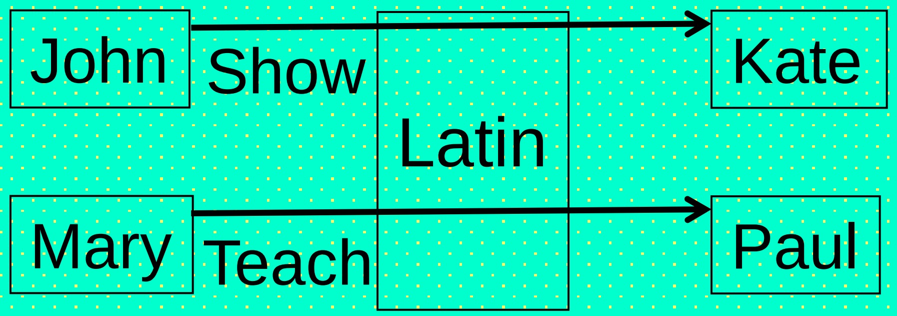
DLG (4 arcs, do <u>not</u> specify to whom Latin is shown or taught)



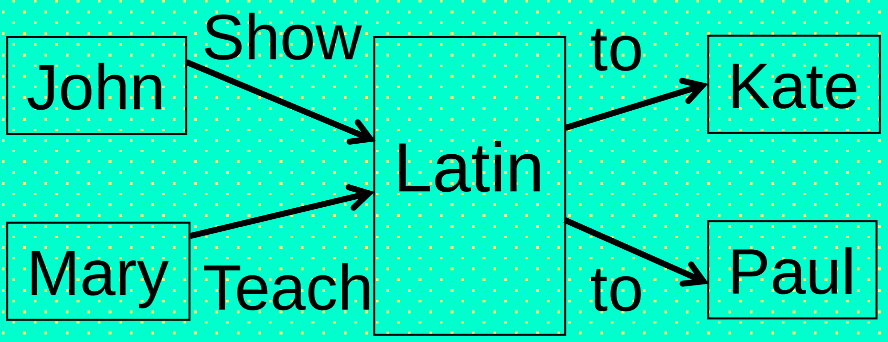


From Hyperarc Crossings to Node Copies as a Normalization Sequence (1**)

Hypergraph (2 hyperarcs, parallel-cutting a node)



DLG (4 arcs, do <u>not</u> specify to whom Latin is shown or taught)

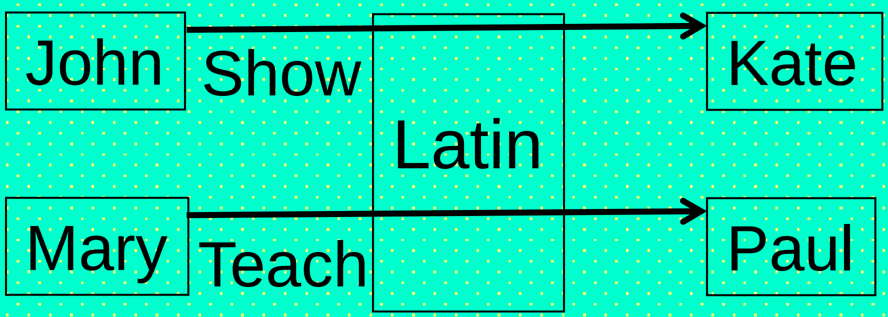


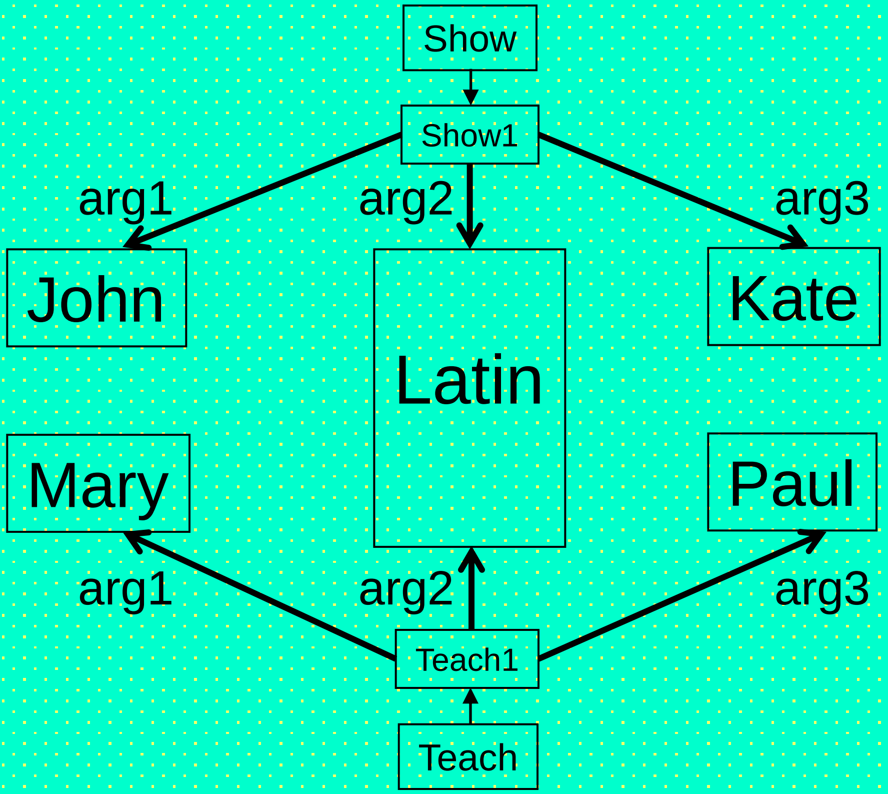
The hyperarc for, e.g., ternary Show(John,Latin,Kate) can be seen as the path composition of 2 arcs for binary Show(John,Latin) and binary to(Latin,Kate)

From Hyperarc Crossings to Node Copies — Insert on Correct Binary Reduction

Hypergraph (2 hyperarcs, parallel-cutting a node)

DLG (8 arcs with 4 'reified' relation/ship nodes to point to arguments)

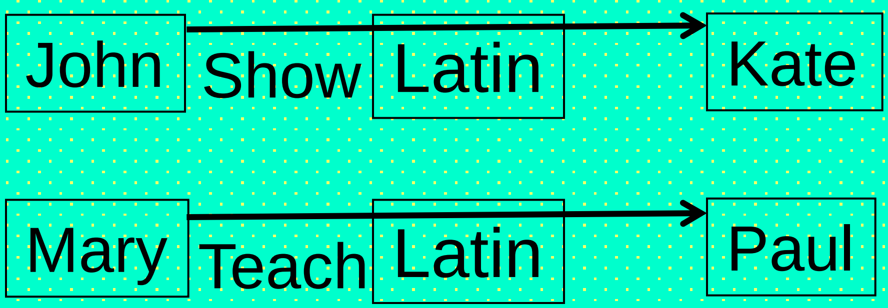




From Hyperarc Crossings to Node Copies as a Normalization Sequence (1***)

Hypergraph (2 hyperarcs, employing a node copy)

Logic (2 relations, employing a symbol copy)



Show(John, Latin, Kate)

$\wedge$

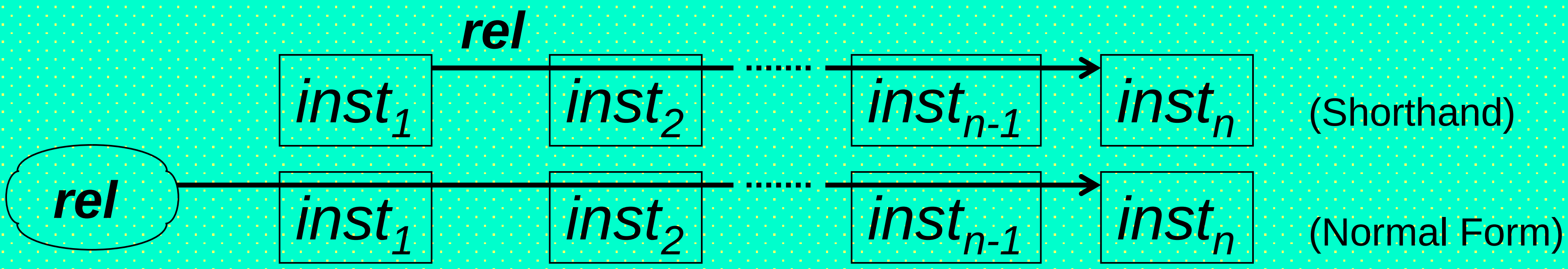
Teach(Mary, Latin, Paul)

*Both '*Latin*' occurrences remain one node even when copied for easier layout: Having a unique name, '*Latin*' copies can be merged again*

From Predicate Labels on Hyperarcs to Labelnodes Starting Hyperarcs

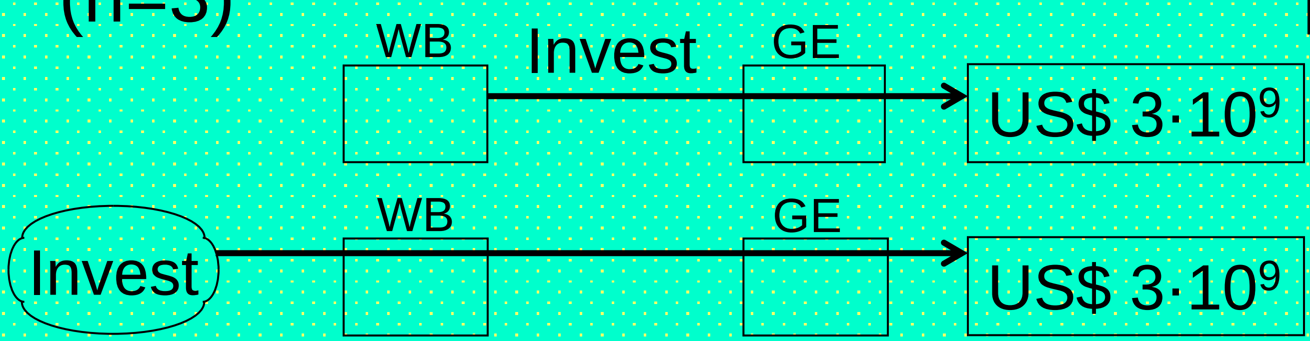
General: Graph (*hyper*arc with *rect4vex*-shaped labelnode)

Logic: *rel*($inst_1$, $inst_2$, ..., $inst_{n-1}$, $inst_n$)



Example: (n=3) Graph

Logic: Invest(|WB, |GE, US\$ $3{\cdot}10^9$)

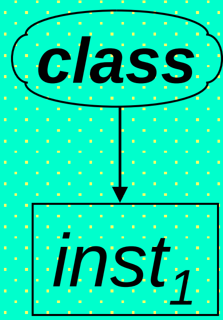


Predicates: Unary Relations (Classes, Concepts, Types)

General: Graph (class applied to instance node)

Logic

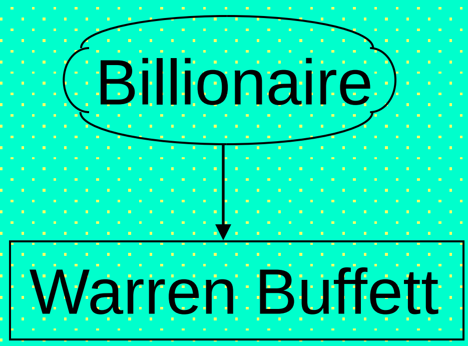
HasInstance



class($inst_1$)

Example: Graph

Logic



Billionaire(
Warren Buffett)

Graphical Elements: Arrows (2)

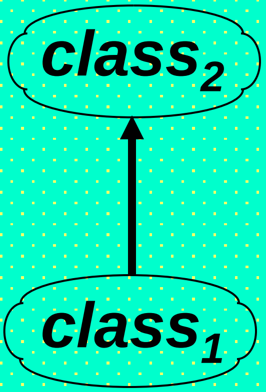
- Arrows for special arcs and hyperarcs
  - $\downarrow$ HasInstance: Connects class, as labelnode, with instance (hyperarc of length 1)
    - As in [DRLHs]() and shown earlier, labelnodes can also be used (instead of labels) for hyperarcs of length > 1
  - $\uparrow$ SubClassOf: Connects subclass, unlabeled, with superclass (arc, i.e. of length 2)
  - $\Uparrow$ Implies: Hyperarc from premise(s) to conclusion
  - Object-IDentified slots and shelves: Bulleted arcs and hyperarcs

Class Hierarchies (Taxonomies): Subclass Relation

General: Graph (two nodes)

