Situations and Evidence for Identity Using Dempster-Shafer Theory

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Abstract

We present a computational framework for identity based on Barwise and Devlin's situation theory. We present an example with constellations of situations identifying an individual to create what we call id-situations, where id-actions are performed, along with supporting situations. We use Semantic Web standards to represent and reason about the situations in our example. We show 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 use the Dempster-Shafer theory of evidence. We enhance Dempster-Shafer theory in two ways to leverage the information available in a constellation of situations. One way exploits the structure within the situations, and the other way interprets the information-relationships in terms of argument schemes.

Introduction

We here present our computational framework for identity. State of the art in identity is represented by the Superidentity project (Creese et al. 2013)(Hodges, Creese, and Goldsmith 2012), which developed a model in identity that connects elements from both the cyber and physical universes. 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 and email addresses. An initial superidentity has a 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, creating a directed graph that outlines the provenance of the elements of identity.

It became apparent, however, 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 Devlins account (Devlin 1995). 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.

The remainder of this paper is organized as follows. The next section introduces situation theory, and the following one outlines the Semantic Web standards we use for representing and reasoning about situations and the information they contain. There follows a section where we describe how we represent and reason about situations and their information, drawing on our running example. We then introduce the Demptser-Shafer theory of evidence and apply it to our running example. The next section outlines how we might exploit the structure of a constellation of situations involved in an identification in combining evidence in Dempster-Shafer theory. The penultimate section outlines another way Dempster-Shafer theory may be applied in situation theory, where a pattern of situations provides the structure for an argument scheme. The last section concludes.

Situation Theory

We follow Devlin's account of situations and information (Devlin 1995). Information is represented using *infons*. An infon is the basic item of information, with the general form $<< R, a_1, ..., a_n, l, t, i >>$, where R is an n-place relation, $a_1, ..., a_n$ 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, $s \vDash \sigma$ 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. An event is essentially a kind of situation, and an action is a kind of event (involving an agent). We take situations as they relate to identity (*id-situations*) to be those that include identity-relevant actions (*id-actions*). We use situation theory to be able to represent id-situations and the situations that support them.

Situation theory arose as part of the development of situation semantics by Barwise and his colleagues (Barwise and Perry 1981). In situation semantics, one identifies an *utterance situation*, in which a speech act is performed, and a *described situation*, which the speech act is about. Besides supporting information, a situation may *carry information* about another situation. This is made possible by constraints. Some such constraints are natural (as in smoke means fire), and some are conventional, such as those constraints by virtue of which a speech act is about a described situation.

Running Examples

We present a series of situations involved in identifying an individual by mugshot and by fingerprint. Our running example is shown in Figures 1 and 2 and involves six situations (within clouds), s_1-s_6. The situations on the right of each figure (s_1 and s_2) are id-situations that are coordinated in that they result in identifying the same individual (via their "name," actually any identifier unique in the context). Id-situation s_1 has an analyst who matches fingerprints on file with those on a doorknob. Id-situation s_2 has the same analyst matching the face in a group shot to a face in the mugshot. The fingerprints on file were produced in s_3, and the fingerprints on the doorknob were produced in s_4. Situation s_4 is a (spatiotemporal) part of the situation portrayed in the ellipse in the portrayal of s_5, where a group of people is socializing. This situation is in turn part of s_5, where someone takes a picture of the group. In situation s_6, a mugshot of the person of interest is produced. It is used in s_2 to pick out the person in question in the group photo. We thus have two id-cases: the fingerprint case, s_1-s_3-s_4, and the mugshot case, s_2-s_4-s_5.

The dashed lines between situations shown on the left and id-situations connect things produced (left) and used (right). In all cases except where the objects produced are themselves used in the id-situation, there are additional copying or rendering situations not shown in in the figures. In a sense, we have one id-situation made of two coordinated id-situations.

We use the empty prefix `:` for the namespace in which we define the basic classes and properties. An instance `s` of class :Situation generally appears as subject in triples identifying the time and location of the situation in terms of subclasses of classes defined in the WGS84 Geo Positioning vocabulary. We thus do not represent time and spatial location in an infon but rather just assume that all infons in a given situation share a common time and place. We move on to using the Semantic Web standards to implement our running examples as per situation theory.

