A Computational Framework for Identity Based on Situation Theory and Dempster-Shafer Theory

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ABSTRACT

A prototype for cyber identity is presented in a computational framework based on Barwise and Devlin's situation theory. We use real-life examples in identifying an individual to create what we call an id-situation; an id-situation is where an id-action is performed. We use the Semantic Web standards to represent these id-situations from our real-life examples. The examples include identifying an individual by fingerprint and by mugshot. Central to our account is how to represent the strength of the evidence, within the situations, as a measure of the support for judgments reached in the id-situation. To measure evidence of an identity from the supporting situations, we used the Dempster-Shafer theory of evidence. This theory is elaborated in this paper to apply to situation theory. ***This paper was advised under faculty member Dr. Albert Esterline {esterlin@ncat.edu}from the Department of Computer Science at NC A&T State University.***

CCS Concepts

• Information systems~Web Ontology Language (OWL) • Applied computing~Computer forensics • Applied computing~Evidence collection, storage and analysis • Information systems~Ontologies • Information systems~Web Ontology Language (OWL)

Keywords

Situations; Semantic Web; Identity; Dempster-Shafer theory

1. INTRODUCTION

In our previous work, we addressed numerical identity and conceptual identity. Numerical identity is the relation each thing has only to itself. Conceptual identity involves the answer to the question [1] "Who are you?" Our work with identity has involved principally with numerical identity, but conceptual identity is of interest because it supports generalizations.

Originally, state of the art in identity is represented by the Superidentity project[2, 3]. This project developed a model in identity that connects elements from both the cyber and physical universes. This feature enhances our ability to make identity attributions. In their terminology, an element of identity has a type, and a characteristic is a multiset of elements of identity of the same type. A superidentity is a set of characteristics. Examples of elements of identity include real names, email addresses, and Facebook IDs. An initial superidentity has at least one seed identity element and is enriched by deriving new elements of identity via functions that transform one or more elements of given types to an element of another type. For example, an email address may be transformed to usernames on social network sites. The enriching continues by iteratively transforming the superidentity, creating a directed graph that outlines the provenance of the elements of identity.

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Furthermore, it became apparent that the elements of identity and transforms of the Superidentity project do not support the internal structure we require. For an alternative, we turned to situation theory based on Devlin's account [8]. A situation may support an unbounded number of items of information, situations can be combined and one can contain another, and we can form abstract situations to classify real situations. Situations really exist in the world but are the principal players in situation semantics (the original manifestation of situation theory).

When we attribute identity, we want something like a legal case. Evidence includes provenance of information, records of how procedures were followed, how information was communicated, and critical narrative detail. Central to our account, a version of Dempster-Shafer theory is used for a quantitative account of the impact of evidence. We use Dempster-Shafer belief functions, or sometimes called support functions, to approach the likelihood of id events.

The rest of this paper is organized as follows. The next section outlines situation theory, and the following summarizes the Semantic Web standards used. It also briefly discusses the ontology created in OWL. Section 3 presents the examples used to introduce our methods and considers how our work relates to situation awareness. Section 4 is our main center for this paper, as it elaborates Dempster-Shafer Theory of Evidence in regards to our examples. Section 5 discusses the combination of situation theory and Dempster Shafer Theory. Section 6 concludes and sketches future work.

2. SITUATION THEORY & SEMANTIC WEB

2.1 Devlin's Situation Theory

We consider Devlin's account of situations and information[9]. An infon is the basic item of information, with the general form

$$\langle\langle R, a1, \ldots, an, l, t, i \rangle\rangle,$$

where R is an n-place relation, $a1, \ldots, an$ are objects appropriate for the corresponding argument places of R, l is a location, t is a temporal location, and i is the polarity, 0 or 1. A polarity of 1 indicates that the objects are thus related in l at t; 0 indicates otherwise. Where s is a situation and σ an infon, $s \models \sigma$ is a proposition and may be true or false; if true, s is said to support σ (σ indeed is information available in s).

A real situation is a single entity that is part of reality and supports an indefinite number of infons, while an abstract situation is a set of infons. We take situations as they relate to identity (id-situations) to be those that include identity-relevant actions (id-actions).

2.2 Semantic Web

To implement situation theory in cyber identity we use tools in the Semantic Web to represent real-life identity examples. The Semantic Web is built off two W3C standards: the resource description framework (RDF)and the RDF schema (RDFS).These are enhanced by the more expressive OWL (Web ontology language) standard (OWL-DL for us). An RDF statement (triple) is of the form subject property object, where property is a binary relation term. RDFS uses RDF triples to define new classes and properties. Individuals (denoted by URIrefs or bnodes) are instances of classes. A set of triples in the Semantic Web is "open," a work in progress.