(Description) Logic

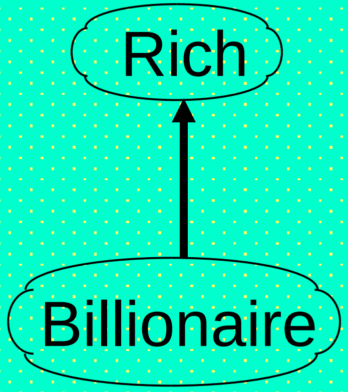
SubClassOf



$$class_1 \sqsubseteq class_2$$

Example: Graph

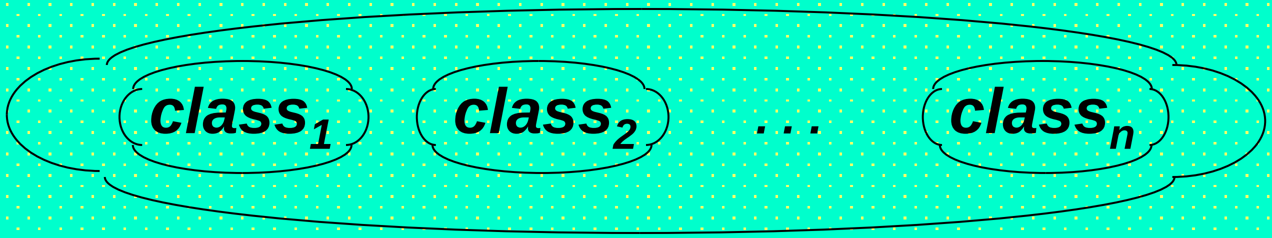
(Description) Logic



$$\text{Billionaire} \sqsubseteq \text{Rich}$$

Intensional-Class Constructions (Ontologies): Class Intersection

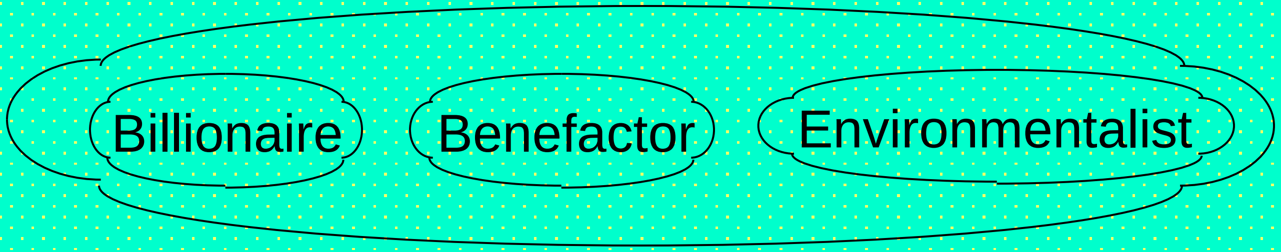
General: Graph (*solid*+*linear* node, as for conjunction)



(Description) Logic

$class_1 \sqcap$
$class_2 \sqcap$
$\dots \sqcap$
$class_n$

Example: Graph

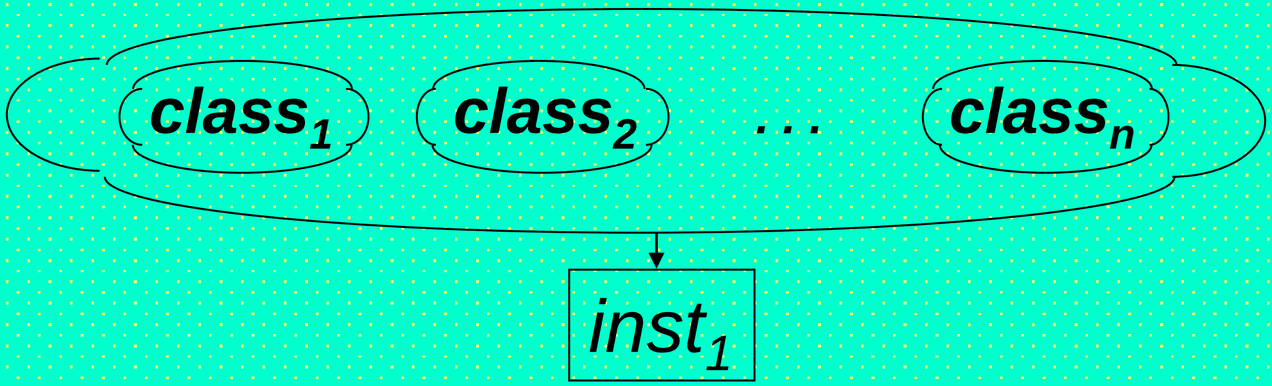


(Description) Logic

Billionaire $\sqcap$
Benefactor $\sqcap$
Environmentalist

Intensional-Class Applications: Class Intersection

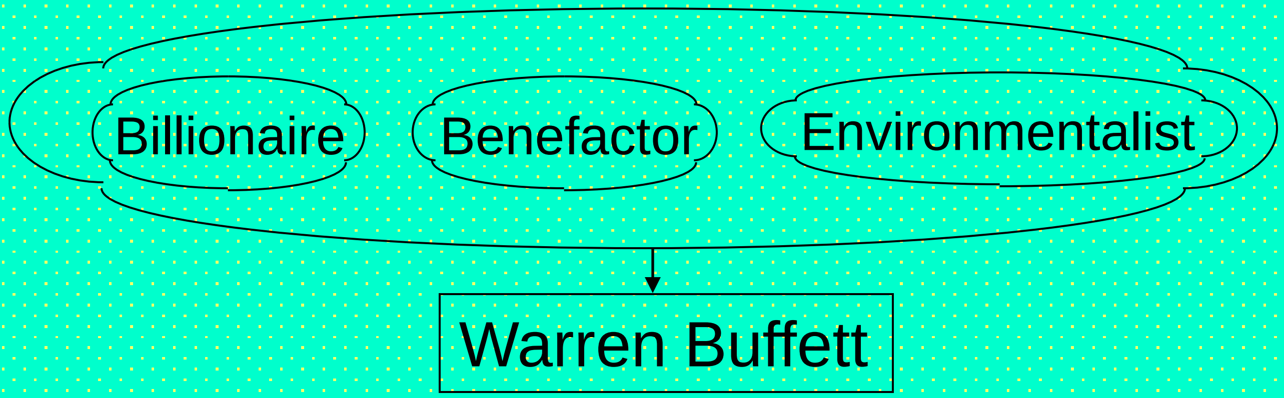
General: Graph (*complex* class applied to instance node)



(xNS-Description) Logic

$(class_1 \sqcap class_2 \sqcap \ldots \sqcap class_n)(inst_1)$

Example: Graph

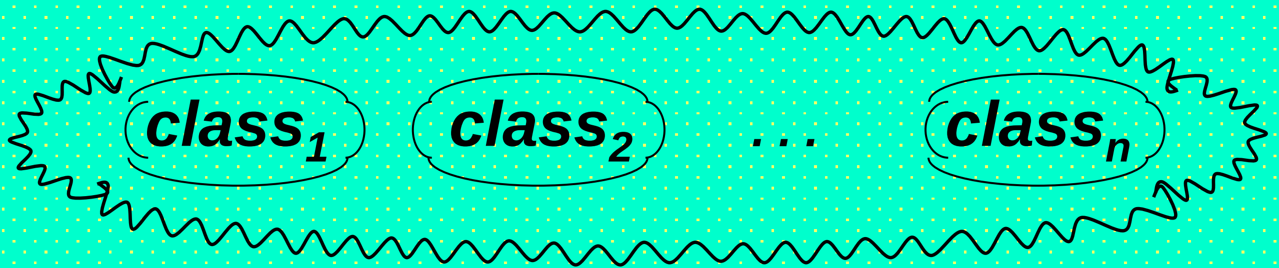


(xNS-Description) Logic

(Billionaire ⊓ Benefactor ⊓ Environmentalist)(Warren Buffett)

Intensional-Class Constructions (Ontologies): Class Union

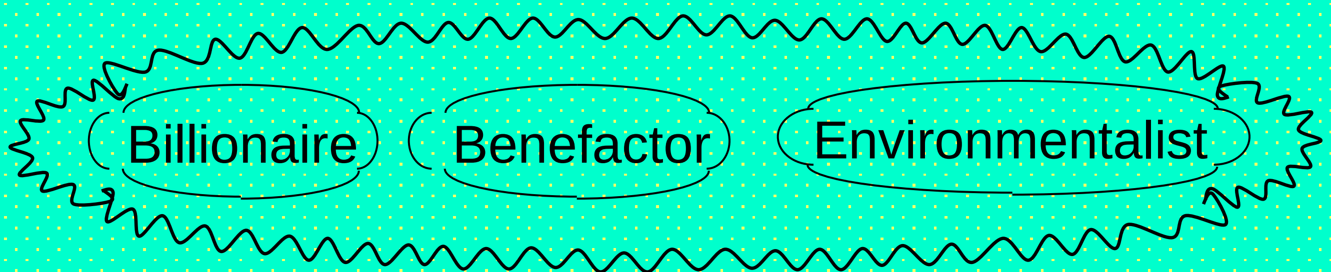
General: Graph (*solid*+*wavy* node, as for disjunction)



(Description) Logic

$$\mathit{class}_1 \sqcup \mathit{class}_2 \sqcup \ldots \sqcup \mathit{class}_n$$

Example: Graph

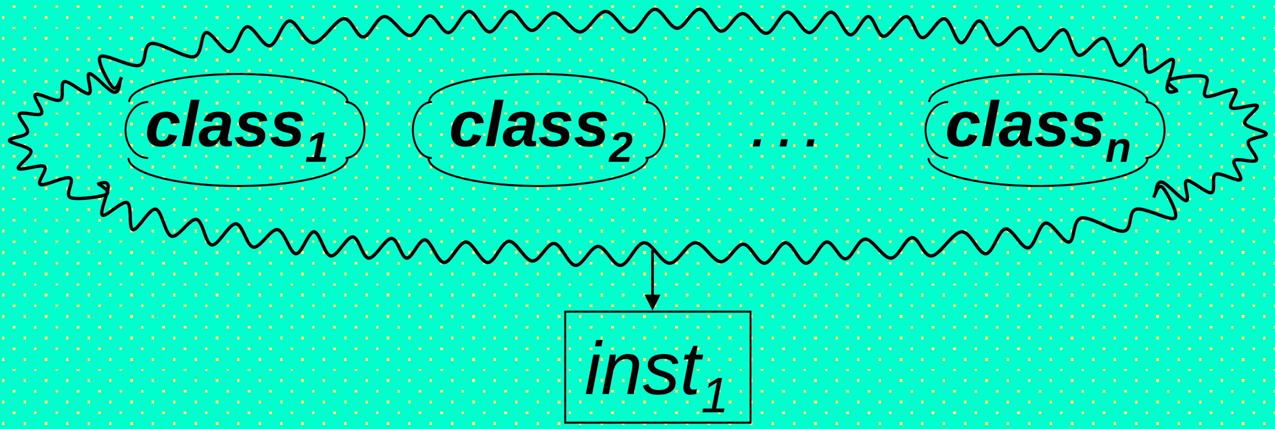


(Description) Logic

Billionaire ⊔ Benefactor ⊔ Environmentalist

Intensional-Class Applications: Class Union

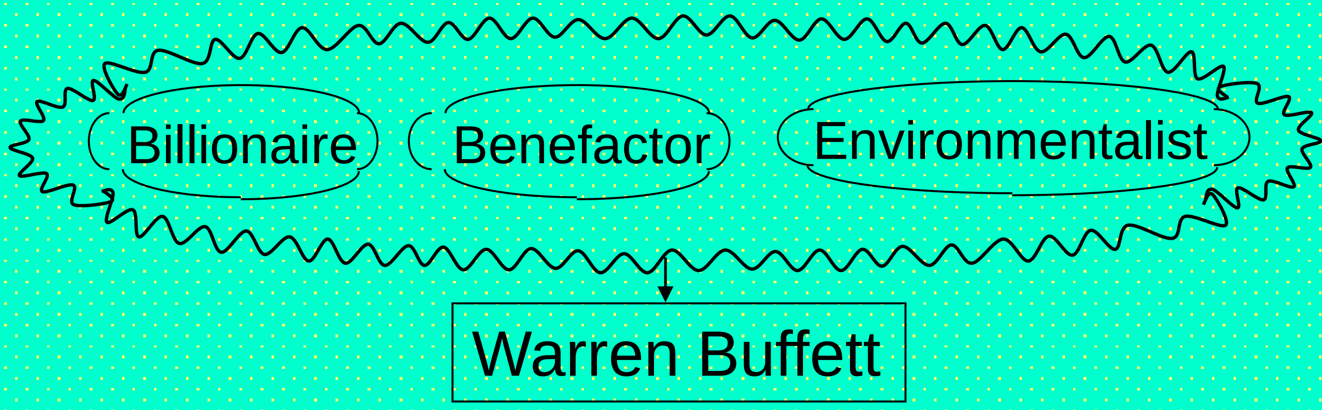
General: Graph (*complex* class applied to instance node)



(xNS-Description) Logic

$(class_1 \sqcup class_2 \sqcup \ldots \sqcup class_n)(inst_1)$

Example: Graph



(xNS-Description) Logic

(Billionaire $\sqcup$ Benefactor $\sqcup$ Environmentalist) (Warren Buffett)

Class Hierarchies (Taxonomy DAGs): Top and Bottom

General: Top (*special* node)

$\top$

(Description) Logic

$\top$

(owl:Thing)

