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Megamodel-driven Traceability Recovery & Exploration of Correspondence & Conformance Links

Bachelorarbeit

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im Studiengang Informatik

vorgelegt von

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(Ort, Datum) (Maximilian Meffert)

Zusammenfassung

TBD.

Abstract

TBD.

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Introduction

TBD.

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TBD.

Chapter 3

Background

This section summarizes the necessary background topics of the thesis. Each topic is introduced as independent as possible, interrelation is done during synthesis of hypotheses for this thesis in chapter 4. However, some of the following sections are sorted in a way that one may be based on its predecessor. In particular sections on the necessary mathematical background share definitions. Introducing them repeatedly would be redundant.

3.1 Predicate Logic

3.2 Relations

This section introduces the necessary aspects of mathematical relations for this thesis. The concept of relations is a generalization of semantic dependencies between two or more mathematical objects. This section is based on [2].

Relations are based on set-theory. We also introduce the necessary constructs of set-theory in order to clarify terminology and notation. A set is a collection of well distinguishable mathematical objects. Objects in a set are called elements of the set. A set does not contain two or more identical elements. The notation $x \in X$ denotes that x is an element of the set X. The symbol $\emptyset$ denotes the *empty set*, which contains no elements. The symbol Ω denotes the universal set, which contains all elements.

Definition 1 (Inclusion) *Let X and Y be a sets. Y* includes *X if and only if:*

$$X \subset Y :\Leftrightarrow \forall x[x \in X \rightarrow x \in Y] \Leftrightarrow \forall x[x \notin X \vee x \in Y] \tag{3.1}$$

Then X is called subset *of Y and Y is called* superset *of X. For an arbitrary set $Z \neq \emptyset$, the statement $\emptyset \subset Z$ is always true, respectively $Z \subset \emptyset$ is always false.*

We also define the opposite property: Y does not include X if and only if:

$$X \not\subset Y :\Leftrightarrow \exists x[x \in X \wedge x \notin Y] \tag{3.2}$$

Definition 2 (Union) *Let X and Y be a sets.*

$$X \cup Y := \{x | x \in X \vee x \in Y\} \tag{3.3}$$

$X \cup Y$ is called union *of X and Y.*

Definition 3 (Intersection) *Let X and Y be a sets.*

$$X \cap Y := \{x | x \in X \wedge x \in Y\} \tag{3.4}$$

$X \cap Y$ is called intersection *of X and Y.*

Definition 4 (Power-Set) *Let X be a set, then the* power-set *of X is defined as:*

$$\mathcal{P}(X) := \{Y | Y \subset X\} \tag{3.5}$$

The definition of inclusion provides an order for power-sets. So we may compare two sets A and B in the sense of *smaller* and *larger*, i.e.:

$$A \text{ is smaller than } B \Leftrightarrow A \subset B \tag{3.6}$$

$$A \text{ is larger than } B \Leftrightarrow B \subset A \tag{3.7}$$

$$A \text{ is the smallest subset of } B \Leftrightarrow \forall C \in \mathcal{P}(B) : A \subset C \tag{3.8}$$

$$A \text{ is the largest subset of } B \Leftrightarrow \forall C \in \mathcal{P}(B) : C \subset A \tag{3.9}$$

Definition 5 (Upper & Lower Bound) *Let Ω be a universe, $X \in \mathcal{P}(\Omega)$ be a set in the universe and $A \subset \mathcal{P}(U), A \neq \emptyset$, non-empty subsets in the universe.*

$$X \textit{ is an } \text{upper bound} \textit{ for } A :\Leftrightarrow \forall Y \in A : Y \subset X \tag{3.10}$$

$$X \textit{ is a } \text{lower bound} \textit{ for } A :\Leftrightarrow \forall Y \in A : X \subset Y \tag{3.11}$$

We also define:

$$\mathbf{U}_A := \{U \in \mathcal{P}(\Omega) | \forall Y \in A : Y \subset U\} \tag{3.12}$$

$$\mathbf{L}_A := \{L \in \mathcal{P}(\Omega) | \forall Y \in A : L \subset Y\} \tag{3.13}$$

as sets of all upper/lower bounds for A.

