Situation-Based Ontologies for a Computational Framework for Identity Focusing on Crime Scenes

Marguerite McDaniel
Dept. of Computer Science
North Carolina Agricultural and Technical State University
Greensboro, NC
mamcdan2@aggies.ncat.edu

Emma Sloan
Dept. of Computer Science
Brown University
Providence, RI
emma_sloan2@brown.edu

Siobahn Day
Dept. of Computer Science
NC A&T State U
Greensboro, NC
scday@aggies.ncat.edu

James Mayes
Dept. of Political Science and Criminal Justice
NC A&T State U
Greensboro, NC
jpmayes@ncat.edu

Albert Esterline, Kaushik Roy, and William Nick
Dept. of Computer Science
NC A&T State U
Greensboro, NC
{esterlin, kroy}@ncat.edu, wmnick@aggies.ncat.ed

***Abstract*— We are interested in how evidence in a case fits together to support a judgment about the identity of an agent. We present a computational framework that extends to the cyber world although our current work focuses on physical evidence from a crime scene. We take Barwise's situation theory as a foundation. Situations support items of information and, by virtue of constraints, some carry information about other situations. In particular, an utterance situation carries information about a described situation. We provide an account of the support for an identity judgment (in an utterance situation called an id-situation) that looks at building a case (called an id-case), like a legal case, since identity cases can lead to multiple situations that impact the value of our evidence. We have developed a novel situation ontology on which we built an id-situation ontology. To capture our current focus, we developed a physical biometrics ontology, a law enforcement ontology, and several supporting stubs. We show how a case can be encoded in the RDF in conformance with our ontologies. We complement our id-situation ontology with SWRL rules to infer the agent in a crime scene and to classify situations and id-cases. Combining possibly conflicting evidence is handled with Dempster-Shafer theory, as reported elsewhere.**

Keywords— ontologies; situation theory; identity framework; evidence; crime scene investigation

I. Introduction

We are interested in how evidence in a case fits together to support a judgment on the identity of an agent. Though current work focuses on evidence from a crime scene, what is presented here is a computational framework that extends to the cyber world. The Superidentity Project [1] represents the state of the art in identity. 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. We, however, want an account of the support for an identity judgment that looks at building a case, like a legal case. We turned to situation theory as developed by Barwise et al. [2] for a robust representation of context and provenance. 'Situation' is their "name for those portions of reality that agents find themselves in, and about which they exchange information" [3]. We use Semantic Web standards, including RDF and OWL, to represent the information present in a constellation of situations that relate to identity judgments. We have developed OWL ontologies, including situation and biometrics ontologies, and have added SWRL rules to draw conclusions. For more on our ontologies, see [4], [5], and [6]. Our framework uses Dempster-Shafer theory for combining possibly conflicting evidence. This aspect is not covered here; see instead [6, 7]

Kokar et al. present their own Situation Theory Ontology (STO) in [8] (see Section X), also formulated in OWL and based on situation theory but with a different structure for basic concepts. Our ontologies can be compared to the Cyber Forensics Ontology [9], an OWL-based ontology that supports classification and investigation of cyber-crime cases through the collection of documentation and evidence. The `Crime_Case` class connects to all other classes. The `Evidence` class includes the evidence type and the collection process, including documentation of the professionals involved. We have no such class as we view the evidence as emerging from the information provided by situations as they assemble to form a case. Still, there are well-defined concepts in this ontology that are worth addressing,

Identity-related situations (*id-situations*) include identity-relevant actions (*id-actions*), which we analyze as assertions of identity statements even when the action includes non-linguistic elements, such as gestures. For example, when I point and say, "(S)he stole it," I use two ways to denote the same person, by pointing and by referring to them as an agent. Identity is an equivalence relation; a collection of identity statements partitions the set of denoting devices used into equivalence classes. Each such class denotes a unique individual. Assert an identity statement linking a denoting device in one class to one in another fuses the two classes, which are our analogues of superidentities.

The remainder of this paper is organized as follows. The next section presents background on situation theory and the semantic web resources. Section III presents our running example, Sections IV-VI discuss our physical biometrics ontologies, supporting ontologies, and our Situation Ontology. Section VII presents our ID Situation Ontology and discusses how we represent our running example. Section VIII discusses the role of objects used as evidence in connecting situations, Section IX discusses our SWRL rules, Section X compares our ontologies to similar ontologies, Section XI compares our framework with other research based on the notion of situation, and Section XII concludes.

II. Background

Our background is largely situation theory for conceptual aspects and Semantic Web resources to express the ontologies and capture data.

