A Brief History (in Relation to NLP) of Graphical Representation Languages and Logics

Work in Progress!

Sylvain Pogodalla

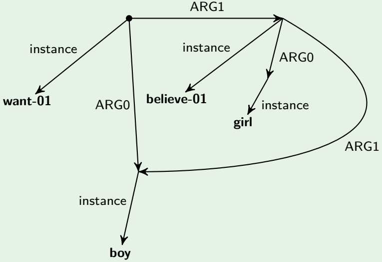
November 24th, 2020

Overview

Abstract Meaning Representation (*ca.* 2014)

(Banarescu et al. 2013; Banarescu et al. 2014)

The boy wants the girl to believe him.



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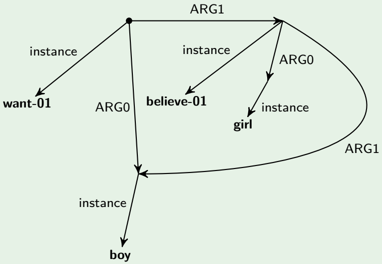

Banarescu et al. (2014)

AMR captures "who is doing what to whom" in a sentence. Each sentence is represented as a rooted, directed, acyclic graph with labels on edges (relations) and leaves (concepts). (...)
AMR implements a simplified, standard neo-Davidsonian semantics (...), using standard feature structure representation (...).

Trendy Contemporary Graphical Representations

Abstract Meaning Representations (AMR)

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- Banarescu et al. (2013), but also Langkilde and Knight (1998)!
- About 70 articles on the AMR research page.
- 178 entries on the AMR bibliography page.
- About 360 articles on the ACL anthology (also in 2020).
- Tutorial at NAACL-HTL 2015 (Schneider, Flanigan, and O'Gorma 2015): "*The Logic of AMR. Practical, Unified, Graph-Based Sentence Semantics for NLP*".

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Schneider, Flanigan, and O'Gorma (2015)

- *AMR is a semantic representation aimed at large-scale human annotation in order to build a giant semantics bank.*
- *Practical, replicable amount of abstraction (limited canonicalization).*
- *Capture many aspects of meaning in a single simple data structure.*

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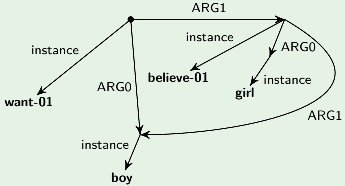

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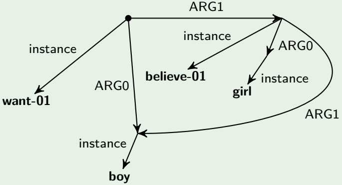

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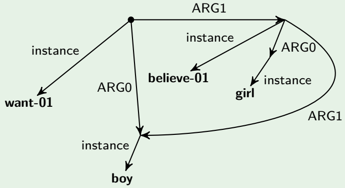

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Features

- Concepts

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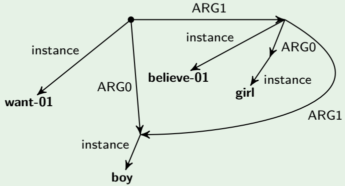

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- Reentrancy (DAG)

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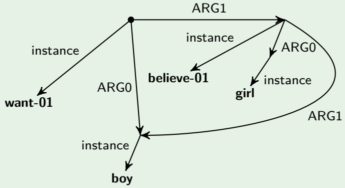

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- Concepts
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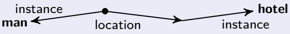

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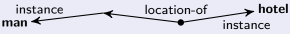

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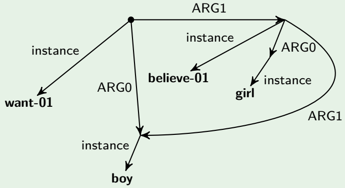

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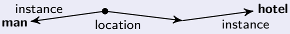

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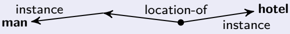

- All concepts drop plurality, articles, and tense and all mention of a term go to the same variable