Because our definition of upper and lower bounds is based on power-sets, existence is guaranteed: Given an arbitrary set S, the S and $\emptyset$ are always elements of $\mathcal{P}(S)$. For each element Y of a non-empty selection $A \subset \mathcal{P}(S)$ of the power-set, $Y \subset S$ and $\emptyset \subset Y$ holds. So S is an upper and $\emptyset$ is a lower bound for A.

Definition 6 (Supremum & Infimum) *Let Ω be a universe, $X \in \mathcal{P}(\Omega)$ be sets in the universe and $A \subset \mathcal{P}(\Omega), A \neq \emptyset$ a non-empty selection of sets in the universe. If*

$$X = \sup A := \bigcup_{Y \in A} Y :\Leftrightarrow X \in \mathbf{U}_A \wedge \forall U \in \mathbf{U}_A : X \subset U \tag{3.14}$$

$$X = \inf A := \bigcap_{Y \in A} Y :\Leftrightarrow X \in \mathbf{L}_A \wedge \forall L \in \mathbf{L}_A : L \subset X \tag{3.15}$$

then X is called supremum/infimum *for A.*

Existence for supremum and infimum is guaranteed, because upper and lower bounds exist as shown above. Thus, for any non-empty selection $A \subset \mathcal{P}(S)$ of a power-set, $\mathbf{U}_A$ and $\mathbf{L}_A$ are not empty. So we need to proof, that $X = \bigcup_{Y \in A} Y$ respectively $X = \bigcap_{Y \in A} Y$ are in fact the smallest upper and the largest lower bound. Or in other words: Does another bound $X' \in \mathbf{U}_A$ respectively $X' \in \mathbf{L}_A$ exist with $X' \neq X$ and $X' \subset X$ respectively $X \subset X'$?

1. Supremum: We assume $X' \in \mathbf{U}_A$ with $X' \neq X$ and $X' \subset X$ for $X = \bigcup_{Y \in A} Y$ exists, then an element $x \in X$ exists, which is not element of X'. Because X

is the union of all sets in selection A, x must be element of at least one of its sets. However, then X' cannot include sets containing x. Thus, X' cannot be an upper bound for A and $X = \sup A$.

2. Infimum: We assume $X' \in \mathbf{L}_A$ with $X' \neq X$ and $X \subset X'$ for $X = \bigcap_{Y \in A} Y$ exists, then an element $x \in X'$ exists, which is not element of X. Because X is the intersection of all sets in selection A, x cannot be element of at least one of its sets. However, then X' must include sets containing x. Thus, X' cannot be a lower bound fo A and $X = \inf A$.

Supremum and Infimum are unique for any non-empty selection of sets in a universe and can be obtained by its union respectively its intersection. [2]

Definition 7 (Cartesian Product) *Let U be a universe and $X_n \in \mathcal{P}(U)$ sets with $i = 1...n, n \in \mathbb{N}$, then:*

$$X_1 \times ... \times X_n := \{(x_1, ..., x_n)\} \tag{3.16}$$

is called Cartesian product.

Definition 8 (Relation) *A relation is a subset of a Cartesian product:*

$$R \subset X_1 \times ... \times X_n \tag{3.17}$$

The relation of only two sets is called binary relation*. Instead of writing $(x, y) \in R$ we may also use the shorter notation xRy.*

An arbitrary relation $R \subset A \times B$ is called *homogeneous* if $A = B$, otherwise it is called *heterogeneous*. However, an arbitrary relation $R \subset A \times B$ is also homogeneous in the sense of $R \subset A \times B \subset (A \cup B) \times (A \cup B)$. For the remainder of this section we focus on homogeneous relations unless noted otherwise.

