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Database Creation for Information Processing Methods, Metrics, and Models (DCIPM3)

by Sean Murray, Frank Small, Michelle C. McVey, Kevin King, Christine Slocum, and Will Tanenbaum

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14. ABSTRACT
One challenge of tactical information processing within the demanding net-centric environment is the fusion of data extracted from various free-form message* databases. The development of high-level data fusion products addresses this challenge; however, development relies heavily on the availability of large, accurate data sets. This report documents the Database Creation for Information Processing Methods, Metrics, and Models (DCIPM3) project that creates, from a U.S. Army Research Laboratory (ARL)-designated context, a notional albeit realistic detailed scenario encompassing a multitude of social interactions. A time ordered event list (TOEL) was created from the scenario that includes references to multiple forms of communication†, events, and interactions between subjects. An extensive message set that includes communication between subjects was derived from the TOEL. The Web Ontology Language (OWL) was used to create an ontology populated with information, e.g., "meet at two," from the message set. Resource Description Framework (RDF) triples were extracted from this ontology. The resulting database from the extracted triples can be used by the information fusion community when both a known social context and a comprehensive database of messages to support that context are required.

*Free-form messages include semi-structured and unstructured verbal, digital, and textual communication.
†Forms of communication include face-to-face verbal communication and telephone conversations; digital communication, such as text messaging and instant messaging online; as well as written textual communication, such as personal letters.

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1. Introduction

The tactical information processing (IP) of messages in a net-centric* environment presents the unique challenge of fusing data extracted from various free-form message† databases. Currently, the issue of data fusion is being addressed through the development of service-oriented-architectures (SOA) (*2*). SOA technology to identify information within free-form messages and insert that information into ontological structures remains in its infancy (*3*). There is still a need for the development of high-level fusion products to overcome the data fusion challenge.

Development relies heavily on the availability of large, accurate, unclassified data sets that are difficult to obtain. The existence, access, and veracity of needed data sets are highly limited. Data sets that are available cannot be considered accurate, as the data is not supported by readily available ground truth information (*4*); data sets are also often limited in social interactions. Accurate social interaction threads are crucial to the development of many high-level fusion products, and a data set incorporating these threads must be developed.

The objective of the Database Creation for Information Processing Methods, Metrics, and Models (DCIPM3) project was to develop a large data set involving social interactions and to create the materials needed to support the evaluation of knowledge discovery tools. The data set's inception lay in a ubiquitous scenario—that of 15 high school students' senior year at a notional high school. From the scenario, a time-ordered event list (TOEL) and a message set were generated. The data was then manually mined from the message set and inserted into an ontology created using Protégé (*5*).

2. Database Development

2.1 Background

The Soft Target Exploitation and Fusion (STEF) Army Technology Objective (ATO) (*6*) was created to develop analytical software services that track an individual and determine his or her sphere of influence. Specifically, locations, times, and interactions can be determined. The 100 Human Intelligence (HUMINT) unclassified message set (*7*), developed to support the STEF ATO, forms the template for the DCIPM3 project.

* Net-centric refers to "a framework for full human and technical connectivity and interoperability that allows all DID users and mission partners to share the information they need" (*1*).

†Free-form messages include semi-structured and unstructured verbal, digital, and textual communication.

To ensure the accuracy of inferences drawn from the data analysis tools, the DCIPM3 team divided into two groups: the scenario development group and the ontology/Resource Description Framework (RDF) triple group. The scenario development group developed and documented the scenario; the ontology/RDF triple group populated a Web Ontology Language (OWL) ontology from the scenario.

2.2 Document Creation

2.2.1 Detailed Scenario

Given an ARL-designated context, a realistic, detailed scenario encompassing a multitude of social interactions was created. The scenario served as the ground truth for the message set and was based on a realistic notional high school. The interactions of 15 notional subjects were followed throughout their senior academic year, allowing for multiple social threads. Rather than using the typical pragmatic scenario of tactical environments, with which the DCIPM3 team had little experience, the high school setting allowed for a more accurate scenario, as the DCIPM3 team was comprised of high school and undergraduate student interns.