AMR Design

Limitations

- No lexical relations (*fruit/berry*, *buy/sell*, *kill/die*)
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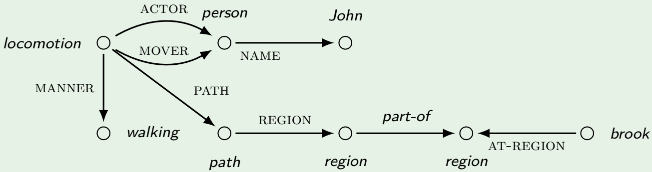
About Quantification

- Bos (2016)
- Stabler (2018)
- Pustejovsky, Lai, and Xue (2019)

Frames (*ca.* 2014)

(Kallmeyer and Osswald 2013; Löbner 2014)

John walks along the brook.



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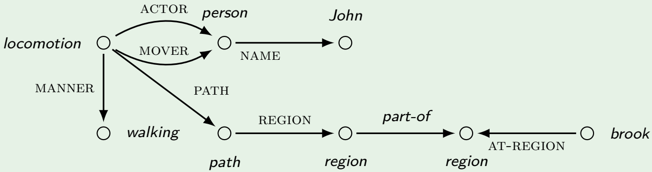

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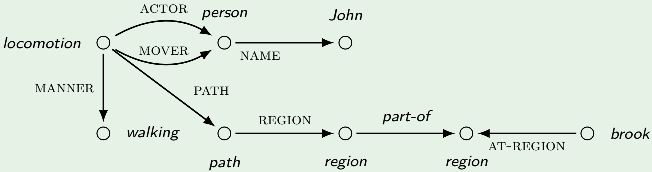

$$\exists e \exists p_e \exists j \exists w \exists p_a \exists r_1 \exists r_2 \exists b. locomotion(l) \wedge person(p_e) \wedge John(j) \wedge walking(w)$$
$$\wedge\ path(p_a) \wedge region(r_1) \wedge region(r_2) \wedge brook(b)$$
$$\wedge\ \text{ACTOR}(l, p_e) \wedge \text{MOVER}(l, p_e) \wedge \text{NAME}(p_e, j) \wedge \text{MANNER}(l, w) \wedge \text{PATH}(l, p_a) \wedge \text{REGION}(p_a, r_1)$$
$$\wedge\ part - of(r_1, r_2) \wedge \text{AT-REGION}(b, r_2)$$

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- *I thought of each case frame as characterizing a small abstract 'scene' or 'situation', so that to understand the semantic structure of the verb it was necessary to understand the properties of such schematized scenes* (Fillmore 1982, p.115)
- *I propose that frames provide the fundamental representation of knowledge in human cognition* (Barsalou 1992)

The Frame Hypothesis (Löbner 2014)

- H1 The human cognitive system operates with a single general format of representations
- H2 If the human cognitive system operates with one general format of representations, this format is essentially Barsalou's frames

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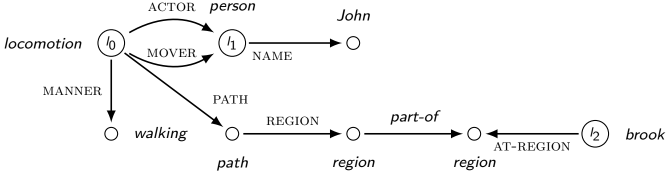
- Decompositional approach to meaning (Osswald and Van Valin 2014)

Formal Representation of Frames

Frames as base-labelled feature structures with types and relations (Kallmeyer and Osswald 2013)



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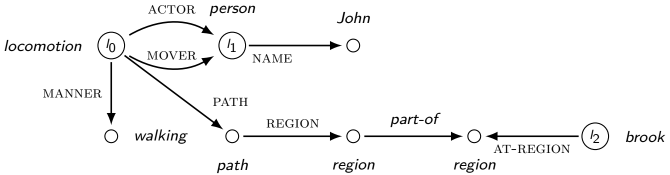