Semantic Web

The Semantic Web is based on two World Wide Web Consortium (W3C) standards: 1) the resource description framework (RDF) and 2) RDF schema (RDFS). These standards are enhanced by the much more expressive OWL (Web ontology language) standard. RDF is a W3C recommendation that provides a data model for annotations in the Semantic Web. An RDF statement (triple) is of the form *subject predicate object*. RDF allows users to annotate web resources in terms of named properties. The values of these named properties can be URIrefs of web resources or literals. Resources that are annotated by RDF are named by uniform resource identifiers (URIs). A URL is a string that identifies a resource on the web. A URI has the same structure as a URL but need not identify a resource on the web. (URLs are URIs but not vice-versa.)A URI reference (URIref) is itself a URI with an optional fragment identifier at the end. URIrefs are written typically as qnames, which are in the form of `prefix:lp`, where the namespace prefix is a URI. A blank node (bnode) is a resource that is not identified by a URIref.

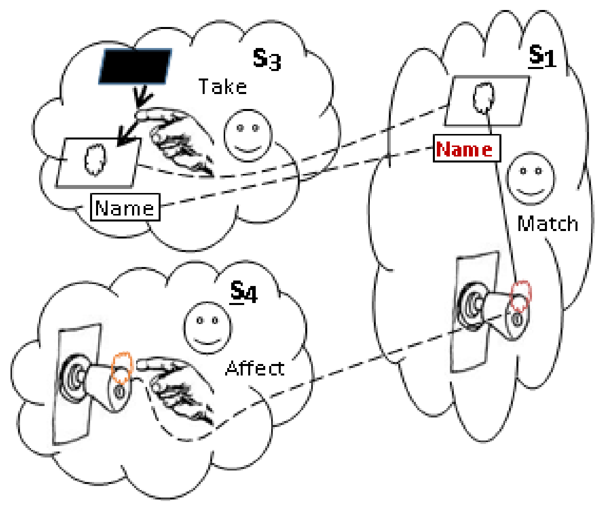

Figure 1: Fingerprint Situation

To represent RDF statements in a machine readable way, the W3C has defined several serializations. One of these serializations is the Notation 3 (N3) serialization. Triples in the N3 serialization are expressed as each of the three components separated by whitespace. When a subject is shared amongst triple, we can abbreviate this by having the subject listed once and separated predicate-object pairs by semicolons:

```
subject predicate1 object1;
    predicate2 object2.
```

RDFS allows for classes and properties to be defined using RDF triples. We state that individual x is an instance of class C with the triple `x rdf:type C`. These individuals could be denoted by a URIref or a bnode. N3 allows "a" to be used as an abbreviation for "`rdf:type`". A class may be a subclasse of other classes, and a property may be a subproperty of other properties. If `p` is a subproperty of `q`, then `x p y` implies `x q y`. If we have `x p y`, then `x` is an instance of the class that is the domain of `p`, and `y` is an instance of its range.

SPARQL is a SQL-like query language for triple stores where a variable is a sequence of alphanumeric characters proceeded by '?', a `WHERE` clause is a sequence of triples each of which might have a variable for its subject, object, or both. SPARQL reports only the variables that appear in the `SELECT` clause.

SWRL is a rule language for the Semantic Web. SWRL rules are in the form *`head`* → *`body`* where *`head`* is the antecedent and *`body`* is the consequence.