A. Situation Theory

Situation theory was articulated by Barwise and Perry in *Situations and Attitudes* (1983) [2] and presented systematically by Devlin [10]. An *infon* is a basic item of information (a "state of affairs"—see [3]) denoted by an atomic proposition, relating one or more objects in a time and place. An infon also has a polarity to allow negative as well as positive facts. A situation *s supports* an infon σ if the information available in *s* includes σ. A *real situation* is a part of reality and supports indefinitely many infons while an *abstract* situation is a finite set of infons, a type that can classify real situations. Situation theory is part of situation semantics, where we identify an *utterance situation*, in which a speech act is performed, and a *described situation*, which it is about. Our id-situation is an utterance situation, and the corresponding crime scene is the described situation. A situation may *carry information* about another situation thanks to *constraints*, some natural (as in smoke means fire) and some conventional, such as those by which a speech act carries information about a described situation.

B. Semantic Web Resources

The Semantic Web is founded on W3C standards [W3C11]: RDF for representing simple facts, the RDF schema (RDFS) for extending the set of terms, and the more expressive OWL for authoring ontologies, that is, conceptualizations of domains. An RDF statement (triple) has the form *subject property object*, where *property* is a binary relation term. This asserts that *subject* has *object* as its value for *property* (e.g., *Fred hasWife Jill*). To denote "resources" (things), RDF uses the Web's uniform resource identifiers (URIs), which are unique across the Web. An individual may belong to one or more classes. A class may be a subclass of a class, and one property may be a subproperty of another. We may identify the domain or range of a property. OWL ontologies are supplemented with conditional rules in SWRL. To apply SWRL rules, we use the Pellet reasoner [11] to infer triples from relations in an OWL ontology.

Semantic Web standards are apt for identity. There is no unique name assumption: two "names" (URIs) may refer to the same individual; we must allow for this in a web context. We may find later that two URIs do or do not denote the same thing. OWL's handling of inverse functional properties (e.g., that established by issuing student IDs) provides clear means to infer identity triples. Related to the non-unique name assumption is the open-world assumption, which fits well with situation theory as situations are partial information structures.

III. Running Example

We consider a crime scene where a theft has occurred at a party, and we have a list of possible suspects in the form of a guest list. Evidence from the scene includes a group photograph from a security camera with one guest's hand on the door to where the valuables were kept and a fingerprint from the doorknob of that door. The entire case consists of a constellation of situations, centering around two separate id-situations for the two pieces of evidence: the fingerprint and the snapshot. We thus have two id-cases.

Situation s_1 is the id-situation for the fingerprint, where an analyst compares fingerprints on file to the forensic one found at the crime scene (see Figure 1). For the comparison, each fingerprint, from the crime scene or from the police department, must be taken and handled in its own situation. Thus, in each of the situations s_{3a}-s_{3d}, a suspect has their fingerprint taken by a forensic professional and put on file, and in situation s_4, the criminal touches the doorknob, placing the forensic fingerprint. The crime scene investigation team then lifts the fingerprint from the doorknob in situation s_5 so that it may be compared against the fingerprints on file.

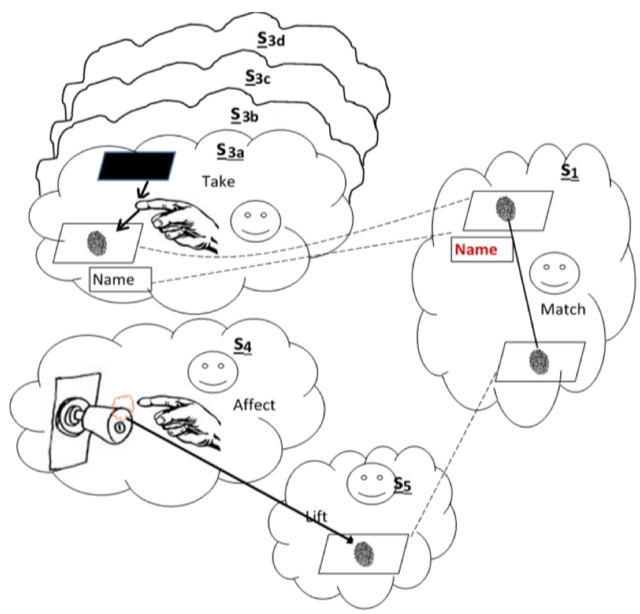

Fig. 1. The fingerprint id-case

Similarly, the id-situation for the security camera image, s_2, is supported by its own constellation of situations forming an id-case (see Figure 2). A forensic professional takes a mugshot of each suspect in situations s_{6a}-s_{6d}. Those mugshots are then compared with the security camera image in s_2. The security camera records the group in situation s_7, which acts as an utterance situation that produces a photo as a persistent description (unlike the fleeting speech of a spoken utterance) of situation s_8, the actual occurrence of a group standing near the door and someone touching the doorknob while at the party. Situation s_4, where a fingerprint is left by touching the doorknob, is a part of situation s_8, the larger scene of what occurred at that moment at the party.

