GBKR

A **G**raph-**B**ased **K**nowledge **R**epresentation and Reasoning Model

Agenda

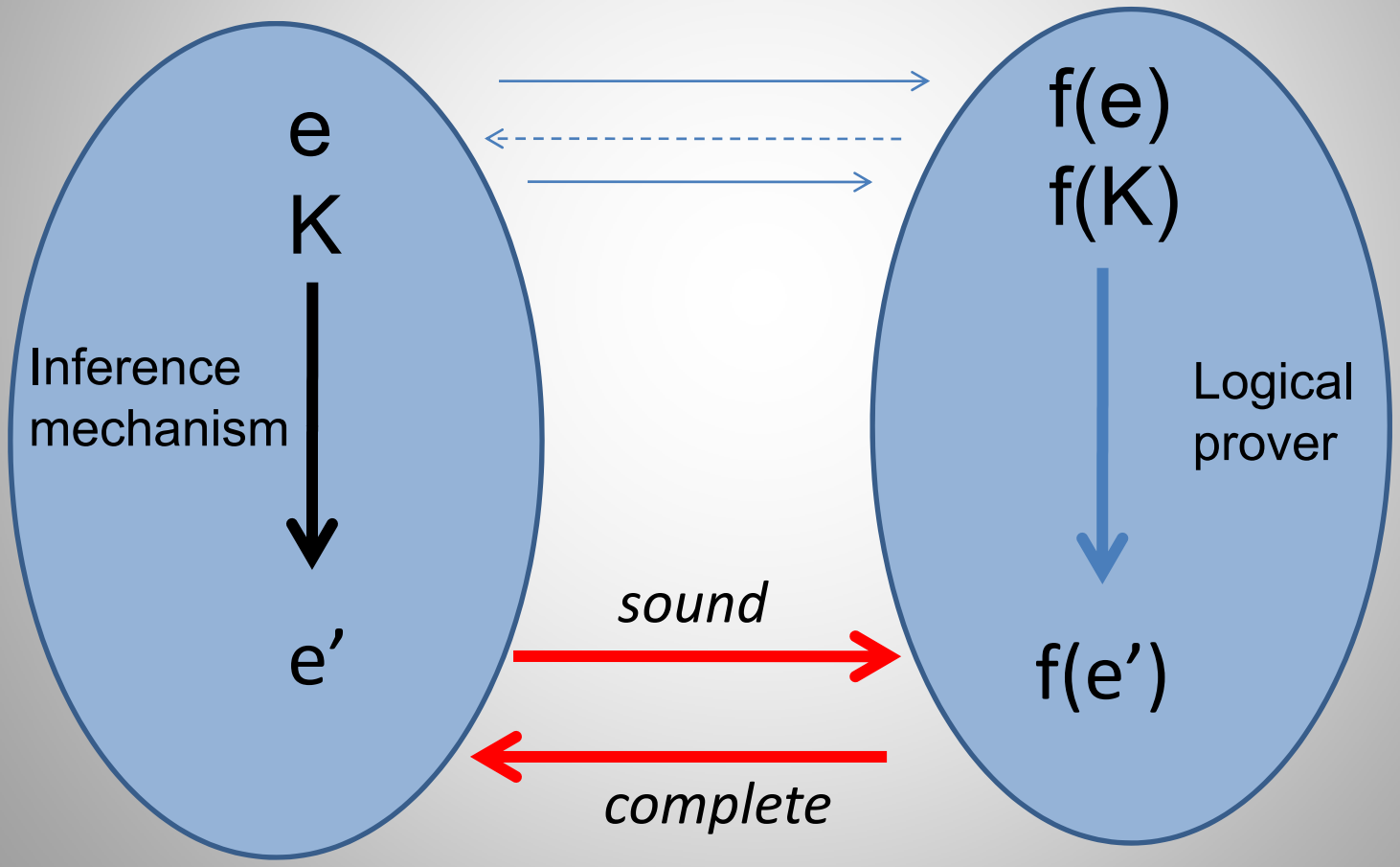
- Knowledge Representation and Reasoning
- GBKR model
- Relationships with Logics
  and other computational models

Knowledge Representation & Reasoning (1)

- **Knowledge-based Systems**
  - Knowledge Base (Ontology, facts, …)
  - Reasoning mechanism

- **Requirements for a KR&R Formalism**
  - Formal semantics (esp. Logical)
  - Structured representation of knowledge
  - Good computational properties

Knowledge Representation & Reasoning (2)



Knowledge Representation & Reasoning (3)

Structured representation of knowledge

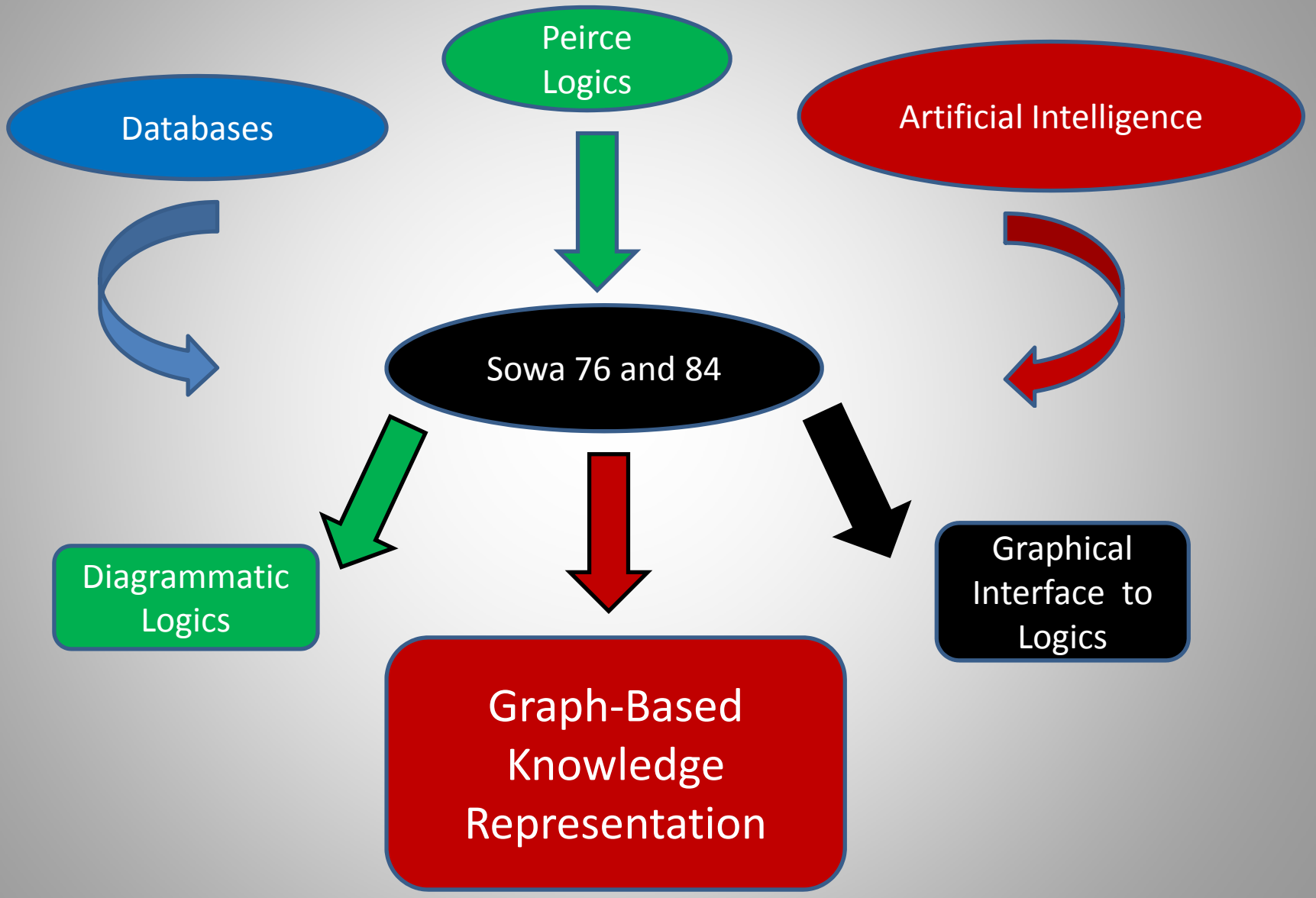
- Semantically related pieces of knowledge should be gathered together
- Distinction between ontological knowledge and factual knowledge
- Rules (e.g. for expressing implicit knowledge)
- Constraints

Knowledge Representation & Reasoning (4)