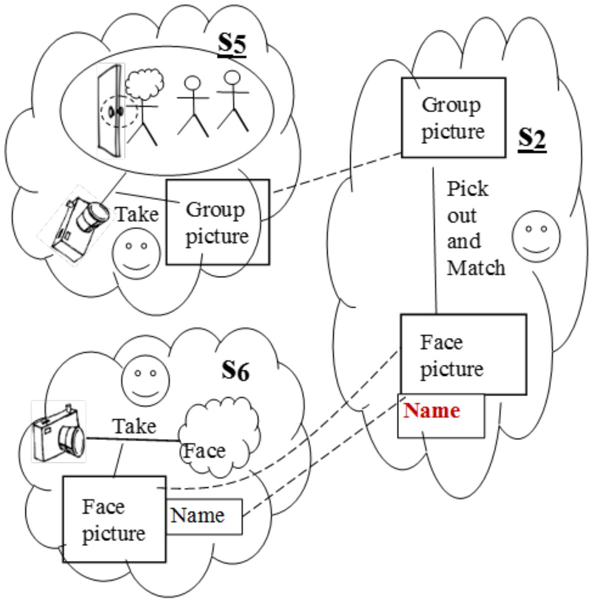

Figure 2: Mugshot Situation

RDF/OWL/SWRL Representation of Examples

That a given situation s has an infon i (an instance of class `:Infon`) is expressed as `s :hasInfon i`. Infon `i` itself has a polarity (property `:hasPolarity`). The various relations are captured by various subclasses of `:Infon`. If *R* is a relation with roles $r_1, r_2, ..., r_n$, then we define a subclass `:RInfon` of `:Infon` and properties `r1, r2, ..., rn` with domain `:RInfon`. This avoids RDF's restriction of relations to binary relations ("properties") since any instance of `:RInfon` may be a subject of any number of triples with one of `r1, r2, ..., rn` as the property.

The fingerprint id-case involves three situations: `s1` (id-situation), `s3` (taking the fingerprint on file), `s4` (taking the forensic fingerprint). We discuss only `s1` in detail. It has three important infons: `i1`, `i1a`, and `i14`. Like all our infons, they have positive polarity; henceforth we assume this. We discuss only `i1` in detail. It is an instance of `:AnalystMatchingFpInfon`, information that an analyst is matching the forensic fingerprint and the fingerprint on file (no suggestion of objective similarity). Three properties are recorded for it: `:fpObserved`, whose value is the URIref of the forensic fingerprint, `:fpRecorded`, whose value is the URIref of the fingerprint on file, and `:fpAnalyst` is for the officer making the match. In N3, this is (`i1`, like all our infons, is represented by a bnode.)

```
_:i1 a :AnalystMatchingFpInfon;
    :fpAnalyst officer:117;
    :fpObserved forensicfp:822;
    :fpRecorded fpfile:496;
    :hasPolairty :PositivePolarity.
```

Infon `i1a` is an instance of `:SimilarFpInfon`, that the forensic fingerprint and the one on file have a similarity measure of 0.94 according to a certain procedure. Infon `i14` is an instance of `:OnInfon`, that the forensic fingerprint is on the doorknob. Situation `s3` has one important infon, `i3`, an instance of `:TakeFpInfon`, that a given officer takes the fingerprint of our suspect.

The photo id-case also involves three situations: `s2` (id-situation), `s5` (taking the forensic photo), and s6 (taking the mug shot). `s2` is analogous to `s1` but lacks the analogue of the fingerprint on the doorknob. `s6` is analogous to `s3` (taking the fingerprint on file). `s5` is only roughly analogous to `s4`. One of `s5`'s infons, `i5`, is an instance of `:ForensicPicInfon` and is the subject of triples identifying the photographer, the camera, the photo produced, and the situation, `s5a`, caught on camera. One infon that `s5a` has is that our suspect is touching the doorknob; it also has

```
sit:s5a :inSituation group:5342;
```

This says that this group is in the situation but does not identify any information associated with the group, yet infon `i5` includes the information that `s5a` is the situation pictured. We also have (where `insys:201` is our suspect)

```
group:5342 a foaf:Group;
    foaf:member insys:201, insys:563.
```

There is thereby in `i5` the information that `insys:201` is pictured in the photo produced; we do not necessarily have the information that `insys:201` is a member of `group:5342`. And we have (where `foaf:depicts` is an information relation)

```
fshot:812 a biom:GroupImage;
  # The group photo (s2, s5)
    foaf:depicts  sit:s5a .
```

There is also a part-whole (mereological) relation between `s4` and `s5`: `s4`, where the suspect touches the doorknob, is a proper part of `s5a`, the situation caught on film in situation s_5.

Assuming all our information is available (possibly distributed) on the Web, we can issue SPARQL queries that navigate across situations connected by, say, shared individuals.