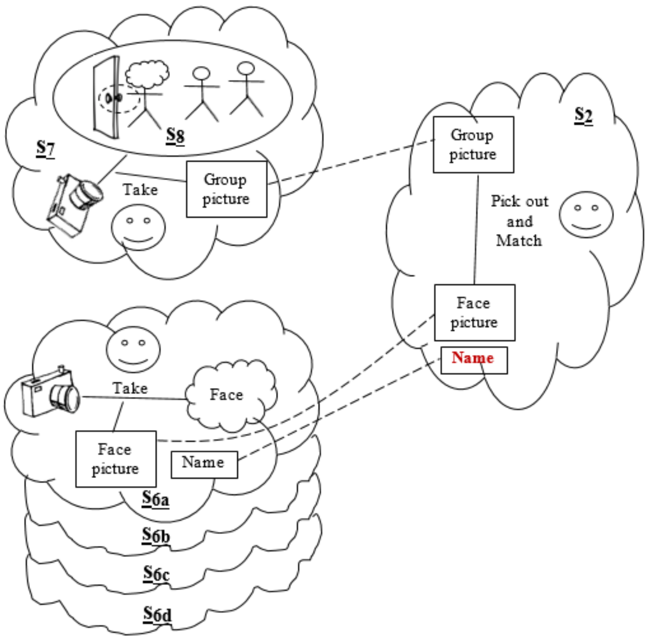

Fig. 2. The mugshot id-case

IV. The Physical Biometrics and Physical Features Ontologies

This section presents the ontologies that are important because of the current focus on crime scene investigation. We refer to a class one level down from *C* in the subclass hierarchy as a *child* of *C*. A *top-level class* is a class that is a child of the most general class, **Thing**. We do not generally use prefixes with class and property names but rather rely on context. Where ***p*** is a property, we use the notation ***p*: *d* → *r*** to indicate that ***p***'s domain is ***d*** and range is ***r***.

In the Physical Biometric Ontology, class **PhysicalBiometricRegistration** (**PBR**) is a child of class **Situation**; an instance of it is a situation where a forensic professional registers some depiction of a surface feature of a person to use for biometric identification. Class **SurfaceFeature** is defined in the Objects Ontology, and subclasses of it that relate to the human body (denoting, e.g., the friction ridges on one's fingers) are defined in the Physical Features Ontology. We define the property **captures: PBR → SurfaceFeature**, which is functional. We define the top-level class **BiometricArtifact** for those things (e.g., fingerprints, mugshots) created in the registration process as well as similar things from a crime scene. It has a child, **BiometricImage**, which itself has children for fingerprint, facial, and group images: Property **produces: PBR → BiometricArtifact**, is functional and inverse functional, and **depicts: BiometricArtifact → SurfaceFeature** is functional.

Physical biometrics records images of surface features of parts of the human body, specifically parts of the eye, which is part of the head, and each finger, which is part of a hand. So, in the Physical Feature Ontology, as children of class **PhysicalObject** (from the Object Ontology) we have **HumanBody** and **HumanBodyPart**. From the Object Ontology, we have the a transitive **hasPart** property. The subproperties of this in the Physical Features Ontology record the structure of the human body. Also from the Object Ontology, we have the property **hasFeature: PhysicalObject → SurfaceFeature**, which is inverse functional. Since our ultimate interest is in identifying people, we relate all these features to the person who has them.

V. Supporting Ontologies

Figure 3 shows the ontologies for this project and the inclusion relations among them. An arrow goes from an included ontology to one that directly includes it. Most of the ontologies include the FOAF ontology (not shown). The previous section covered the chain of ontologies on the right of this figure, which relate to the physical biometric aspects that we model at this stage in our framework. The main interest is in the ID Situation Ontology (specializing of the Situation Ontology), which could relate to any methods for identifying agents, not just a biometric one. In this section, we cover supporting ontologies: We created very simple Geopolitics and Geography Ontologies, which are essentially stubs. We are currently reviewing standard ontologies and will include fragments of them in place of our stubs. The Procedures Ontology is for automated procedures that play a role in processing evidence. It is currently a stub with one top-level class, `Procedure`, with a subclass for procedures to measure the similarity between two biometric artifacts.

