Chapter 2
Formalization of “Context” for Information Fusion

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Abstract Context exploitation can provide benefits for information fusion by establishing expectations of world states, explaining received data, and resolving ambiguous interpretations; thereby improving process efficiency, reliability, and trustworthiness of the fusion product. While everybody recognizes the importance of considering context in inferencing, designers of information fusion processes only recently have begun to incorporate context explicitly into fusion processes. Effective context exploitation requires a clear understanding of what context is, how to represent it in a formal way, and how to use it for particular information fusion applications. Although these problems are similar to the ones discussed by researchers in many other fields, consideration of context in designing information fusion systems also poses additional challenges such as understanding the relationships between situations and context, utilizing context for understanding and fusion of natural language data, context dynamics, context recognition, and contextual reasoning under the uncertainty inherent in fusion problems. This chapter provides a brief discussion on possible ways of confronting these challenges while designing information fusion systems.

Keywords Context *of* and context *for* · Contextual and problem variables · Context quality · Abduction · Natural language understanding

2.1 Introduction

The problem of context has a long history in such diverse fields as artificial intelligence, philosophy, psychology, and linguistics, among others. Although the value of considering context in information fusion is obvious, system designers

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have only recently considered methods for systematically exploiting the rich contextual information that is often available in their system applications. In particular, there is an untapped potential to exploit the enormous quantity of available multimedia and multispectral data—together with information from diverse, geographically distributed sources—to provide context for information fusion to improve understanding of the entire domain of interest. Much of this information may be of low or of indeterminate quality. It may be uncertain, unreliable, redundant, or conflicting, and its relevance to a particular inference problem may not be self-evident.

Context can be used both to transform source data into information and knowledge [1, 2] and to acquire knowledge [3, 4]. Context may provide information about the conditions of data and information[1] acquisition, and it may constrain and influence the reasoning about objects and situations of interest. In addition, there is an enormous body of potentially valuable information in the form of natural language: across the Internet, in social media (Twitter, Facebook, Flicker, etc.) and traditional media sources (television, newspapers, etc.), as well as in various forms of intelligence reporting. Natural language sources may provide essential contextual information not available from structured sensor data alone. Natural language understanding is also vital in modeling interpersonal communications. However, natural language is itself fraught with ambiguities—phonetic, lexical, syntactic, semantic, pragmatic—that can only be resolved by contextual considerations.

Context is represented by contextual information that may be obtained from various sources and formalized in different ways. Various formal context definitions and formalization models will be discussed in Sect. 2.2. In general, context consideration can improve and simplify agent interactions in multi-agent-based fusion systems, which may be comprised of either automatic, human, or both human and automatic agents. Figure 2.1 shows some important relationships between context and a fusion-based human–machine system. The context engine here interacts with and supports fusion at all levels by

- representing an initial overall context under considerations;
- establishing relevance, thereby constraining ontology of the domain, observations, rules, and statistics;
- providing the fusion processes with constraints on relationships among objects, situations, hypotheses, arguments, beliefs, and preferences;
- supporting situation and threat discovery;
- constraining the feasible meanings of messages, thereby facilitating effective communications among actors.

Designing dynamic fusion processes requires clear understanding of what context is and the relation between context on the one hand, and data, information, and

[1]While we recognize the difference between data and information, we will generally use these terms interchangeably throughout this chapter.