The scenario, created first, established the background for the message set, and included a brief overview of the town demographic, a summary of the most pivotal events, and in-depth narrations for the academic year. The detailed scenario provides an extensive account for each event. Entries include actions, thoughts, and feelings of the notional characters. An excerpt from the detailed scenario document can be found in figure 1.

> On Thursday August 28 Mr. Brown announces to the homeroom that the pep rally will be the following Friday. Mike and Kevin talk about last years pep rally where the principal got soaked in sloppy Joe meat by the football team. Megan brings up the stunts of the cheerleaders last year, and how this year the squad is superior. Joy, Steve, and Julie, remained silent and took little interest in the announcement, and even looked upset. They do not enjoy big social events with the school yelling, and acting foolish. Later that day Megan, who is in Student Government Association (SGA), attends a meeting that addresses the lineup of events to have at the pep rally, with other representatives. Megan pushes to have more time for her cheerleading squad to perform in front of the student body.

Figure 1. Excerpt from detailed scenario document.

2.2.2 Time Ordered Event List

A TOEL was created to maintain a homogenous flow of events during the high school year. The timeline and messages from the HUMINT message set served as guidelines for crafting the TOEL. The TOEL breaks the scenario into the individual forms of communication, events, and interactions between subjects. Each event in the TOEL includes a time stamp, date, and location. Along with each stamp is a brief description of the primary event that transpired. Events possess varying levels of significance to each subject's development, e.g., from a notional character daydreaming in a class to the degradation of a once strong relationship. An example entry from the TOEL is presented as figure 2.

> 4th day
> 8/28/08: Thursday
> Homeroom- Mr. Brown talks about the pep rally. It brings up memories for Kevin, Megan, and Mike about last years pep rally. Joy, Steve, and Julie are not as excited.
> After school- Student Government Association meets, to discuss the pep rally. Megan asks for an extended time slot for the cheerleading squad to perform during the pep rally.

Figure 2. Example of an entry in the time ordered event list.

While many of the documented events had some level of importance to the development of similar sequential events of a notional subject, many dead ends and random events were also developed and included to allow for the additional exploration of database analysis tools under these circumstances.

Flowcharts were created from the TOEL to provide a visual representation of how events are linked together in threads. The flowchart shown in figure 3 illustrates the events and relationship between two individuals, Kevin and Megan.