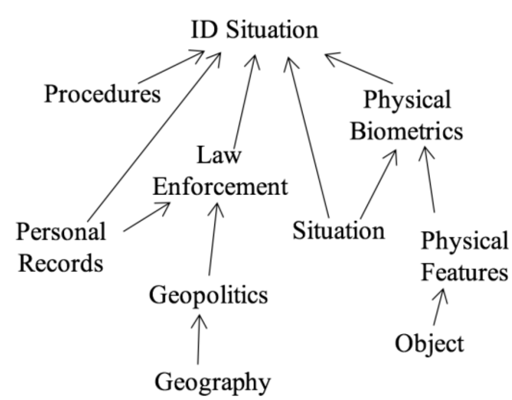

Fig. 3. The ontologies and their inclusion relations

The most important of the supporting ontologies is the Law Enforcement Ontology. The FOAF ontology has a top-level **Agent** class with children **Organization** and **Person**. We provide a child **LawEnforcementAgency** of **Organization** and a child **LawEnforcementProfessional** of **Person** and formulate subclasses of it to capture the relevant kinds of personnel. We also provide a child **Suspect** of **Person** for those on the other side of the law. With respect to **LawEnforcementProfessional,** individuals who handle evidence are generally from law enforcement, and an emerging standard is for them to be certified as forensic professionals. Children of this class include **ForensicProfessional** (for criminal justice lab scientists or CSI professionals), **PoliceOfficer** (for those with the power to enforce the law), **PoliceInvestigator** (for the investigators), and **ProsecutionProfessional** (for legal staff). There is an affiliation property associating agents with organizations and a certification property associating forensic professionals with certificates. Our Personal Records Ontology defines a child **Record** of FOAF **Document** and a child **PoliceRecord** of **Record** along with an inverse-functional property **hasRecord**.

VI. THE SITUATION ONTOLOGY

The main classes in the Situation Ontology are `Situation` and `Infon`. To keep things simple, we associate time and location with a situation rather than with its infons. There is a reflexive and transitive object property `includes` to indicate that one situation is a part of another. The property relating infons to situations is `supports`. There is also a functional property `references: Infon → Situation` for an item of information referring to a situation (as in an utterance). Since all our examples involve only positive polarity, we ignore polarity here.

We encode the relation in an infon by defining a different child of `Infon` for each relation. Each role (argument position) in a relation is represented by a property with the corresponding subclass of `Infon` as its domain and a range class or datatype providing appropriate values for that argument position. This scheme overcomes RDF's restriction to binary relations and allows for variable-arity relations. Most subclasses of `Infon` are defined in the ID Situation Ontology since they relate to identity and biometrics.

VII. THE ID SITUATION ONTOLOGY AND ENCODING OUR RUNNING EXAMPLE

Here we present the children of **Infon** for the fingerprint id-case and illustrate their use by describing the RDF encoding in one situation. We then give an overview of the mugshot id-case. We then discuss possible children of **Situation** and the class **IdCase**.

A. The Fingerprint Id-Case

s_1 is the id-situation for the fingerprints. It supports two essential infons, both instances of children of **MatchingFpInfon** (a child of **Infon**), which is information that an attempt is made to match a fingerprint from the scene against a recorded fingerprint. One child of this class is **AnalystMatchingFpInfon**, information that an attempt is made to match a fingerprint from the scene against a recorded fingerprint, and the other is **SimilarFpInfon**, information on the similarity measure for the match and the procedure giving this measure. For the first suspect, s_1 supports the following two infons (denoted by blank nodes, with "_" in place of a prefix). The N3 notation allows us to represent multiple triples with the same subject by listing the subject once followed by the predicate-object pairs separated by semicolons.

```
_:i11a a idterms:AnalystMatchingFpInfon;
  idterms:fpAnalyst forprof:117;
    idterms:fpObserved forensicfp:652;
    idterms:fpRecorded fpfile:496;… .
_:i1a a idterms::SimilarFpInfon;
    idterms:fpObserved forensicfp:652;
    idterms:fpRecorded fpfile:496;
    idterms:simMeasure "0.92";
    idterms:simProc similar:Proc1;… .
```

For URI prefixes, we use **idterms** for the ID Situation Ontology. We assume that the relevant agency has indexed the individuals with natural numbers that serve as unique identifiers. We introduce prefixes for individuals thus indexed: **forprof** for forensic professionals, **forensicfp** for fingerprints collected at crime scenes, and **fpfile** for fingerprints on file. We also assume unique identifiers with prefix **similar** for the procedures used to measure the similarity of samples. The same pair of fingerprints appears in both infons. There are similar pairs of infons for the other suspects.