General: Bottom (*special* node)

$\bot$

(Description) Logic

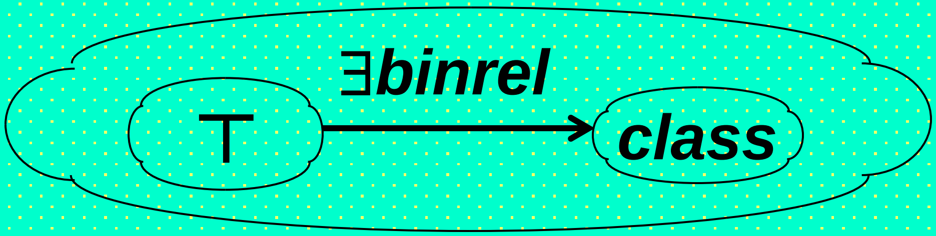
$\bot$

(owl:Nothing)

Intensional Class Constructions (Ontologies):

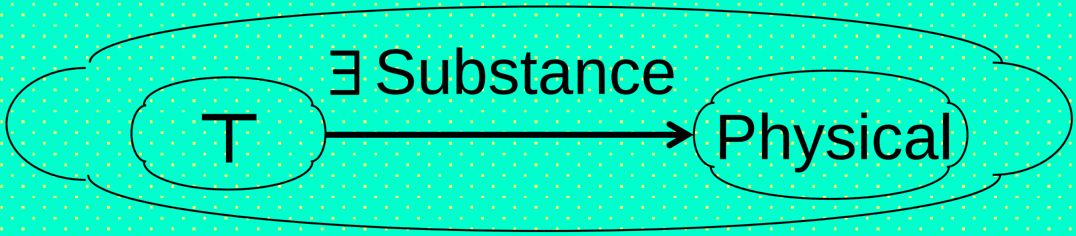
Class-Property Restriction—Existential (1*)

General: Graph (normal) (Description) Logic



$\exists binrel\,.\,class$

Example: Graph (Description) Logic

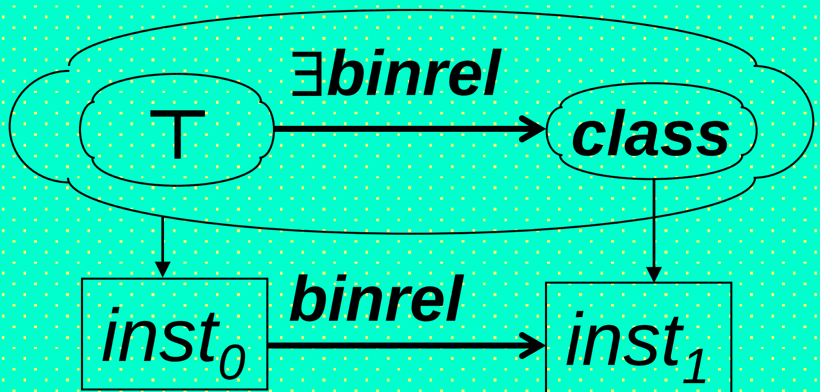


$\exists \text{Substance}\,.\,\text{Physical}$

A kind of schema, where T*op class is specialized to have (multi-valued) attribute/property,* Substance*, with* *<u>at least one</u>* *value typed by class* Physical

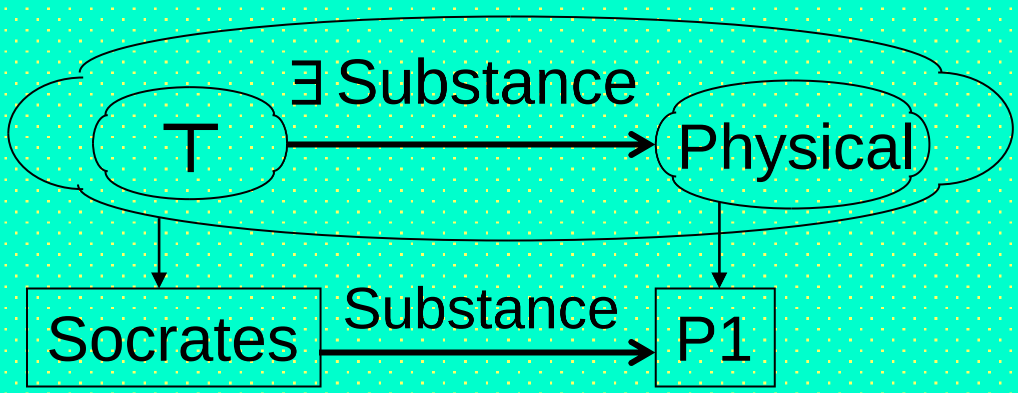
Instance Assertions (Populated Ontologies): Using Restriction for ABox—Existential (1*)

General: Graph (normal) (xNS-Description) Logic



$\exists binrel.class(inst_0) \wedge$
$class(inst_1) \wedge$
$binrel(inst_0, inst_1)$

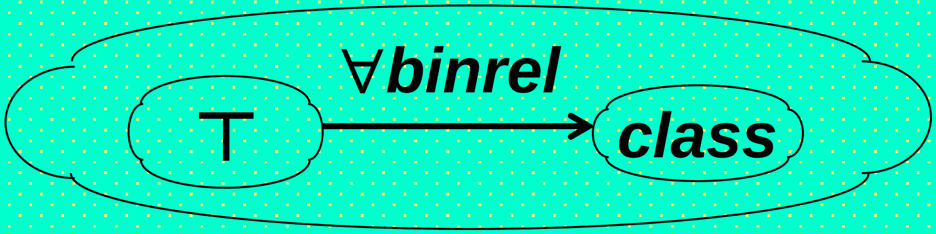
Example: Graph (xNS-Description) Logic



∃Substance.Physical (Socrates) ∧
Physical(P1) ∧
Substance(Socrates, P1)

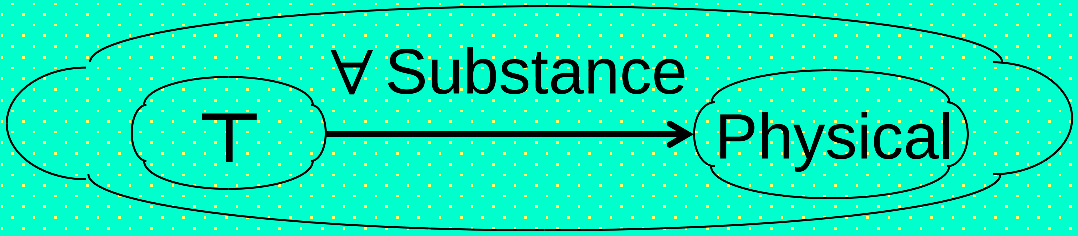
Intensional Class Constructions (Ontologies): Class-Property Restriction—Universal (1*)

General: Graph (normal) (Description) Logic



$\forall binrel\,.\,class$

Example: Graph (Description) Logic

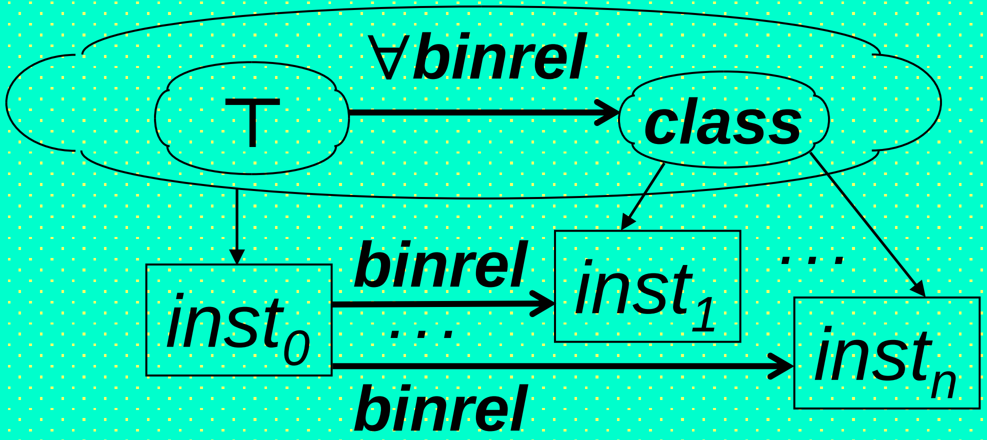


$\forall \text{Substance}\,.\,\text{Physical}$

A kind of schema, where T*op class is specialized to have (multi-valued) attribute/property,* Substance*, with* <u>*each*</u> *value typed by class* Physical

Instance Assertions (Populated Ontologies): Using Restriction for ABox—Universal (1*)

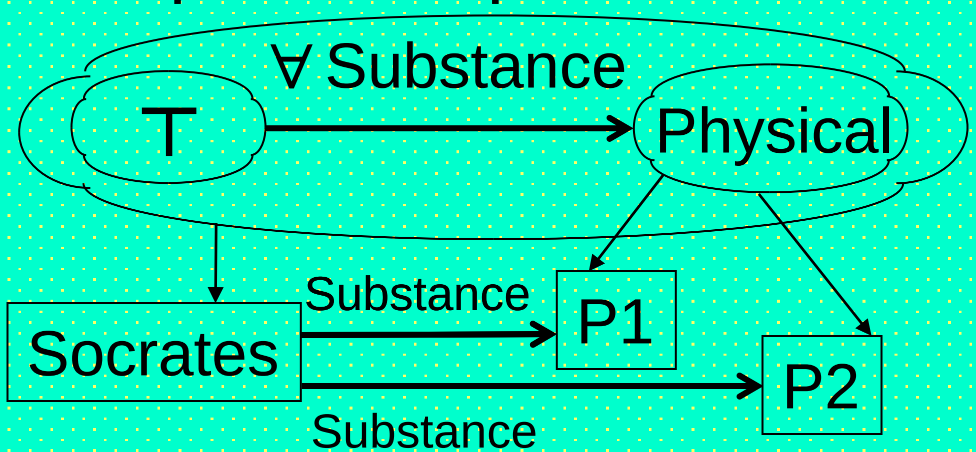
General: Graph (normal)



(xNS-Description) Logic

$\forall binrel.class(inst_0) \wedge$
$class(inst_1) \wedge$
$\ldots$
$class(inst_n) \wedge$
$binrel(inst_0, inst_1) \wedge$
$\ldots$
$binrel(inst_0, inst_n)$

Example: Graph



(xNS-Description) Logic

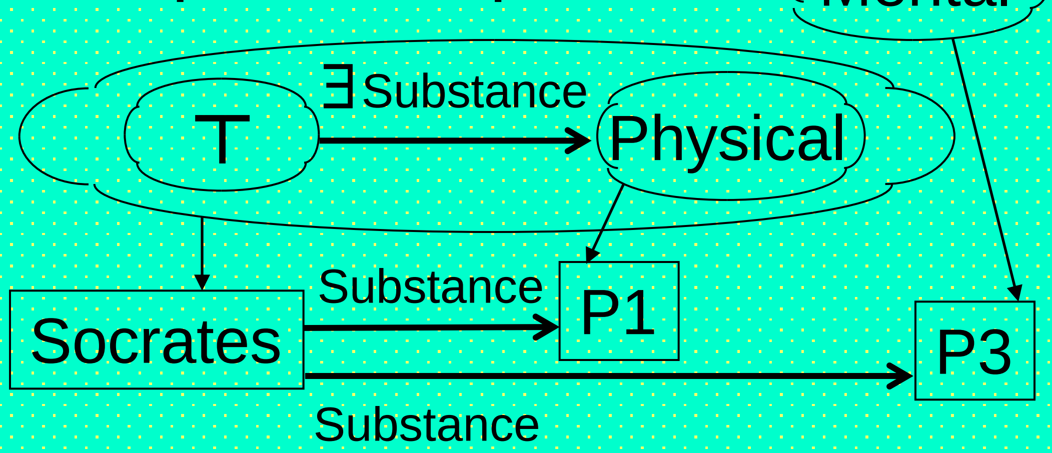
∀Substance.Physical (Socrates) ∧
Physical(P1) ∧
Physical(P2) ∧
Substance(Socrates, P1) ∧
Substance(Socrates, P2)

Existential vs. Universal Restriction

(Physical/Mental Assumed Disjoint: Can Be Explicated via Bottom Intersection)