$$\begin{bmatrix} \textit{motion} & & \\ \text{AGENT} & \boxed{1} & \begin{bmatrix} \textit{person} & \\ \text{NAME} & \begin{bmatrix} \textit{John} \end{bmatrix} \end{bmatrix} \\ \text{MOVER} & \boxed{1} & \\ \text{PATH} & & \begin{bmatrix} \textit{path} & \\ \text{REGION} & \boxed{v} \begin{bmatrix} \textit{region} \end{bmatrix} \end{bmatrix} \\ \text{MANNER} & \begin{bmatrix} \textit{walking} \end{bmatrix} & \end{bmatrix}$$

$$\begin{bmatrix} \textit{brook} & \\ \text{AT-REGION} & \boxed{w} \begin{bmatrix} \textit{region} \end{bmatrix} \end{bmatrix}$$

$\textit{part-of}\,(\boxed{v},\boxed{w})$

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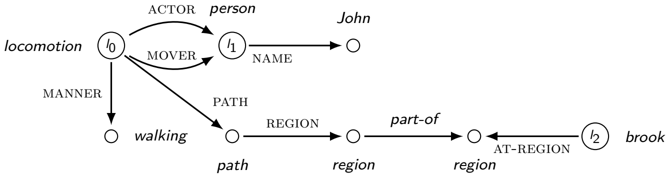

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$$\textit{part-of}\,(\boxed{v},\boxed{w})$$

Labelled attribute-value description language (LAVD)

$$\boxed{0} : \textit{motion} \wedge$$
$$\boxed{0} \cdot \text{AGENT} \triangleq \boxed{1} \wedge$$
$$\boxed{0} \cdot \text{AGENT} \doteq \boxed{0} \cdot \text{MOVER} \wedge$$
$$\boxed{0} \cdot \text{PATH} : \textit{path} \wedge$$
$$\boxed{0} \cdot \text{MANNER} : \textit{walking} \wedge$$
$$\boxed{1} : \textit{person} \wedge \boxed{1} \cdot \text{NAME} : \textit{John}$$
$$\boxed{2} : \textit{brook} \wedge$$
$$\langle \boxed{0} \cdot \text{PATH} \cdot \text{REGION}, \boxed{2} \cdot \text{AT-REGION} \rangle : \textit{part-of}$$

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About Quantification

- Kallmeyer and Richter (2014)
- Kallmeyer, Osswald, and Pogodalla (2017)
- Richard (2019) (to be closely looked at. . .)

AMR and Frames

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- Structured information
- About factual knowledge (“who is doing what to whom”, “described situations or state of affairs”)
- In spirit: database/knowledge representation

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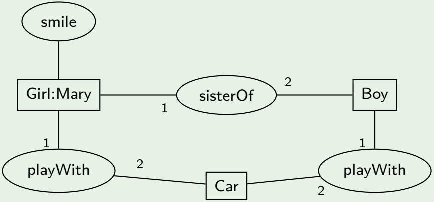
Common Features

- Frame/AMR as models?
- No explicit role for inference in description assessment
- Caveats in negation and universal quantification modeling
- No formal relation to other graphical database/knowledge representation formalisms

Conceptual Graphs

(Sowa 1976; Sowa 1984)

Example



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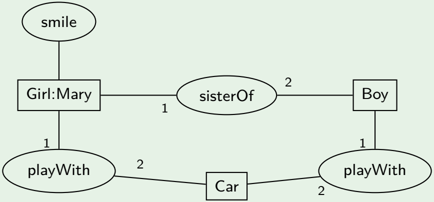

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It is the synthesis of many works in AI, but its roots are mainly found in the following areas: natural language processing, semantic networks, databases and logics, especially the existential graphs of Pierce, which form a diagrammatical system of logics.