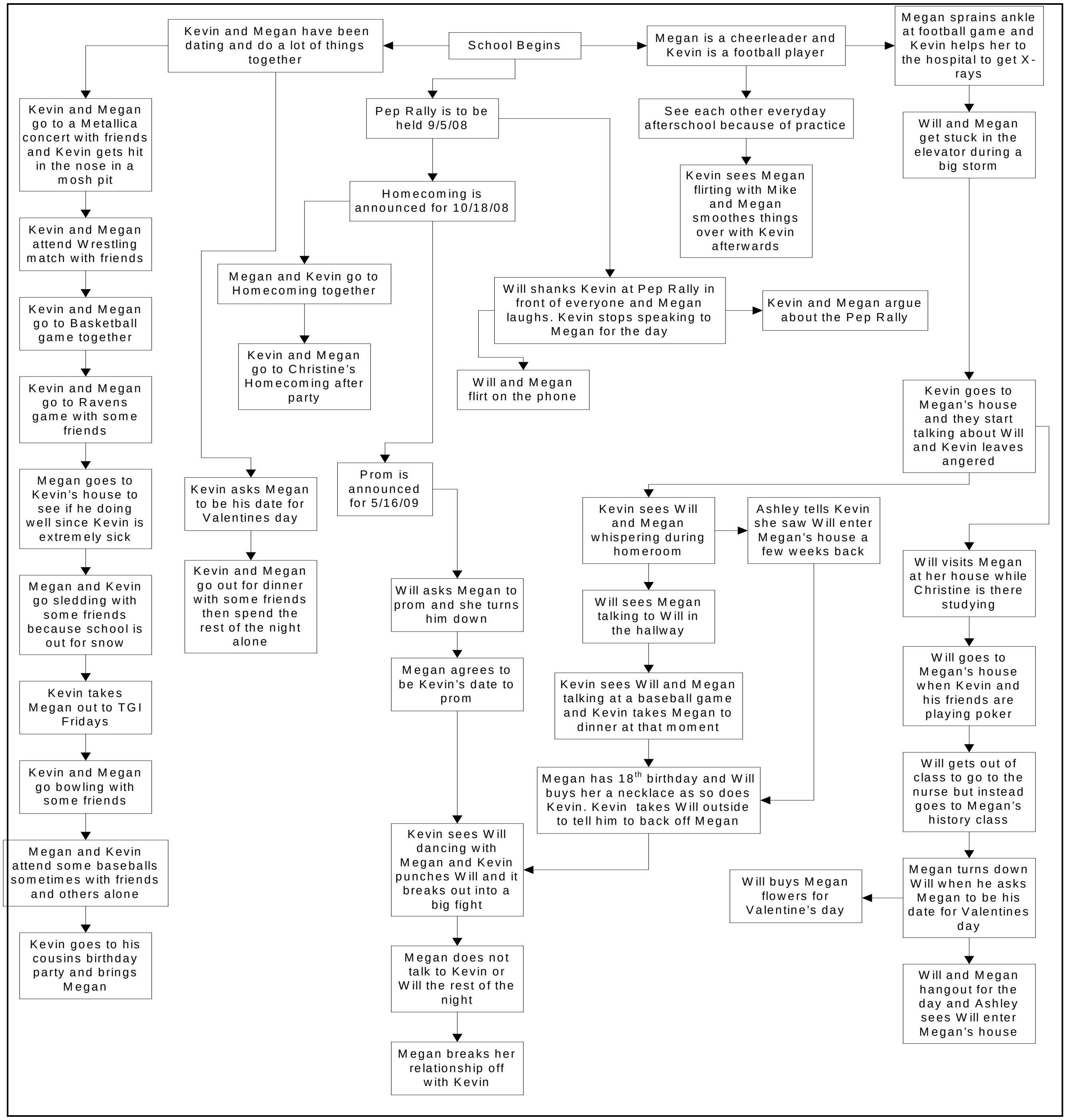

Figure 3. Flow chart illustrating relationship between Kevin and Megan.

2.2.3 Message Set

An extensive message set was produced from the TOEL and scenario. This task included the creation of semi-structured and unstructured free form messages. Each message entry involved at least one of the notional characters, as well as various forms of communication with other individuals.‡ A standard entry included the date, location, and type of communication, followed by the conversation itself. An example of a standard message can be viewed in figure 4.

> 4th day
> 8/28/08: Thursday
> Homeroom- 08:50:33 Conversation
> Mr. Brown- There will be a pep rally on 9/5/08; everyone must attend, and try to not get to out of control.
> Mike- Remember last year?
> Kevin- Ya' mean when, seniors dumped sloppy joe stuff on Principal Thomas?!
> Mike- Yeah! Sloppy Joes are awesome.
> Megan- Sloppy Joes are gross. Even still, the sloppy joes weren't as bad as last year's cheerleaders…
> Mike- Hoho! Harsh!
> Megan- Seriously though… Our cheer: WAY better.
>
> SGA meeting- 15:02:43 Conversation
> Megan- The cheer leaders will need a 5 minute block to perform.
> Marge- 5 minutes! Is that really necessary?
> Megan- That is how long our dance is!
> Marge- Fine…moving on.

Figure 4. Example of a standard message from the message set.

2.3 Protégé-OWL for Ontology Building

2.3.1 Software Overview

"Protégé is a free, open-source platform that provides...a suite of tools...[for] the creation, visualization, and manipulation of ontologies (*5*)." Protégé-OWL is an editor for the Protégé platform that enables users to build ontologies in the OWL, a World Wide Web Consortium (W3C) standard for Semantic Web applications. Formal semantics specified by OWL allow an ontology's logical consequences to be derived in knowledge discovery applications.

‡Forms of communication include verbal communication; digital communication such as text messaging and instant messaging online; as well as written textual communication such as personal letters.