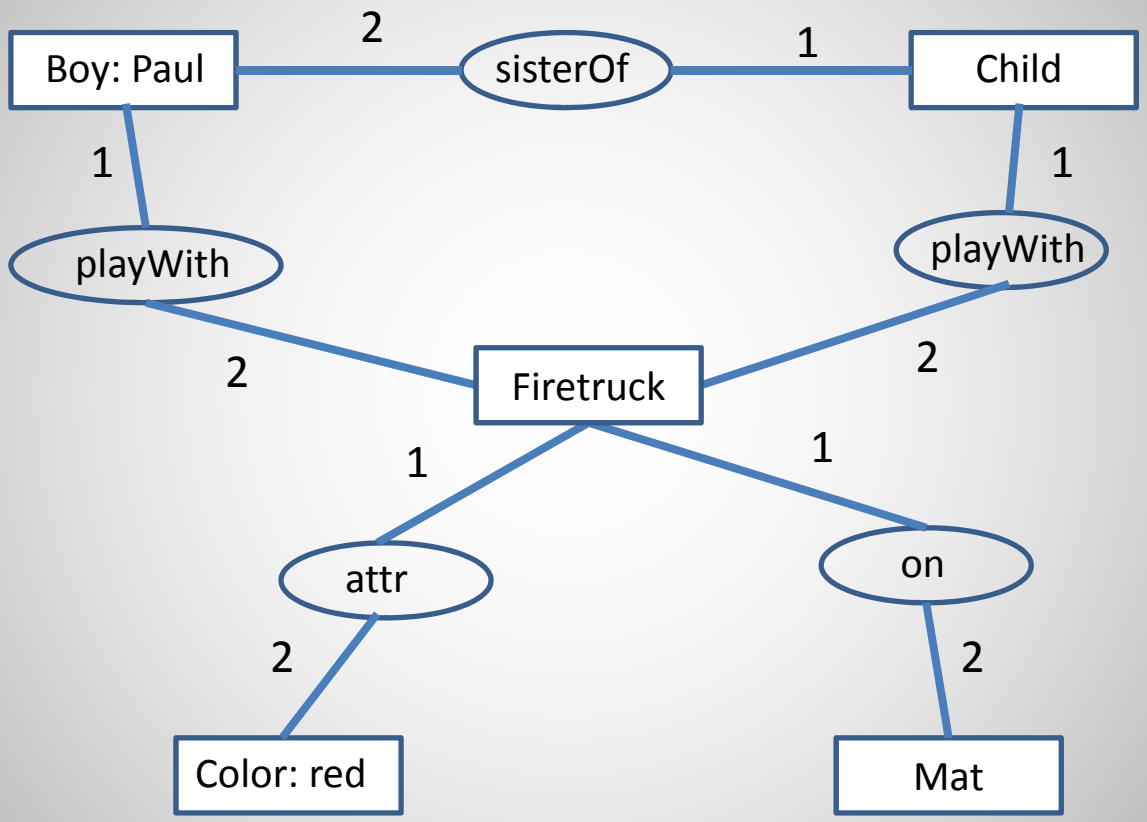
Good computational properties

- Efficient algorithms
- Human computer interface

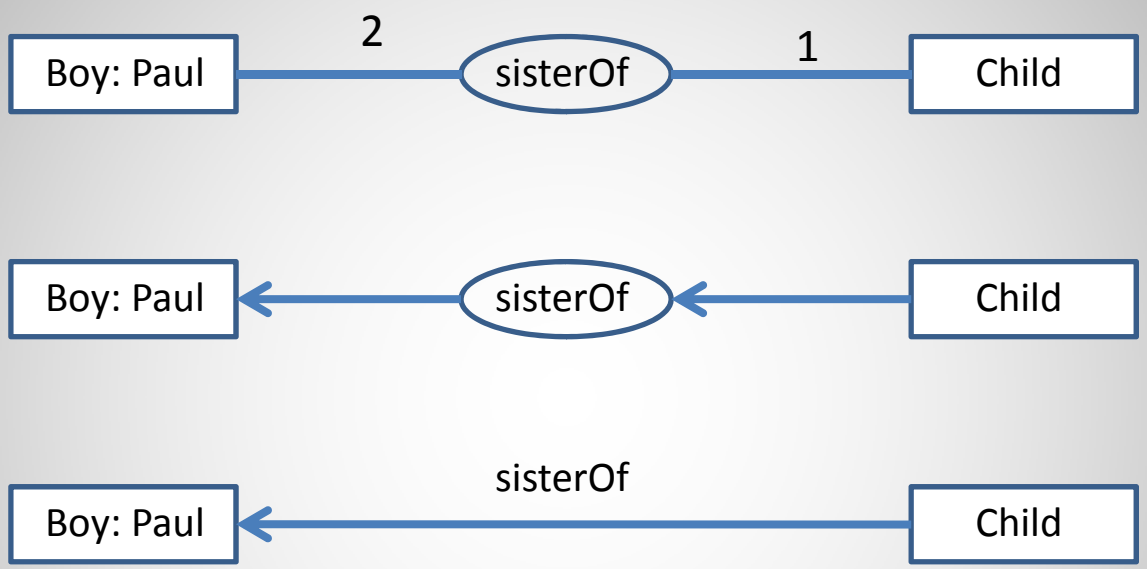
GBKR Sketchy Genealogy



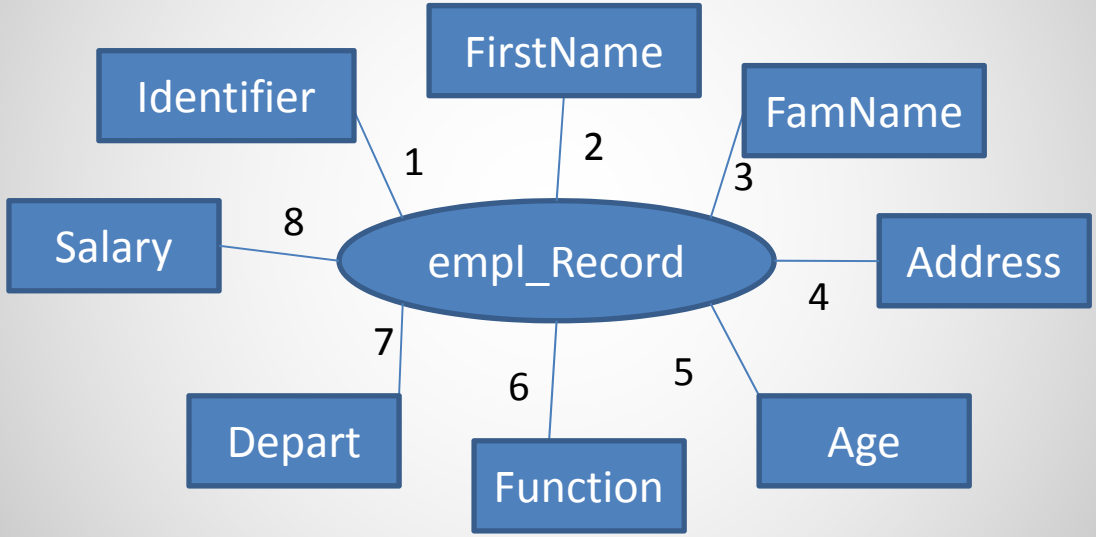
GBKR Basic graph 1



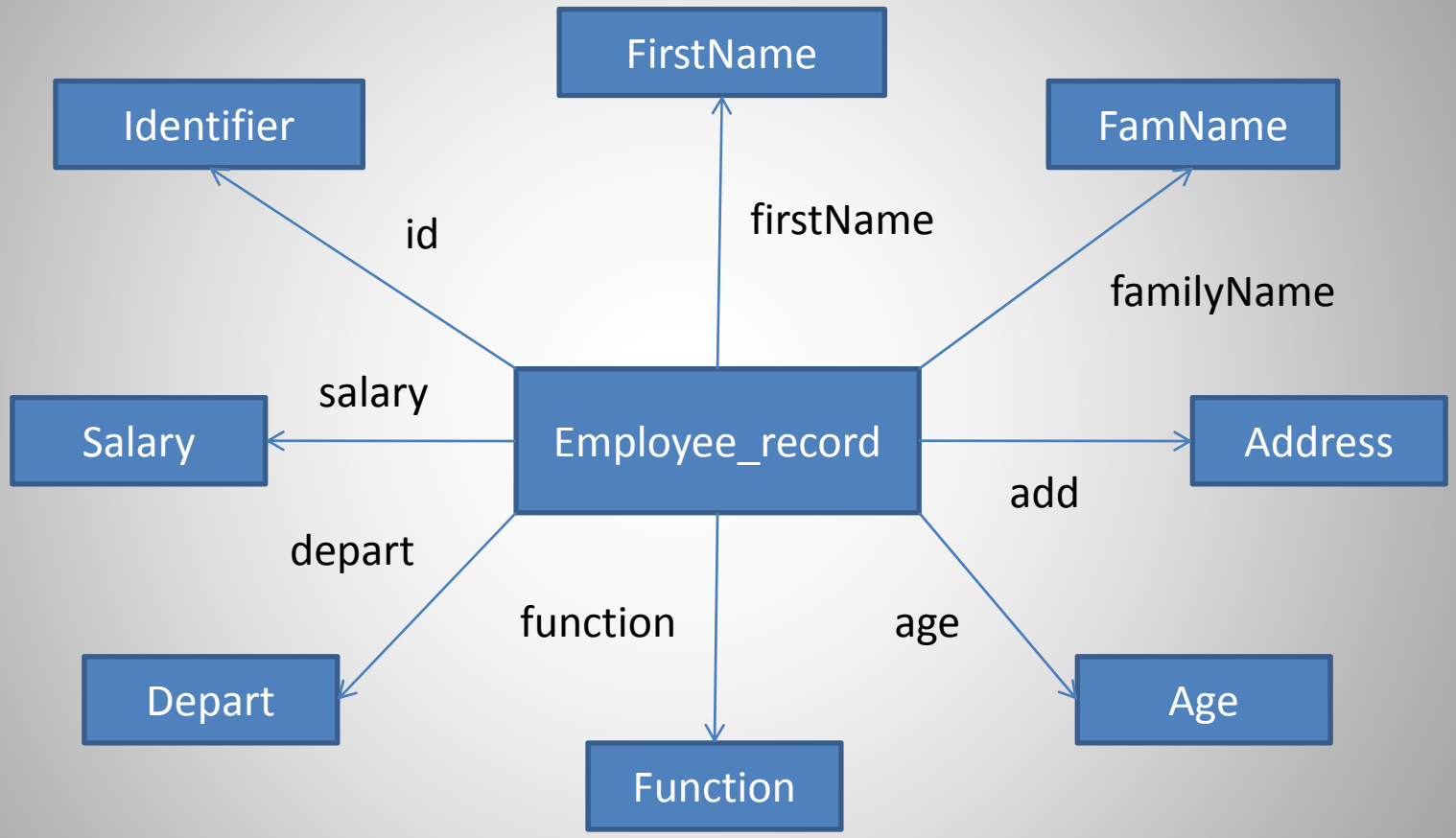
GBKR Basic graph 2



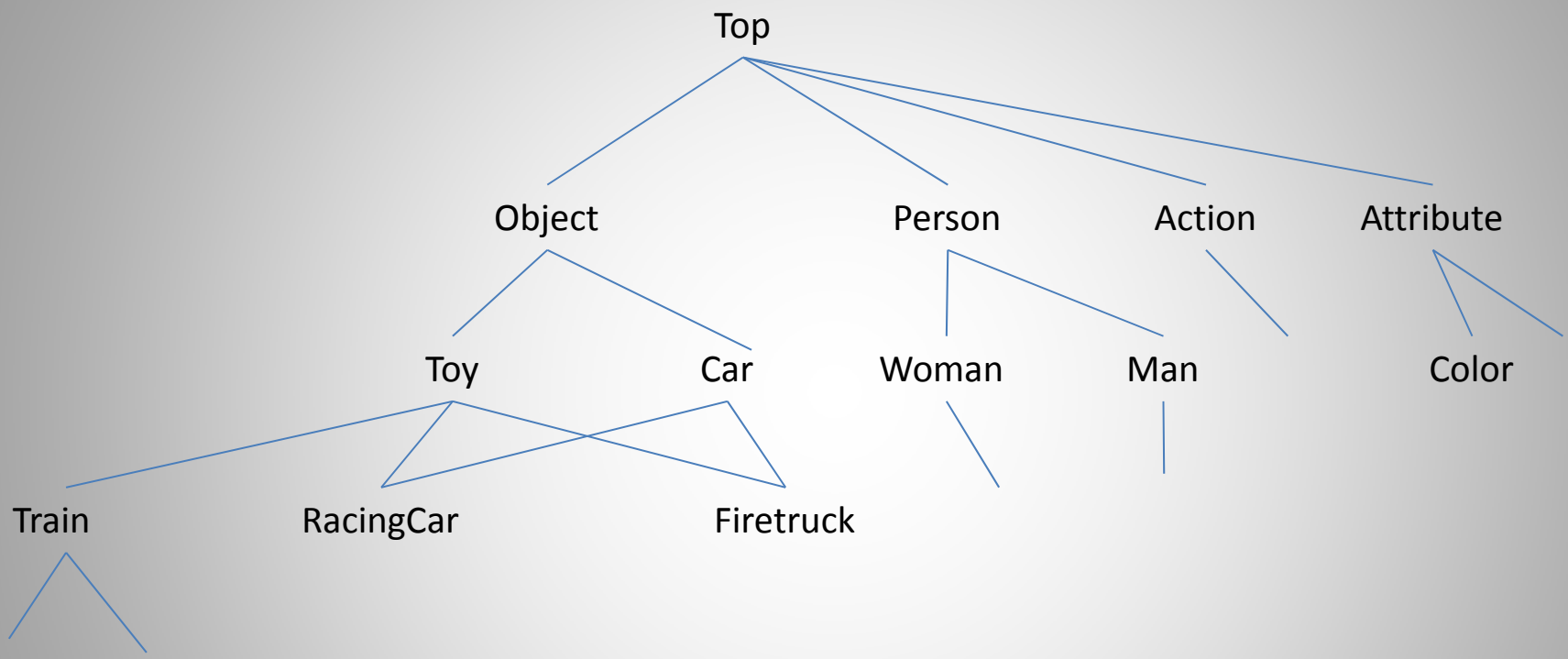
GBKR n-ary relation



GBKR binary role relations

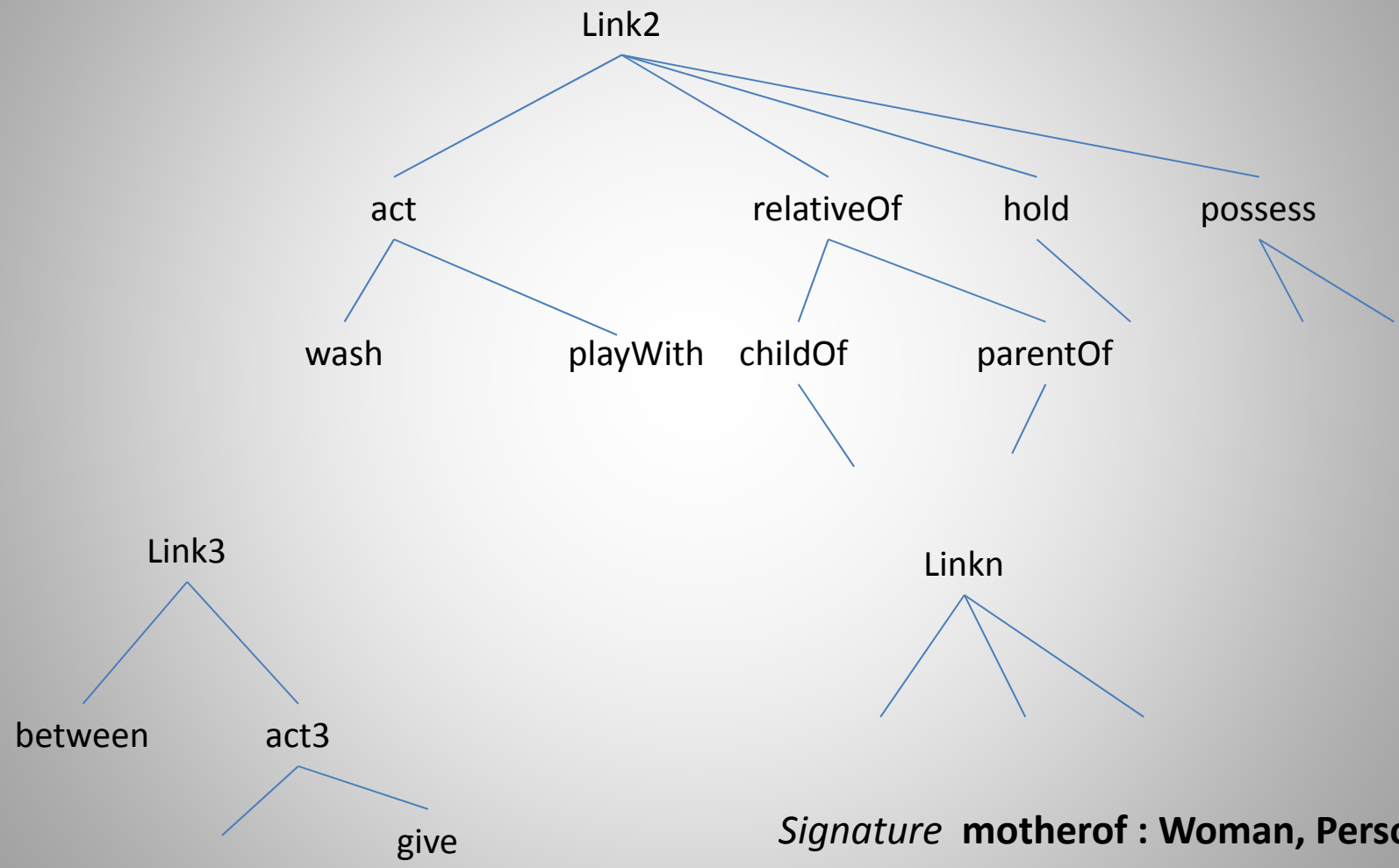


GBKR vocabulary 1