Consistent

Example: Graph

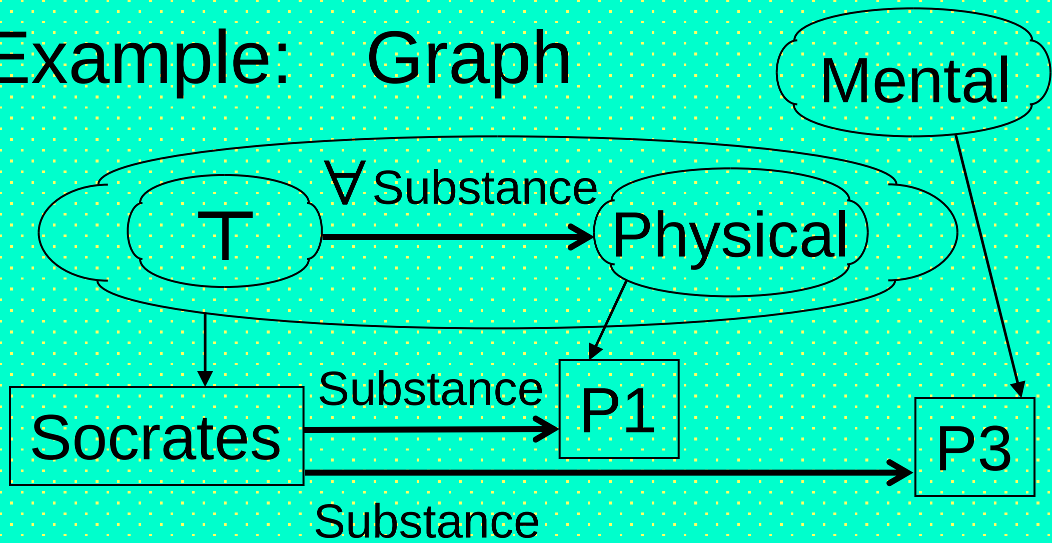


(xNS-Description) Logic

∃Substance.Physical (Socrates) ∧
Physical(P1) ∧
Mental(P3) ∧
Substance(Socrates, P1) ∧
Substance(Socrates, P3)

Inconsistent

Example: Graph

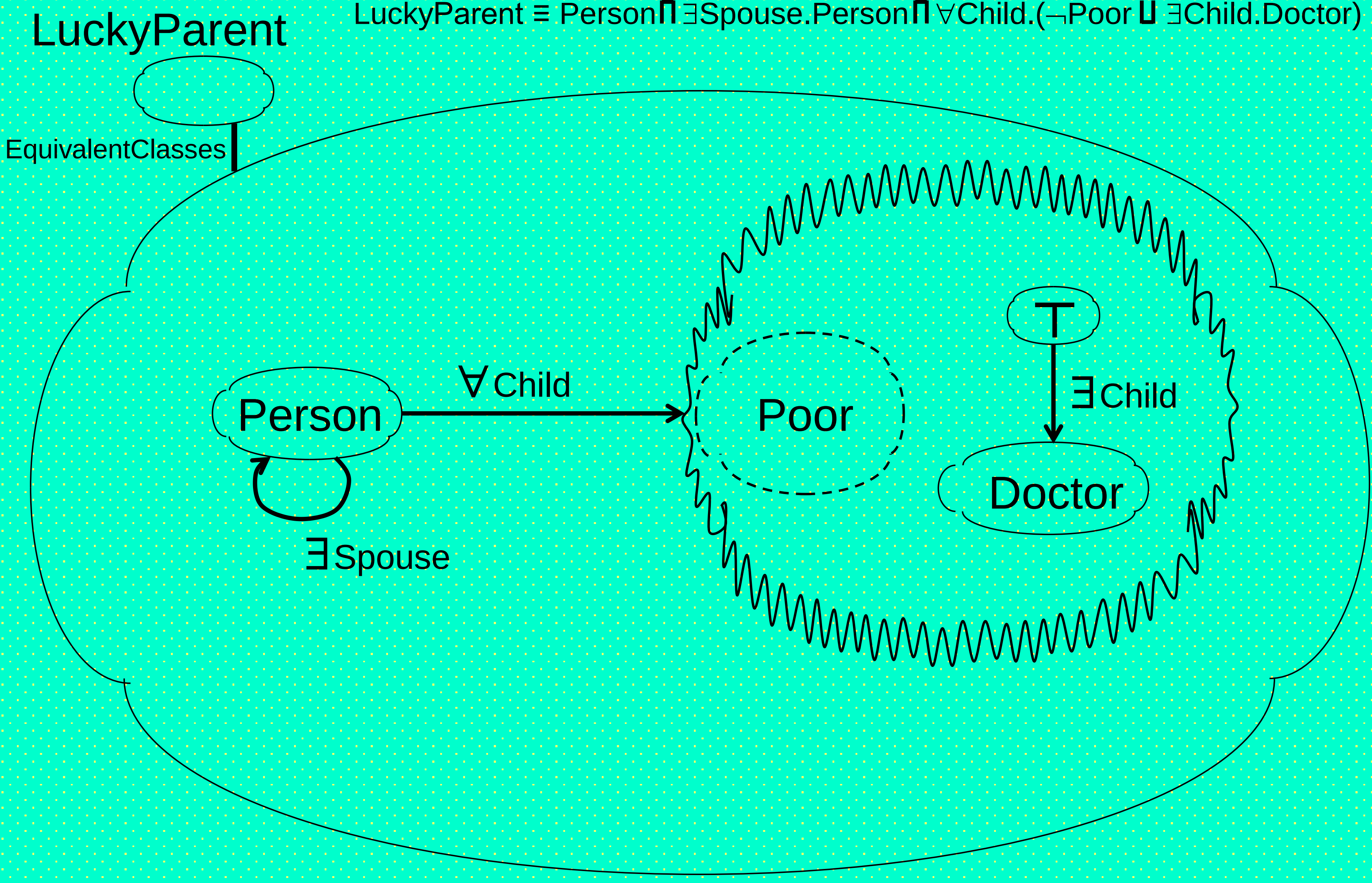


(xNS-Description) Logic

∀Substance.Physical (Socrates) ∧
Physical(P1) ∧
Mental(P3) ∧
Substance(Socrates, P1) ∧
Substance(Socrates, P3)

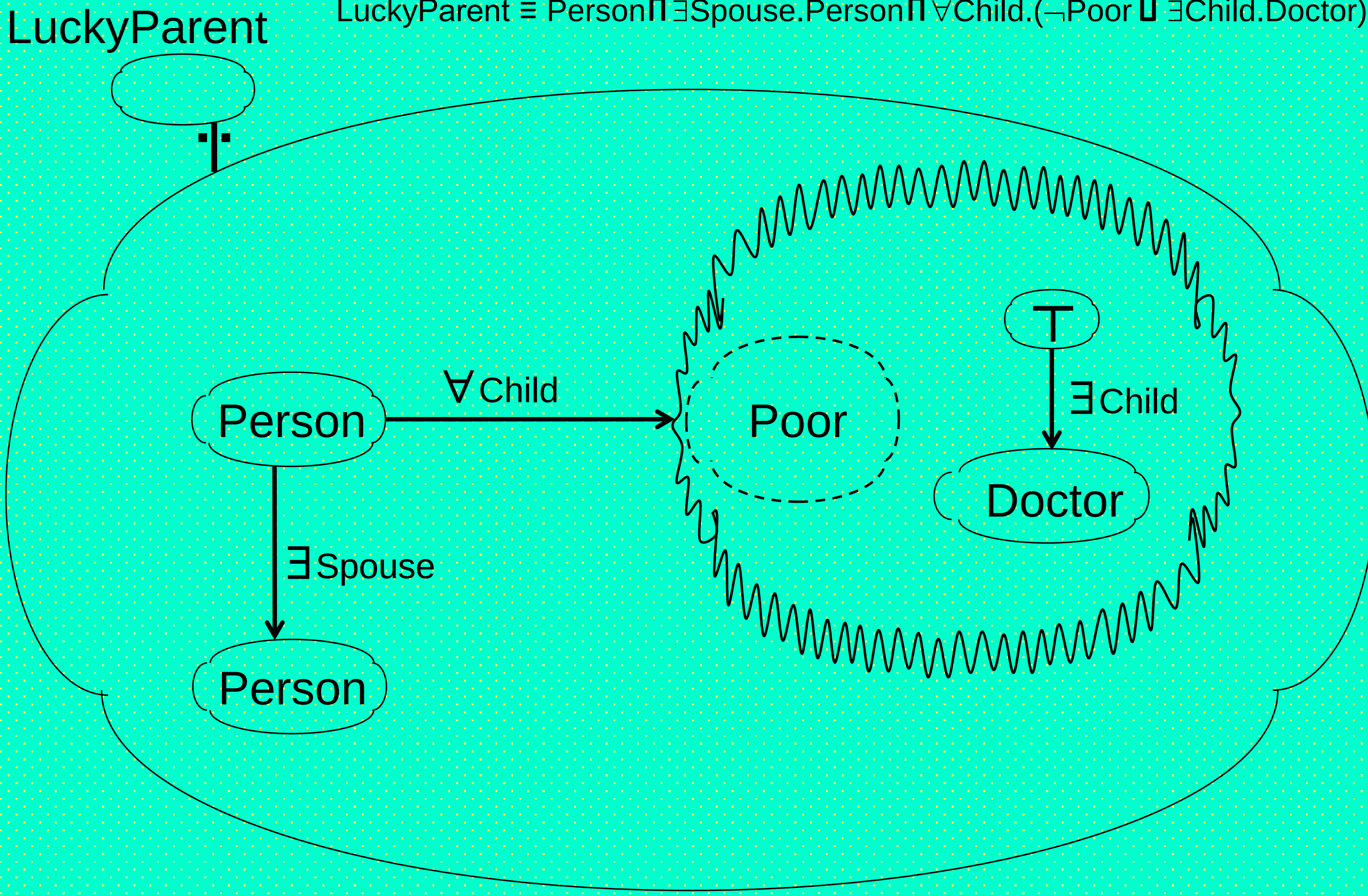
LuckyParent Example (1)

LuckyParent ≡ Person ⊓ ∃Spouse.Person ⊓ ∀Child.(¬Poor ⊔ ∃Child.Doctor)



LuckyParent Example (1*)

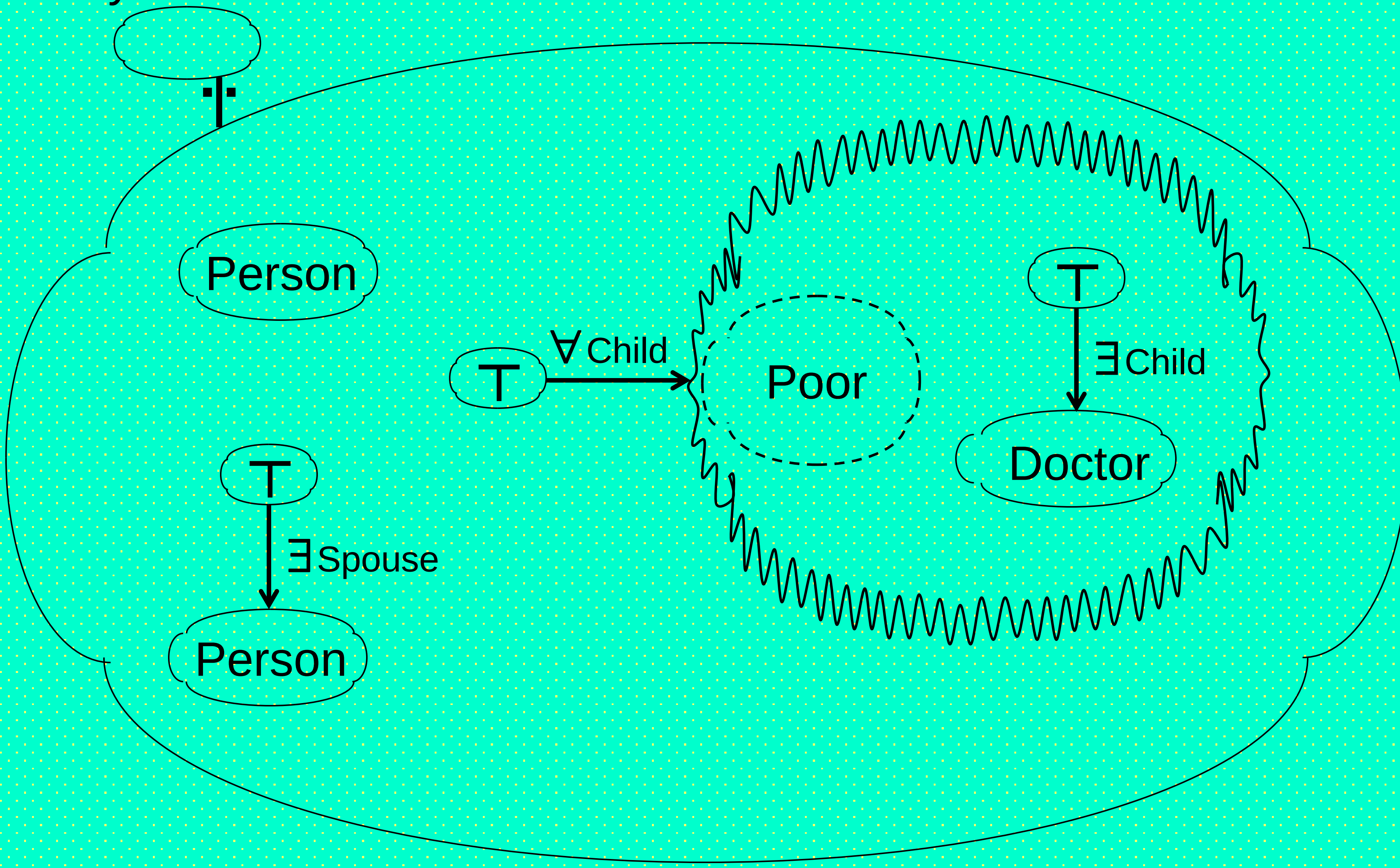
LuckyParent ≡ Person ⊓ ∃Spouse.Person ⊓ ∀Child.(¬Poor ⊔ ∃Child.Doctor)