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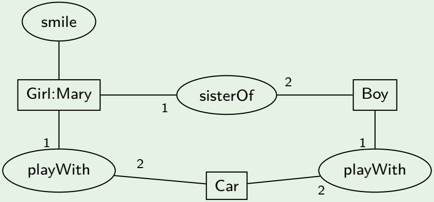

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- Clear distinction between ontological knowledge (concept and relation types) and factual knowledge
- Relations can be of any arity
- CGs *have a logical semantics* in FOL

Formal Semantics and Homomorphisms for CGs

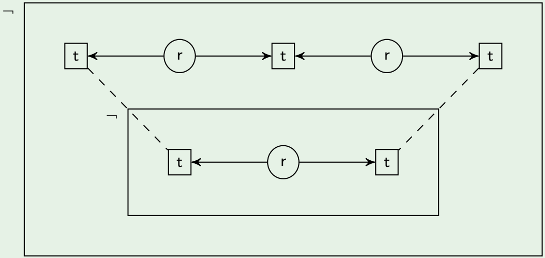
Theorem

Homomorphism (between basic graphs) is sound (Sowa 1984) and complete (Mugnier 1992; Chein and Mugnier 1992) with respect to logical deduction, i.e., given two BGs G and H, there is a homomorphism from G to H iff $\Phi(G)$ can be deduced from $\Phi(H)$.

- BGs: existential, positive, conjunctive fragment of FOL
- Are there more expressive conceptual graphs?

Full Conceptual Graphs I

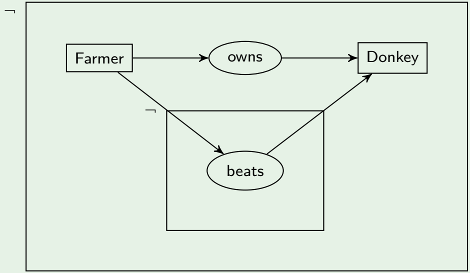
Example



- Inspired from Peirce's existential graphs
- Sound and complete set of inference rules that cannot, however, directly lead to automated reasoning (possibly requires to insert *any* graph)

Full Conceptual Graphs II

Example



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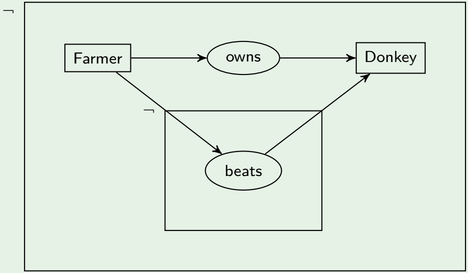
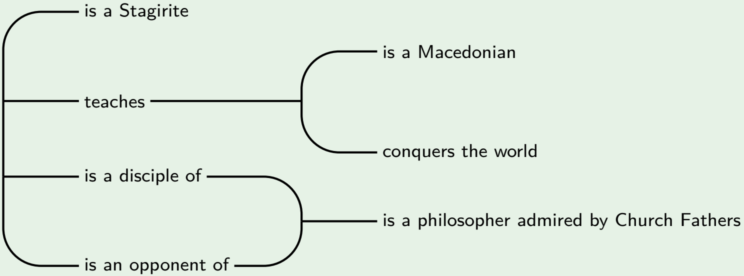


I skip the DRT representations. . .

Peirce's Existential Graphs

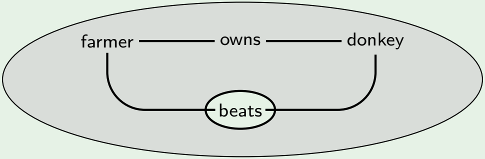
(Roberts 1992; Roberts 2009; Dau 2002; Dau 2003)

Example (Sowa 2006)



“The Logic of the Future”

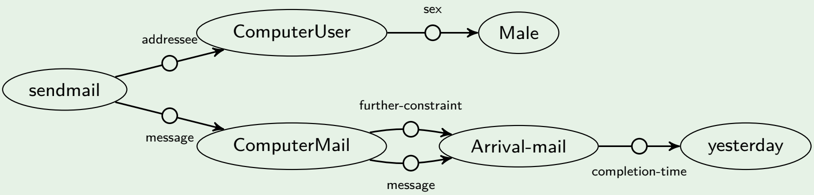
Example (Sowa 2006)



Conceptual Information Representation Language

Brachman and Schmolze 1985

Send him the messages that arrived yesterday (Sondheimer, Weischedel, and Bobrow 1984)