In order to clarify our notation, when we are specifically working with relations instead of ordinary sets, we use the symbols $\sqsubset$ for inclusion,$\not\sqsubset$ for non-inclusion, $\sqcup$ for union and $\sqcap$ for intersection, i.e.:

$$R \sqsubset S :\Leftrightarrow \forall x, y[(x, y) \in R \to (x, y) \in S] \tag{3.18}$$

$$R \not\sqsubset S :\Leftrightarrow \exists x, y[(x, y) \in R \wedge (x, y) \notin S] \tag{3.19}$$

$$R \sqcup S := \{(x, y)|(x, y) \in R \vee (x, y) \in S\} \tag{3.20}$$

$$R \sqcap S := \{(x, y)|(x, y) \in R \wedge (x, y) \in S\} \tag{3.21}$$

Furthermore, we use $\mathcal{R}(A)$ to denote the set of all homogeneous relations in set A and the symbols $\mathcal{O}$ and $\mathcal{A}$ to denote the empty relation and the universal relation:

$$\mathcal{R}(A) := \{R|R \subset A \times A\} \tag{3.22}$$

$$(\mathcal{O} := \emptyset) \subset A \times A \qquad \Leftrightarrow \forall R \in \mathcal{R}(A)[\mathcal{O} \sqsubset R] \tag{3.23}$$

$$(\mathcal{A} := A \times A) \subset A \times A \qquad \Leftrightarrow \forall R \in \mathcal{R}(A)[R \sqsubset \mathcal{A}] \tag{3.24}$$

Definition 9 (Composition of Binary Relations) *Let $R, S \in \mathcal{R}(A)$. Then $R \circ S \in \mathcal{R}(A)$ is defined*

$$R \circ S = RS := \{(r, s) \in A \times A|\exists x \in A : (r, x) \in R \wedge (x, s) \in S\} \tag{3.25}$$

and called composition *or* multiplication *of R and S. Instead of writing $R \circ S$ we also write simply RS.*

In conjunction with $\sqsubset$ composition is monotone:

$$\forall P, Q, R \in \mathcal{R}(A) : P \sqsubset Q \to R \circ P \sqsubset R \circ Q \tag{3.26}$$

$$\forall P, Q, R \in \mathcal{R}(A) : P \sqsubset Q \to P \circ R \sqsubset Q \circ R \tag{3.27}$$

- ($\Rightarrow$) Following the definition of composition, it can easily be observed, if Q includes P, all elements of P are also in Q:

$$\forall x, y : (x, y) \in R \circ P \tag{3.28}$$

$$\to \exists z : (x, z) \in R \wedge (z, y) \in P \overset{P \sqsubset Q}{\to} \exists z : (x, z) \in R \wedge (z, y) \in Q \tag{3.29}$$

$$\to (x, y) \in R \circ Q \tag{3.30}$$

An analogous deduction can be shown for the right hand side composition of R.

- ($\Leftarrow$) The opposite direction can be proven indirectly, assuming $R \circ P \sqsubset R \circ Q$ holds, but $P \sqsubset Q$ does not:

Definition 10 (Identity Relation) *The relation $\mathcal{I} \in \mathcal{R}(A)$*

$$\mathcal{I} := \{(a, b) \in A \times A | a = b\} = \{(a, a) | a \in A\} \subset A \times A \tag{3.31}$$

is called identity relation.

$(\mathcal{R}(A), \circ, \mathcal{I})$ is a monoid, i.e. for all relations in $\mathcal{R}(A)$ composition is associative and $\mathcal{I}$ serves as it's identity element:

$$(Q \circ R) \circ S = Q \circ (R \circ S) \tag{3.32}$$

$$R \circ \mathcal{I} = \mathcal{I} \circ R = R \tag{3.33}$$

Also, $\mathcal{O}$ serves as absorbing element for composition:

$$R \circ \mathcal{O} = \mathcal{O} \circ R = \mathcal{O} \tag{3.34}$$

Because $(\mathcal{R}(A), \circ, \mathcal{I})$ is a monoid, we can define exponentiation:

Definition 11 (Exponentiation of Relations) *Let $R \in \mathcal{R}(A)$ and $n \in \mathbb{N}$.*

$$R^0 := \mathcal{I} \tag{3.35}$$

$$R^n := R \circ R^{n-1} \tag{3.36}$$

Consider the following example:

$$A = \{a, b, c, d\} \tag{3.37}$$

$$R = \{(a, b), (a, c), (c, d)\} \tag{3.38}$$

$$R^0 = \{(a, a), (b, b), (c, c), (d, d)\} \tag{3.39}$$

$$R^1 = R \circ R^0 = R \circ \mathcal{I} = \{(a, b), (a, c), (c, d)\} \tag{3.40}$$