Individuals : Paul is a Boy, Doudou is a Cuddly_Toy, Garfield is a Cat …

GBKR vocabulary 2



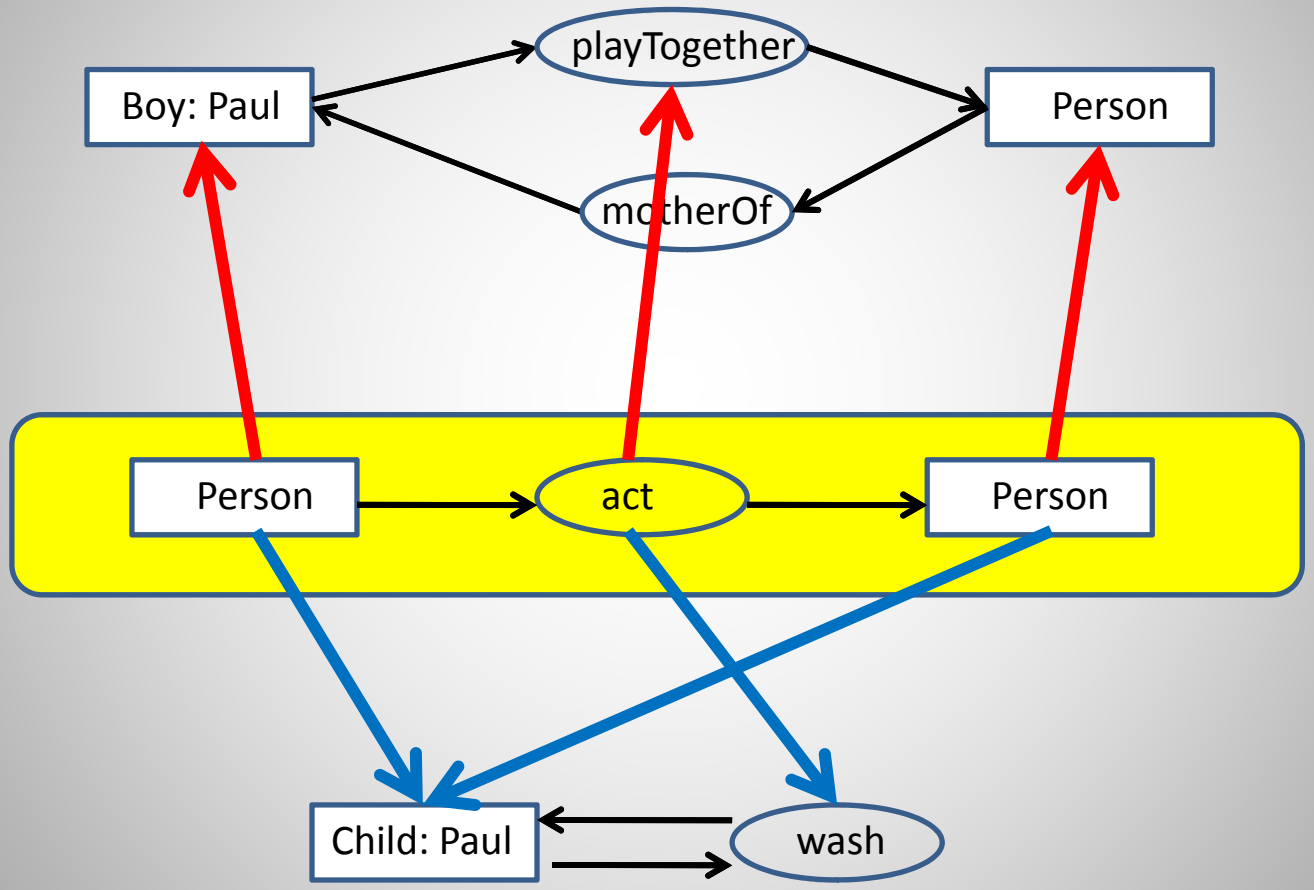
Signature **motherof : Woman, Person**

GBKR vocabulary 3

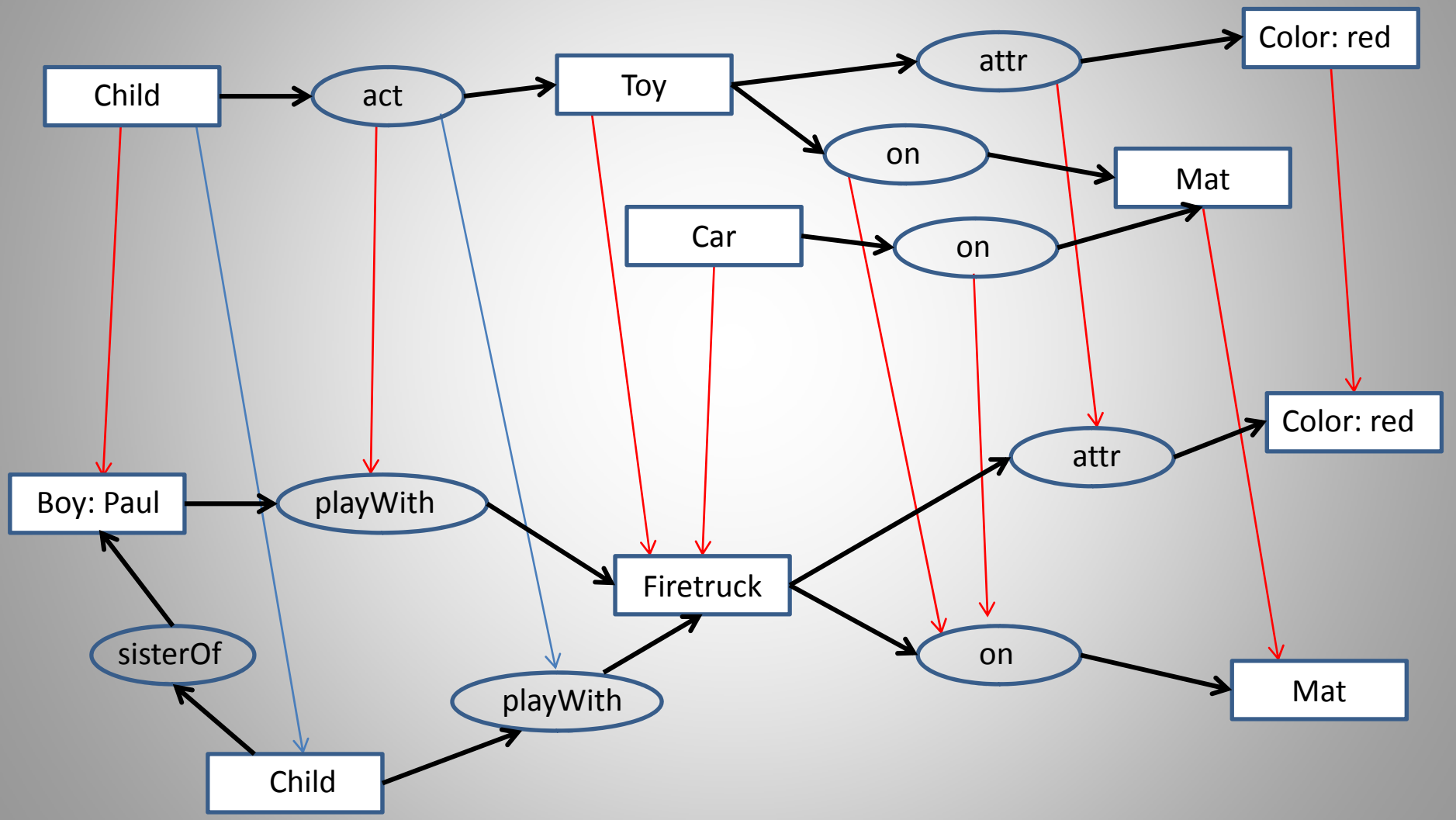
Vocabulary: a light-weight ontology

- hierachies of concept types (classes) and relations
- hierarchical orders: any partial order
- « a kind of » is distinct form « is instance of »
- n-ary relations, $n \geq 1$
- signature of relations (e.g. domain and range for binary)