We have identified a few important infons for each real situation s_1-s_6, but each supports an unbounded number of infons. We need abstract situations as types to classify real situations and constellations in a way conducive to identification. For classifying, we use SWRL rules. Where `C` is a class and `x` is an individual, `C(x)` is true iff the triple `x rdf:type C` holds. Where `p` is a property, `x` is a URIref or bnode, and `y` is a URIref, a bnode, or a literal, `p(x, y)` is true iff the triple `x p y` holds. If certain conditions hold of a situation '`?s`' (note that SWRL variable names begin with '`?`'), we classify it as some subclass of class `:Situation`. Our classifying SWRL rules, then, have the form

```
Situation(?s), ... -> SituationSubClass(?s)
```

The conditions that fill in the ellipsis relate to the infons that `?s` has, one or more sequences like

```
hasInfon(?s, ?i), ...,
  hasPolarity(?i, ?po),
   polarityValue(?pol, ?val), equal(?val, 1)
```

The ellipsis here is filled in with specifics on the roles of the relation represented by the infon. The sequence of atoms after the ellipsis forces positive infon polarity. All our infons have positive polarity, so we ignore this.

The case-type with the photos involves three situation types, identified with the classes `:Mug` (a mug shot is taken), `:Pic` (a forensic picture is taken), and `:PicId` (id-situation type). A situation is of type `:Mug` if it has an infon of type `:TakeMugshotInfon` involving a recorded mugshot, a subject, and an administrative officer responsible for the mugshot. A situation `?s` is of type `:Pic` if it has a `:ForensicPicInfon` involving an officer taking the photo, a group image that is the photo, and a situation captured by the photo and that includes the group depicted in the photo. This describes a situation that references another. A `:Pic` situation, then, is like an utterance situation, best compared to a situation where the "uttering" is writing, although speech and writing abstract away information.

The case-type with fingerprints also involves three situation types, identified with the classes `:FpFile` (a fingerprint is recorded), `:Touch` (a forensic fingerprint is left), and `:FpId` (id-situation type).

Recall that an id-situation together with its supporting situations is an id-case. We form id-case types, abstract versions of id-cases. Generally, an id-case type glues together several situation types, which requires (for connections) exposing more information in the situations than is exposed for the situation types. We define SWRL rules to classify cases as subclasses of a generic `:Case` class.

In the envisioned scenario, the two id-cases are coordinated since the filed fingerprint and mugshot of a single suspect are used to establish his presence in a gathering. We introduce symmetric property `:coordinatedIdCase` whose domain and range are `:IdCase`. We have a SWRL rule for determining that an instance of `MugIdCase` and an instance of `FingerpIdCase` are coordinated by checking not only that the label on the mugshot is the same as that on the fingerprint on file but also that we have one and the same id-situation. The criterion for identity of situations is beyond the scope of this paper.

Dempster-Shafer Theory of Evidence

We want a measure of how the evidence supports the judgment in an id-situation. It should reflect the structure of an id-case and fuse belief constraints from different sources. In our example, s_1 and s_2 are essentially a single utterance situation (the identity judgment), and the situation in the photo in s_5 is the described situation. Imagine that, in s_1, 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 s_1 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.

We adapt the Dempster-Shafer theory of evidence (Halpern 2003). The frame of discernment (the set of possible values), W, includes here people who might have left the fingerprint or have their mugshot considered. In s_1, we have a measure of how well the fingerprint on file matches the fingerprint on the scene. We also have similarity measures for 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, for subsets of W; those subsets with non-zero mass are called *focal elements*. 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 in [0,1]. Where $m(.)$ is the mass function, $m(U)$ is the probability of observing U, so the definition of the belief function in terms of the mass function is $Bel_m(U) = \sum_{U^* \subseteq U} m(U^*)$.

For our example, suppose that the similarity measures for the singletons {Fred}, {Bill}, {Sue}, and {Mary} to the fingerprint on the doorknob are, respectively, 0.4, 0.075, 0.075, and 0.0. In addition, there is some evidence, mass 0.05, of the fingerprint belonging to {Sue, Bill} (i.e., to Sue or Bill without distinction). And perhaps someone other than the people mentioned left the fingerprint on the doorknob. The evidence for this chance has about half the strength as the evidence for {Fred}; as a singleton set, it receives 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 fingerprint could have got on the doorknob, not only by those mentioned, but perhaps left before or after the situation considered.

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 $Bel(U) = 1 - Plaus(\bar{U})$.

Table 1 shows the values of the Dempster-Shafer functions for each focal element for s_1. *All* represents the entire frame of discernment; its mass 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.