$$R^2 = R \circ R^1 = R \circ R = \{(a, d)\} \tag{3.41}$$

$$R^3 = R \circ R^2 = \mathcal{O} \tag{3.42}$$

$$R^4 = R^5 = R^6 = ... = R \circ \mathcal{O} = \mathcal{O} \tag{3.43}$$

Definition 12 (Reflexivity) *A relation $R \in \mathcal{R}(A)$ is called:*

$$\text{reflexive} :\Leftrightarrow \forall a \in A : (a,a) \in R \tag{3.44}$$

$$\text{irreflexive} :\Leftrightarrow \forall a \in A : (a,a) \notin R \tag{3.45}$$

Definition 13 (Reflexive Closure) *Let $R \in \mathcal{R}(A)$. Then*

$$R^{\circ} := \inf\{S | R \sqsubset S \wedge S \textit{ reflexive } \} = R \sqcup \mathcal{I} \tag{3.46}$$

is called reflexive closure *of R.*

The reflexive closure of a homogeneous relation R is the infimum or largest lower bound of the set $A = \{S|R \sqsubset S \wedge S \text{ reflexive } \}$ containing all reflexive relations, which include R. The smallest reflexive relation is $\mathcal{I}$. The smallest relation including R is R itself. So, for an arbitrary relation $R' \in A$ the inclusions $R \sqsubset R'$, $\mathcal{I} \sqsubset R'$ and $(R \sqcup \mathcal{I}) \sqsubset R'$ hold. Thus $R \sqcup \mathcal{I}$ is a lower bound for A and $(R \sqcup \mathcal{I}) \sqsubset \inf A$ holds. Vice versa, $R \sqcup \mathcal{I}$ is an element of A and any relation $R'' \sqsubset (R \sqcup \mathcal{I})$ does either not include R or is not reflexive. Thus $R \sqcup \mathcal{I}$ is also the smallest relation in A and $\inf A \sqsubset (R \sqcup \mathcal{I})$. From $(R \sqcup \mathcal{I}) \sqsubset \inf A$ and $\inf A \sqsubset (R \sqcup \mathcal{I})$ follows $\inf A = (R \sqcup \mathcal{I})$. [2]

Definition 14 (Symmetry) *A relation $R \in \mathcal{R}(A)$ is called:*

$$\text{symmetric} :\Leftrightarrow \forall a,b \in A : (a,b) \in R \Rightarrow (b,a) \in R \tag{3.47}$$

$$\text{asymmetric} :\Leftrightarrow \forall a,b \in A : (a,b) \in R \Rightarrow (b,a) \notin R \tag{3.48}$$

$$\text{antisymmetric} :\Leftrightarrow \forall a,b \in A : (a,b) \in R \wedge (b,a) \in R \Rightarrow a = b \tag{3.49}$$

Definition 15 (Transitivity) *A relation $R \in \mathcal{R}(A)$ is called:*

$$\text{transitive} :\Leftrightarrow R^2 \sqsubset R \tag{3.50}$$

$$:\Leftrightarrow \forall a,b,c \in A : (a,b) \in R \wedge (b,c) \in R \rightarrow (a,c) \in R \tag{3.51}$$

$$\text{intransitive} :\Leftrightarrow R^2 \not\sqsubset R \tag{3.52}$$

$$:\Leftrightarrow \forall a,b,c \in A : (a,b) \in R \wedge (b,c) \in R \rightarrow (a,c) \notin R \tag{3.53}$$

The equivalent characterization of transitivity is $R^2 \sqsubset R$ is easily obtained:

$$\forall a, b, c \in A : (a, b) \in R \wedge (b, c) \in R \Rightarrow (a, c) \in R \tag{3.54}$$
$$\Leftrightarrow \forall a, c \in A : (a, c) \in RR \rightarrow (a, c) \in R \tag{3.55}$$
$$\Leftrightarrow \forall a, c \in A : (a, c) \in R^2 \rightarrow (a, c) \in R \tag{3.56}$$
$$\Leftrightarrow R^2 \sqsubset R \tag{3.57}$$