s_{3a} is the situation where the fingerprints of the first subject were taken and recorded. It supports one essential infon, which is the information that a forensic professional takes the fingerprint of a subject. There is one such infon for each of the remaining three situations. s_4 is the described situation, where someone (yet to be identified) leaves their fingerprint on the doorknob. There are two essential items of information here, that the fingerprint is on the doorknob, and that some suspect left their fingerprint on a thing. There is, however, a gap in our knowledge since we do not know the identity of the suspect; the point of the investigation is to assert a triple identifying the fingerprint producer. s_5, where the fingerprint on the doorknob is lifted, has one essential item of information, that a forensic professional lifts a fingerprint that is on something.

B. The Mugshot Id-Case

s_2, the id-situation for the mugshots, supports two essential infons similar to those in the fingerprint id-situation, s_1. The photo of the culprit is just a part of the photo that the officer took: the part showing their face. s_{6a}, where the mugshot of the first subject was taken and recorded, supports one essential infon that a given forensic professional takes and records a mugshot of a suspect with a given camera. There is one such infon for each of the remaining three situations.

s_7, where a forensic professional takes a picture, has two significant infons. One is that a certain officer takes a picture of a given situation with a given camera thereby producing a given group photo. s_7 is an utterance situation since it produces an artifact that by convention carries information about another situation, viz., s_8. The other significant infon in s_7 is that a certain group is in the described situation, s_8. When our culprit is identified, we add a triple asserting that they are a member of the group.

The described situation, s_8, has one significant infon, for the touching. The toucher has yet to be identified, so all we have is the touched object, the doorknob. Once we have identified the culprit, we add a triple for the toucher. This infon is supported by the described situation while s_7 carries this infon by virtue of the photo it produces. There is a part-whole relation between s_4, where the suspect touches the doorknob, and s_8, the situation caught on film in situation s_7.

C. Situation Classes and Id-Cases

The ID Situation Ontology has subclasses of class **Situation**. Such a class is an abstract situation. We have, for example, subclass **PicID** for a mugshot-based id-situation. Determining whether a given situation is an instance of a situation class is a classification problem. This ontology also has a class **IdCase** for a constellation of situations making up id-cases. Property **hasSituation: IdCase → Situation** relates an id-case to its constituent situations and has subproperties **hasResourceSituation** and **hasIdSituation** (a functional property). There is an equivalence property **coordindatedIdCase: IdCase → IdCase** that relates id-cases that address the same "case" (like our mugshot and fingerprint cases). There are subclasses of **IdCase**. In Section 9, we consider SWRL rules for classifying situations and id-cases.

VIII. OBJECTS AND THE CHAIN OF CUSTODY

Situations (or events) and objects are complementary [12]. Objects are created, copied, changed, and destroyed in situations, and situations contain objects variously related. Although our point of departure is situations, objects are significant at several points. Some objects are passive participants while others, such as the camera, play essential roles in capturing evidence. To support our conclusions from the evidence, we may need to fall back to facts about these objects.

The objects of primary interest are biometric artifacts, threads that stitch together situations. In the mugshot id-case, for example, mugshots are recorded (situations s_{6a}-s_{6d}), providing objects used in id-situation s_2, and a group picture is taken at the scene (s_7), providing the facial image against which the mugshots are compared. In a legal setting, if biometric artifacts are to serve as evidence, we need guarantees that they are genuine all along the chain. Chain of Custody (CoC) theory addresses what is needed "to ensure the integrity of evidence" through requiring the mapping of who, what, where, and how evidence is collected and handled [13]. There are essentially four types of evidence typically used in legal proceedings governed by the rules of evidence: real, demonstrative, documentary, and testimonial [14]. Our computational framework facilitates application of CoC theory and (for now) focuses on real evidence: tangible evidence used to prove a fact that is at issue in a case [14].