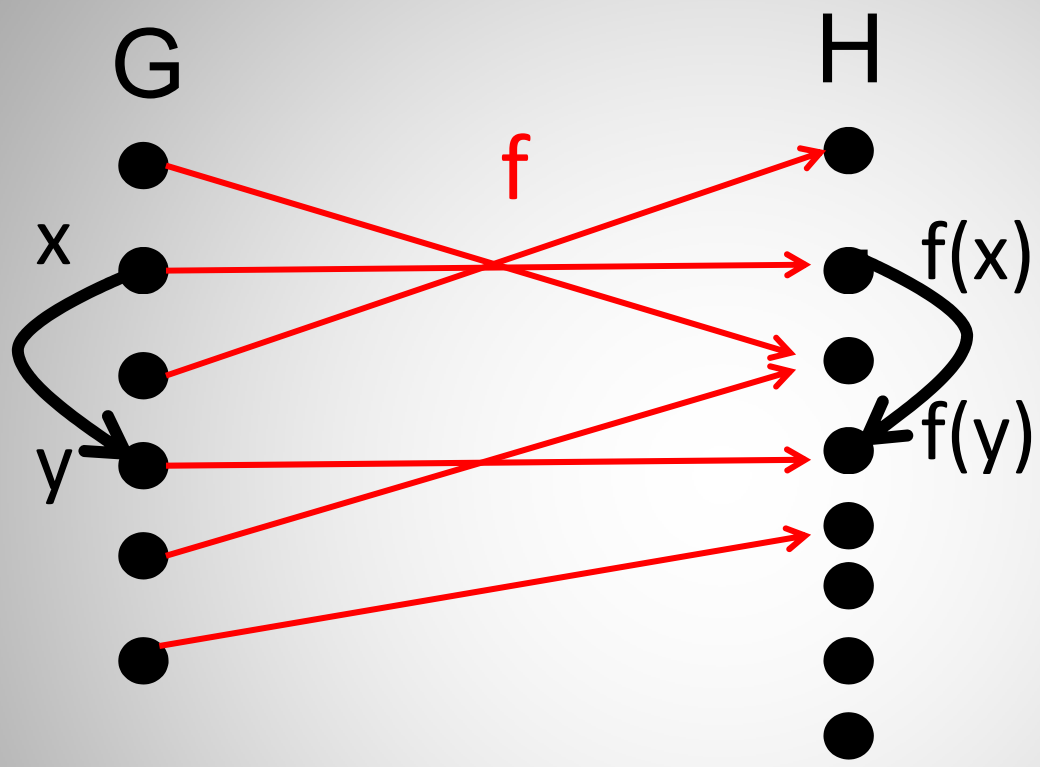
GBKR query/answer 1



GBKR query/answer 2

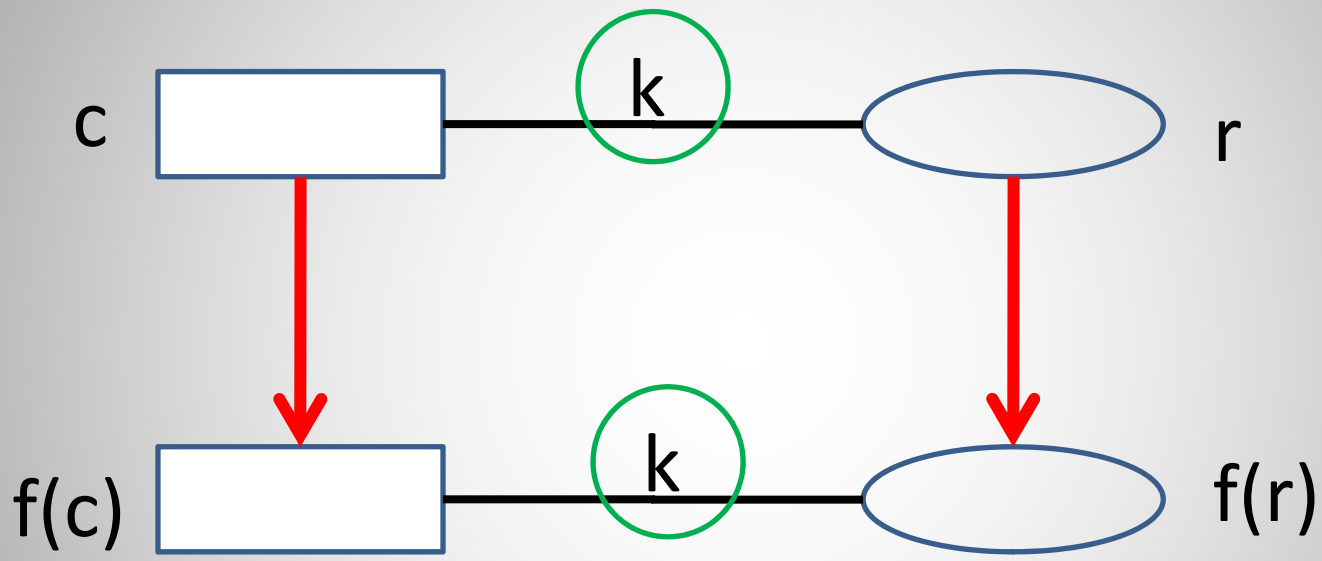


GBKR graph homomorphism 1



xy arc in G $\Rightarrow$ f(x)f(y) arc in H

GBKR graph homomorphism 2



label(c)≥ label(f(c)) (e.g. Person ≥ (Boy, Paul))

label(r)≥ label(f(r)) (e.g. act ≥ playWith)

GBKR graph homomorphism 3

Subsumption relation between graphs

G subsumes H if there is a hom from G to H

Fundamental for structuring a set of graphs

Preorder

Minimal (irredundant) graph

Basis for other operations

GBKR graph homomorphism 4

Is there an homomorphism from G to H?

NP-complete

- Efficient backtrack algorithms
- Polynomial cases: G is a tree, tree-width bounded

Polynomial in data complexity

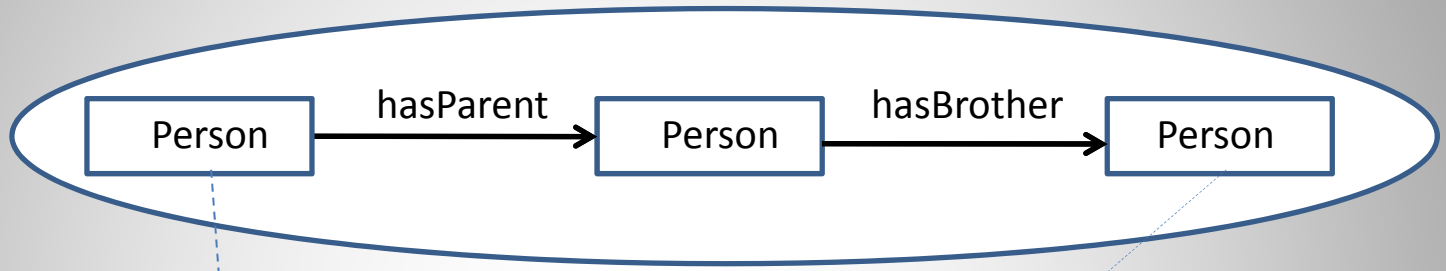
- Size of G not considered

GBKR rules 1

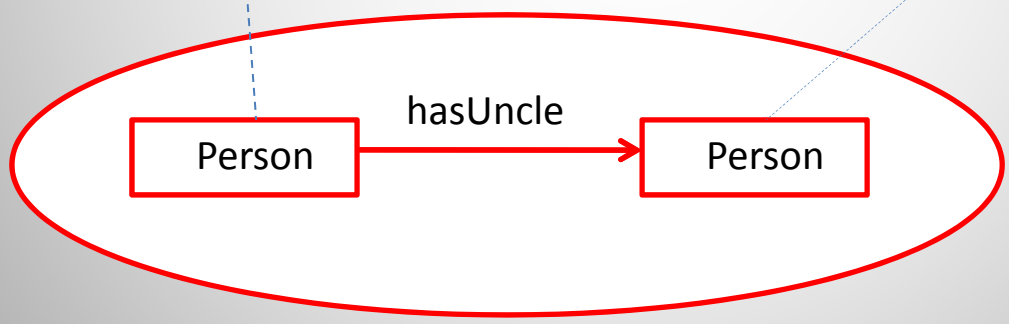
- Fundamental component in knowledge-based systems
- **If** hypothesis H **then** conclusion C
- **If** a piece of knowledge H is present
  then the piece of knowledge C can be added
- Represent general implicit knowledge
- Forward chaining
- Backward chaining