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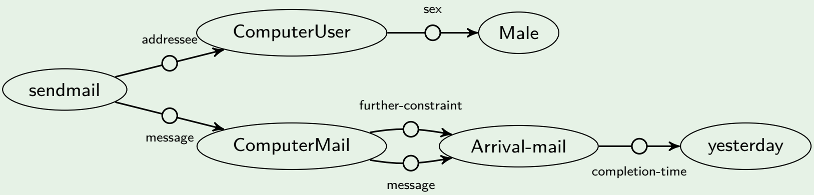

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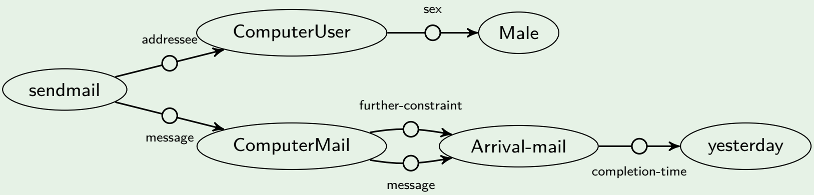

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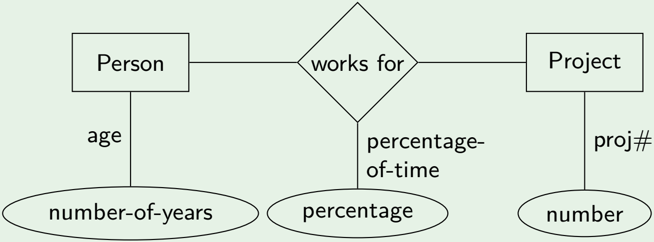
KL-ONE aspires to a bipartite view of the knowledge-representation task. Over the course of its development, we began to tease out the distinction between KL-ONE constructs whose intent was primarily for elaborating descriptions and those whose intent was for making statements. In a sense, KL-ONE was beginning to divide into two different formalisms—one for assertion and one for description.

Entity-Relationship Models

(Chen 1976)

A 40-year-old person works on the 2175-project for 20% of his time



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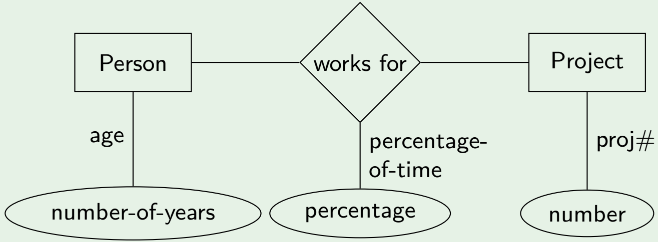

Chen (1983)

There is a critical need for devising rules or guidelines for converting English descriptions into ER diagrams. This motivates our research into the correspondence between English sentence structure and entity-relationship diagrams.

About Knowledge Representation Formalisms I

Chein and Mugnier (2009)

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The correspondence between knowledge about an application domain and an expression in the KR formalism representing this knowledge must be as tight as possible. Due to the importance of natural language and schemas in the description of knowledge, a KR formalism should allow the user to easily represent simple phrases in natural language and simple schemas.

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The correspondence between knowledge about an application domain and an expression in the KR formalism representing this knowledge must be as tight as possible. Due to the importance of natural language and schemas in the description of knowledge, a KR formalism should allow the user to easily represent simple phrases in natural language and simple schemas. The ability for describing such a correspondence, i.e., the natural semantics of a formal expression, is a good empirical criteria for delimiting the usability of the formalism.

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Basic Conceptual Graphs (BG)

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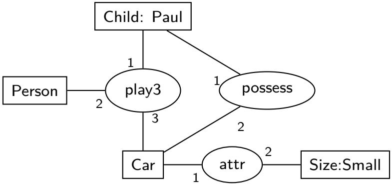

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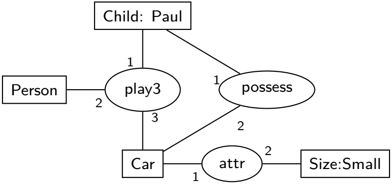