SPARQL is a query language for triple stores. A WHERE clause typically is a sequence of implicitly conjoined triples that may have variables as subjects or objects. SPARQL reports the verifying instances for those variables listed in the SELECT clause. We use SPARQL provided by the Jena Semantic Web framework[7].

2.3 Identity Ontology

In previous work, the ontology we created had main contributions from the use of Semantic Web standards (RDF, RDFS, OWL, and SWRL) to capture the information present in id-situations and supporting situations in a way that supports cross-situation queries and reasoning that classifies situations and constellations of situations. Semantic Web resources are ideal for representing situations since the Semantic Web is open and situations are partial information structures.

Because artifacts and agents are shared across situations in our example situations, we can frame SPARQL queries that cross situations. Now, a *real situation* is a part of reality that supports an indefinite number of infons, while an *abstract* situation is a set of infons. We present SWRL rules that classify (real) situations as instances of certain abstract situations. We also have rules that classify constellations of situations as instances of (abstract) id-cases and even as instances of pairs of id-cases that are coordinated in that a given person is identified via different modalities. We noted how situations in our application area, while not dynamic like those typically of interest in studies of situation awareness, rely, like those situations, on trust in automation and in our collaborators.

3. The Examples and RDF Representation

Our example involves six situations, *s1-s6*. *s1* and *s2* are id-situations coordinated in that they result in identifying the same individual (via their "name"). In *Figure 1*, *s1* matches fingerprints on file with those on a doorknob. The fingerprints on file were produced in *s3*, and the fingerprints on the doorknob were produced in *s4*.

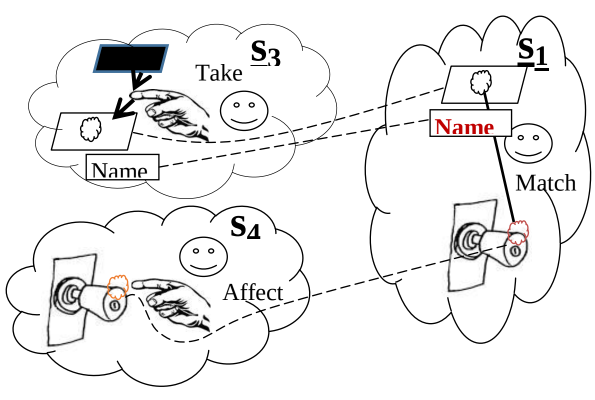
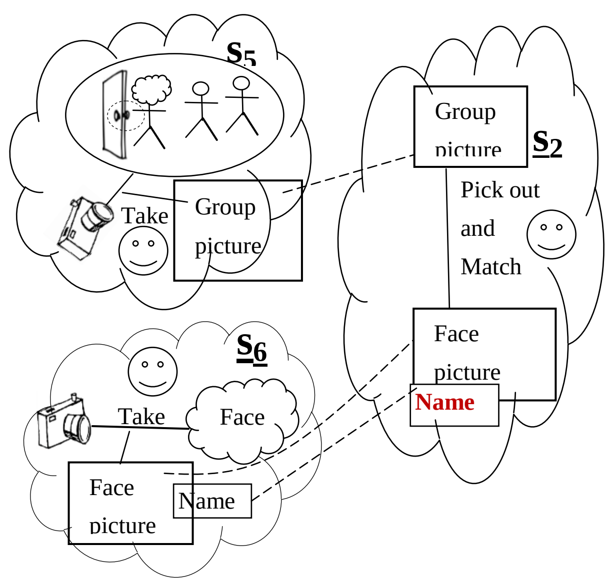


Figure 1. Fingerprint Situation

s4 is a part of a situation itself contained in *s5*, which is in *Figure 2*, where a group of people is socializing. In *s5*, someone takes a group picture. A mugshot is produced in *s6* and used in *s2* to pick out the person in question in the group photo. We thus have two id-cases: the fingerprint case, *s1-s3-s4*, and the mugshot case, *s2-s4-s5*.

Figure 2. Mugshot Situation



In our previous work, representation and classification of situations and id-cases, as well as reasoning about them, were done with these Semantic-Web standards: RDF, OWL, etc. (See [4] for details.) That a given situation s has an infon i (an instance of *class: Infon*) is expressed as *"s: hasInfon i."* The various relations are captured by various subclasses of :Infon. This avoids RDF's restriction of relations to binary relations ("properties") since any instance of a subclass of :Infon may be a subject of any number of triples. We can issue SPARQL queries that navigate across situations connected by, say, shared individuals. For example, we might ask for the URIrefs and the name of the officer in *s3* responsible for the mugshot used in *s2*. For classifying situations according to their types (abstract situations), we use SWRL rules of the form *Situation(?s), ... -> SituationSubClass(?s)* The conditions that fill in the ellipsis relate to the infons that *?s* has. We also classify constellations of situations as instances of id-case types.