IX. SWRL RULES

SWRL rules allow us to infer new triples and thus fill in our descriptions of objects, situations, and agents based on triples already in our ontologies. Functional and especially inverse functional properties let us conclude identity (cf. **owl:sameAs**) directly. Consider the following rule:

FingerprintImage(?m1), FingerprintImage(?m2),
SurfaceFeature(?x1), SurfaceFeature(?x2),
depicts(?m1, ?x1), depicts(?m2, ?x2),
matches(?m1, ?m2),
Person(?p1), Person(?p2),
personHasFeature(?pl, ?x1),
personHasFeature(?p2, ?x2)
->
sameAs(?pl, ?p2)

The antecedent here states that both ?m1 and ?m2 depict a fingerprint surface feature; person **?p1** has feature **?x1**, and person **?p2** has feature **?x2.** The consequence is that **?p1** and **?p2** are identical because both fingerprints align to the same person. This relies on **personHasFeature** being inverse functional. The above rule can apply to any kind of biometric images by replacing the first two atoms in the antecedent with

BiometricImage(?m1), BiometricImage(?m2).

In the rest of this section, we first consider a rule for filling in the missing agent in a described situation and considering rules for classifying situations and id-cases.

A. Identifying the Culprit

Typically, there is a described situation where the culprit is unidentified, and we have an id-situation where the evidence is presented for pronouncing a judgment on the identity of the culprit in the described situation. For example, in the fingerprint case, s_4 is the described situation, where someone yet to be identified leaves their fingerprint on the doorknob. Matching fingerprints on file against the fingerprint from the doorknob takes places in the id-situation, s_1. Once we have an identity judgment, we can fill in the value for the **fpProducer** property for the instance of **LeaveFpInfon** supported by s_4. We have created a rule that does the updates subsequent to identifying the culprit. This includes supplying toucher in **TouchInfon** and an agent in **AgentInfon** for the described situation s_8. We also assert a triple of the form ***x* sitterms:agentInSit *s***, indicating the ***x*** is the agent of interest in situation ***s***. This is top-level information not associated with any other situation that provides one way of identifying the agent. Note that inference will generally identify several suspects as "the" culprit since inference does not consider the goodness of biometric matches; we handle level of evidence with Dempster-Shafer theory [6], our application of which is not covered here.

B. Classifying Situations and Id-Cases

We need abstract situations as types to classify real situations and abstract id-cases to classify constellations of situations in a way conducive to identification. The ID Situation Ontology has subclasses of class **Situation**, essentially abstract situations, and it has an **IdCase** class, which has subclasses for classification. Determining whether a given situation should be an instance of a given situation class is a classification problem that hinges on whether the real situation supports certain infon subclasses. When we described our running example, we described real situations, but the descriptions themselves, where we talked about essential infons, basically formulated abstract situations. 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 **supports(?s, ?i), In-**

fonSubClass(?i), …, The ellipsis here is filled in with specifics on the roles of the relation represented by the infon. We could also classify an instance **?c** of **IdCase** as an instance of a subclass, say, **IdCaseS**, of **IdCase**. In doing so, we would identify which situations in **?c** are resource situations and which one is the id-situation. Finally, we have a SWRL rule for determining that an instance of the mugshot id-case and an instance of the fingerprint id-case are coordinated by checking that we have one and the same described situation.

X. SIMILAR ONTOLOGIES

Two standard ontologies similar to our own are PROV-O and STO, which we address in turn. The W3C has established a specification called PROV for expressing provenance information [15] and a corresponding OWL-based ontology, PROV-O [16]. Its emphasis is on the provenance of digital products. The main classes of PROV-O include Entity, Activity, and Agent. An entity may be utilized in an activity, while an activity may generate an entity. An agent takes a role in an activity it is responsible for and thereby has entities attributed to it. Times are linked to major events, including when an entity was created or used and when an activity started and ended. The closest content in PROV-O to our Situation Ontology is Activity. Provenance in our ontology is indicated by relations among situations in a case. Situations are connected by objects (Entities) that cross situations. Our Situation and Id-Situation ontologies are fundamentally different from PROV-O as we explicitly construct cases from situations, thereby assembling the evidence.

Kokar et al. [8] developed their own Situation Theory Ontology (STO) motivated in part by the need for clear concepts in situation awareness. (See Kokar and Endsley [17] for a general overview of STO addressing situation awareness.) STO encodes most of the formalism developed by Devlin [10] in an OWL ontology. In contrast, our framework utilizes Devlin's work as a general meta-level specification, typically without explicitly encoding notions in OWL. STO puts emphasis on described (or "focal") situations. Its primary focus is on situations supporting infons, with little attention on a situation carrying information about another. Our major concern is with evidence, which typically relates to things not present. The crux for our framework is the id-situation, an utterance situation, making critical pronouncements about the described situation. While Barwise and Devlin address information carried through speech acts in a natural language, we emphasize information carried by the production, transfer, and use of objects.