LuckyParent Example (1**)

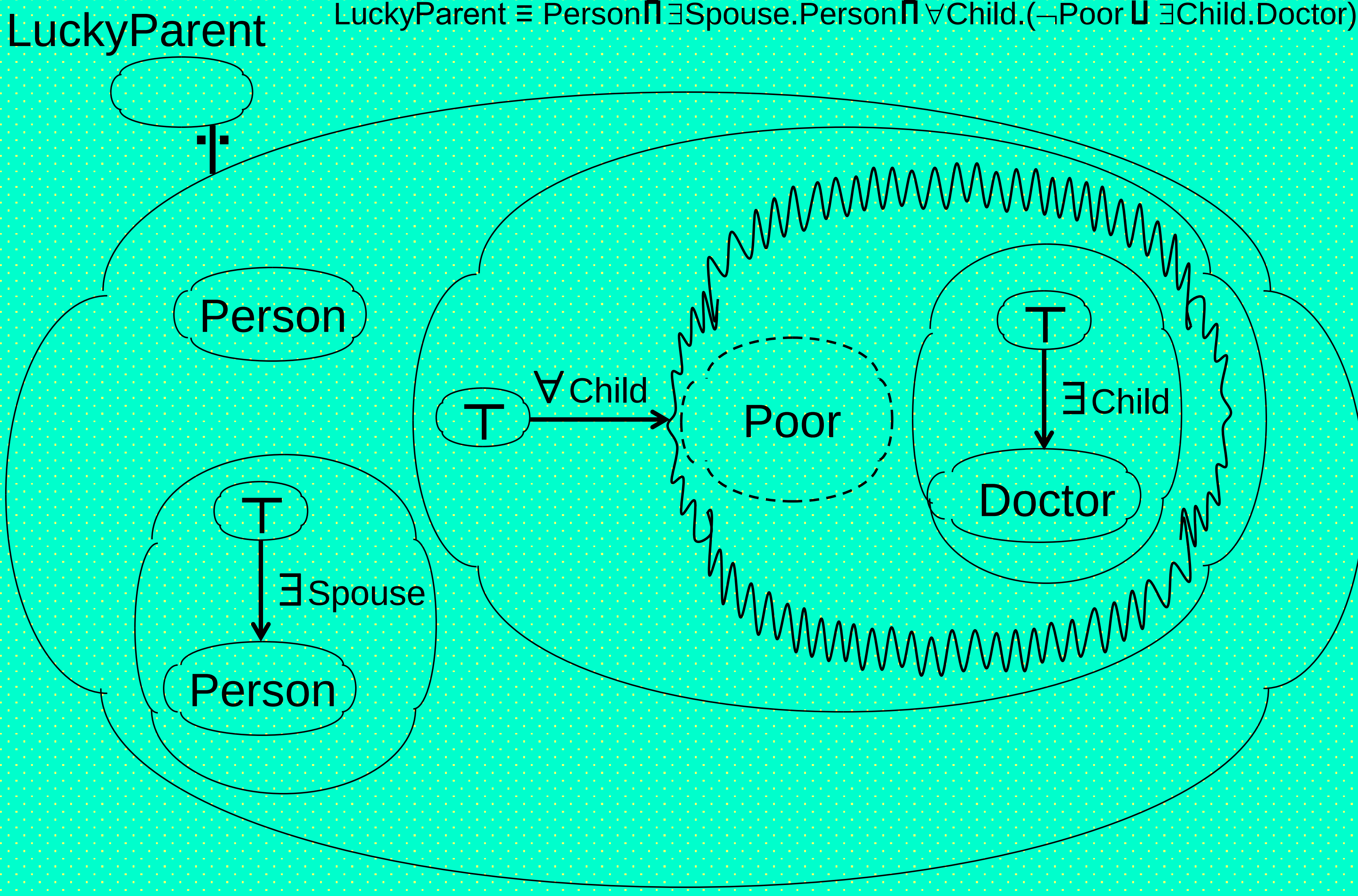
$LuckyParent \equiv Person \sqcap \exists Spouse.Person \sqcap \forall Child.(\neg Poor \sqcup \exists Child.Doctor)$

LuckyParent



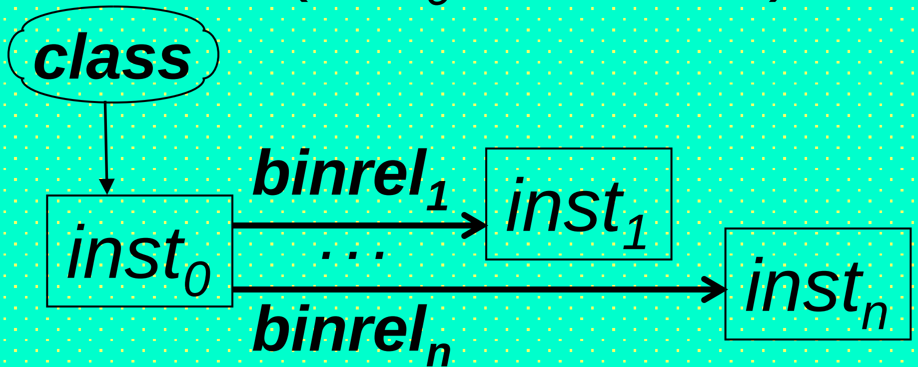
LuckyParent Example (1**)

LuckyParent ≡ Person ⊓ ∃Spouse.Person ⊓ ∀Child.(¬Poor ⊔ ∃Child.Doctor)



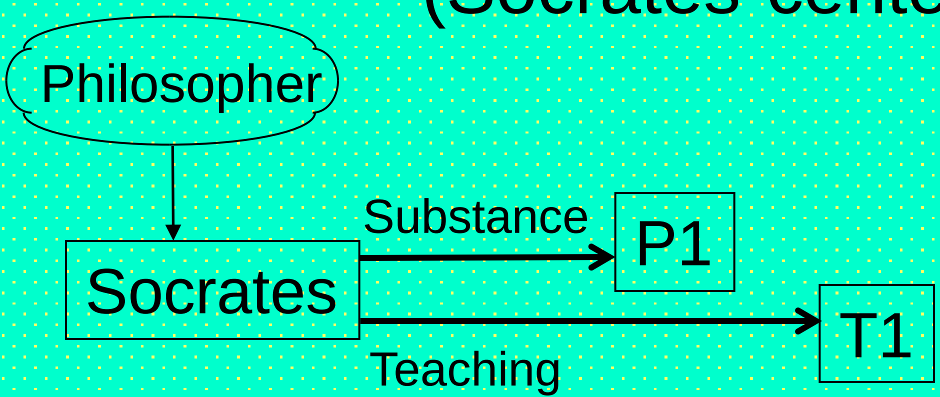
Object-Centered Logic: Grouping Binary Relations Around Instance

General: Graph ($inst_0$-centered) — (Object-Centered) Logic



$class(inst_0) \wedge$
$binrel_1(inst_0, inst_1) \wedge$
...
$binrel_n(inst_0, inst_n)$

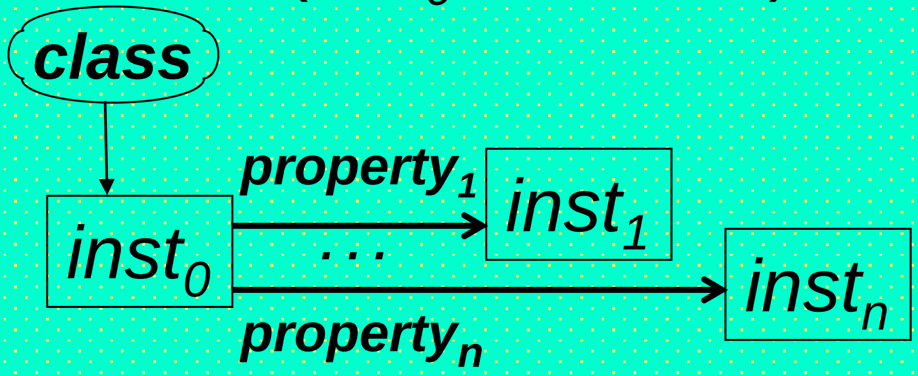
Example: Graph (Socrates-centered) — (Object-Centered) Logic



Philosopher(Socrates) $\wedge$
Substance(Socrates, P1) $\wedge$
Teaching(Socrates, T1)

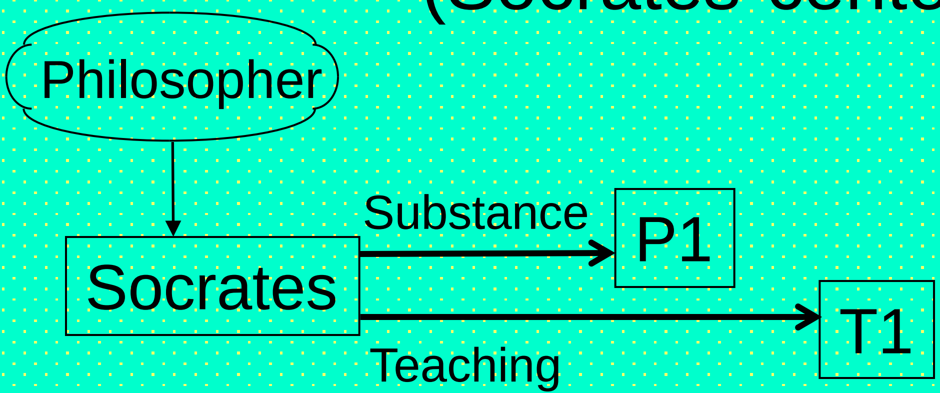
RDF-Triple (‘Subject’-Centered) Logic: Grouping Properties Around Instance

General: Graph ($inst_0$-centered) (Subject-Centered) Logic



{($inst_0$, rdf:type, *class*),
 ($inst_0$, $property_1$, $inst_1$),
. . .
 ($inst_0$, $property_n$, $inst_n$)}

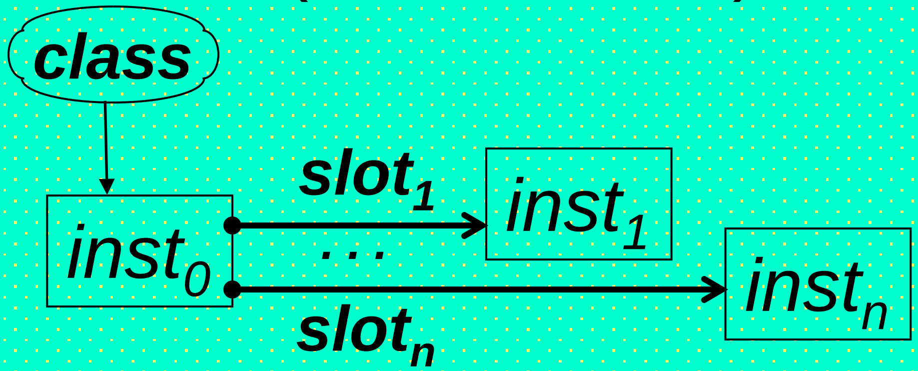
Example: Graph (Socrates-centered) (Subject-Centered) Logic



{(Socrates, rdf:type, Philosopher),
 (Socrates, Substance, P1),
 (Socrates, Teaching, T1)}

Logic of Frames ('Records'): Associating Slots with OID-Distinguished Instance

General: Graph (*bulleted* arcs)

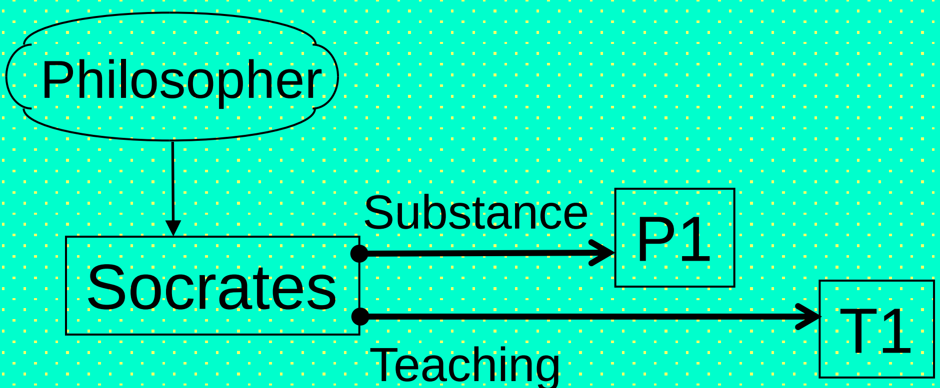


(PSOA Frame) Logic

$inst_0\#class($
$\quad slot_1\text{->}inst_1;$
$\quad . . .$
$\quad slot_n\text{->}inst_n)$