GBKR rules 2

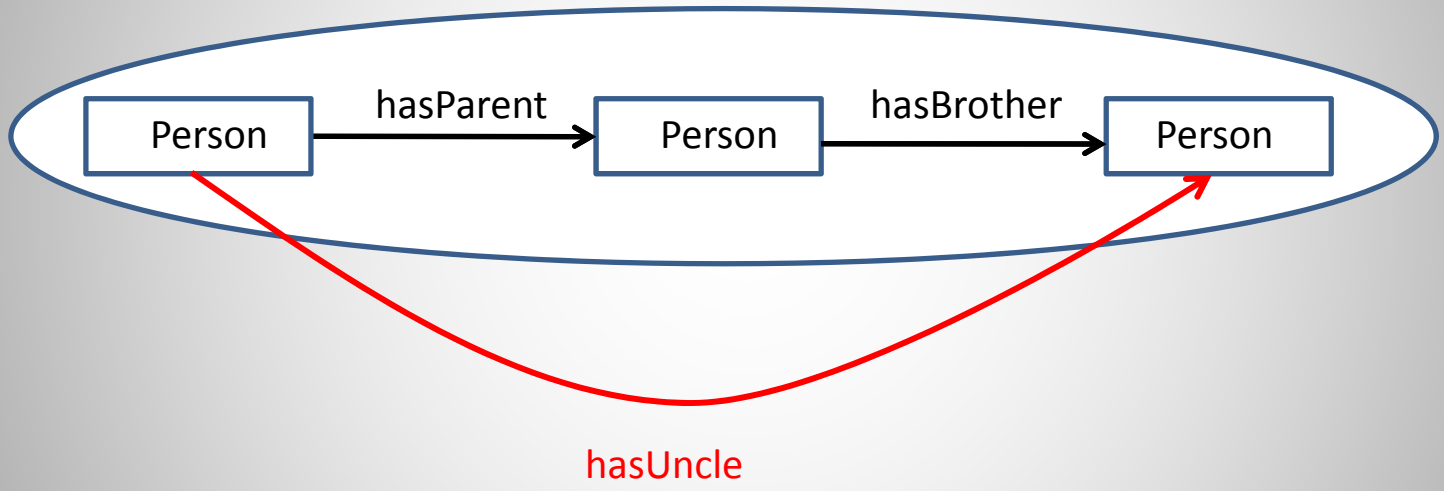
IF



THEN

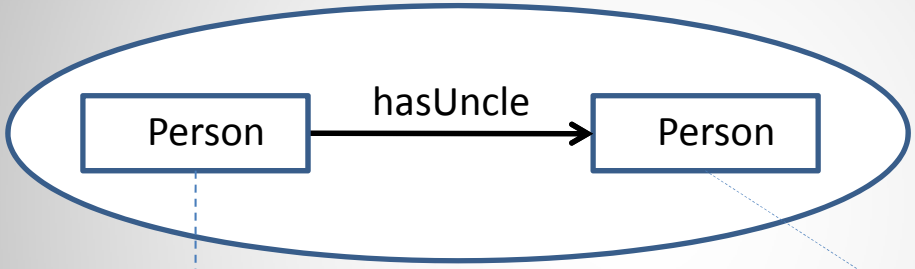


GBKR rules 3



GBKR rules 4

IF



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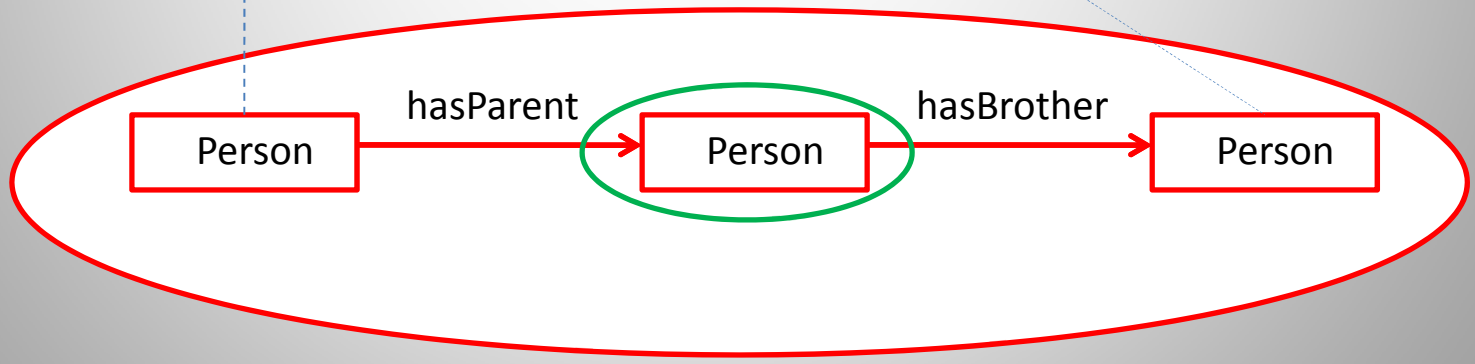
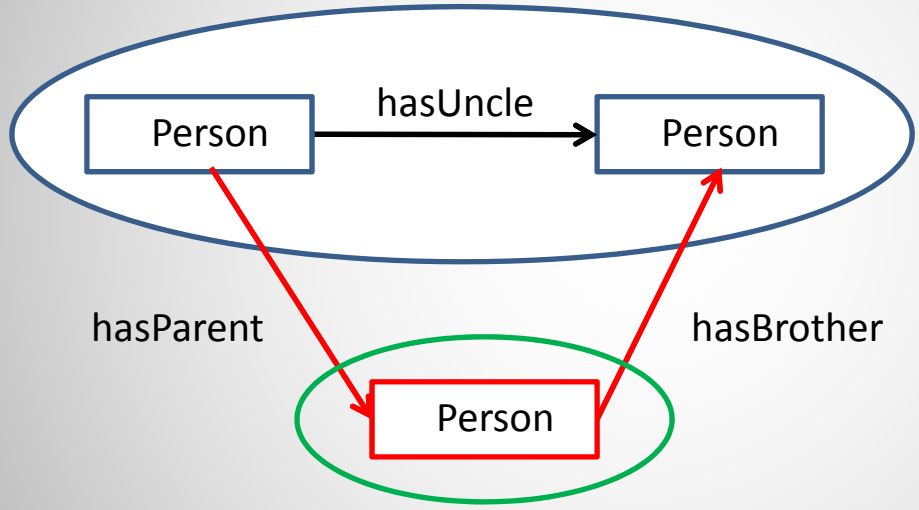
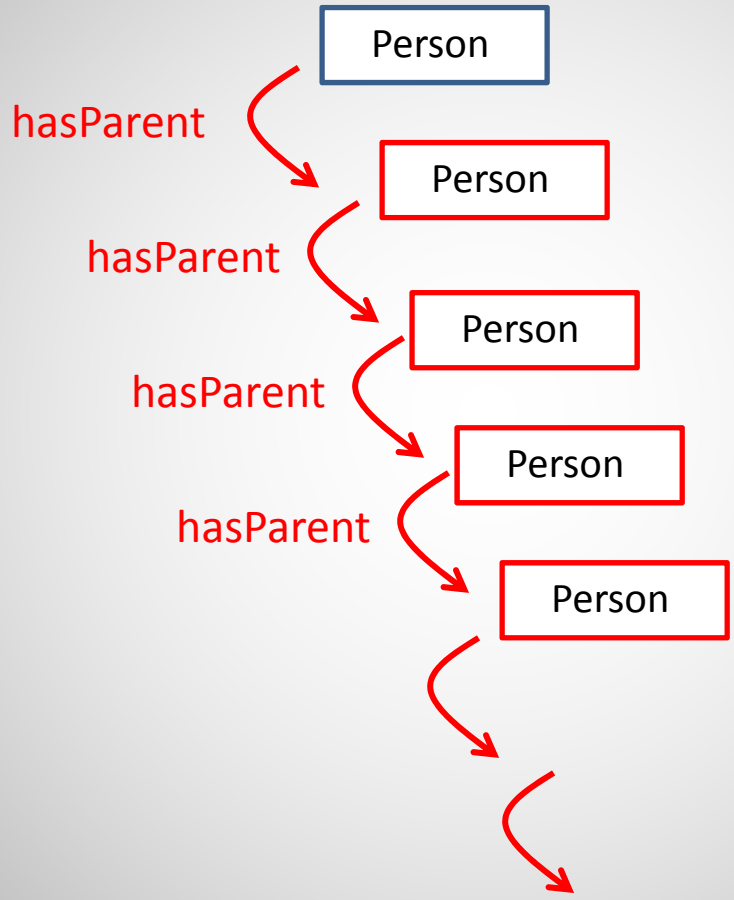


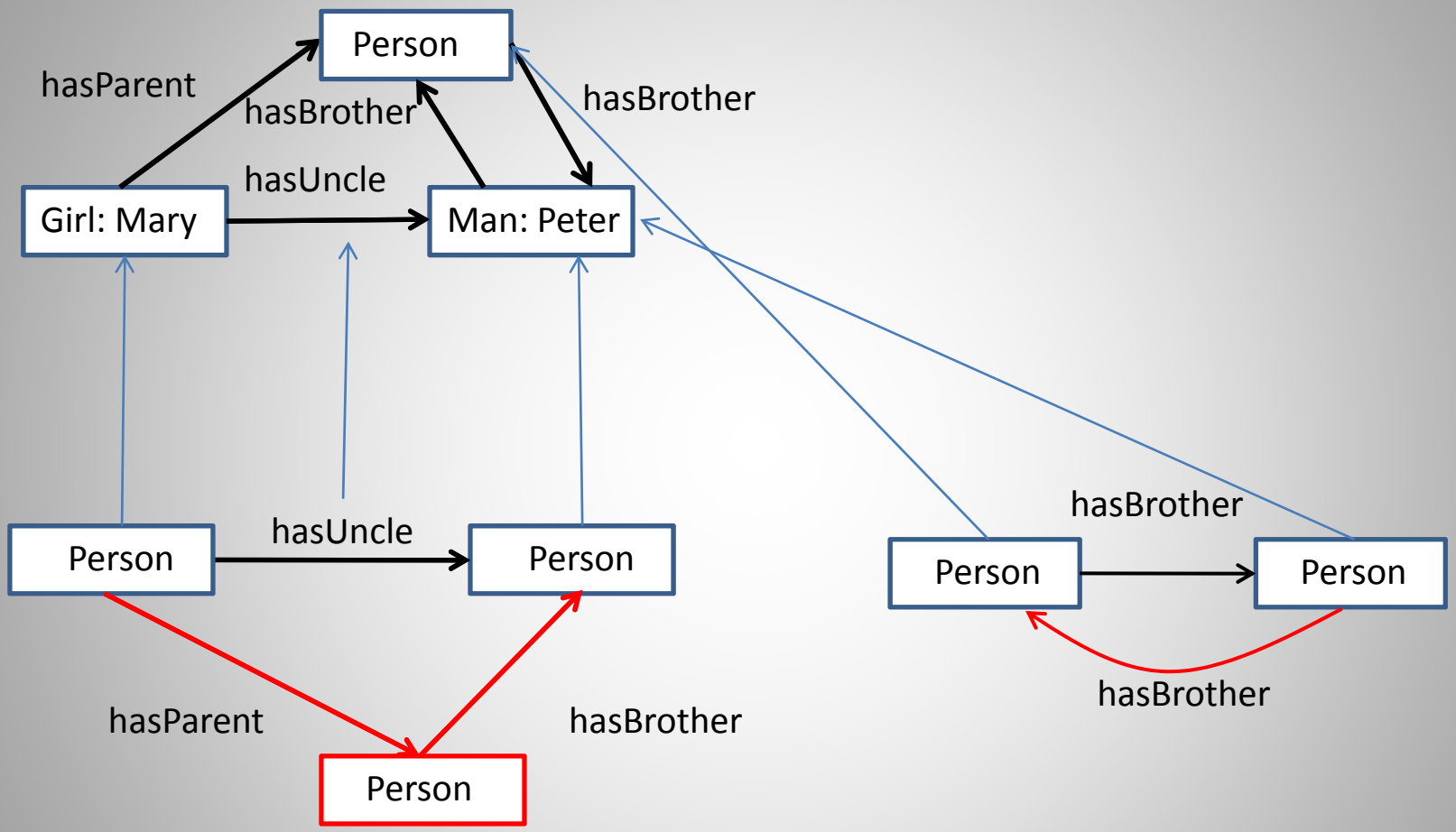
GBKR rules 4



GBKR rules 5


Person
hasParent
Person
hasParent
Person
hasParent
Person
hasParent
Person

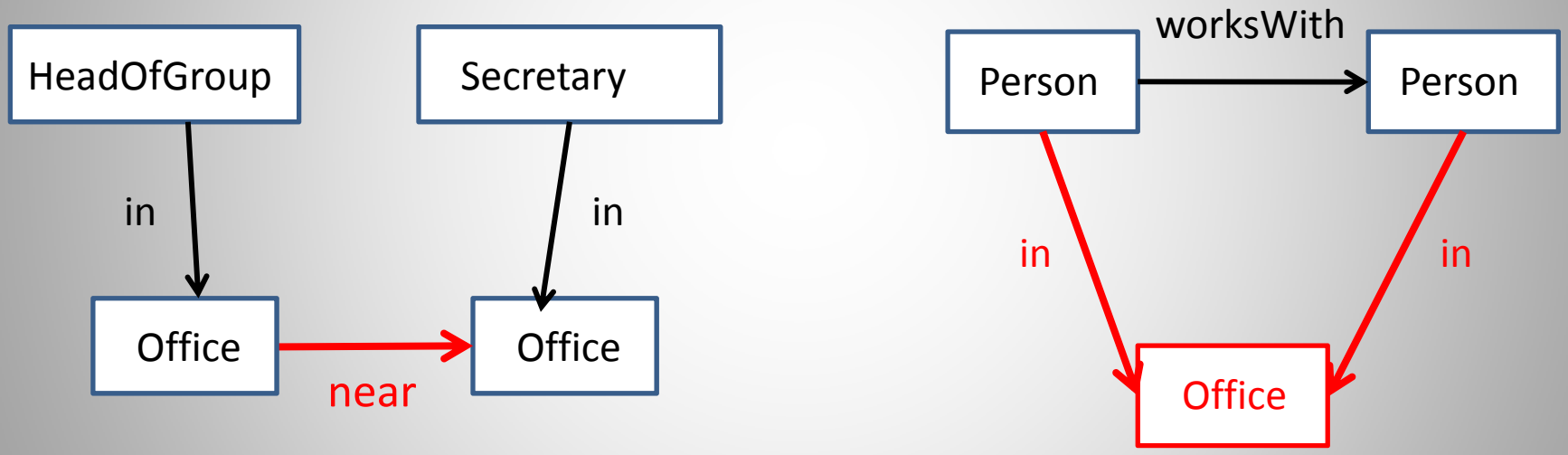
GBKR rules 7


Person
hasParent
hasBrother
hasBrother
hasUncle
Girl: Mary
Man: Peter
hasBrother
Person
hasUncle
Person
Person
Person
hasBrother
hasBrother
hasParent
hasBrother
Person

GBKR rules 6

- Equivalent to TGDs in relational databases
- New results obtained with graph viewpoint
- Backward chaining
- Computability/Complexity

GBKR constraints



GBKR other constructs

Conjunctive types
Equality
Nested graphs
Atomic negation
Type definitions
Operations: joins, …

GBKR hierarchy of models

F an initial world , V a vocabulary, C a set of constraints, R a set of inference rules, E a set of evolution rules (to make evolve a consistent world into a new consistent one)

F is Q deducible from (F,V)?

FC does F satisfies C and is Q deducible from (F,V)?