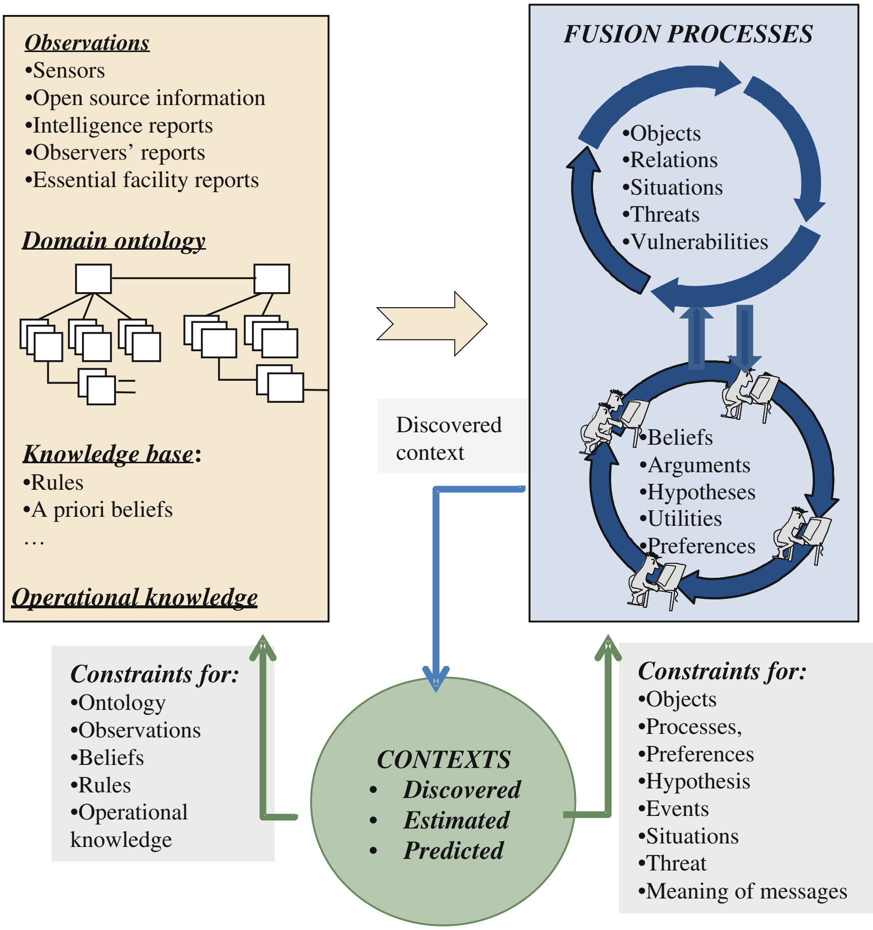

Fig. 2.1 Context and information fusion

knowledge on the other. It is also necessary to understand (a) how to represent context in a formal way to support contextual reasoning in fusion processing; (b) the role of context in inter-level information exchange; and (c) how to deal with context dynamics, context recognition and discovery, and contextual reasoning under uncertainty inherent in data fusion problems. The remaining sections of this chapter discuss potential solutions to these problems. Thus, Sect. 2.2 presents context definitions; Sect. 2.3 discusses relationship between context and knowledge; Sect. 2.4 describes various context models; Sect. 2.5 examines relationship between context and information quality while Sect. 2.6 discusses the problem of context in natural language understanding. Finally, the chapter concludes in Sect. 2.7.

2.2 What Is Context?

The notion of context has been used in diverse research areas for a long time but "while most people tacitly understand what context is they find it hard to elucidate [5]." Context has many facets that sometime leads to defining it based on certain narrow characteristics of the particular problem being addressed. For example, in [6] context is defined as objects, location, identities of nearby people, and objects. In other works [7], it is considered as a computable description of the terrain elements, the external resources and the possible inferences that is essential to support the fusion process while in [8] context is represented by the operational knowledge. Such definitions are too specific to the problem under consideration making it difficult, even sometime impossible, to understand which characteristics of all situations are important and should be taken into account in general. In [9] context is defined as the subset of physical and conceptual states of interest to a particular entity while in [10] it is defined as the whole set of secondary characteristics of a situation or secondary properties of a cognitive or motivational state of an individual which may modify the effect of an effective stimulation (stimulus) or an oriented activity.

Brezillon in [11] defines context as a collection of relevant conditions such as space, time, environment, and surrounding influences that make a situation unique and comprehensible. That author further categorizes context as primary or secondary to distinguish between relatively fixed characteristics of the situation and the ones that are more dynamic. Such and other similar definitions (see, e.g. [12, 13]) are too general and equate context to the surrounding environment or situation. They do not provide specifics for understanding the difference between context and situation, a distinction that is very important to situation assessment, one of the important components of information fusion.

A definition that does allow for better understanding of context—and therefore one that is more appropriate for formalizing and utilizing context in building information fusion processes—was proposed in [14]. This definition assumes two different context paradigms introduced in [14] and further discussed in [13] and [15]: "*Context of X*" (CO) and "*Context for X*" (CF), which correspond to two basic meanings conveyed by dictionaries [14]:

> To knit or bind together; to unite closely (CO) and
> That which surrounds, and gives meaning to, something else (CF).