4. Dempster-Shafer Theory of Evidence

We want some measure of the extent to which the evidence supports the judgment in an id-situation. Such a measure should reflect the structure of an id-case and fuse belief constraints from different sources. In our example *s1* and *s2* are essentially a single utterance situation (the identity judgment), and the situation in the photo in *s5* is the described situation. Imagine that, in *s1*, the analyst has access to fingerprints for several likely suspects, each associated with a supporting situation in which a fingerprint was recorded. The RDF for *s1* includes a measure of how similar the fingerprint on file is to the fingerprint from the scene; in the expanded view, it includes such measures for all available fingerprints.

4.1 Belief Function

We adapt the Dempster-Shafer theory of evidence [5]. The frame of discernment (the set of possible values we consider), *W*, includes in our example people who might have left the fingerprint or have their mugshot considered. In *s1*, it includes a measure of how well the fingerprint on file matches the fingerprint on the scene. We also have similarity measures on other people who might have left the fingerprint on the door in *Figure 1*, say Fred, Bill, Sue, and Mary.

Available evidence (e.g., similarity measures) provides some degree of support ("mass"), from 0.0 to 1.0. The sum of the mass for all subsets of *W* is 1.0. Where $U \subseteq W$, the belief that *U* holds, *Bel(U)*, is the sum of the support (mass) on subsets of *U*, a number between the interval [0,1].Where *m(.)* is the mass function, $m(U)$ can be seen as the probability of observing U. Therefore, the definition of the belief functions in terms of mass function is $Bel_m(U) = \sum_{U^* \subseteq U} m(U^*)$. This becomes the sum of the probabilities of the evidence that are guaranteed to be within U. Focal elements are those subsets of *W* that have nonzero mass;they include singleton sets for each of these. Again, the sum of the masses for the focal elements must be 1.0 once we have considered all evidence.

To start with, the similarity measures for the singletons {Fred}, {Bill}, {Sue}, and {Mary} to the fingerprint on the doorknob are assigned as in *Table 1*.

Table 1. Mass Measures for Fingerprint in *s1*

Focal Element	Mass
Fred	0.4
Bill	0.075
Sue	0.075
Mary	0.0

In addition, there is some linking evidence of the fingerprint belonging to {Sue, Bill} (i.e., to Sue or Bill), and the mass is 0.05. There is also some chance that someone other than the people mentioned may have left the fingerprint on the doorknob. The evidence for this chance has about half the strength as the evidence for {Fred}, therefore as a singleton set it receives the mass 0.2. We suppose that there is some interest in whether the person is either male or female. Since there is no reason to imply the unknown fingerprint belongs to a male rather than a female or vice versa, we split this mass between a fictional female, Nulla, and a fictional male, Nullus.

The sum of the masses so far is 0.8. The remaining 0.2 covers all ways the purported fingerprint could have got on the doorknob, not only left by those mentioned, but perhaps left before or after the situation transpired.

4.2 Plausibility Function

Corresponding to the belief function is the plausibility function. The plausibility that U holds, *Plaus(U)*, is the sum of the probabilities of the evidence compatible with the world being in *U*: $Plaus_m(U) = \sum_{U^* s.t. U^* \cap U \neq \emptyset} m(U^*)$. For $U \subseteq W$, $Bel(U) \leq Plaus(U)$. Note that, where $\bar{U}$ is the complement of *U*, $Plaus(U) = 1 - Bel(\bar{U})$ and $Bel(U) = 1 - Plaus(\bar{U})$.

4.3 Details on the Application of the Dempster-Shafer Theory of Evidence

Table 2 corresponds to *s1*. Here we have the values of the Dempster-Shafer functions for each focal element. *All* represents the entire frame of discernment; its mass is what was not assigned elsewhere. We show the values of the belief and plausibility functions only for focal elements; there are other subsets of *W* that have non-zero belief and plausibility.

Table 2. Fingerprint mass, belief, and Plausibility

Focal element	Mass	Belief	Plausibility
{Fred}	0.400	0.400	0.600
All	0.200	1.000	1.000
{Sue}	0.075	0.075	0.325
{Mary}	0.000	0.000	0.200
{Bill}	0.075	0.075	0.325
{Nullus}	0.100	0.100	0.300
{Bill,Sue}	0.050	0.200	0.400
{Nulla}	0.100	0.100	0.300

Table 3 corresponds to *s2*. There is similar reasoning regarding the matches against the mugshots, which results in a mass function and thence belief and plausibility.