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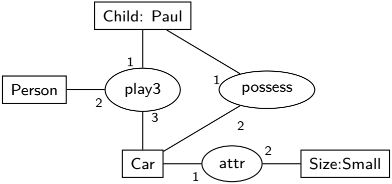

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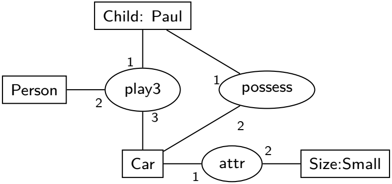

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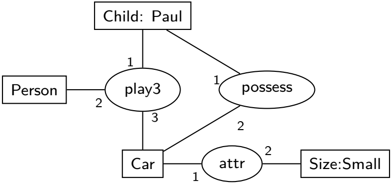

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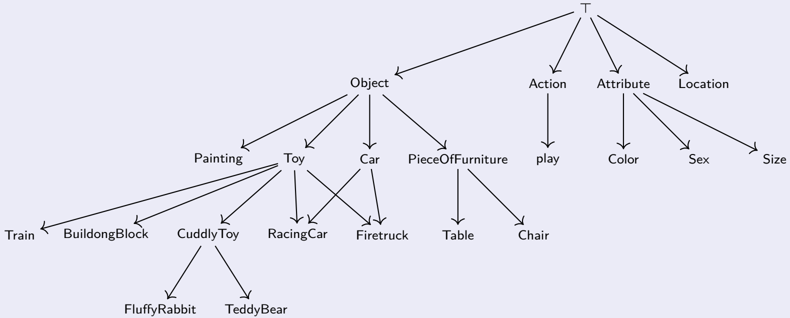
- $\mathcal{I}$ is the set of *individual markers*. $*$ denotes the *generic marker* and $\mathcal{M} = \{*\} \cup \mathcal{I}$ denotes the *set of markers*. $*$ is greater than any element in $\mathcal{I}$ and elements in $\mathcal{I}$ are pairwise incomparable.

Vocabulary and Ontologies I

Concept Type Set



Vocabulary and Ontologies II

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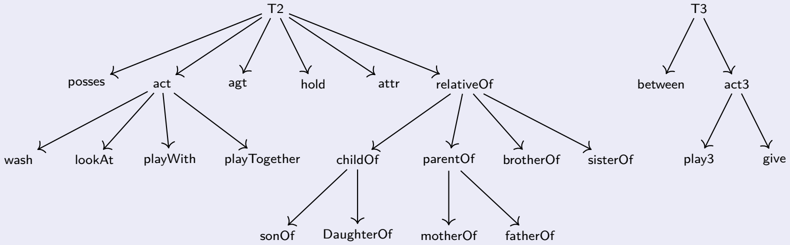

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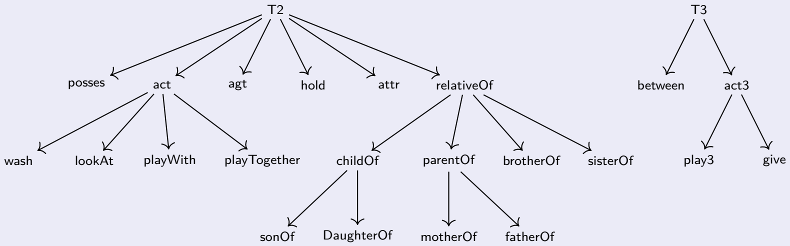

Type of Individuals and Relation Signatures

- Individual markers can be typed: $\tau(m) \in T_C$ is the most specific type of m.
- A relation symbol can specify the maximal concept type of each of its arguments

Basic Conceptual Graphs

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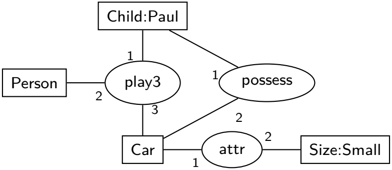

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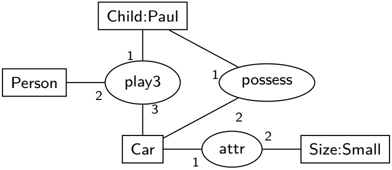