A reference item X is a topic of interest represented by any physical or conceptual entity, for example, a situation and event of interest such as a natural phenomenon or terrorist threat.[2] Reference items are represented by a set of state variables and their relationships that an agent wishes to evaluate (*problem*

[2]A topic might be a real entity, but it doesn't have to be. The atmospheric conditions on Mars are used as a context for inferring a low probability that there are living beings there. Life on Mars that is the reference item, not the Martians (who may not exist).

variables). A CO is a part of the environment representing a set of items and relationships of interest "grouped or contained by X." We have certain expectations about X based on a given CO, e.g., in the context of earthquake we can expect damaged roads and bridges or in the context of wildfire we can expect burn victims. Alternatively, a CF defines the contextual space of items externally related to and referenced by X: the weather provides a *context for* search and rescue after an earthquake (*context of*). In both examples *earthquake* represents a reference item.

A set of items and relationships defining context can be called *context variables.* Context variables characterizing CF represent auxiliary variables determined (by some process) to be relevant to a given problem. They affect knowledge about problem variables contained in a CO, reasoning about them and, therefore, affect decisions and actions based on the values and behaviors of problem variables. While COs can be declared, inferred, or discovered as the result of reasoning, CFs are either given, obtained as the result of direct observations, or extracted from the application-specific ontology. A CO is a background context, which provides a more general and stable environment while a CF offers secondary characteristics, which can be more dynamic.

Consideration of CO and CF provides for complex hierarchical relationships among characteristics of problem variables and context variables. It also offers a clear understanding of relations between context and situations. Reasoning about entities and relationships while considering them as problem variables within a certain context corresponds to reasoning about situations. Such reasoning produces an answer to the question "what is going on in the part of the environment corresponding to the reference item(s) within a specific context?" Context variables can serve as problem variables when they represent reference items for a different context. Thus we can define a *problem context* as a meta-situation (situation of higher level of granularity) comprising a set of relationships involving context variables. Various information needs may require assessment of different reference items and different context at various times and at different levels of granularity.

2.3 Context and Knowledge

The ultimate goal of context-sensitive information fusion is to support decision-making and actions by providing knowledge about problem variables to each decision maker, relevant to his goals and function. Thus it is important to consider the concept of *knowledge* along with the concept of *context*. The authors of [16] show strong relationships between these concepts. They consider context as "a shared knowledge space that is explored and exploited by participants." They introduce the notions of *external* and *contextual knowledge*: *External knowledge* is a part of context, which represents the general knowledge of the environment related to the problem but not directly relevant to a certain step of the decision-making or action. *Contextual knowledge* is a part of the context, which is relevant to a given problem at hand for a given agent (human or automatic).

It contains knowledge necessary for reasoning and decision-making applicable to all kinds of inferencing encountered in data fusion. Contextual knowledge is the part of knowledge that can have several realizations ("proceduralized contexts"), which instantiates contextual knowledge and transforms it into "functional knowledge" used for reasoning, decision-making, or action according to a specific focus of a specific agent. We can consider external, contextual, and proceduralized knowledge as CO and CF at different levels of granularity. Although the concepts of *knowledge* and *context* share multiple characteristics, they differ when it comes to decision-making and action: context is subjective and specific to goals and functions of the decision maker and represents a part of the knowledge used for decision-making and action. In contrast, knowledge is objective and not task oriented and is related to theoretical understanding of the phenomena ("knowing that") [16, 17].

2.4 Context Formalization

Several papers in the literature discuss context models (see, e.g. [15, 18–20]). Among the major types of context models considered, the *key-value*, *ontology-based*, and *logic-based* models appear to be the most applicable to information fusion. We shall survey these types of context representation and discuss their applicability to different context-aware information fusion problems.

The simplest of context models considered are *key-value models* [21], in which context is represented by values of context attributes (e.g., location) as environmental information. A key-value model utilizes exact matching algorithms on these attributes, in the same way that objects are usually represented and recognized in general. These models are easy to manage and may be used for CF representation. They may suffice for use in object assessment [22] but they lack capabilities for complex structuring required by situation and threat assessment.

As defined in the previous section, context is a meta-situation for a set of problem variables under consideration; therefore its formalization appropriate for higher level fusion processing requires more complex modeling to permit representation not only of context attributes but also of objects, their characteristics, and interrelationships. Models with these characteristics are similar to ones used for situation assessment and include *ontology-based* and *logic-based* models.