OWL was selected for modeling the high school scenario to ensure compatibility with conventional reasoners and for its capability to determine implied and explicit relations. The OWL ontology is in a format that will optimize knowledge discovery opportunities and facilitate rapid integration into diverse analysis programs.

2.3.2 Ontology Objects

Ontologies are comprised of class and property definitions and are populated by class instances, called "individuals." In Protégé-OWL, abstract class *`Thing`* is the superclass[§] of all other classes; all user-defined classes must derive—as children or further descendants—from *`Thing`*. Subclasses inherit all parent properties and usually define additional, unique properties; inherited properties may be overridden by explicit subclass redefinitions.

To illustrate the concept of class property inheritance, consider a class *`Vehicle`* for which properties `capacity` and `position` are defined and let two subclasses, *`Automobile`* and *`Aircraft`*, extend *`Vehicle`*. The *`Vehicle`* class definition specifies `capacity` as an integer referring to the maximum number of human occupants the vehicle can accommodate and specifies `position` to be a floating-point triple of the format (latitude, longitude, altitude). *`Automobile`* inherits `capacity` and `position` properties from its parent class but, because the vehicle type is restricted to land movement, *`Automobile`* redefines `position` as a floating-point double of the format (latitude, longitude) for more appropriate two-dimensional positioning. *`Aircraft`* does not redefine `position` or `capacity` but defines the additional property `tilt`.

Protégé-OWL supports object and datatype property definitions. Object properties express relations between two class individuals (e.g., ***`X`***`.next_to(`***`Y`***`)`), while datatype properties are literal values of instance attributes (e.g., `age` = `26`, `female` = `True`, and `female` = `'John Doe'`). Inverse properties may also be defined for all object properties, assigning reciprocal meanings to the receiving objects. When the object property of an individual is defined and there exists an inverse to the property, the inverse is automatically defined for the recipient (e.g., for individuals ***`Mary`*** and ***`Suzie`***, ***`Mary`***`.motherOf(`***`Suzie`***`)` ↔ ***`Suzie`***`.daughterOf(`***`Y`***`)`).

2.3.3 DCIPM3 Ontology

A schema was designed for the DCIPM3 ontology to ensure consistent, logical, and complete representation of all system dynamics detailed in the project documents. Central to the schema is *`Thing`* subclass *`Event`*, which has the fully qualified class path *`Thing`*`::`*`Event`* and cannot be directly instantiated. *`Event`* has instantiative children *`TravelEvent`*, *`FinancialEvent`*, *`SportsEvent`*, *`HealthEvent`*, *`BandEvent`*, *`LeisureEvent`*, *`SchoolEvent`*, *`EmploymentEvent`*, *`CommunicationEvent`*, and *`ConflictEvent`*, many of which have their

[§]A superclass, or parent class, is that from which a subclass derives. Subclasses, also called children classes, are said to "extend" the superclasses.

own subclasses. Abstract classes *Thing::Person*, *Thing::Equipment*, *Thing::Organization*, and *Thing::Location* are also defined in the schema with instantiative subclasses.

During database population, a *Thing::Event::**[**] individual is created in the DCIPM3 ontology for each item in the message set. Datatype properties `hasStartDate` and `hasStartTime` are defined for each individual, as well as class-specific object properties, each of which relates the event instance to another individual. Properties may be restricted to certain datatypes, allowed values, or user-defined class instances.

Consider ***WillProposition***, a *Thing::Event::Communication::Conversation::PhoneCall* individual from the DCIPM3 ontology. From the given class path, one can infer that ***WillProposition*** was a telephone call and, more generally, a conversation, as well as a means of communication. *PhoneCall*→ ***WillProposition*** denotes the event's class derivation.

For class *Thing::Person::SchoolPerson::StudentPerson*, let *StudentPerson*→ ***MeganCrocker***, ***WillAnderson***. ***WillProposition*** properties include `hasStartTime` = `12:22:03`, `hasStartDate` = `September 6, 2008`, `hasParticipant(`***MeganCrocker***`)`, `hasParticipant(`***WillAnderson***`)`, and `hasTopic(`***MeganCrocker***`)`. `hasStartTime` and `hasStartDate` are restricted to single values of the *time* and *date* types, respectively. `hasParticipant` is an object method with multiple allowed values and a range restricted to *Thing::Person::** individuals. `hasTopic`, also an object property, may only have one value of a *Thing::Person::** individual.