Table 3. Mugshot mass, belief, and Plausibility

Focal element	Mass	Belief	Plausibility
{Fred}	0.350	0.350	0.550
All	0.200	1.000	1.000
{Sue}	0.000	0.000	0.200
{Mary}	0.050	0.050	0.400
{Bill}	0.050	0.050	0.250
{Mary,Nulla}	0.150	0.300	0.500
{Nullus}	0.100	0.100	0.300
{Nulla}	0.100	0.100	0.450

4.3.1 Dempster-Shafer Rule of Combination

Given mass functions m_1 (e.g., for the fingerprints) and m_2 (e.g., for the mugshots) defined on some frame *W*, we use Dempster's Rule of Combination to construct a new mass function $m_1 \oplus m_2$ that fuses the belief constraints of m_1 and m_2 (e.g., combining the evidence from both the fingerprints and mugshots):

$$(m_1 \oplus m_2)(U) = \sum_{U_1, U_2 s.t. U_1 \cap U_2 = U} m_1(U_1) m_2(U_2)/c$$

where normalizing constant c is the sum of the products $m_1(U_1) \oplus m_2(U_2)$ of all overlapping pairs U_1, U_2:

$$c = \sum_{U_1, U_2 s.t. U_1 \cap U_2 \neq \emptyset} m_1(U_1) m_2(U_2)$$

Table 4. Combined for fingerprint and mugshot

Focal element	Mass	Belief	Plausibility
{Fred}	0.536	0.536	0.610
All	0.074	1.000	1.000
{Sue}	0.028	0.028	0.120
{Mary}	0.018	0.018	0.148
{Bill}	0.058	0.058	0.150
{Mary,Nulla}	0.055	0.194	0.268
{Nullus}	0.092	0.092	0.166
{Bill,Sue}	0.018	0.104	0.178
{Nulla}	0.120	0.120	0.249

Table 4 shows the focal elements of $m_1 \oplus m_2$ (i.e., those subsets of *W* with non-zero mass) and their mass, belief, and plausibility values.

5. Situation theory and Dempster-Shafer Theory

To reflect the structure of an id-case, we consider the work by Lalmas et al. [6], who combine situation theory and Dempster-Shafer theory for an account of information retrieval. They consider constraints as conditionals, $\psi \rightarrow \varphi$, where ψ and φ are types, with a measure of certainty, $cert(\psi \rightarrow \varphi)$. If $cert(\psi \rightarrow \varphi) < 1$, then $\psi \rightarrow \varphi$ leads from one situation *s* (say, where there is smoke) to another, *s′* (where there is fire), which may be just an extension of *s* in that it supports all the infons supported by *s*. They require that, for type ψ, where *C* is the set of constraints, $\sum_{\psi \rightarrow \varphi \in C} cert(\psi \rightarrow \varphi) = 1$

One of our constraints is that there must be an appropriate supporting situation in which the fingerprint file was produced. Our frame of discernment *W* is a finite number of fingerprint files. The masses in the singletons are now on the constraints (or sets of constraints). Where $\psi \rightarrow \varphi$ leads from situation *s* to *s′*, Lalmas et al. define the mass of *s′* in terms of the mass of *s* and the certainty of $\psi \rightarrow \varphi$: $m_{i+1}(s') = cert(\varphi \rightarrow \psi) \cdot m_i(s)$. s′ itself may actually be a set of alternative situations the sum of whose masses equals $cert(\varphi \rightarrow \psi) \cdot m_i(s)$. So we invoke the notion of a frame of discernment *W′* being the *refinement* of a frame *W*; essentially *W′* is a finer partition of the universe of possibilities than *W*.

When we impose a constraint that leads to a fingerprint-producing situation, the frame is refined by adding information relevant to the acceptability of the fingerprint file. This might reduce the belief due to matching the fingerprint. Instead of something like Mary as a frame element, we have things like (Mary, off23, 11/25/2007); the frame is something like a product space. We effectively expand the id-situation to include the supporting situations.

6. Conclusion

We have presented the prototype for cyber identity based on situation theory. In essence, situation theory addresses situations in the real world and breaking them down into discrete items of information called infons. We captured the abstract version of the example situations shown by defining a set of infons. This is done in order to classify id-situations, where an id-action is performed. The examples had two id-cases which was the fingerprint and mugshot. The id-cases were represented in the semantic web standards and resources. This was done in an ontology worked in a previous paper. Therefore, this paper focused on measuring the uncertainty within the prototype.

To measure the evidence within the situations to create a legal case, we used the Dempster-Shafer theory of evidence. This theory provided mass functions, belief functions, and plausibility function. Once these concepts were utilized for each id-case, we have the calculated measures for the evidence in situations *s1-s6* in our example. This enabled us to use Rule of Combination to combine the evidence found in both id-cases, thus giving the evidence some measure and credibility regarding the identification of the owner of the fingerprint on the doorknob with the person whose face is in the picture.

Future work will focus on incorporating situation theory constraints within our version of Dempster-Shafer theory and handling larger datasets.

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