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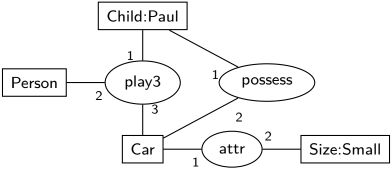

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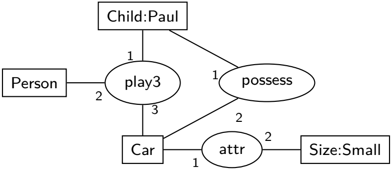

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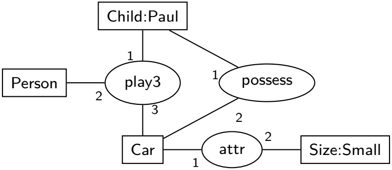

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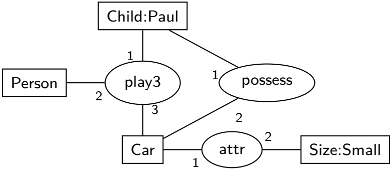

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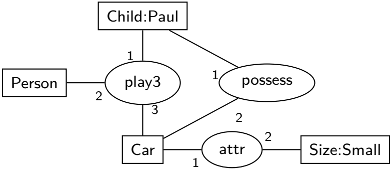

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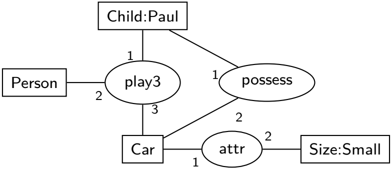

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- Edges incident to a relation node are totally ordered and labeled from 1 to the arity of its type.

Basic Conceptual Graphs

Definition

Remark

- A BG doe not need to be connected.
- The empty BG $G_{\varnothing} = (\varnothing, \varnothing, \varnothing, \varnothing)$ is a BG.
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Definition (Ordered set of concept labels)

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$$(t, m) \leqslant (t', m') \text{ iff } t \leqslant t' \text{ and } m \leqslant m'$$

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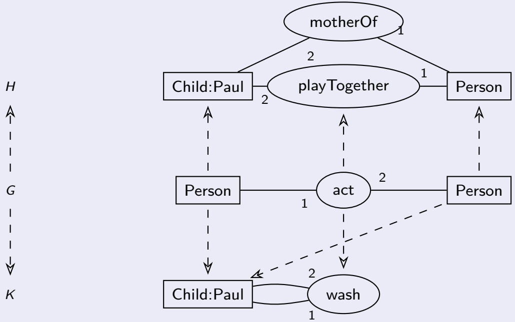

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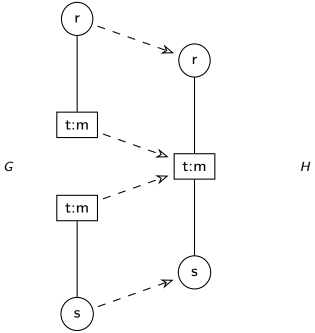

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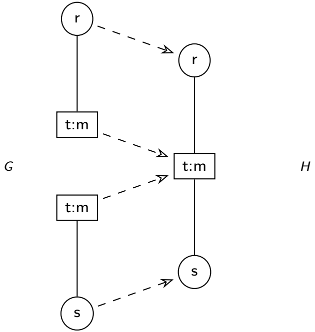

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Proposition

$\succcurlyeq$ is a preorder on the BGs (and it is not an order). $\succcurlyeq_i$ is an order on the BGs.

Irredundant BGs

Definition (Irredundant and redundant BG)

A BG is said *redundant* if it is hom-equivalent to one of its strict subgraph. Otherwise it is said *irredundant*.