2.3.4 Ontology Relationships

Individuals stored in the ontology are models of data entities with respect to the larger context in which they exist. Information is explicitly asserted for each entity, describing individual characteristics and the individual's direct relationships to other entities in the ontology. Upon direct examination of a given individual, the entity's properties appear much as they would in a relational database. Unlike relational data representations, however, an ontology also reveals the extended and implicit relationships between individuals.

Every individual is an instance of a particular class and all classes relate to each other by some degree of hierarchical removal, having all derived somehow from *Thing*. Furthermore, class definitions restrict object properties to finite domains and ranges, based on realistic limitations of the data entities being represented. So, object property values are indicators of how each individual relates to the system.[††] The property values of one individual may impact the meaning of many other individuals in the ontology, even if the entities are unrelated explicitly.

[**] A fully qualified class path with a terminating asterisk denotes an arbitrary class descendant. For example, any class descending from *Person* can be expressed as *Thing::Person::**.

[††] The global domain of an ontology is known as the system, which encompasses all individuals of every class.

Implicit Knowledge: Example Case Study

For example, consider an ontology with class definitions `Animal::Predator`, `Animal::Prey`, and `Habitat`. `Animal` defines an object property `niche` with a range restricted to a single `Habitat` instance; both `Predator` and `Prey`, which have instantiative subclasses but cannot be instantiated directly, inherit this property. Reciprocal to `niche` is the inverse `Habitat` property `contains` that is restricted to an arbitrary number of `Animal` individuals (i.e., `Animal.niche(Habitat)` ↔ `Habitat.contains(Animal)`). If individual ***`Tiger`*** is instantiated with `niche` = ***`Jungle`***, then ***`Tiger`*** is automatically defined as a value of ***`Jungle`*** property `contains`. Additionally, `Prey` defines `dangerous` as an object property with range restricted to the specific `Predator` subclasses which pose threats, and `Predator` defines `food` as an object property with range restricted to the edible `Prey` subclasses.

Suppose that a number of actual habitats are surveyed for animals, and that these animals are entered into the ontology described above. During ontology population, the surveyors instantiate `Habitat` individuals for each habitat they sampled but do not enter values for the `Habitat.contains` property directly. Instead, the surveyors define values of `Animal.niche` for all predators and prey, resulting in the automatic assignment of the animals' instances to corresponding values of `Habitat.contains`.

Consider a knowledge discovery application that is tasked with determining the surveyed habitat's overall health. Criteria for health are based on the ratio of predators to prey in a given habitat, with consideration for the specific prey and predator restrictions of predator and prey values, respectively. Overall assessment of a habitat's health, then, depends on information contained in both `Animal::*` and `Habitat` individuals. While `Habitat` individuals don't contain information about the survival requirements of specific animals, `Animal::*` individuals have no information about their habitat or the other inhabiting individuals.

The exemplified habitat ontology demonstrates the power of ontological modeling, inherent in the object-oriented representations of data entities with meaningful interrelationships. Entity properties indicate *what* and *how* an object is being related to, and these associations can be implicitly extended to yield comprehensive perspectives of entire systems.

2.4 RDF Triple Extraction

A semantic reasoner is an engine that infers implicit relationships from asserted facts and can be used for extracting object relationships from individuals in an ontology. Reasoners explore all levels of defined and implied relationships according to the rules of an ontology language. The RDF is a W3C specification for modeling data which expresses subject-predicate-object relationships as triples (i.e., 3-tuples of the form [subject, predicate, object]); this framework was chosen to describe the rules extracted from the DCIPM3 OWL database. Each RDF triple is marked-up by XML in conformance with the RDF schema.