If $\mathcal{T}(A) := \{R \in \mathcal{R}(A) | R^2 \sqsubset R\}$ is the set over all transitive relations of set A, it's infimum $I := \inf \mathcal{T}(A)$ is also transitive. Assuming it is not, at least one element exists, which is in I^2, but not in I. Because I is the infimum of $\mathcal{T}(A)$, all transitive relations R must include it. Thus the same element is in R^2, but not in R. However, this is a contradiction, because R is transitive and all elements in R^2 must be in R.

$$\neg(I^2 \sqsubset I) \Leftrightarrow \forall x, y : \neg[(x, y) \in I^2 \rightarrow (x, y) \in I] \tag{3.58}$$
$$\Leftrightarrow \forall x, y : (x, y) \in I^2 \wedge (x, y) \notin I \tag{3.59}$$
$$\Leftrightarrow \forall x, y \exists z : (x, z) \in I \wedge (z, y) \in I \wedge (x, y) \notin I \tag{3.60}$$
$$\Leftrightarrow \forall x, y \exists z : (x, z) \in R \wedge (z, y) \in R \wedge (x, y) \notin R \tag{3.61}$$
$$\Leftrightarrow \forall x, y : (x, y) \in R^2 \wedge (x, y) \notin R \tag{3.62}$$
$$\Leftrightarrow \forall x, y : \neg[(x, y) \in R^2 \rightarrow (x, y) \in R] \tag{3.63}$$
$$\Leftrightarrow \neg(R^2 \sqsubset R) \lightning \tag{3.64}$$

Definition 16 (Transitive Closure) *Let $R \in \mathcal{R}(A)$ and $i \in \mathbb{N}$. Then*

$$R^+ := \inf\{S | R \sqsubset S \wedge S \textit{ transitive }\} = \sup\{R^i | i \geq 1\} \tag{3.65}$$

is called transitive closure *of R.*

The transitive closure of a relation is the infimum or greatest lower bound of the set $A = \{S | R \sqsubset S \wedge S \text{ transitive }\}$ containing all transitive relations, which include R. Because A contains only transitive relations, its infimum $I = \inf A$ is also transitive.

$PR \sqsubset QS$

$\Leftrightarrow \forall x, y : (x, y) \in PR \rightarrow (x, y) \in QS$

$\Leftrightarrow \forall x, y \exists z : (x, z) \in P \wedge (z, y) \in R \rightarrow (x, z) \in Q \wedge (z, y) \in S$

$\Leftrightarrow \forall x, y \exists z : (x, z) \notin P \vee (z, y) \notin R \vee [(x, z) \in Q \wedge (z, y) \in S]$

$\Leftrightarrow \forall x, y \exists z : [(x, z) \notin P \vee (z, y) \notin R \vee (x, z) \in Q] \wedge [(x, z) \notin P \vee (z, y) \notin R \vee (z, y) \in S]$

$\Leftrightarrow \forall x, y \exists z : [(z, y) \notin R \vee [(x, z) \notin P \vee (x, z) \in Q]] \wedge [(x, z) \notin P \vee [(z, y) \notin R \vee (z, y) \in S]]$

$\Leftrightarrow \forall x, y \exists z : [(z, y) \notin R \vee [(x, z) \in P \rightarrow (x, z) \in Q]] \wedge [(x, z) \notin P \vee [(z, y) \in R \rightarrow (z, y) \in S]]$

$\Leftrightarrow \forall x, y \exists z : [(z, y) \notin R \vee P \sqsubset Q] \wedge [(x, z) \notin P \vee R \sqsubset S]$

$PR \not\sqsubset QS$

$\Leftrightarrow \exists x, y : (x, y) \in PR \wedge (x, y) \notin QS$

$\Leftrightarrow \exists x, y, z : [(x, z) \in P \wedge (z, y) \in R] \wedge \neg[(x, z) \in Q \wedge (z, y) \in S]$

$\Leftrightarrow \exists x, y, z : [(x, z) \in P \wedge (z, y) \in R] \wedge [(x, z) \notin Q \vee (z, y) \notin S]$

$\Leftrightarrow \exists x, y, z : [(x, z) \in P \wedge (z, y) \in R \wedge (x, z) \notin Q] \vee [(x, z) \in P \wedge (z, y) \in R \wedge (z, y) \notin S]$