STO explicitly represents in OWL relations (properties) between situations (utterance situation and focal situation, focal situation and resource situation), and it expresses constraints between situation types in OWL. For us, objects and agents cross situations, stitching them together to form a case, which captures the evidence-relevant relations among the situations. (Sometimes, however, an infon explicitly refers to another situation, as in the case of the crime-scene photo.) The constraints arise from the conventions followed in investigation, with a foundation in the properties of things. Our Situation ontology is smaller than STO, introducing little more than situations and the infons they support, and our Id Situation Ontology introduces id-cases. While STO has a property that relates an infon to a relation, we have subclasses of Infon corresponding to relations. We make a bigger point out of the partial nature of situations. If there is no information regarding a given argument in a relation, we just omit it.

We agree with STO on the importance of inference when managing information carried or supported through situations. Our approach is consistent with STO since we address a broader scope (e.g., situations constructing a case). STO also encodes much of what we leave at the meta-level of our framework.

XI. SITUATION MANAGEMENT AND AWARENESS

The two research areas that lay claim most strongly to the notion of situation are situation management (SM) and situation awareness (SA). We here summarize how these areas relate to our framework, starting with SM. Jakobson et al. define SM as a "goal-directed process of (a) sensing and information collection, (b) perceiving and recognizing situations, (c) analyzing past situations and predicting future situations," and (d) planning so that goals are reached while meeting constraints [18]. The three aspects of SM are the investigative aspect (past), the control aspect (present), and the predictive aspect (future). Our concerns are clearly with the investigative aspect. In SM, this is the realm of "retrospective analysis of causal situations," but, for us, the operative notion is not causality but evidence. We, unlike SM, are concerned with human activity; the constraints that allow evidence to arise and combine in a case are constraints of human convention. SM does not address how one situation carries information about another or how situations fit together to form a case.

SA is generally an issue in complex, dynamic contexts. According to Endsley [19], SA is "the perception of the elements in the environment …, the comprehension of their meaning and the projection of their status in the near future." For us, only comprehension ("the integration of multiple pieces of information and a determination of their relevance to the person's goals") is critical as our situations generally are not very dynamic. A precondition of our building a case is that we actually trust information from multiple situations. Trust, in fact, has been found to be important in SA, specifically, trust in automation and in our collaborators. Parasuraman et al. [20] found that trust in automation lets us reduce mental workload and thus enhance SA. An id-situation depends on trust in others in resource situations and on trust in the artifacts and processes produced or followed in resource situations. Trust ties in with comprehension since an investigator trusts what is provided by resource situations without need to consider their details and effectively follows a script coordinating with those performing tasks in resource situations.

XII. CONCLUSION

We have reported on our computational framework for the identity of agents, which emphasizes evidence for asserting that an individual picked out in one way is the same as that picked out in another. Our framework rests on situation theory. For establishing identity, we assemble a case (as in the legal sense) as a constellation of situations with one or more id-situations, where judgments are made identifying the culprit. An id-situation is an "utterance situation," and the crime scene is the corresponding described situation. There are resource situations that produce biometric artifacts, which tie together the situations as long as the chain of custody for the evidence is respected. There are domains here with well determined (if implicit) conceptualizations, captured as OWL ontologies. Our Situation Ontology supports our ID Situation Ontology for situations and constellations of situations involved in id-judgements and evidence (or cases) supporting them. We complement this with SWRL rules that classify situations and id-cases. Our Physical Biometrics Ontology relates to our ID Situation Ontology, and we have a Law Enforcement Ontology. We leverage these conceptualizations for a framework that can incorporate a wide variety of evidence for identifying agents. In an aspect not covered here, Dempster-Shafer theory is used in combining possibly conflicting evidence—see [6].

We are working on physical biometrics as per crime scene investigation, which is a good starting point as procedures here impact legal proceedings and so are subject to scrutiny, protocol, and policy. In working with online authentication [21], we are addressing behavioral biometrics (e.g., swipe patterns on mobile devices). We intend eventually to address any kind of evidence for identity and to develop ontologies as required. We are developing a webpage interface to this framework. The Criminal Justice program at North Carolina A&T State University will use it in four of its courses and in its signature co-curricular project [22]. The work reported here could have significant impact in several areas. Besides criminal justice, our framework can apply to online authentication and online search for individuals from partial descriptions.

Acknowledgment

This research is based upon work supported by the NSF REU (grant (#1460864) and the ARO (Contract No. W911NF-15-1-0524). The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright annotation thereon.

References

[1] S. Creese, T. Gibson-Robinson, M. Goldsmith, D. Hodges, D. Kim, O. Love, *et al.*, "Tools for understanding identity," in *Proc. of the 2013 IEEE Conf on Technologies for Homeland Security*, 2013, pp. 558-563.