Ontology is an established framework for knowledge representation and for reasoning about situations [23, 24]. Since contexts can be considered as situations, ontology-based models offer an appropriate way of their modeling. These models can provide a high degree of rigor in specifying core concepts, sub-concepts, facts, and their inter-relationships to enable realistic representation of contextual knowledge for reasoning, information sharing, and reuse. Current approaches to ontology-based context modeling can be classified into three main areas: contextualization of ontologies, ontology design patterns, and context-aware systems [25].

Logic-based models define contexts in terms of facts, expressions, and rules. McCarthy [20] introduces a formalization of logic-based models built on a relation *ist*(c,p), read as "proposition p holds in the context c." The *ist* concept can be interpreted as validity: *ist*(c, p) is true if and only if the proposition p is true in context c. McCarthy's context formalization includes two main forms of expression:

- *c': ist*(c,p) means that p is true in context c, and *ist*(c,p) itself is asserted in an context of a higher level of granularity;
- *value*(c,e) defines the value of term e in the context c, which means that context c defines some values for e.

Information fusion systems generally deal with uncertain data and therefore we would like context representation in logic-based models to allow for uncertain statements, rules, and beliefs assigned to them. To use *ist*(c,p) concept for making assertions about uncertain situational items, it is necessary to expand McCarthy's definition of *ist*(c, p) by incorporating of an uncertainty measure—expressed as probability, possibility, or belief—in place of McCarthy's binary *belief*. For example, *bel*(a,*ist*(c,p)) can be used to represent an agent a's belief that proposition p is true in the context c. Since an agent's knowledge about context can be uncertain, *bel* may represent a combination of belief in the validity of proposition p and belief associated with context characteristics.

McCarthy introduces hierarchical relationships among contexts by defining partial ordering over contexts ($c_1 \preceq c_2$), which means that context c_2 is no less general than context c_1; i.e., c_2 contains all the information of the context c_1 and possibly more. McCarthy also defines a "lifting" formula [20] that relates propositions in a context to more general propositions and terms in a broader context (an "outer context"). The partial ordering of context along with the notion of lifting allows for formalization of relations between problem variables and CF and CO at a selected level of granularity.

A similar logic-based context formalization is presented in [26], in which context is related to knowledge and defined in terms of a set of facts from the knowledge base along with the reasoning method allowing to compute with it. Under this formulation, a context c_i is a triple $(\lambda_i, \alpha_i, \delta_i)$, where λ_i is the formal language used to describe what is true in that context, e.g., propositional language; α_i is a set of axioms; and δ_i is an inference mechanism. In this formalization, McCarthy's formula *c'*: *ist*(c,p),—with context c and an outer context *c'*—becomes $\frac{\langle A,c \rangle}{\langle ist(c,A),c' \rangle}$; i.e., "if A can be proven in context c, then we can prove in context c' that we can prove A in c."

Another representation of this type is the *extended situation theory* [27], which modifies situation theory [28, 29] to allow for uncertain information, as commonly encountered in data fusion. Situation theory represents units of information as *infons,* which are denoted as $\sigma = (R, a1, \ldots, a_n, i)$, where R is an n-place relation and $a1, \ldots, a_n$ are state variables that range over entities of types appropriate for a given relation R. In "classical" situation theory, i is a binary variable, which is equal to 1 if a relationship $R(a1, \ldots, a_n)$ holds, 0 otherwise. An operator ‘ $\models$’ expresses the notion of contextual applicability, so that ‘s $\models \sigma$’ can be read as “situation s supports σ” or “σ is true in situation s.” This operator allows consistent representation of factual, conditional, hypothetical, and estimated information [29].

In extended situation theory [27], context is modeled by situation types corresponding to objects of a situation theory that supports two kinds of infons: (i) factual infons to state facts, and (ii) constraints, which correspond to parametric conditionals capturing the if-then relations holding within the context. To capture uncertain if-then relations holding within the context representing a part of the uncertain environment, it is necessary to consider *uncertain* infons. Extended situation theory incorporates uncertain infons simply by redefining the binary variable i of classical situation theory as a continuous variable $i \in [0, 1]$ to represent the belief that R holds. An equivalent probabilistic extension of situation theory was derived independently in [30].