$inst_0 \in class,$
$\quad slot_1 = inst_1,$
$\quad . . .$
$\quad slot_n = inst_n$

Example: Graph

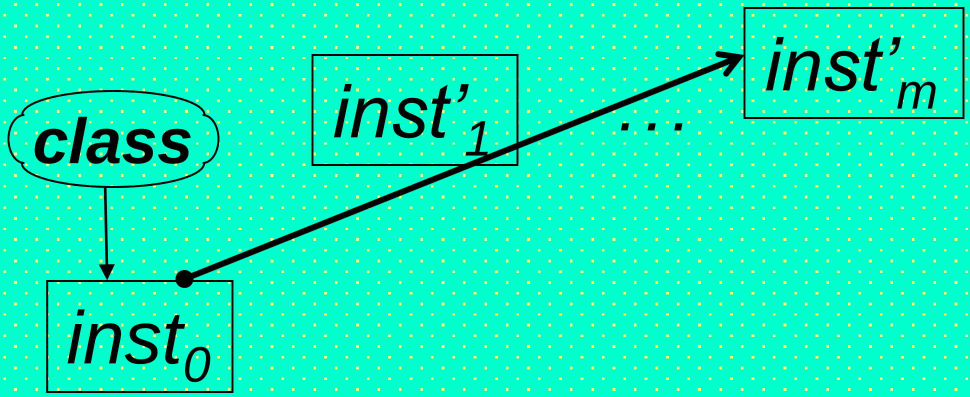


(PSOA Frame) Logic

Socrates#Philosopher(
  Substance->P1;
  Teaching->T1)

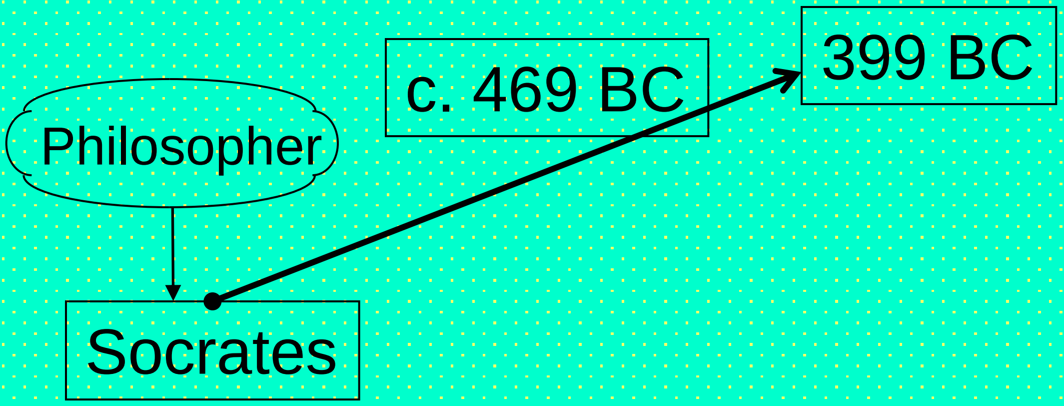
Logic of Shelves ('Arrays'): Associating Tuple(s) with OID-Distinguished Instance

General: Graph (*bulleted* hyperarc) (PSOA Shelf) Logic



$inst_0\#class(inst'_1, \ldots, inst'_m)$

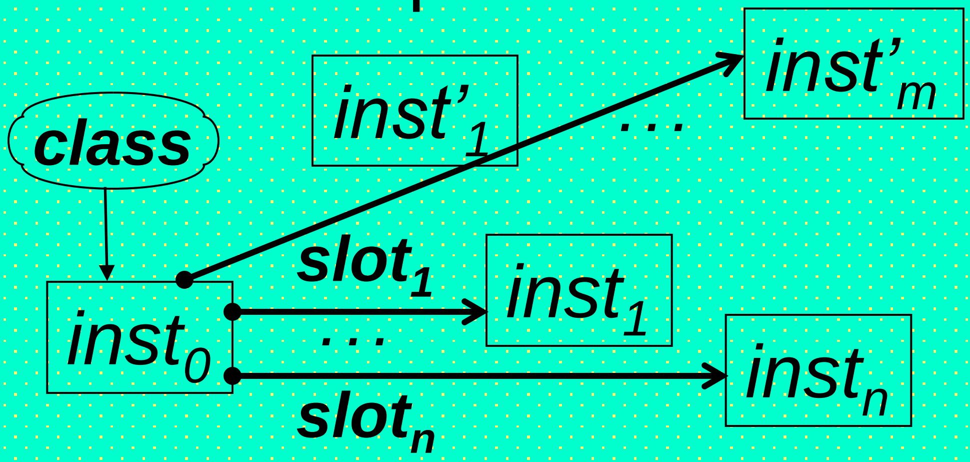
Example: Graph (PSOA Shelf) Logic



Socrates#Philosopher(
c. 469 BC, 399 BC)

Positional-Slotted-Term Logic: Associating Tuple(s)+Slots with OID-Disting'ed Instance

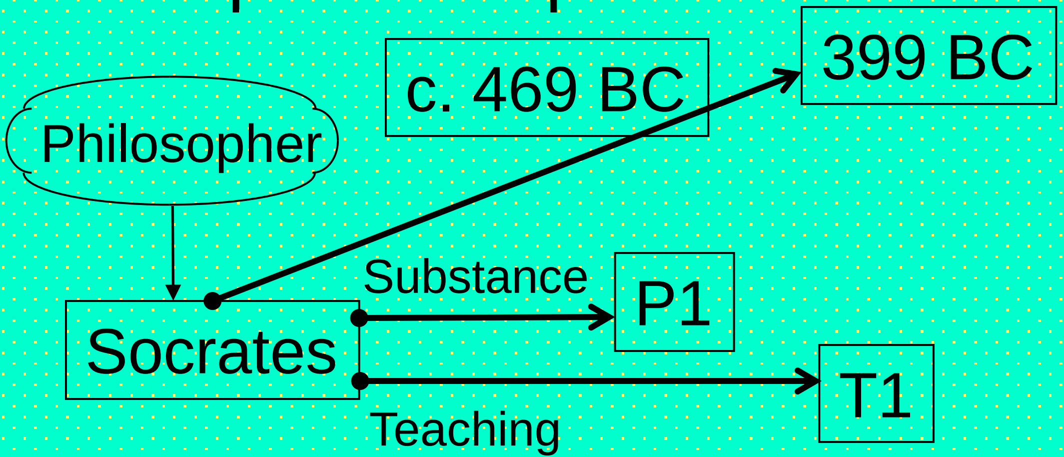
General: Graph



(PSOA Positional-Slotted-Term) Logic

$inst_0\#class($
$\quad inst'_1, \ldots, inst'_m;$
$\quad slot_1\text{->}inst_1;$
$\quad \ldots$
$\quad slot_n\text{->}inst_n)$

Example: Graph

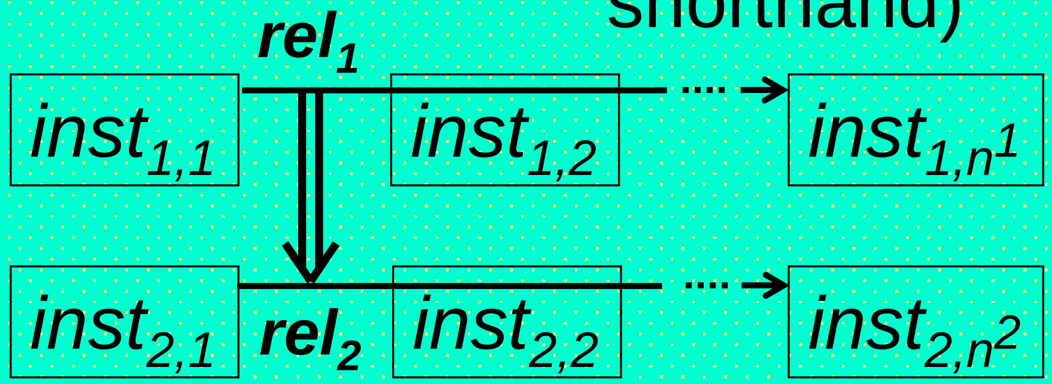


(PSOA Positional-Slotted-Term) Logic

Socrates#Philosopher(
c. 469 BC, 399 BC;
Substance->P1;
Teaching->T1)

Rules: Relations Imply Relations (1)

General: Graph (ground, shorthand)

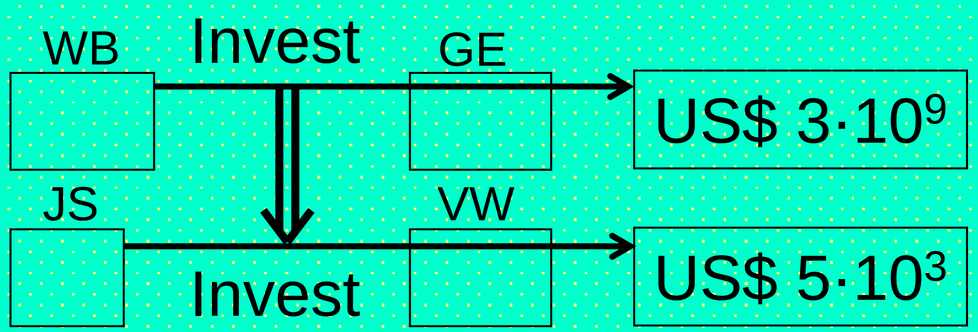


Logic

$rel_1(inst_{1,1}, inst_{1,2}, \ldots, inst_{1,n^1}) \Rightarrow$

$rel_2(inst_{2,1}, inst_{2,2}, \ldots, inst_{2,n^2})$

Example: Graph



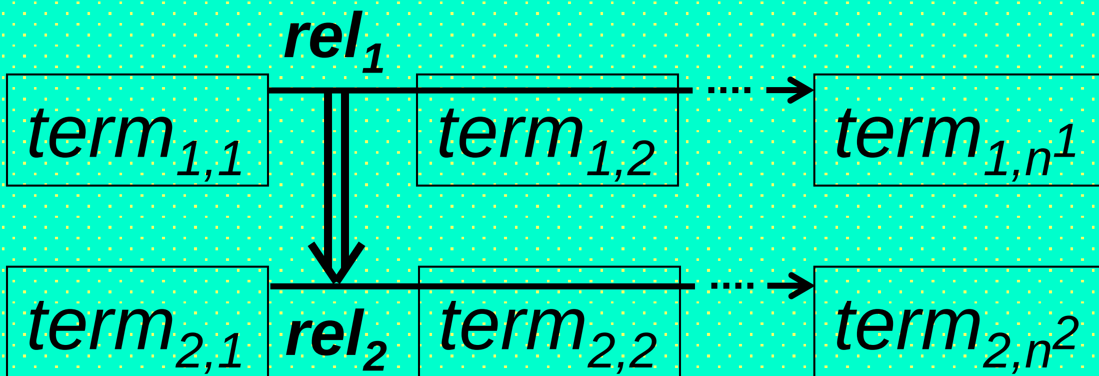
Logic

Invest(|WB, |GE, US\$ $3 \cdot 10^9$) $\Rightarrow$

Invest(|JS, |VW, US\$ $5 \cdot 10^3$)

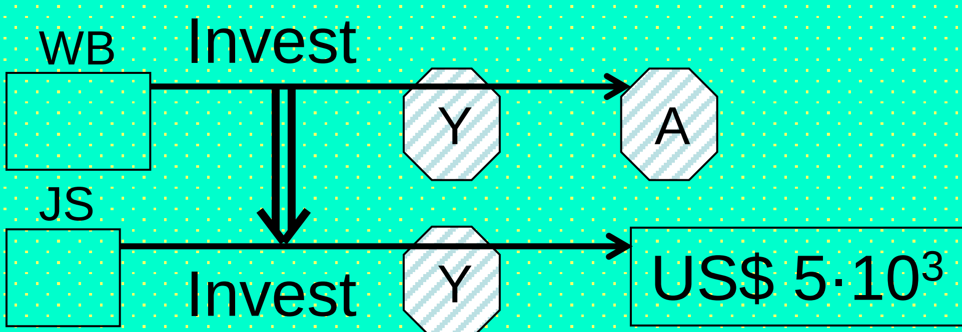
Rules: Relations Imply Relations (3)

General: Graph (inst/var terms) — Logic



$(\forall var_{i,j})$
$rel_1(term_{1,1},\ term_{1,2},\ \ldots,\ term_{1,n^1}) \Rightarrow$
$rel_2(term_{2,1},\ term_{2,2},\ \ldots,\ term_{2,n^2})$