All triples deriving from an individual share a common subject, given by the instance name. Every value for each of the individual's properties corresponds to a unique triple, where the property name becomes the predicate and the value becomes the object. Extending the prior example of ***WillProposition***, consider the following conversion of this individual's properties into triples:

> `hasStartTime` = `12:22:03` ⇒ (WillProposition, hasStartTime, 12:22:03)
> `hasStartDate` = `September 6, 2008` ⇒ (WillProposition, hasStartDate, September 6, 2008)
> `hasParticipant`[‡‡] = ***MeganCrocker*** ⇒ (WillProposition, hasParticipant, MeganCrocker)
> `hasParticipant` = ***WillAnderson*** ⇒ (WillProposition, hasParticipant, WillAnderson)
> `hasTopic` = ***MeganCrocker*** ⇒ (WillProposition, hasTopic, MeganCrocker)

Given the logical class and property names, a human reader should be able to identify the explicit, simple meaning in each triple and then further extrapolate a composite understanding of ***WillProposition***. Outlined below is a progression of logical inferencing by which a human might discover some implicit relationships in ***WillProposition***:

> *Thing*::*Event*::*Communication*::*Conversation*::*PhoneCall*→
> ***WillProposition***
> ⇒ ***WillProposition*** was a phone call (**p**)
> ⇒ ***WillProposition*** was a conversation (**q**)
> ⇒ ***WillProposition*** was a form of communication (**r**)
> ⇒ ***WillProposition*** was an event (**s**)
>
> ***MeganCrocker*** instance name
> ⇒ First name of the instance is "Megan," last name is "Crocker" (**t**)
>
> ***WillAnderson*** instance name
> ⇒ First name of the instance is "Will," last name is "Anderson" (**u**)
>
> ***MeganCrocker*** and ***WillAnderson*** participated in ***WillProposition*** ∧ **p** ∧ **t** ∧ **u**
> ⇒ Megan and Will participated in a phone call (**v**)
>
> ***WillProposition*** instance name
> ⇒ Will proposed (**w**)
>
> *MeganCrocker* was the topic ∧ **t** ∧ **q**
> ⇒ Megan was the topic of conversation (**x**)
>
> ***WillProposition*** started at 12:22:03 on Sep. 6, 2008 ∧ **v** ∧ **w** ∧ **x**
> ⇒ Will proposed to Megan during a phone conversation that started at 12:22:03 on Sep. 6, 2008

[‡‡]Although `hasParticipant` is a single property in Protégé-OWL, for the purposes of RDF triples extraction, both values are treated as single values of `hasParticipant`, which occurs twice in this individual. Note that in normal object modeling, properties must be uniquely named.

The above example is simplified; in actual RDF triple extraction, information such as the fully qualified class path on the first line could only be used if the encoded parent-child relationships were explicitly broken down into triples (e.g., [Conversation, parentOf, PhoneCall] or [WillProposition, instanceOf, PhoneCall]). Semantic reasoners use the process exemplified by ***WillProposition*** to perform RDF triple extraction.

3. Summary and Conclusions

Within the demanding net-centric environment of information processing, the fusion of data extracted from various free-form message databases is crucial. The development of high-level data fusion products addresses this challenge; however, development relies on the availability of large, accurate data sets. The DCIPM3 project resulted in the creation of a notional, albeit realistic, detailed scenario and TOEL encompassing a multitude of social interactions. An extensive message set was then derived from the TOEL that includes communications between subjects. The detailed, realistic scenario and TOEL serve as ground truth documents. The resulting ontological database is suitable for use in future testing of knowledge discovery tools for providing a system from which to inference rules. The OWL was used to create an ontology populated with RDF triples from the message set.

The creation of the ontological database—supported by ground truth scenario documents—is a critical step towards providing the information fusion community the needed resources to accurately evaluate knowledge discovery tools.

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List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
ATO	Army Technology Objective
DCIPM3	Database Creation for Information Processing Methods, Metrics, and Models
HUMINT	Human Intelligence
IP	information processing
OWL	Web Ontology Language
RDF	Resource Description Framework
SGA	Student Government Association
SOA	service-oriented-architectures
STEF	Soft Target Exploitation and Fusion
TOEL	time-ordered event list
W3C	World Wide Web Consortium

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