2.5 Context and Information Quality

Quality of Context is defined in [31] as “any information describing the quality of information that is used as context information.” Another definition is given in [32], where *Quality of Context* is defined as “any inherent information that describes context information and can be used to determine the worth of information for a specific application.” These definitions specify different types of information quality with the former referring to objective measures of quality such as the accuracy, certainty, or reliability of measurements or estimations; while the latter characterizes both objective and subjective quality, which uses values of objective quality to measure the “fitness of use,” i.e. the degree to which context satisfies the needs of a particular application.

Having this in mind we propose to define the quality of a context as the degree to which it satisfies the needs of an application, expressed as a function of quality of the data defining the context. Such an application could be, for example, refining uncertainty in sensors’ output, in communications, in situation, and threat assessment, or in the utility of actions. The degree to which context satisfies the needs of a particular application can be represented either by a single quality characteristic (e.g., the credibility of object recognition) or by a combination of characteristics (e.g., the result of combination of credibility and reliability of a hypothesis about the state of the environment). Selection of a particular quality characteristic or combination depends on the application.

The information defining a context can be obtained from available databases, observations, the result of sensor fusion, received reports, mining of available information sources (e.g., traditional and social media), or from various levels of information fusion. Of course, the quality of any such information as well as the inference process for obtaining it could be insufficient for a particular use: it might be uncertain, unreliable, irrelevant, or conflicting. Knowledge of the quality of this information and its effect on the quality of context characterization can improve contextual knowledge. At the same time, knowledge about a current context (“CO”) can improve the quality of observation and fusion results.

There are two interrelated problems concerning both information and context quality: imperfect information used in context estimation and discovery negatively impacts context quality while imperfect context characterization adversely affects the characterization of quality of information used in fusion as well as the fusion results. This interrelationship represents one of the challenges of modeling and evaluating context quality and of using context in defining the quality of information used in fusion and the quality of fusion process results.

Information quality is a type of meta-information (information about information). As such, it is best characterized and measured in terms of its attributes. Certain attributes can be considered as “the higher-level quality,” which measures how well the quality of information is assessed.

The need for considering information quality stems from the fact that there are limitations to fusion processes as well as to processes of assessing the value of the attributes of information quality. These limitations are often due to lack of context consideration or to insufficient quality of context and contextual attributes. The lack of proper consideration of context may result in using inadequate or erroneous domain knowledge or inappropriate models and parameters for quality assessment.

Several attributes of information quality have been cited including quality of information, quality of information source, and quality of information presentation [33]. Furthermore, each of these attributes can be characterized in terms of various interdependent factors such as credibility, accuracy, timeliness, relevance, etc. There are several important quality characteristics affecting quality of context estimation and discovery and thereby affecting the quality of information fusion results. Figure 2.2 shows interrelationships among the quality observations and reports, fusion processes, quality of context, and important quality characteristics influencing them. As shown, fusion designed to estimate problem variables can be over direct estimations and contextual information selected or weighted for accuracy, reliability, consistency, and relevance. Indices are shown for contexts, both CO and CF, to stress that relevant contexts are often dynamic. Fusion outputs can be state estimates at any fusion level (of objects, situations, impacts, etc.). Context consideration can improve the results of fusion products by taking into account the quality of input information (e.g., reliability of observations and reports) as well as quality of interim results of the processes involved in fusion. For instance, a CO can serve for selecting relevant observations and provide expectations for sensor and process management. A *CF* can, for example, be used to improve fusion results by incorporating context-based reliability into sources’ predictive uncertainty models such as probability or belief [34].

A very important quality characteristic is *relevance*. Relevance in context-sensitive information fusion processes is used for estimation and selection of contextual variables, and for evaluation and dynamic selection of input information. The problem here is to decide which piece of information should be considered relevant and how the level of relevance should be measured. According