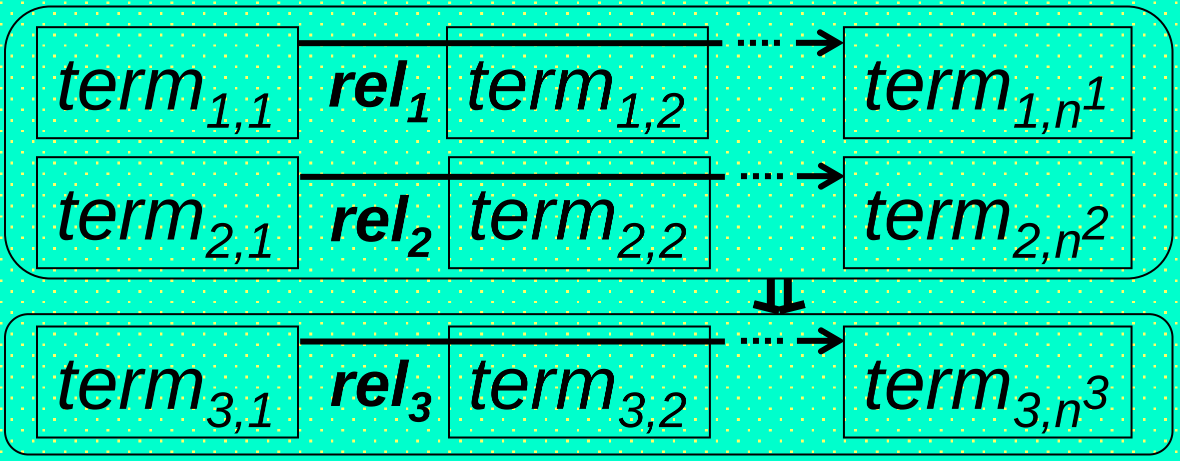
Example: Graph — Logic



$(\forall\ Y, A)$
Invest(|WB, Y, A) $\Rightarrow$
Invest(|JS, Y, US\$ $5\cdot 10^3$)

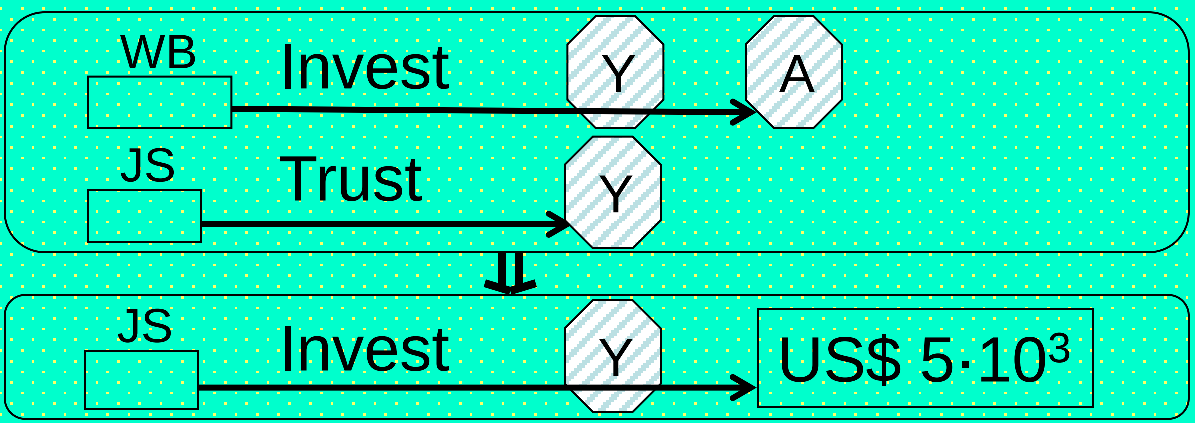
Rules: Conjuncts Imply Relations (1*)

General: Graph (prenormal) Logic



$(\forall var_{i,j})$
$rel_1(term_{1,1}, term_{1,2}, \ldots, term_{1,n^1}) \wedge$
$rel_2(term_{2,1}, term_{2,2}, \ldots, term_{2,n^2}) \Rightarrow$
$rel_3(term_{3,1}, term_{3,2}, \ldots, term_{3,n^3})$

Example: Graph Logic



$(\forall\ Y, A)$
Invest(|WB, Y, A) $\wedge$
Trust(|JS, Y) $\Rightarrow$
Invest(|JS, Y, US\$ $5\cdot10^3$)

Rules: Conjuncts Imply Relations (2)

Example: RuleML/XML

```
<Implies closure="universal">
  <And>
    <Atom>
      <Rel>Invest</Rel>
      <Ind unique="no">WB</Ind>
      <Var>Y</Var>
      <Var>A</Var>
    </Atom>
    <Atom>
      <Rel>Trust</Rel>
      <Ind unique="no">JS</Ind>
      <Var>Y</Var>
    </Atom>
  </And>
  <Atom>
    <Rel>Invest</Rel>
    <Ind unique="no">JS</Ind>
    <Var>Y</Var>
    <Data>US$ 5·10³</Data>    <!– superscript “³” to be parsed as Unicode U+00B3 -->
  </Atom>
</Implies>
```

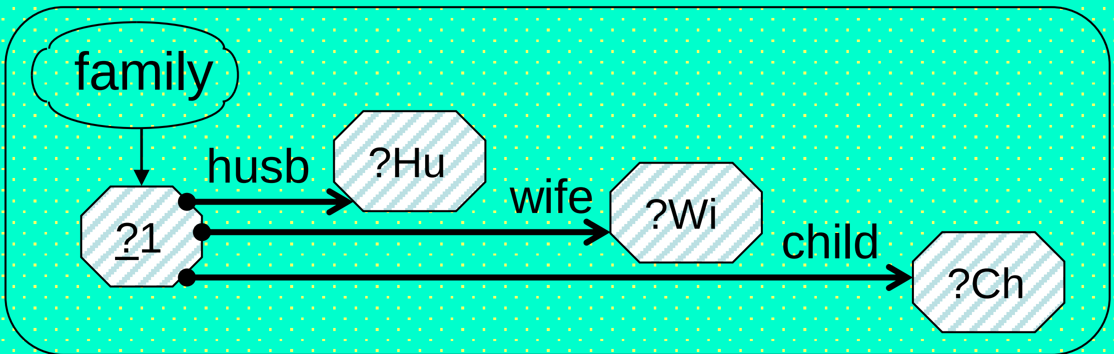
Logic

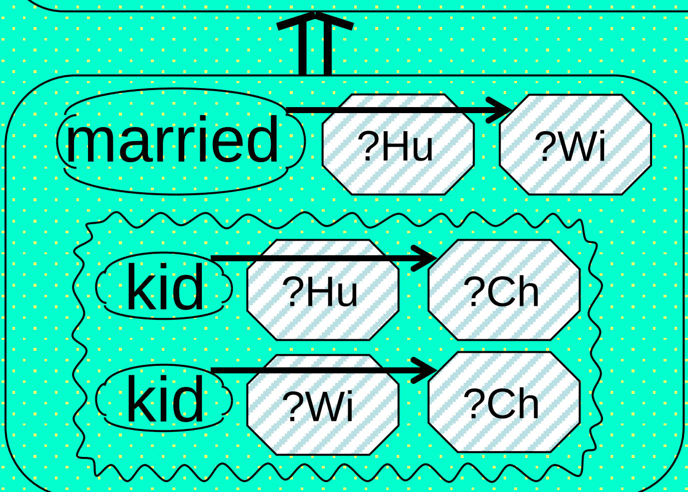
$$(\forall\ Y, A)\ (\mathrm{Invest}(|\mathrm{WB}, Y, A) \wedge \mathrm{Trust}(|\mathrm{JS}, Y) \Rightarrow \mathrm{Invest}(|\mathrm{JS}, Y, \mathrm{US\$}\ 5 \cdot 10^3))$$

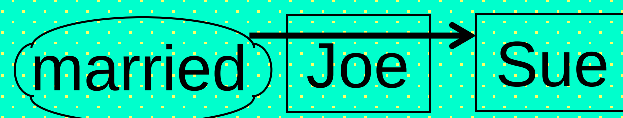
Proposing an attribute unique *with value* "no" *for NNS, and* "yes" *for UNS as the default*

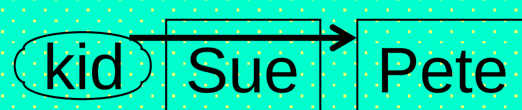
Positional-Slotted-Term Logic: Rule-defined Anonymous Family Frame (Visualized from IJCAI-2011 Presentation)

Example: Graph







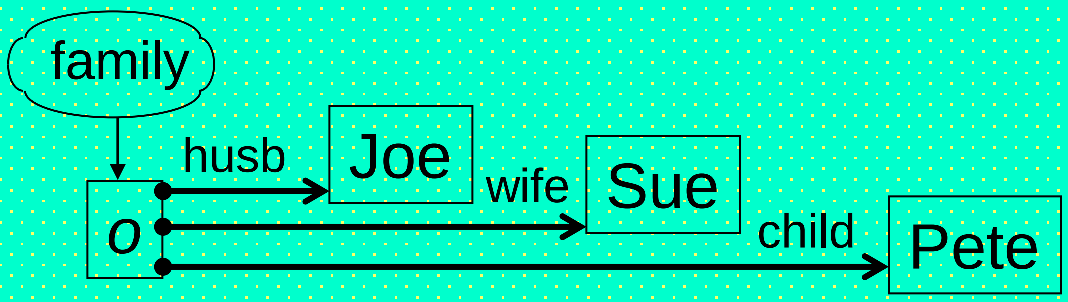


(PSOA Positional-Slotted-Term) Logic

```
Group (
  Forall ?Hu ?Wi ?Ch (
   ?1#family(husb->?Hu
                wife->?Wi
                child->?Ch)   :-
     And(married(?Hu ?Wi)
          Or(kid(?Hu ?Ch)
              kid(?Wi ?Ch))) )
  married(Joe Sue)
  kid(Sue Pete)
      )
```

Positional-Slotted-Term Logic: Ground Facts, incl. Deduced Frame, Model Family Semantics

Example: Graph

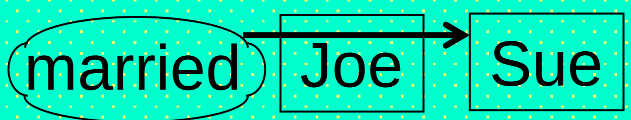


(PSOA Positional-Slotted-Term) Logic

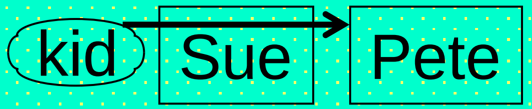
Group (

o#family(husb->Joe
wife->Sue
child->Pete)

Previous slide's existential variable ?1 *in rule head becomes new OID constant o in frame fact, deduced from relational facts*



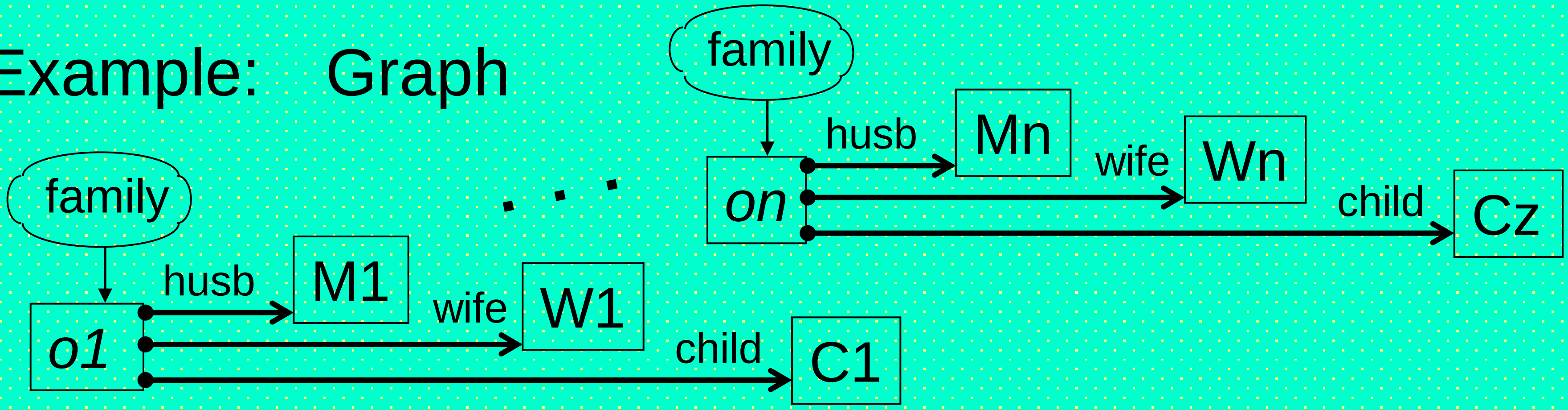
married(Joe Sue)
kid(Sue Pete)
)