FR is Q deducible from (F_k ,V)? where F_k is a R-derivation of F

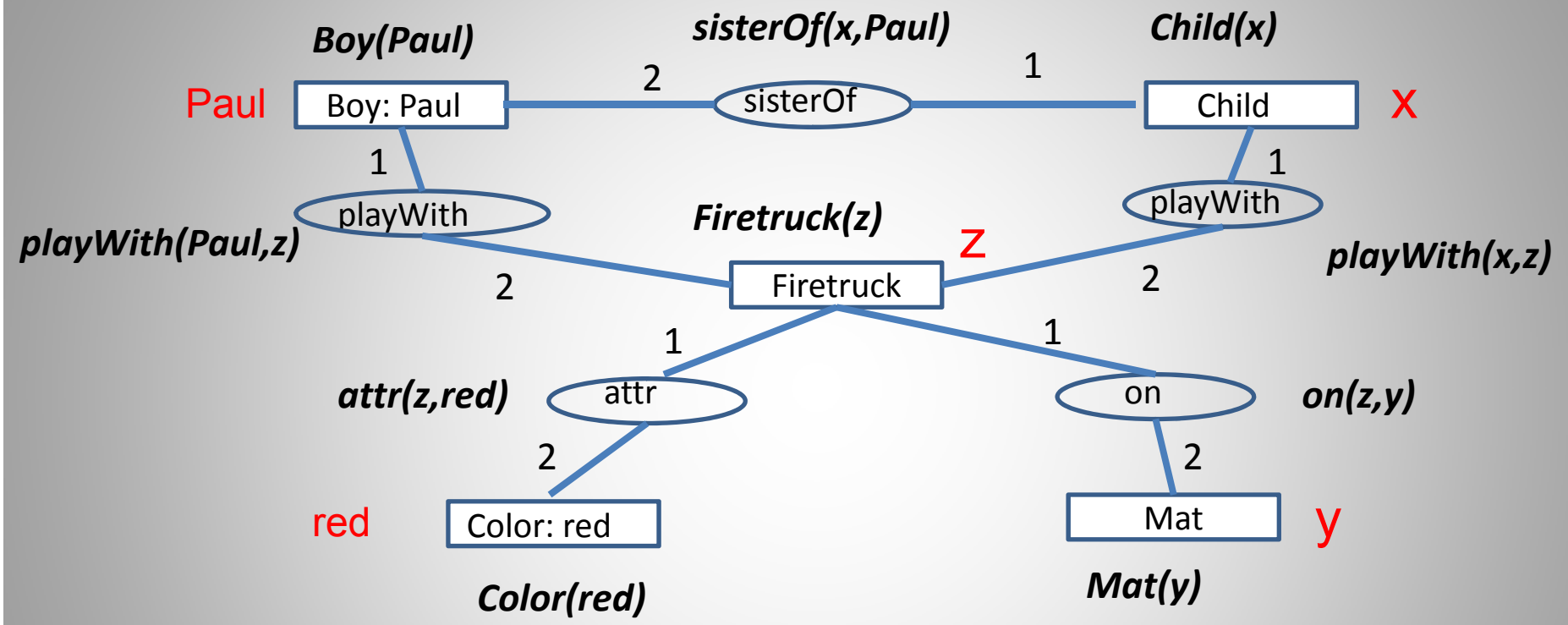
FCR does (F,R) satisfies C and is Q deducible from (F,R)?

FCE does (F,E) satisfies C and is Q deducible from (F,E)?

FRCE deduction pb asks wether F can evolve into a consistent world satisfying the goal Q.

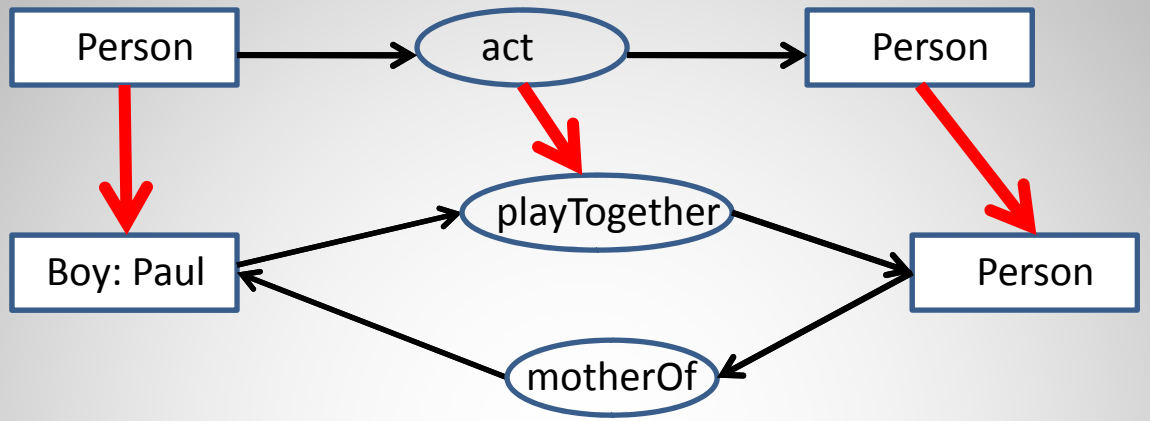
Pause!

GBKR FOL semantics 1



Φ(G)=∃x∃y∃zChild(x)∧Mat(y)∧Firetruck(z)∧Boy(Paul)∧Color(red)∧ sisterOf(x, Paul)∧playWith(Paul, z)∧playWith(x, z)∧attr(z, red)∧on(z,y)

GBKR FOL semantics 2



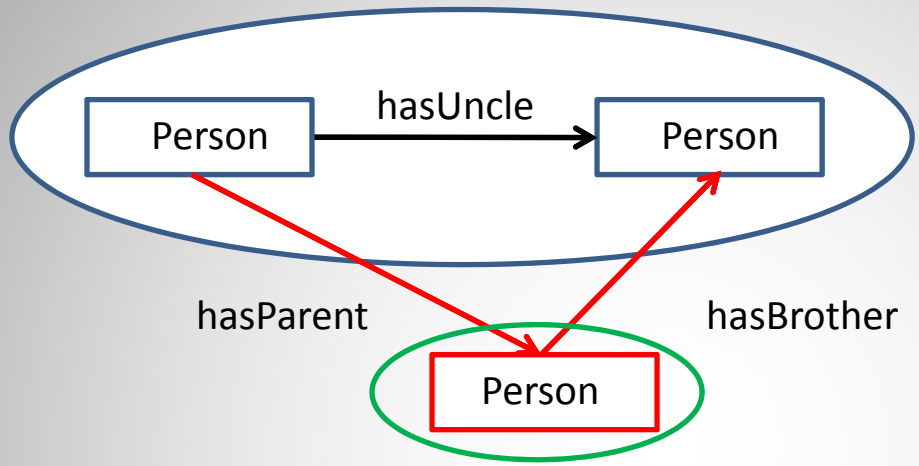
$(\forall x Boy(x) \rightarrow Person(x)) \wedge (\forall x \forall y playTogether(x,y) \rightarrow act(x,y)) \wedge$

$\exists x\ (Boy(Paul) \wedge Person(x) \wedge playTogether(Paul,x) \wedge motherOf(x,Paul)\ )$

$\rightarrow$

$\exists x\ \exists y Person(x) \wedge Person(y) \wedge act(x,y)$

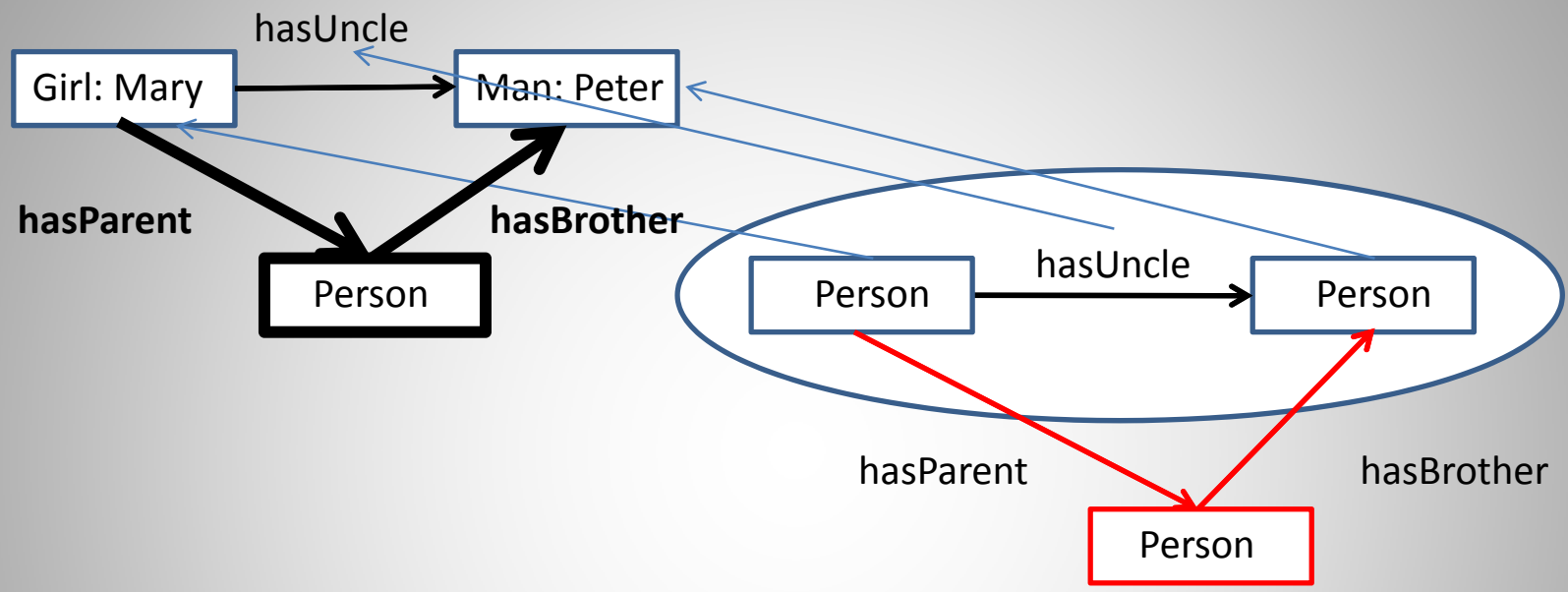
GBKR FOL semantics 3



$$\forall x \forall y \Big((\text{Person}(x) \wedge \text{Person}(y) \wedge \text{hasUncle}(x,y)) \rightarrow$$

$$\exists z \text{Person}(z) \wedge \text{hasParent}(x,z) \wedge \text{hasBrother}(z,y) \Big)$$

GBKR FOL semantics 4



$\forall x(Girl(x) \rightarrow Person(x)) \wedge \forall x(Man(x) \rightarrow Person(x)) \wedge$