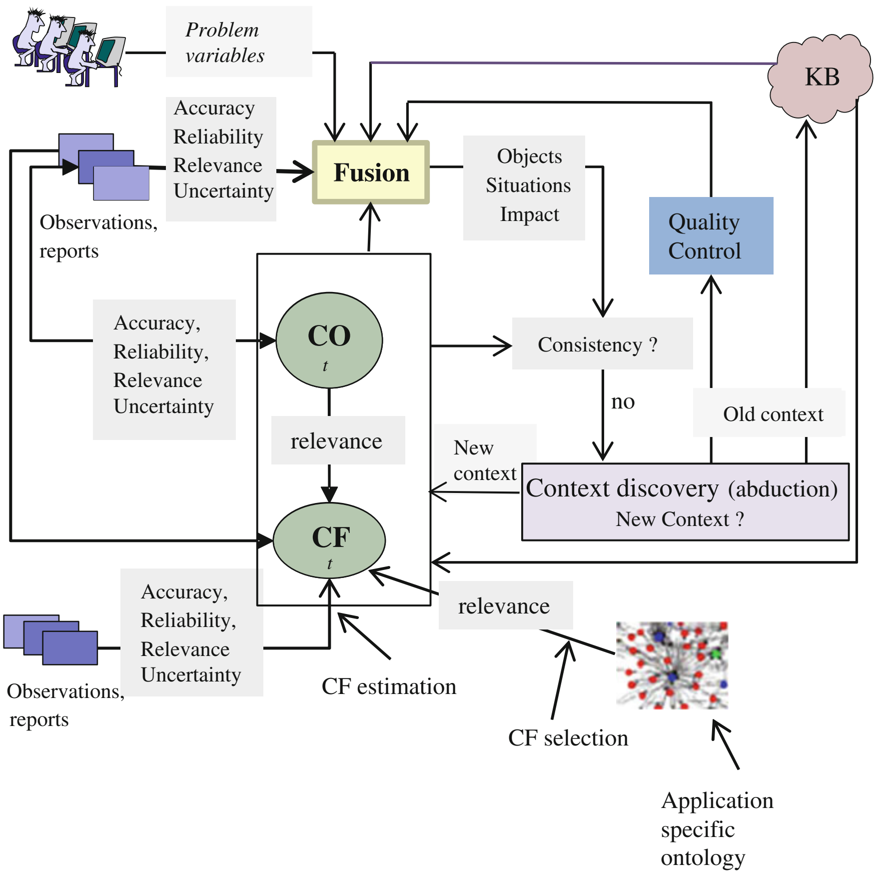

Fig. 2.2 Interrelationships among the quality observations and reports, fusion processes, quality of context, CO and CF, and important quality characteristics influencing them

to the Webster dictionary (http://www.merriam-webster.com/), information is relevant if it has "significant and demonstrable bearing on the matter at hand." Relevant information can improve knowledge whereas considering irrelevant information as relevant can degrade knowledge. Consideration of relevance is especially important for selection of CF, which has to be relevant to both CO and problem variables. Selection of CF can be performed based on constraints imposed by a domain-specific ontology. Contextual variables can be considered relevant if incorporation of them into fusion processes can:

- reduce uncertainty and increase accuracy of fusion results;
- improve utility of information (e.g., of refining the value of a problem variable) and ultimately of decisions and actions based on fusion results utilizing this information; or
- decrease information conflict [15].

Relevance is often time-dependent and its evaluation can involve a dynamic process. This, of course, can increase computation cost of selection of context variables and fusion processes.

Selection of contextual variable assumes that we can determine the ambient "context of" a given reference item or inference problem. In some cases this context is defined (declared or estimated). However, in some cases context can be unknown or different from what was expected. This often happens in highly dynamic environments, in which observations, situational items, and relationships constantly change. In such cases, relevant context needs to be discovered. Discovery of underlying new context can be initiated based on another important characteristic of context quality: *consistency*. New context can be manifested by new observations or estimated reference items that are inconsistent with the currently assumed context characteristics, for example, contained in the knowledge base. The major problems here are how and when to decide whether inconsistency exits, what is the source of this inconsistency, and whether the currently assumed context is no longer relevant.

Context consistency is evaluated based on comparison of the characteristics and behavior of problem variables based on the observed or estimated data and information with the ones that are defined by contextual knowledge, which includes both CO and CF. Inconsistency can be the result of such factors as (1) poorly characterized observations and reports; (2) insufficient quality of estimated characteristics and behavior of situational items based on these observations and evaluated within current context; (3) incomplete or inadequate domain knowledge about current context; (4) poor quality of context characteristics, e.g. consideration of irrelevant contextual variables or the fact that the defined earlier context has changed. Discovery of the source of this inconsistency can be performed by abductive reasoning (so-called "reasoning for best explanations") [35]. The result of abductive reasoning can improve inferencing in different ways. It can lead to discovery of new, hidden context, which in turn can improve the estimation of problem variables. It can also lead to discovery of the fact that the inconsistency was the result of poor quality of observations, reports, their processing or insufficient quality of estimated or containing in the knowledge base certain context characteristics, which can lead to their better estimation.