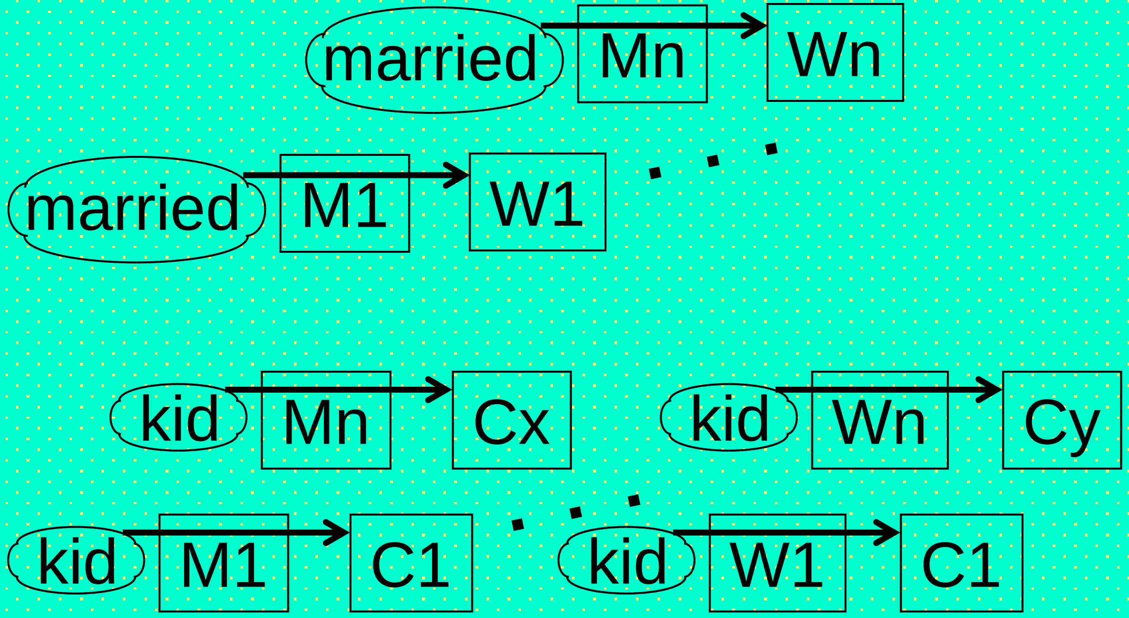


For reference implementation of PSOA querying see [*PSOATransRun*]

Positional-Slotted-Term Logic: Conversely, Given Facts, Rule Can Be Inductively Learned

Example: Graph



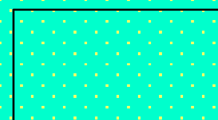
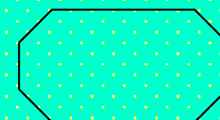
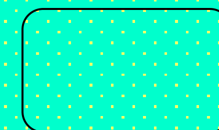
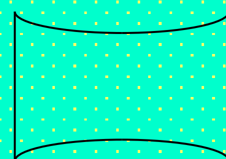
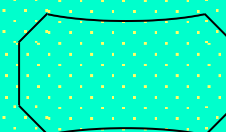
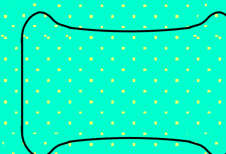
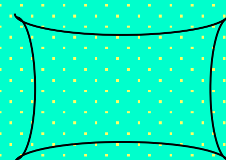
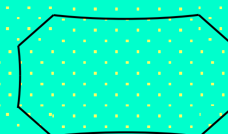
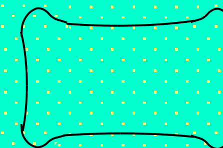
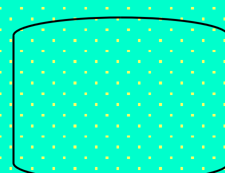
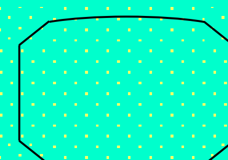
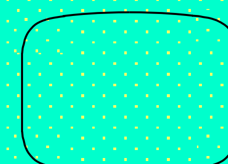
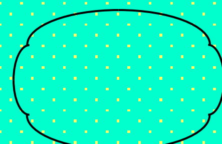
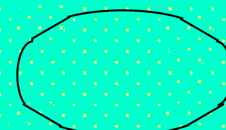
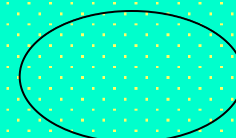


Abstracting OID constants o1, ... , on to regain existential variable ?1 *of previous rule, now induced from matching relational and frame facts*

Orthogonal Graphical Features — Axes of Grailog Systematics

- Box axes:
  - Corners: pointed vs. snipped vs. rounded
    - To quote/copy vs. reify/instantiate vs. evaluate contents (cf. Lisp, Prolog, Relfun, Hilog, RIF, and IKL)
  - Shapes (rectangle-derived): composed from sides that are straight vs. concave vs. convex
    - For neutral vs. function vs. relation contents
  - Contents: elementary vs. complex nodes
- Arrow axes:
  - Shafts: single vs. double
  - Heads: triangular vs. diamond
  - Tails: plain vs. bulleted vs. colonized
- Box & Arrow (line-style) axes: solid vs. dashed, linear vs. (box only) wavy

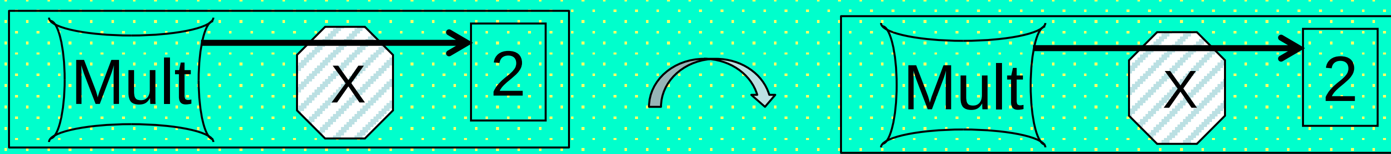
Graphical Elements: Box Systematics — Axes of Corners and Shapes

Corner: / *Shape:*	Per ... Copy ***Rect-***	... Instantiation ***Snip-***	... Value ***Round-***
Neutral ***-angle***			
Individual **(**Function Application**)** ***-2cave***			
Function ***-4cave***			
Proposition (Relation Application) ***-2vex***			
Relation (incl. Class) ***-4vex***			

Graphical Elements: Boxes — Function/Relation-Neutral Shape of Angles Varied w.r.t. Corner Dimension

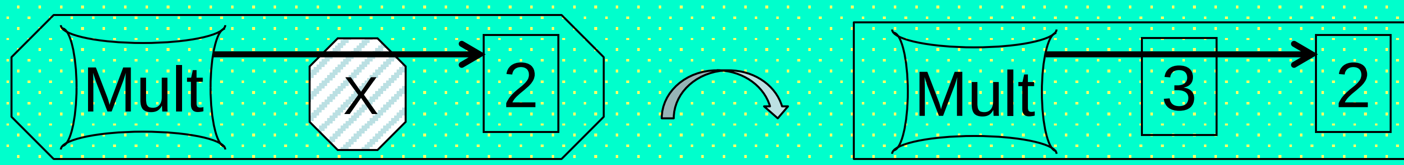
– ***Rectangle***: Neutral ‘per copy’ nodes *quote* their contents

X=3 :



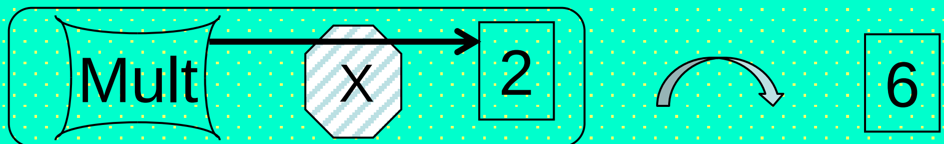
– ***Snipangle*** (octagon): Neutral ‘per instantiation’ nodes *dereference* contained variables to values from context

X=3 :



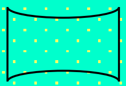
– ***Roundangle*** (rounded angles): Neutral ‘per value’ nodes *evaluate* their contents through instantiation of variables and activation of function/relation applications

X=3 :

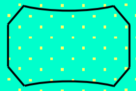


Assuming Mult built-in function

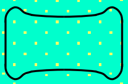
Graphical Elements: Boxes — Concave



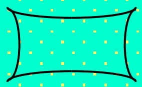
– ***Rect2cave*** (rectangle with 2 concave - top/bottom - sides): Elementary nodes for individuals (instances). Complex nodes for quoted instance-denoting terms (constructor-function applications)



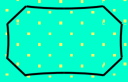
– ***Snip2cave*** (snipped): Elementary nodes for variables. Complex nodes for instantiated (reified) function applications



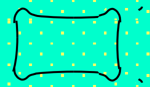
– ***Round2cave*** (rounded): Complex nodes for evaluated built-in or equation-defined function applications



– ***Rect4cave*** (4 concave sides): Elementary nodes for fct's. Complex nodes for quoted functional (function-denoting) terms

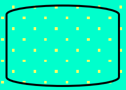


– ***Snip4cave***: Complex nodes for instantiated funct'l terms

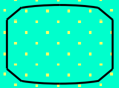


– ***Round4cave***: Complex nodes for evaluated functional applications (active, function-returning applications)

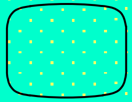
Graphical Elements: Boxes — Convex



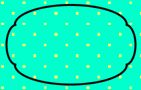
- *Rect2vex* (rectangle with 2 convex - top/bottom - sides): Elementary nodes for truth constants (true, false, unknown). Complex nodes for quoted truth-denoting propositions (embedded relation applications)



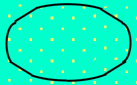
- *Snip2vex*: Complex nodes for instantiated (reified) relation applications



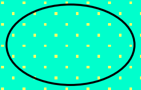
- *Round2vex*: Complex nodes for evaluated relation applications (e.g. as atomic formulas) and for connective uses



- *Rect4vex*: Elementary nodes for relations, e.g. unary ones (classes). Complex nodes for quoted relational (relation-denoting) terms



- *Snip4vex*: Complex nodes for instantiated relat'l terms



- *Round4vex* (oval): Complex nodes for evaluated relat'l applications (active, relation-returning applications)

Conclusions (1)

- Grailog 1.0 incorporates feedback on earlier versions
- Graphical elements for novel box & arrow systematics using orthogonal graphical features
  - Leaving color (except for IRIs) for other purposes, e.g. highlighting subgraphs (for retrieval and inference)
- Introducing Unique vs. Non-unique Name Specification
- Focus on *mapping* to a family of logics as in RuleML
- Use cases from *cognition* to *technology* to *business*
  - E.g. “Logical Foundations of Cognitive Science”: http://www.ict.tuwien.ac.at/lva/Boley_LFCS/index.html
- *Processing* of earlier Grailog-like DRLHs studied in Lisp, FIT, and Relfun
- For Grailog, aligned with Web-rule standard RuleML: http://wiki.ruleml.org/index.php/Grailog

Conclusions (2)

- **Symbolic-to-visual** mappings implemented as Semantic Web Techniques Fall 2012 Projects:
  - **Team 1** *A Grailog Visualizer for Datalog RuleML via XSLT 2.0 Translation to SVG* by Sven Schmidt and Martin Koch: An Int'l Rule Challenge 2013 paper & demo introduced Grailog KS Viz
  - **Team 8** *Visualizing SWRL's Unary/Binary Datalog RuleML in Grailog* by Bo Yan, Junyan Zhang, and Ismail Akbari: A Canadian Semantic Web Symposium 2013 paper gave an overview
- Grailog invites feature **choice** or *combination*
  - E.g. **n-ary hyperarcs** or **n-slot frames** or *both*
- **Grailog Initiative** on open standardization calls for further feedback for future 1.x versions

Future Work (1)

- Refine/extend Grailog, e.g. along with API4KB effort
  - Compare with other graph formalisms, e.g. Conceptual Graphs (http://conceptualstructures.org) and CoGui tool
  - Define mappings to/fro UML structure diagrams + OCL, adopting UML behavior diagrams (http://www.uml.org)
- Implement further tools, e.g. as use case for (Functional) RuleML (http://ruleml.org/fun) engines
  - More mappings between graphs, logic, and RuleML/XML:
Grailog *generators*: Further symbolic-to-visual mappings
Grailog *parsers*: Initial visual-to-symbolic mappings
  - Graph indexing & querying (cf. http://www.hypergraphdb.org)
  - Graph transformations (normal form, typing homomorphism, merge, ...)
  - Advanced graph-theoretical operations (e.g., path tracing)
  - Exploit Grailog parallelism in implementation

Future Work (2)

- Develop a Grailog structure editor, e.g. supporting:
  - Auto-specialize of neutral application boxes (angles) to function apps (2caves) or relation apps (2vexes), depending on contents
  - Auto-specialize of neutral operator boxes (angles) to functions (4caves) or relations (4vexes), depending on context
- Benefit from, and contribute to, Protégé visualization plug-ins such as Jambalaya/OntoGraf and OWLViz for OWL ontologies and Axiomé for SWRL rules
- Proceed from the 2-dimensional (planar) Grailog to a 3-dimensional (spatial) one
  - Utilize advantages of crossing-free layout, spatial shortcuts, and analogical representation of 3D worlds
  - Mitigate disadvantages of occlusion and of harder spatial orientation and navigation
- Consider the 4th (temporal) dimension of animations to visualize logical inferences, graph processing, etc.