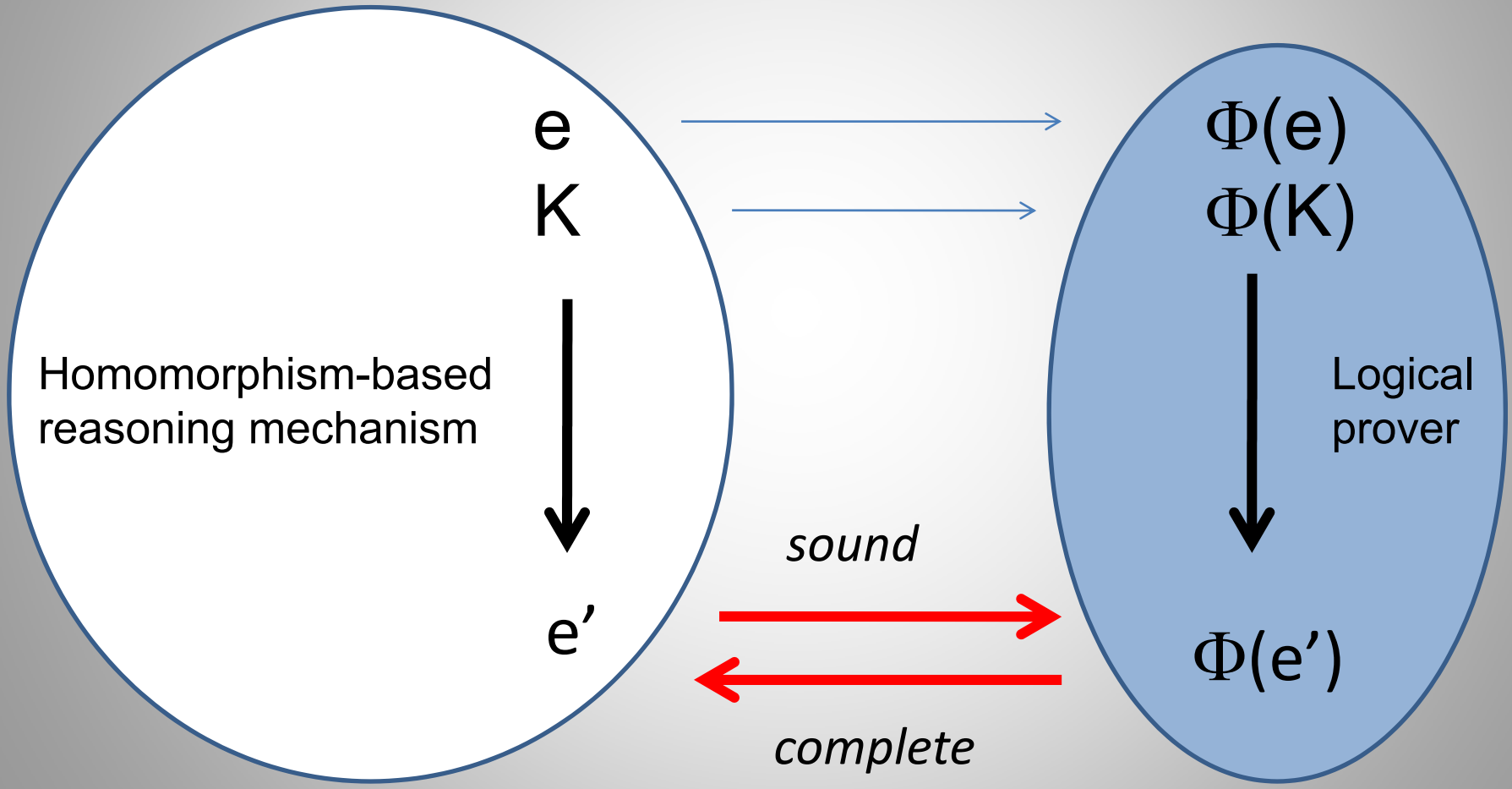
$\forall x \forall y(Person(x) \wedge Person(y) \wedge hasUncle(x,y) \rightarrow \exists z Person(z) \wedge hasParent(x,z) \wedge hasBrother(z,y)) \wedge$

$Girl(Mary) \wedge Man(Peter) \wedge hasUncle(Mary,Peter)$

$\rightarrow$

$\exists z Person(z) \wedge hasParent(Mary,z) \wedge hasBrother(z,Peter)$

GBKR Soundness and completeness



GBKR equivalent formalisms 2

Large variety of graphs
Directed graphs, undirected graphs,
multigraphs, labeled graphs, hypergraphs

Transformations of one kind to another
Polynomial reductions for homomorphism problems
Parsimonious equivalence between some of them especially:
Homomorphism for GBKR graphs and
Homomorphism for simple unlabeled (directed or undirected) graphs

GBKR equivalent formalisms 3

Relational structures and relational databases

Query evaluation problem
Instance: a database instance D and a conjunctive query q
Question: Does D contain an answer to q?

Query containment problem
Instance: two queries q and q'?
Question: for any D does q(D) contain q'(D)?

These pbs are polynomially equivalent to GBKR graph hom

GBKR equivalent formalisms 4

Constraint satisfaction problem

Variables $x_1, \ldots, x_n$

Domains $D_1, \ldots, D_n$

Constraints $C_1, \ldots, C_k$

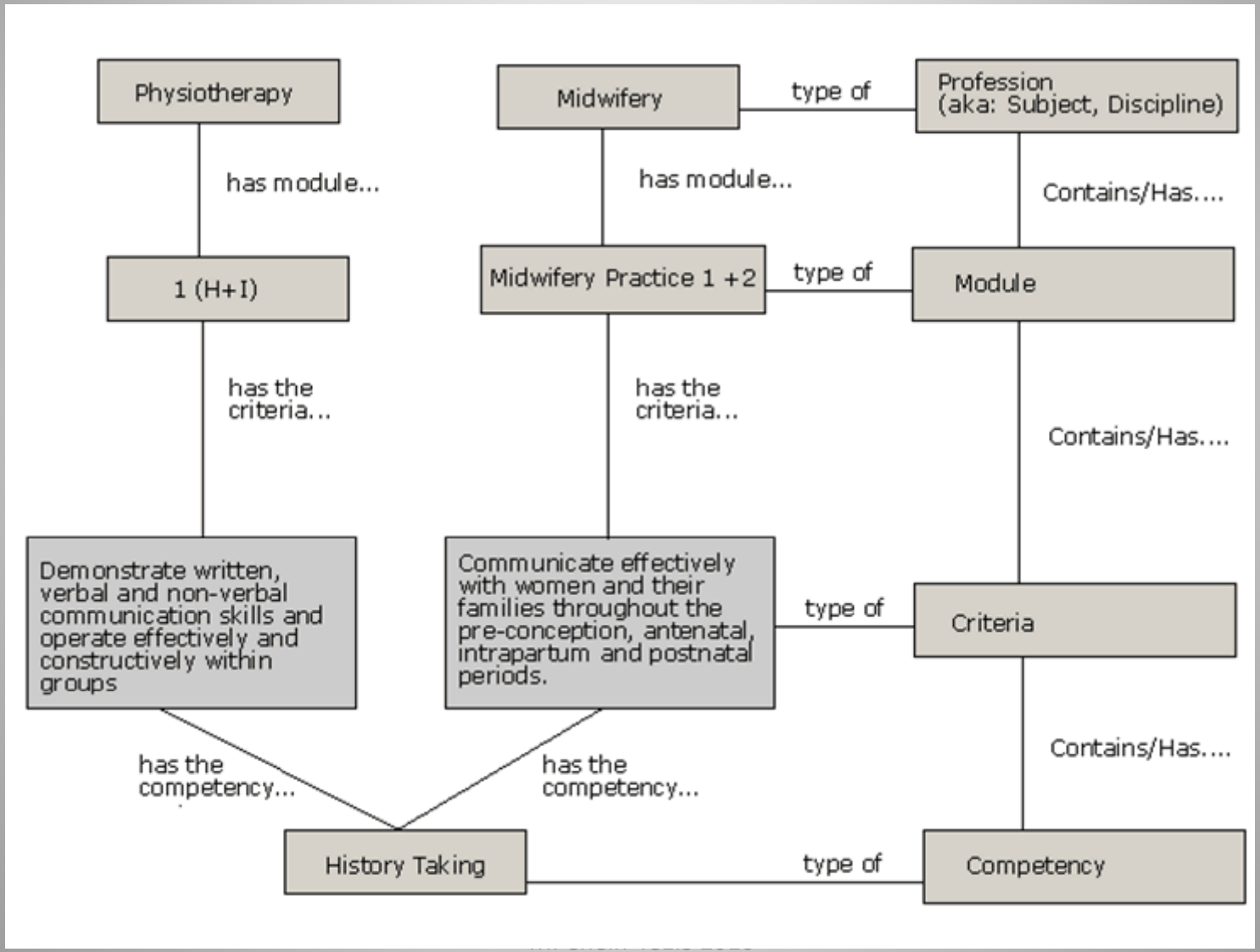
Solution: an assigment of the variables satisfying the constraints