2.6 Context and Natural Language Understanding

The importance of natural language understanding in the information fusion domain has grown significantly due to increased role of "raw" natural language in information fusion processes. The Internet has expanded the body of readily accessed natural language information from traditional media sources (television, books, newspapers, etc.). Additional important information may be buried within the enormous amount of dynamic information contained in social media (Facebook, Instagram, Twitter, etc.). However, natural language is itself fraught with ambiguities—phonetic, lexical, syntactic, semantic, pragmatic—that can only be resolved by contextual considerations.

Exploitation of natural language sources requires that semantic, referential, and pragmatic information content be extracted, aligned in quality and relevance and fused with other available information. Therefore, the types and issues of context exploitation that apply to these basic fusion functions apply to natural language understanding.

Polysemy—a word having multiple different but related meanings—is so pervasive that it is often unnoticed by native speakers. All the common verbs and prepositions in English—*have, give, take, up, in* and their ilk—are massively ambiguous and can only be understood in context: a person can have brown eyes, have pneumonia, have an idea, have a fight, have it out, take a coin, take a drink, take a taxi, take a nap, take it easy, look up, show up, throw up, finish up, run up (a bill, a flight of stairs),… Much polysemy is due to the pervasiveness of metaphorical meanings. As Pinker notes, "Metaphor is so widespread in language that it's hard to find expressions for abstract ideas that are *not* metaphors" [36].[3] A dispute between the White House and the Kremlin is not really a dispute between two buildings. We have not really traveled anywhere when we follow a train of thought, pursue a dream, or reach a conclusion.

So natural language expressions are often wildly ambiguous when viewed out of context. "*When I use a word*," *Humpty Dumpty said, in a rather scornful tone,* "*it means just what I choose it to mean—neither more nor less*." [39]. Nonetheless, pace Mr. Dumpty, the conventions of language and of discourse do impose constraints on the range and distribution of possible meanings. Many cases of polysemy follow regular and predictable patterns.

Furthermore, a most general constraint on meanings is a pragmatic one: as means for conveying information (expressive as well as literal declarative information), the meanings a speaker assigns to utterances should be readily inferable by hearers.[4] This is Grice's cooperative principle [40]. A speaker is expected to choose his expressions such that their understanding is evident, given their range of conventional meanings and the discourse, situational and participant contexts. Context can guide expectations for meanings in amusing ways, e.g. in hearing "a forest full of toiletries." Here, the discourse context (CO) can provide false lexicologic and semantic clues (the syllable /trēs/ in the context of 'forest').

Indeed, many linguistic expressions are intrinsically undetermined in the absence of context. Beside polysemy, context exploitation is usually essential to resolve

[3]Indeed, George Lakoff and other developers of Generative Semantics and Cognitive Linguistics have argued that "Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature" [37, 38]. They argue that our minds begin with a small number of basic experiential concepts involving substance, space, time and causation. From these we generate ever more abstract concepts by metaphor: time is conceived as moving object, goals are destinations, knowing is seeing, society is a family, etc. [36].

[4]Our discussion throughout this chapter is independent of the communication means; therefore, 'speaker' and 'hearer' will do equal service for 'writer' and 'reader'.

referential ambiguity and relativity of scale [41]. As an example of the latter, in interpreting a statement, “Malacoda is near Calcabrina,” it would help if we know whether Malacoda and Calcabrina are mitochondrial structures, towns, or galaxies; or whether the statement occurs within a conversation concerning microbiology, geography, or astronomy, etc.[5]

Natural language understanding can be posed as a hearer’s (or reader’s) problem of inferring a speaker’s (or writer’s) intended phonetic, syntactic, semantic, and referential interpretation of an utterance. The hearer uses contextual clues to hypothesize the speaker’s intended meaning. Specifically, the hearer is required to estimate a three-place relationship, involving a text string, its speaker, and the latter’s intended meaning. Note that we treat *meaning* as a random variable, with various possible instantiated values. As Humpty Dumpty demonstrates, it is a relational variable involving symbols and their users.

As such inference problems almost always rely on fusion of the utterance or text segment with contextual information in the discourse or discourse setting, they involve the basic data fusion functions: data alignment, data association, and state estimation.