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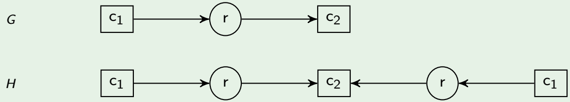

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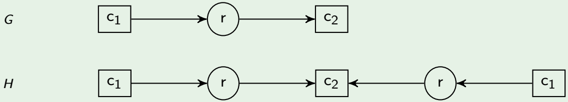

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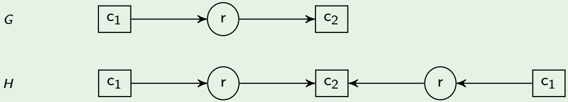

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Let $\mathcal{G}$ be the class of irredundant BGs defined over a given vocabulary. Then $(\mathcal{G}, \succcurlyeq)$ is a lattice.

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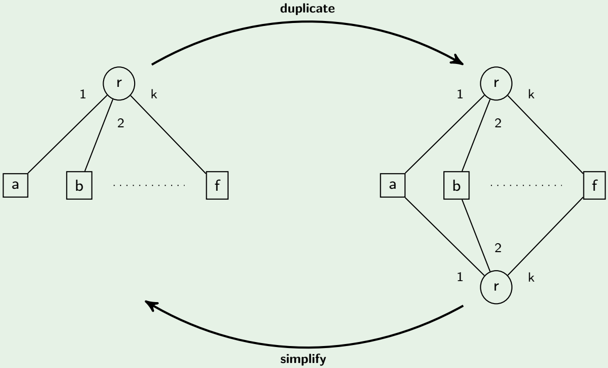
Detach Split a concept into two concepts.

Substract Given a BG G and a set of connected component $C_1, , \dots, C_k$ of G, $substract(G, C_1, \dots, C_k)$ is the BG obtained from G by deleting $C_1, \dots, C_k$.

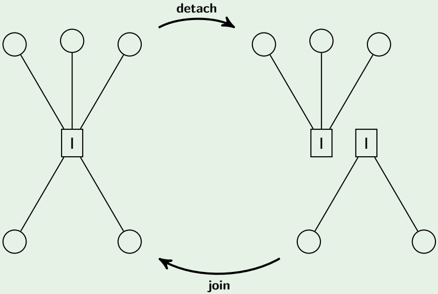
Elementary Generalization Operations II

Example (Duplication and simplification)



Elementary Generalization Operations III

Example (Detach and join)



Elementary Specialization Operations

Definition (Elementary specialization operations)

The five elementary specialization operations are:

Copy

Relation simplify Given a BG G and two twin relations r and r' (relation with the same type and the same list of neighbors), $relationSimplify(G, r')$ is the BG obtained from G by deleting r'.

Restrict Given a BG G, a node n of G and a label $l \leqslant l(n)$, $restrict(G, n, l)$ is the BG obtained from G by decreasing the label of n to l.

Join Given a BG G and two concepts c_1 and c_2 of G with the same label, $join(G, c_1, c_2)$ is the BG obtained from G by merging c_1 and c_2 in a new node c.

Disjoint sum

Elementary Operations and Subsumption

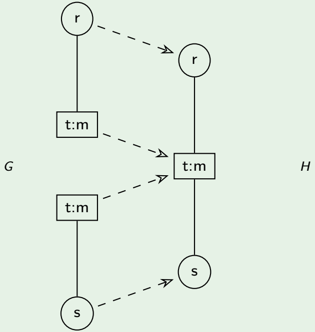
Theorem (Homomorphism and generalization)

Let G and H be two BGs. The following propositions are equivalent:

1. *G is a generalization of H*
2. *H is a specialization of G*
3. *there is a homomorphism from G to H, i.e., $G \succcurlyeq H$*

Next to Come: Normal BGs

Example

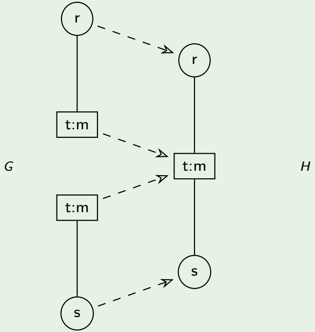


$G \succcurlyeq H$ but $H \not\succcurlyeq G$

But we expect G and H to be "semantically" equivalent...

Next to Come: Normal BGs

Example



$G \succcurlyeq H$ but $H \not\succcurlyeq G$

But we expect G and H to be "semantically" equivalent...
Solution in the next episode!

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