$\Leftrightarrow \exists x, y, z : [P \not\sqsubset Q \wedge (z, y) \in R] \vee [(x, z) \in P \wedge R \not\sqsubset S]$

$\Leftrightarrow \forall x, y, z : \neg([P \not\sqsubset Q \wedge (z, y) \in R] \vee [(x, z) \in P \wedge R \not\sqsubset S])$

$\Leftrightarrow \forall x, y, z : [P \sqsubset Q \vee (z, y) \notin R] \wedge [(x, z) \notin P \vee R \sqsubset S]$

$\Leftrightarrow \forall x, y, z : [[P \sqsubset Q \vee (z, y) \notin R] \wedge (x, z) \notin P] \vee [[P \sqsubset Q \vee (z, y) \notin R] \wedge R \sqsubset S]$

$\Leftrightarrow \forall x, y, z : [P \sqsubset Q \wedge (x, z) \notin P] \vee [(z, y) \notin R \wedge (x, z) \notin P] \vee [P \sqsubset Q \wedge R \sqsubset S] \vee [(z, y) \notin R \wedge R \sqsubset S]$

$\Leftrightarrow \forall x, y, z : [P \sqsubset Q \wedge (x, z) \notin P] \vee [(x, y) \notin PR] \vee [P \sqsubset Q \wedge R \sqsubset S] \vee [(z, y) \notin R \wedge R \sqsubset S]$

Definition 17 (Transitive-Reflexive Closure) $R^* := R^+ \cup I$ *is called reflexive-transitive closure*

Definition 18 (Order Relation) *content...*

3.3 Mereology

[3]

$$x \text{ partOf } x \qquad \text{(Reflexivity)} \qquad (3.66)$$

$$x \text{ partOf } y \wedge y \text{ partOf } x \Rightarrow x = y \qquad \text{(Antisymmetry)} \qquad (3.67)$$

$$x \text{ partOf } y \wedge y \text{ partOf } z \Rightarrow x \text{ partOf } z \qquad \text{(Transitivity)} \qquad (3.68)$$

TBD.

3.4 Formal Languages & Grammars

3.4.1 Context-Free Languages & Grammars

3.5 Traceability

[4] [1] TBD.

3.5.1 Traceability Relationship

3.5.2 Traceability Link

3.5.3 Traceability Recovery

3.5.4 Traceability Exploration

3.6 Ontologies

TBD.

3.7 Megamodeling

TBD.

3.7.1 MegaL

3.7.1.1 MegaL/Xtext

3.8 Program Analysis

TBD.

3.9 XML Data Binding

TBD.

3.9.1 Java Architecture for XML Binding (JAXB)

3.10 Object Relational Mapping

TBD.

3.10.1 Java Persistence API (JPA)

3.10.2 Hibernate

3.11 Another Tool For Language Recognition (ANTLR)

Chapter 4

Hypotheses

TBD.

4.1 Fragments

4.2 Correspondence

4.3 Conformance

Chapter 5

Methodology

TBD.

5.1 The 101companies Human Resource Management System

Description of the 101companies Human Resource Management System

5.2 Link Proper Part Ratio

The ratio between all proper parts of two artifacts and the proper parts of the same artifacts in a relationship.

$$\pi_{R,A_1,A_2} = \frac{|\{(p_1,p_2) \in R : p_1 \text{ properPartOf } A_1 \wedge p_2 \text{ properPartOf } A_2\}|}{|\{p : p \text{ properPartOf } A_1 \vee p \text{ properPartOf } A_2\}|}$$

Chapter 6

Requirements

TBD.

R1 asdf

R2 asdf

R3 asdf

R4 asdf

Chapter 7

Design

TBD.

Chapter 8

Implementation

TBD.

8.1 Context-Free Grammar Fragmentation

8.2 Name Correspondence Heuristic

Heuristics are quick and "simple" methods for finding good approximate solutions for complex problems. The Name Correspondence Heuristic determines correspondence between artifacts simply by finding similarities of names in those artifacts.

TBD.

Chapter 9

Results

TBD.

Chapter 10

Conclusion

TBD.

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