Data alignment issues occur in phonetic, syntactic, and semantic registration problems. These processes establish the assumed language conventions between speakers and hearers: what language is being spoken, what systematic biases are present in a speaker’s dialect, etc.

Data association issues occur in conversational syntactic problems: subject–verb–object associations and referential associations among noun phrases (e.g., anaphora). As in the general cases described in previous sections, determining relevant contexts for syntactic semantic and referential understanding is a data association problem.

Estimation and recognition issues occur in conversational semantics problems: estimating the meanings that speakers intend for their product and of the pragmatic effects of the production; i.e., the speech acts and their impacts [40–42].

Data used in these inference processes can include the received acoustic or visual signal data from the specific utterance or text segment. They can also use contextual information, to include

- *Discourse context*: Information in the surrounding spoken or written discourse;
- *Discourse situation context*: Information concerning the physical and social environment in which the discourse occurs, including assumed linguistic conventions;
- *Discourse participant context*: Information about the backgrounds and interests of the speakers and intended hearers.[6]

[5]They are demons in the eighth circle, fifth bolge, of Dante’s Inferno.

[6]These follow the applicable types of evidence that we have employed in source characterization; i.e. in inferring and predicting the fidelity of information received from an information source [43].

What counts as a relevant segment of discourse regarding a given utterance will be determined by Grice's cooperative principle, noted above [40]. The cooperative principle as it applies to speakers is that one should contribute to a conversation only such utterances as further the aims and direction of the conversation. The cooperative principle as it applies to hearers may be read as one of tolerance: to assume that each speaker is himself honoring that principle, unless there are good grounds for thinking otherwise [40, 44].

As in the general data fusion problem, determining the relevance of candidate discourse, situation or participant contexts can be formulated in terms of the estimation of contextual variables (e.g., in estimating the value of the variable *scale* in interpreting the use of the word 'near').

If the estimation of semantic meaning is a problem akin to the classic *estimation* problems of data fusion: target location, classification, etc. Similarly, the estimation of data associations in natural language—including association of candidate contexts—is akin to the classical *data association* problems of data fusion: report-to-track, track-to-track association, etc.

Consider the problem of understanding anaphoric reference (or cross reference) in the discourse fragment

1. *A man met a woman with nine children. She told them to introduce themselves to him.*

Without knowing anything of the textual or discourse context, we can use gender and number to associate the pronouns and noun phrases with some confidence.

If, however, the fragment is

2. *A woman met another woman with a child. She told her to introduce herself to her;*

then the anaphoric-referential ambiguity is such that we are pressed to grasp for contextual clues, perhaps social expectations as who would be more likely to make such a request of a child given the vaguely defined relationships among the characters [43].

As in physical target tracking, referential association is based on the hypothesis of common referents. Just as in tracking, three types of evidence are used to associate pronouns and noun phrases: (a) expected spatio–temporal proximity; i.e., distance within a discourse, based on a discourse dynamic model, analogous to a kinematic dynamic model; (b) feature similarity, to include syntactic features: gender and number as well as semantic features (e.g., descriptive information in a noun phrase); and (c) situationally derived expectations as to relevant topics and attitudes of the interlocutors [44].

Correspondence measures may be used as well: in feature-aided target tracking this is correspondence with the observable features of an assumed referenced target; in anaphoric analysis this is correspondence with the characteristics of an assumed referent. For example, if in Washington, DC., in May 2008 (a "CO") we overheard someone saying "… his support in the Afro-American community is holding, but she's losing support among woman," a reasonable hypothesis is that Senators

Obama and Clinton are being discussed in the context of the 2008 U.S. presidential election. An utterance of this expression either five years before or after 2008 would likely be massively ambiguous.

2.7 Conclusions

This chapter has discussed the problems of context definitions, formalization, quality, and exploitation in information fusion, including understanding and fusion of natural language data.

Contexts can be characterized as meta-situations at various levels of granularity. As such contexts can be used to:

- support reasoning at each fusion level;
- eliminate or reduce ambiguity;
- detect inconsistencies;
- explain observations; and
- constrain fusion processing.

One of the significant problems of context exploitation is the interrelationship among context quality, the quality of observations, and the results of fusion processes. Solution of this problem is necessary for improved fusion performance. This and the problem of context discovery in uncertain dynamic environments pose a significant challenge in linguistic pragmatics, as in data fusion in general.

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