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 1: Fingerprint Mass, Belief, and Plausibility

For s_2, focal elements are subsets of W with non-zero probability of containing the person whose mugshot matches the picture of the culprit in the forensic picture. Suppose that the mass for the focal elements are Fred: 0.35; All: 0.2; {Sue}: 0.0; {Mary}: 0.05; {Bill}: 0.05; {Mary,Nulla}: 0.15; {Nullus}: 0.100; and {Nulla}: 0.100. 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):

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

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:

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

Table 2 shows the shows the values of the Dempster-Shafer functions for each focal element of $m_1 \oplus m_2$.

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 2: Combined for fingerprint and mugshot

Dempster-Shafer Theory & Situation Theory

To reflect the structure of an id-case in our account of evidence, we consider the work by Lalmas et al. (Lalmas and Van Rijsbergen 1994), who combine situation theory and Dempster-Shafer theory for an account of information retrieval. They consider constraints as conditionals, $\psi \rightarrow \phi$, where ψ and ϕ are types, with a measure of certainty, $cert(\psi \rightarrow \phi)$. If $cert(\psi \rightarrow \phi) < 1$, then $\psi \rightarrow \phi$ leads from one situation s (say, where there is smoke) to another, $s\prime$ (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, $\sum_{\psi \rightarrow \phi \in C} cert(\psi \rightarrow \phi) = 1$

One of our constraints is that there must be an appropriate supporting situation in which the fingerprint file was produced. We read this, as it were, backwards or teleologically: if there is a situation in which a fingerprint file is produced, then there is a situation in which it is used. 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 $\psi \rightarrow \phi$ leads from situation s to s', Lalmas et al. define the mass of $s\prime$ in terms of the mass of s and the certainty of $\psi \rightarrow \phi$: $m_{i+1}(s') = cert(\psi \rightarrow \phi)m_i(s)$. s' itself may actually be a set of alternative situations the sum of whose masses equals $cert(\psi \rightarrow \phi)m_i(s)$. 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 from 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) for a fingerprint purportedly of Mary; the frame is effectively a product space, $Suspects \times AdministeringOfficers \times Dates$. We effectively expand the id-situation to include the supporting situations.

Issues arise with respect to the structure of this product space and how the mass is aggregated to contribute to evidence in the id-situation (where a judgment is made). A focal element is a subset of this product space that is assigned a non-zero mass. We can consider something like marginal distributions: for a given (suspect, administering-officer) pair, we add up the mass across all the dates for that pair. Going further, for a given suspect, we add up all the mass for the triples that involve that suspect.

The certainty on the constraint from the fingerprint-producing situation to the existence of the fingerprint file in the id-situation is a measure of the general acceptability of introducing a fingerprint file into an investigation. What the mass of the supporting situation is taken to be depends on how the evidence is being used. If the investigation engenders suspicion of a given administering officer, then, within the supporting situation, the mass for identifying the suspect would be reduced. These considerations revolve around the relation between the id-situation and a supporting situation as well as the nature of the supporting situation. These are essentially ontological considerations.

Dempster-Shafer Argument Schemes

How evidence regarding supporting situations is incorporated into an overall evaluation can perhaps be answered in a nonontological manner following the work by Tang et al. in combining argumentation with an explicit representation of evidence (Tang et al. 2013) (see also (Tang et al. 2012)). They introduce a logical language L with the usual truth-functional connectives. Atomic propositions are constructed from a finite set of predicate symbols and a finite set of individual constants, with no function symbols, so there are only finitely many possible ground terms. Individual variables occur only in rules (for generality, with uniform substitution across premises and conclusion). The frame of discernment, Ω, is the set of possible truth assignments to all the (ground) atomic propositions: if there are n such propositions, there are 2^n elements of Ω (i.e., rows in the truth table). The interpretation of proposition θ (atomic or not), $I(\theta)$, is a subset of Ω. Propositions θ, $\psi \in L$ are logically equivalent iff $I(\theta) = I(\psi)$. Where $true$ and $false$ are the obvious constants, $I(true) = \Omega$ and $I(false) = \varnothing$. An inference rule δ for L is of the form:

$$\delta = \frac{p_1, ..., p_m}{c}$$

where $p_1, ..., p_m; c \in L$. The p_i are the set of *premises* of the rule, and c is its *conclusion*.