Parsimonious reduction between CSP and BH-homomorphism

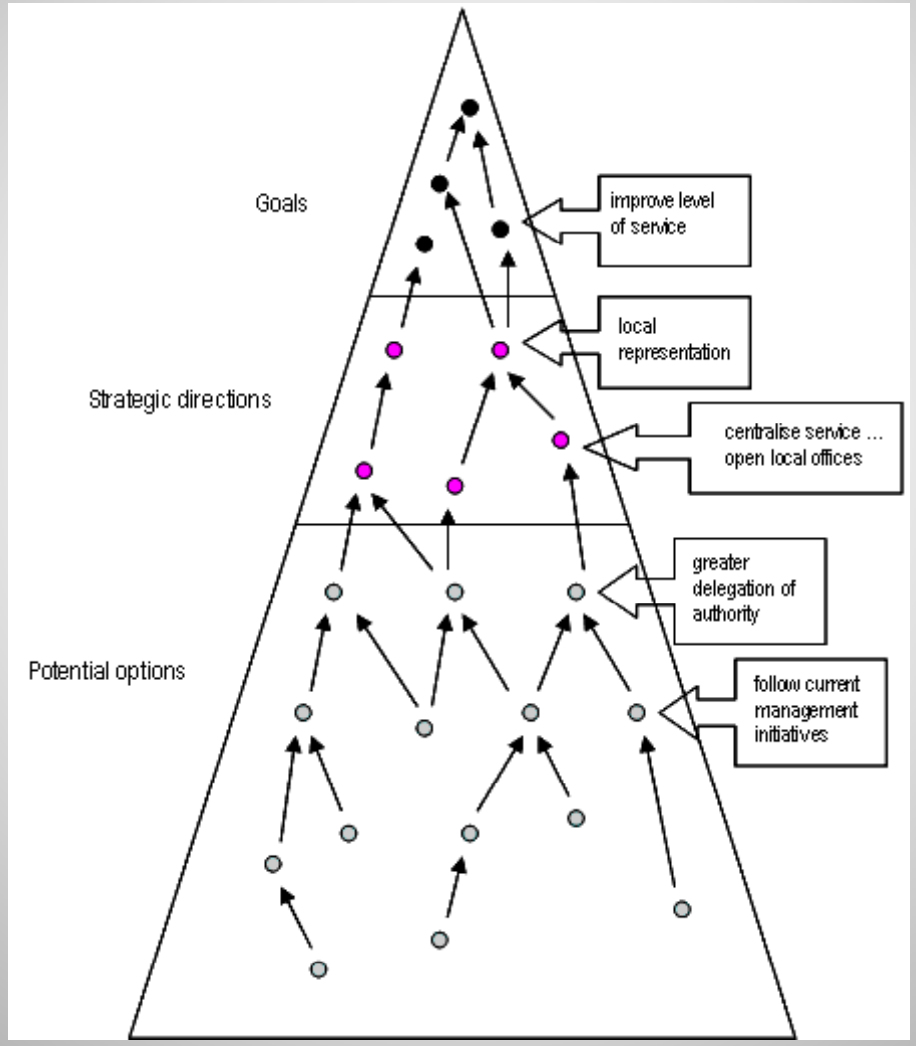
Graph(ical) Models

- Semantic Networks
- Entity-Relationship Model
- KL-One
- UML

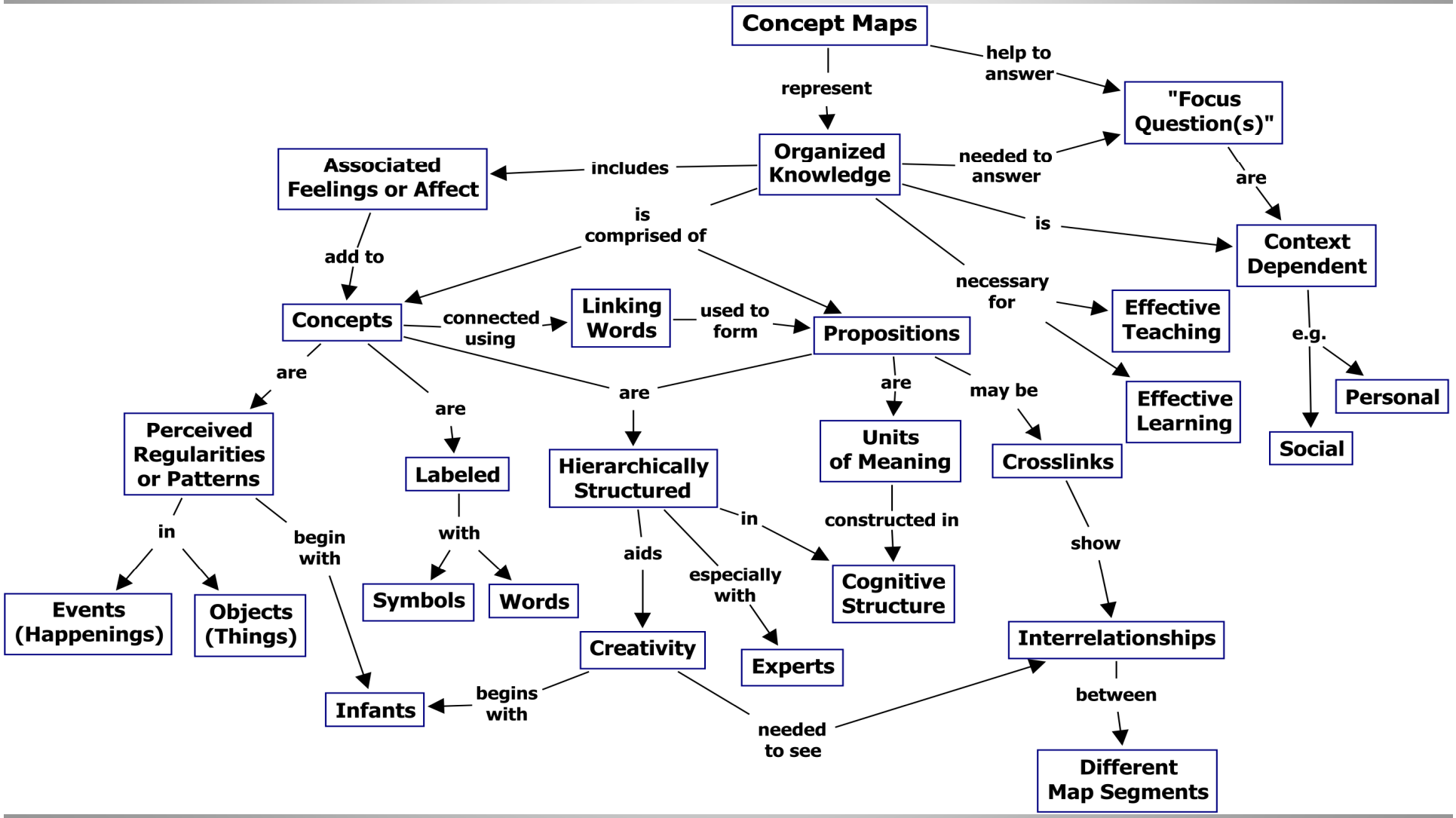
Topic Maps


Physiotherapy
has module...
1 (H+I)
has the criteria...
Demonstrate written, verbal and non-verbal communication skills and operate effectively and constructively within groups
has the competency...
Midwifery
type of
Profession (aka: Subject, Discipline)
has module...
Contains/Has....
Midwifery Practice 1 +2
type of
Module
has the criteria...
Contains/Has....
Communicate effectively with women and their families throughout the pre-conception, antenatal, intrapartum and postnatal periods.
type of
Criteria
has the competency...
Contains/Has....
History Taking
type of
Competency

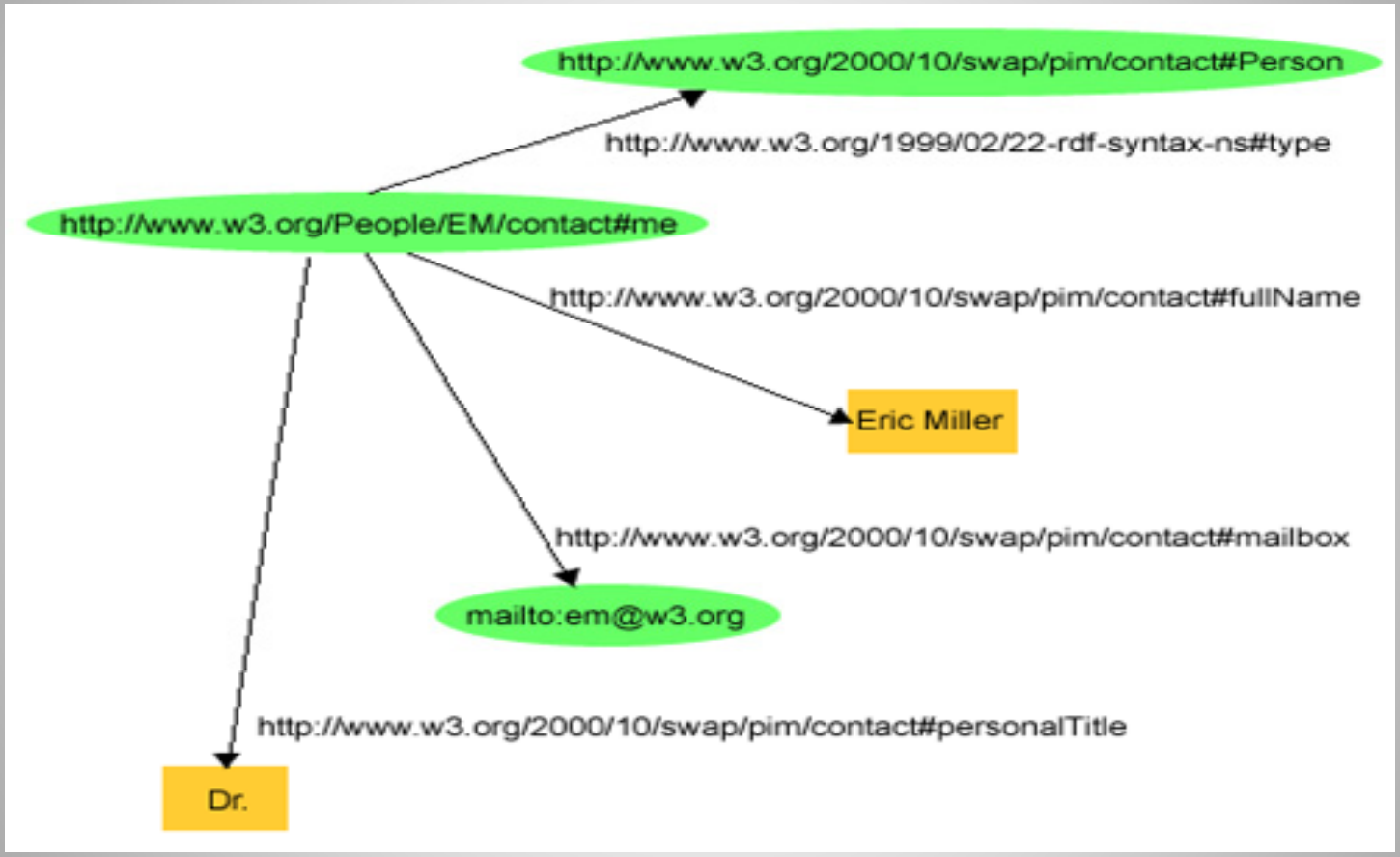
Cognitive Maps



Concept Maps



RDF/S


http://www.w3.org/2000/10/swap/pim/contact#Person
http://www.w3.org/1999/02/22-rdf-syntax-ns#type
http://www.w3.org/People/EM/contact#me
http://www.w3.org/2000/10/swap/pim/contact#fullName
Eric Miller
http://www.w3.org/2000/10/swap/pim/contact#mailbox
mailto:em@w3.org
http://www.w3.org/2000/10/swap/pim/contact#personalTitle
Dr.

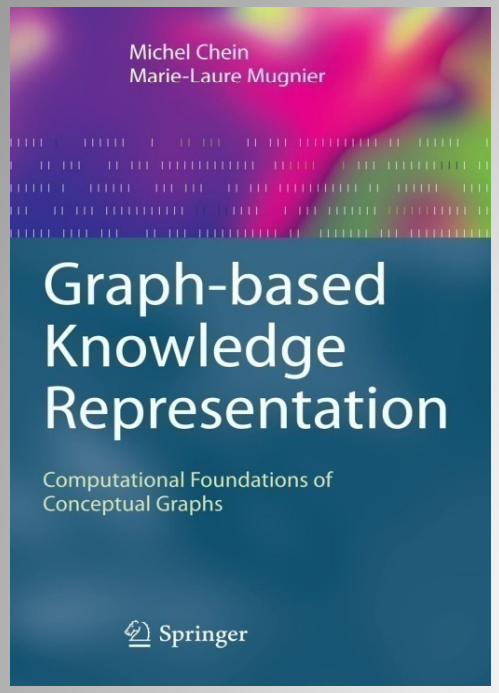
Strengths

- Formal semantics (FOL or model theory)
- Structured representation of knowledge
- Good computational properties
- Numerous algos
- Diagrammatic/Linear
- Visual aspects GUI easily interpreted
- Support for intuition

Weaknesses

- Diagrammatic/Linear
  - Ambiguity in interpretation, a formal (linear !) semantics is needed
- Visual aspects
  - difficulty large or automatically built graphs
- Support for intuition
  - imprecision (modality)

Difficulty to build a relevant ontology



COGUI **http://www.lirmm.fr/cogui/**

GUI, developed in Java, for building GBKR knowledge bases

COGXML format, COGITANT compatible

There is a translator from and to RDF(S)

COGITANT **http://cogitant.sourceforge.net/**

Library of *C++* classes build applications based on the GBKR model.

Classes for each object of the model (vocabulary, graph, rule, constraint...)

and for the main operations of the model (homomorphism, application of rules...).

Thank you for your attention!

GBKR equivalent formalisms 1

Parsimonious reduction

A polynomial reduction from P1 to P2 is ***parsimonious*** if the number of solutions of any YES instance of P1 is equal to the number of solutions of its corresponding YES instance of P2

Parsimonious equivalence

Two problems P1 and P2 are ***parsimoniously equivalent*** if each of them is parsimoniously reducible to the other

Description Logics

- Rooted in frames and semantic networks
- Remedy critiques on their ancestors
  - distinction between ontology and facts
  - provided with FOL semantics
- Small intersection
  - rooted trees with binary relations
  - DL tailored for the comparison ELIRO1

Difficulty to build a knowledge base manually and a fortiori automatically

GBKR hierarchy of models

$\mathcal{F}$ is Q deducible from $(\mathcal{F},\mathcal{V})$?

$\mathcal{F}$ describes an initial world and $\mathcal{V}$ a vocabulary

$\mathcal{FC}$ does $\mathcal{F}$ satisfies C and is Q deducible from $(\mathcal{F},\mathcal{V})$?

$\mathcal{C}$ constraints define the consistency of a world

$\mathcal{FR}$ is Q deducible from $(\mathcal{F}_k,\mathcal{V})$ where $\mathcal{F}_k$ is a $\mathcal{R}$-derivation of $\mathcal{F}$?

$\mathcal{R}$ inference rules complete the description of any world

$\mathcal{FCR}$ does $(\mathcal{F},\mathcal{R})$ satisfies $\mathcal{C}$ and is Q deducible from $(\mathcal{F},\mathcal{R})$?

$\mathcal{FCE}$ does $(\mathcal{F},\mathcal{E})$ satisfies $\mathcal{C}$ and is Q deducible from $(\mathcal{F},\mathcal{E})$?

$\mathcal{E}$ evolution rules try to make evolve a consistent world into a new consistent one

$$\mathcal{FRCE}$$

The deduction pb asks wether $\mathcal{F}$ can evolve into a consistent world satisfying the goal Q.