[2] J. Barwise and J. Perry, *Situations and Attitudes*, Menlo Park, CA: Center for the Study of Language (CSLI) Publications 1983.

[3] J. Barwise, *The situation in logic*. Menlo Park, CA: Center for the Study of Language (CSLI) Publications, 1989.

[4] Y. Dominguez, W. Nick, and A. Esterline, "Situations, identity, and the semantic web," in *Proc of the IEEE CogSIMA Conf*, 2016, pp. 109-115.

[5] W. Nick, Y. Dominguez, and A. Esterline, "Situations and Evidence for Identity Using Dempster-Shafer Theory," in *Proc. of the Modern Artificial Intelligence and Cognitive Science Conf.*, 2016, pp. 81-87.

[6] E. Sloan, M. McDaniel, W. Nick, J. Mayes, and A. Esterline, "Structure and Evidence in Identity Cases," in *Proc. of the 2016 IEEE Symposium on Computational Intelligence in Cyber Security*, 2016.

[7] E. Sloan, M. McDaniel, W. Nick, J. Mayes, and A. Esterline, "Marshalling Situation-based Evidence in Identity Cases," in *Proc. of the IEEE Southeast Conference*, 2017, in press.

[8] M. M. Kokar, C. J. Matheus, and K. Baclawski, "Ontology-based situation awareness," Information Fusion, vol. 10, pp. 83-98, 2009.

[9] H. Park, S. Cho, and H.-C. Kwon, "Cyber forensics ontology for cyber criminal investigation," in *Proc of tht Int Conf on Forensics in Telecommunications, Information, and Multimedia*, 2009, pp. 160-165.

[10] K. Devlin, *Logic and information*: Cambridge University Press, 1995.

[11] E. Sirin, B. Parsia, B. C. Grau, A. Kalyanpur, and Y. Katz, "Pellet: A practical owl-dl reasoner," in *Proc Web Semantics: Science, Services and Agents on the World Wide Web*, vol. 5, pp. 51-53, 2007.

[12] A. Galton and R. Mizoguchi, "The water falls but the waterfall does not fall: New perspectives on objects, processes and events," Applied Ontology, vol. 4, pp. 71-107, 2009.

[13] P. C. Giannelli, "Chain of Custody," Faculty Publications, vol. 16, no. 4, 1993.

[14] Citizens Information. (2014). *Real evidence* [Online]. Available: http://www.citizensinformation.ie/en/justice/evidence/real_evidence.html

[15] Y. Gil, J. Cheney, P. Groth, O. Hartig, S. Miles, L. Moreau, *et al.* (2010). *Provenance XG Final Report* [Online. Available: http://www.w3.org/2005/Incubator/prov/XGR-prov-20101214/

[16] T. Lebo, S. Sahoo, and D. McGuinness. (2013). *PROV-O: The PROV Ontology* [Online]. Available: https://www.w3.org/TR/2013/REC-prov-o-20130430/

[17] M.R. Endsley, and M.M.Kokar, "Situation Awareness and Cognitive Modeling", IEEE Intelligent Systems, vol. 27, no. 3, pp. 91-96, 2012.

[18] G. Jakobson, J. Buford, and L. Lewis, "Situation management: Basic concepts and approaches," in *Information Fusion and Geographic Information Systems*, V.V. Popovich, M. Schrenk, and K.V. Korolenko, Eds. New York, NY: Springer, 2007, pp. 18-33.

[19] M. R. Endsley, "Theoretical underpinnings of situation awareness: A critical review," in *Situation Awareness Analysis and Measurement*, M.R. Endsley and and D. Garland, Eds., Mahwah, NJ:P Lawrence Erlbaum Associates, 2000, pp. 3-32.

[20] R. Parasuraman, T. B. Sheridan, and C. D. Wickens, "Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs," Journal of Cognitive Engineering and Decision Making, vol. 2, pp. 140-160, 2008.

[21] J. Jenkins, W. Nick, K. Roy, A. Esterline, and J. Bloch, "Author identification using Sequential Minimal Optimization," in *Proc of SoutheastCon*, 2016, pp. 1-2.

[22] S. O. Fakayode, J. P. Mayes, M. I. Kanipes, D. Johnson, and E. L. Cuthbertson, "Promoting Student Learning in Criminal Justice, STEM, and Forensic Science: Aggie Sleuth Initiative (AggieSI)-Guided Inquiry Learning Experience," Journal of Criminal Justice Educatio*n*, pp. 1-15, 2016.