It is straightforward to go from a frame of discernment where elements are structures on individuals to a frame of discernment where elements are logical propositions over a finite set of predicate symbols. To take our example $(Mary, off23, 11/25/2007) \in Suspects \times AdministeringOfficers \times Dates$, assume we have one-place predicates $suspect(x)$, $adminOfficer(x)$, and $date(x)$, meaning, respectively, that x is the suspect (whose fingerprint is taken), that x is the administrating officer, and that x is the date (when the fingerprint was taken). Assume also that we have individual constants *Mary*, *off23*, and *11/25/2007* with the obvious denotations. Then our example triple translates to the conjunction $suspect(Mary) \wedge adminOfficer(off23) \wedge date(11/25/2007)$. Set-theoretical operators correspond in obvious ways to truth-functional operators, which again relate to set-theoretical operators on the interpretations of propositions.

We have a set Σ of formulae $\langle h, E\rangle$ where $\langle h, E\rangle$ is an evidence argument that has $h \in L$ associated with supporting evidence E for which there is a mass function, $E = \{e_1 : m_1, ..., e_n : m_n\}$ such that $\sum_{i=0}^{n} m_i = 1.0$. (Note that here a mass function is being associated with a single proposition.) To write a mass function value in isolation, we write $m(E, e_i)$. Given evidence argument $\langle h, e\rangle$, the belief $b(h)$, disbelief $d(h)$, and uncertainty $u(h)$ of h are defined as

- $b(h) = \sum_{I(e_i)\subseteq I(h)} m(E, e_i)$ = the sum of the mass of all the focal elements in E that are part of the evidence for h.
- $d(h) = \sum_{I(e_i)\cap I(h)=\varnothing} m(E, e_i)$ = the sum of all the mass for all the focal elements that are evidence for $\neg h$.
- $u(h) = 1 - b(h) - d(h)$ = the sum of the mass of the formulae that imply neither h nor $\neg h$.

We can define the plausibility of h as $1 - d(h)$. We also have a set Δ of rules $\{\delta, E\}$ where rule δ is associated with evidence E.

For an example of the use of a rule, suppose that the proposition in question is that the fingerprint is Bill's, $fprint(Bill)$, and suppose that the associated evidence is as follows (which duplicates the mass function used in the example in the above example) $E_1 = \{fprint(Fred) : 0.4, fprint(Sue) : 0.075, fprint(Bill) : 0.075,\ fprint(Nullus)\ :\ 0.1, fprint(Nulla)\ :\ 0.1, fprint(Bill) \vee fprint(Sue) : 0.05, fprint(All) : 0.2\}$

Suppose also that we have the following rule δ with evidence
$E_5 = \{fprint(X) \wedge thief(X)\ :\ 0.8,\ fprint(X) \wedge \neg thief(X) : 0.2\}$
Note that the proposition constituting the premise is carried down to be conjoined with the stated conclusion; this is to specialize the conclusion to the individual to which variable X is bound.

It is more informative to combine the evidence E_1 as a whole and the evidence E_5, where we take products, instantiating X to the individual constant in the corresponding element of $E1$ (treating $fprint(Bill)fprint(Sue)$ as $fprint(Bill \sqcup Sue)$, where $Bill \sqcup Sue$ is a composite object). The result is shown in Table 3, where a number in a cell is the mass value of $fprint(X) \wedge thief(X)$ or $fprint(X) \wedge \neg thief(X)$, depending on the row, where the value of X is indicated in the column. Note that the sum of all values is 1.0. We have, for example $Bel(fprint(Bill) \wedge thief(Bill)) = 0.06$ and

	Person	Fred	Bill	Sue	Nulla
Thief?	**Yes**	0.32	0.06	0.06	0.08
	No	0.08	0.015	0.015	0.04

	Person	Nullus	Bill or Sue	All
Thief?	**Yes**	0.08	0.04	0.16
	No	0.02	0.01	0.04

Table 3: Result of Applying our Rule δ with evidence E_5

$Plaus(fprint(Bill) \wedge thief(Bill)) = 0.26$. This example is particularly simple, and we intentionally avoided combining evidence to indicate how the rules are applied.

