GBKR

A Graph-Based Knowledge Representation and Reasoning Model
Agenda

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

Inference mechanism

Logical prover

sound

complete
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
Good computational properties

• Efficient algorithms

• Human computer interface
GBKR Basic graph 1
GBKR Basic graph 2

Boy: Paul sisterOf 2 Child

Boy: Paul sisterOf Child

Boy: Paul sisterOf Child
GBKR binary role relations

- Identifier
- FamName
- Salary
- Depart
- Function
- Address
- Age
GBK R vocabulary 1

Individuals: Paul is a Boy, Doudou is a Cuddly_Toy, Garfield is a Cat ...
GBKR vocabulary 2

Signature motherof : Woman, Person

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Vocabulary: a light-weight ontology

- hierarchies 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)
Boy: Paul

Boy: Paul playTogether Person

Boy: Paul motherOf Person

Person

Boy: Paul act Person

Person

Child: Paul

Child: Paul wash

GBKR query/answer 1
$xy$ arc in $G \Rightarrow f(x)f(y)$ arc in $H$
label(c) ≥ label(f(c)) (e.g. Person ≥ (Boy, Paul))
label(r) ≥ label(f(r)) (e.g. act ≥ playWith)
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
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

Person hasParent Person hasBrother Person

THEN

Person hasUncle Person
GBKR rules 3

Person hasParent Person hasBrother Person

hasUncle
GBKR rules 4

IF

Person hasUncle Person

THEN

Person hasParent Person hasBrother Person
GBKR rules 4

Person hasUncle Person

Person hasParent Person
Person hasBrother Person
GBK rules 5

Person

hasParent

Person

hasParent

Person

hasParent

Person

hasParent

Person
GBKR rules 7

- Girl: Mary
- Man: Peter
- Person
- Person
- Person

Relationships:
- hasParent
- hasBrother
- hasUncle
- hasBrother
GBKR rules 6

- Equivalent to TGDs in relational databases
- New results obtained with graph viewpoint
- Backward chaining
- Computability/Complexity
Conjunctive types
Equality
Nested graphs
Atomic negation
Type definitions
Operations: joins, ...
GBK 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 whether \( F \) can evolve into a consistent world satisfying the goal \( Q \).
Pause!
\[ \Phi(G) = \exists x \exists y \exists z \text{Child}(x) \land \text{Mat}(y) \land \text{Firetruck}(z) \land \text{Boy}(Paul) \land \text{Color(red)} \land \text{sisterOf}(x, Paul) \land \text{playWith}(Paul, z) \land \text{playWith}(x, z) \land \text{attr}(z, \text{red}) \land \text{on}(z, y) \]
$$(\forall x \text{Boy}(x) \rightarrow \text{Person}(x)) \land (\forall x \forall y \text{playTogether}(x,y) \rightarrow \text{act}(x,y))$$

$$\exists x (\text{Boy}(Paul) \land \text{Person}(x) \land \text{playTogether}(Paul,x) \land \text{motherOf}(x,Paul))$$

$$\rightarrow$$

$$\exists x \exists y \text{Person}(x) \land \text{Person}(y) \land \text{act}(x,y)$$
∀x∀y(Person(x) ∧ Person(y) ∧ hasUncle(x,y)) → ∃zPerson(z) ∧ hasParent(x,z) ∧ hasBrother(z,y)
∀x(Girl(x) → Person(x)) ∧ ∀x(Man(x) → Person(x)) ∧
∀x∀y(Person(x) ∧ Person(y) ∧ hasUncle(x, y) → ∃z Person(z) ∧ hasParent(x, z) ∧ hasBrother(z, y)) ∧

Girl(Mary) ∧ Man(Peter) ∧ hasUncle(Mary, Peter)

→

∃z Person(z) ∧ hasParent(Mary, z) ∧ hasBrother(z, Peter)
GBKR  Soundness and completeness

Homomorphism-based reasoning mechanism

e
K

\[ \Phi(e) \]

\[ \Phi(K) \]

Logical prover

\[ \Phi(e') \]

sound

complete

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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
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
**Constraint satisfaction problem**

*Variables* $x_1, \ldots, x_n$

*Domains* $D_1, \ldots, D_n$

*Constraints* $C_1, \ldots, C_k$

Solution: an assignment 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...
  - has the criteria...
    - Demonstrate written, verbal and non-verbal communication skills and operate effectively and constructively within groups

- Midwifery
  - has module...
  - has the criteria...
    - Communicate effectively with women and their families throughout the pre-conception, antenatal, intrapartum and postnatal periods.

- Midwifery Practice 1 + 2
  - type of Module
  - contains/has...

- Profession (aka: Subject, Discipline)
  - type of Module
  - contains/has...

- History Taking
  - type of Competency
  - contains/has...
Cognitive Maps

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RDF/S
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
GUI, developed in Java, for building GBKR knowledge bases
COGXML format, COGITANT compatible
There is a translator from and to RDF(S)

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!
Parsimonious reduction
A polynomial reduction from $P_1$ to $P_2$ is *parsimonious* if the number of solutions of any YES instance of $P_1$ is equal to the number of solutions of its corresponding YES instance of $P_2$.

Parsimonious equivalence
Two problems $P_1$ and $P_2$ 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

\( F \) is \( Q \) deducible from \((F, V)\)?

\( F \) describes an initial world and \( V \) a vocabulary

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

\( C \) constraints define the consistency of a world

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

\( R \) inference rules complete the description of any world

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

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

\( E \) evolution rules try to make evolve a consistent world into a new consistent one

\( FRCE \)

The deduction pb asks wether \( F \) can evolve into a consistent world satisfying the goal \( Q \).