Tang et al. (Tang et al. 2013) consider the several ways of combining evidence that have been suggested in the context of Dempster-Shafer theory, considering them all to fit into the general pattern of:

- A rule pattern in Δ: $\delta = \frac{p_1,\ldots,p_m}{c}$
- A Dempster-Shafer argument scheme specifying
  - the pattern of the evidence of the premises: $\langle h_1, E_1\rangle ... \langle h_n, E_n\rangle$
  - optional evidence for rule applicability E_δ
  - an an associated conclusion evidence derivation process: we compute the evidence for the conclusion from the evidence for the premises possibly including the rule evidence

When we go to apply an argument scheme, we ask certain critical questions. Only if the answers to all these questions are affirmative are we entitle to apply the scheme. Each scheme is associated with a particular rule for combining evidence. We have seen the oldest and most common rule: Dempster's rule. Another common rule is Yager's rule (see (Curley 2007) for an intuitive comparison with Dempster's rule), which treats conflicting evidence as uncertainty. See (Sentz and Ferson 2002) for a systematic presentation of various rules for combining evidence.

What we are interested in, however, is how to go from information produced in supporting situations to its use as evidence in an id-situation. (In contrast, the rule above, without combination, used the results of id-actions as evidence for various actors being thieves.) This is usually a combination problem. A closer look, however, reveals that the language used in supporting situation s_3 is different from the language used in the id-situation, s_1. One way they differ is that s_1 is an utterance situation while s_3 is a described situation. In terms of vocabulary, s_3 talks about an administering officer, the time and place the fingerprint is taken, and the method used. And s_1 talks about the fingerprint from the scene, matching the two fingerprints, and the time and place the matching is done. Both situations talk about the fingerprint produced in s_3 and used in s_1 and the person thereby identified. Considering the questions Tang et al. pose, the appropriate rule here is Zhang's center combination rule, which is based on two frames of discernment S and T from two disjoint sublanguage L_S and L_T of L. It assumes that we are concerned with the truth of sentences in L_T but we only have evidence expressed in L_S and in $L_S \in L_T$. For $A_T \cup L_T$, we are given two pieces of evidence, E_1 in L_S and E_2 in $L_S \cup L_T$. This scheme can be used where question 1 for Demster's rule is answered "no" since the evidence does not directly support the conclusion of interest because of the change in language. Zhang's rule is especially useful in transforming the evidence from a source domain L_S into a targeting domain L_T with the connection evidence in their super domain $L_S \cup L_T$.

There is, however, more than combining evidence going on as information supported by s_3 is taken as evidence in s_1. How this fitting into a forensic picture contributes to the resulting mass function must be captured by the rule $\delta \in \Delta$ that is applied. This plays a role similar to that of a constraint, $\psi \rightarrow \phi$, along with its level of certainty, in the application of Dempster-Shafer theory to situations.

Conclusion

We have presented a computational framework for identity based on situation theory, where we identify id-cases, each consisting of an id-situation (where an identity judgment is made) and supporting situations. We have shown how to encode in RDF information supported by a situation in terms of infons (items of information). We have shown how to use OWL and SWRL to define rules that classify situations thus encoded under types (i.e., abstract situations). We have also defined SWRL rules for identifying types of id-cases and coordinated id-cases. We also address quantifying the evidence that supports the judgment in an id-situation. For this, we use the Dempster-Shafer theory of evidence, applying it to our running example. To capture how supporting situations contribute to the evidence for a judgment, we considered two approaches. One approach associates a certainty with a constraint by virtue of which one situation carries information about another, and it introduces a refinement of the frame of discernment related to the target situation. The second approach sees the support that situations provide for the id-situation in the framework of argument schemes framed in terms of Dempster-Shafer theory.

Following the argument-schemes approach, we wish to approximate the outcomes of informal reasoning and largely capture the post hoc rationalizations by which actors justify their decisions. The classic here is Toulmin's *The Uses of Argument* (Toulmin 1958), which presents a diagram for directing one's analysis of arguments. The subject is sometimes known as informal logic. There is a coherent literature under the rubric "argumentation theory" (cf., e.g., (Walton 2013)(Van Eemeren et al. 1996)). Argumentation is central to the law, and legal scholars have addressed evidence in this context (Twining 2006) (Anderson, Schum, and Twining 2005). Note that a legal perspective may be central to ones view of individuals and numerical identity: Locke famously called "person" a forensic term (and held personal identity, or self, to be founded on continuity of consciousness not of some [unknowable] substance) (Locke 1689).

On the other hand, capturing the constraints and refining the frame of discernment would have the benefit of associating evidence with the inherent structure of the case. Future work, then, besides including enhancements to the implementation, will attempt to reconcile these two approaches to how supporting situations contribute to the evidence for a judgment.

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