Situated Agents in Linguistic Contexts

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Abstract: The paper looks at motivations from interdisciplinary applications for some of the major situation-theoretical objects. We present potential applications of situation theory to computational semantics by introducing situational modelling of linguistic contexts and agents such as speakers and listeners in context.

1 INTRODUCTION

Underspecification, partiality, and context dependency are signature features of natural languages and, more generally, of information. These features present major difficulties in related theoretical developments and adequate applications, incl. development of dedicated software systems, decision-problem models and solutions involving models of states, events, actions, context, and other situations. The methodology is demonstrated by Situation Semantics for processing human language, but it can be applied to broader models of information in nature and for computational semantics of both natural and artificial languages. Various domain-dependent versions of situation theory and situation semantics are gaining appearance in contemporary technologies, software systems, and intelligent ontology systems. One of the most prominent applications of Situation Theory and Situation Semantics is for development of intelligent user-computer interfaces.

Situation theory is a type based information theory. It takes some set-theoretic objects as its basic objects and uses them in constructs of more complex situation theoretic objects, including situated types. For a detailed discussion of situation theoretic objects, such as types and propositions similar to the ones used in this paper, see (Barwise and Perry, 1983). For a more formal introduction, see (Loukanova, 2011b). Here we present a brief introduction to some of the most prospective features of Situation Theory including generalized, restricted parameters, which we then use for mathematical modelling of linguistic contexts and agents.

Primitive Individuals. A collection (typically, a set) $\mathcal{A}_{IND}$ is designated as the set of primitive *individuals* of the situation theory:

$$\mathcal{A}_{IND} = \{a, b, c, \ldots\} \tag{1}$$

The objects in $\mathcal{A}_{IND}$ are set-theoretic objects, but they are considered as primitives, not as complex situation-theoretic constructions. In various versions of situation theory, designated for specific applications, some of the individuals in $\mathcal{A}_{IND}$ may be parts of other individuals in $\mathcal{A}_{IND}$, and as such can be in respective *part-of* relations.

Space-time Locations. Simplified versions of situation theory use a collection (typically, a set) $\mathcal{A}_{LOC}$ of space-time points and regions units:

$$\mathcal{A}_{LOC} = \{l, l_0, l_1, \ldots\} \tag{2}$$

The collection $\mathcal{A}_{LOC}$ is endorsed with relations of time precedence $\prec$, time overlapping $\circ$, space overlapping $\circ$, and inclusion $\subseteq_t$, $\subseteq_s$, $\subseteq$, between locations. In some versions of situation theory, the space-tile locations can be given by complex objects. E.g., a simple option (equivalent to the above) is that space-time locations are pairs of two components, one for space locations, and one for time points or periods.

Primitive Relations. Significantly, situation theory has a collection (typically, a set) $\mathcal{A}_{REL}$ of abstract, primitive objects that are relations:

$$\mathcal{A}_{REL} = \{r_0, r_1, \ldots\} \tag{3}$$

The elements of $\mathcal{A}_{REL}$ are abstract representatives of real or virtual relations. For example, if situation theory is used to model real world situations, these are abstract representatives of properties of objects and

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relations between objects. E.g., humans (as well as other living species) are attuned to distinguish properties of and relations between objects, perceptually in the reality, or cognitively, i.e., conceptually. We normally can recognise the property of an object to be a book, while the specifics of that property may be context dependent, a hardback book, a paperback, or e-book. The set $\mathcal{A}_{REL}$ depends on the actual application of Situation Theory[1]. For example,

$$\mathcal{A}_{REL} = \{\, man, woman, dog, run, smile, like, \dots \} \quad (4)$$

By introducing more complex situation-theoretic objects, it is possible to define the extension of any given relation r, in any given situation s as the set of tuples of objects being in the relation r in s. For example, we can distinguish when a primitive relation of reading holds between two objects: a reader and an object that is read.

Primitive Types. A collection (typically, a relatively small set) of objects, which are called *primitive* or *basic* types:

$$B_{TYPE} = \{\, IND, LOC, REL, POL, ARG, \quad (5a)$$
$$INFON, SIT, PROP, PAR, TYPE, \models \} \quad (5b)$$

where *IND* is the type of individuals; *LOC*: of space-time locations; *REL* of relations; *TYPE*: of basic and complex types; *PAR*: of parameters; *POL*: of two polarity objects, e.g., presented by the natural numbers 0 and 1; *ARG*: of abstract argument roles (primitive and complex); *INFON*: of situation-theoretical objects that are basic or complex information units, defined later; *PROP*: of abstract objects that are propositions; *SIT*: of situations; $\models$ is a type called "supports".

Definition 1 (Assignment of Primitive Argument Roles)**.** A set of argument roles is assigned to each of the primitive relations and each of the primitive types by a function *Args* with the domain and range of which are such that $Dom(Args) = \mathcal{A}_{REL} \cup B_{TYPE}$, and $Range(Args) \subseteq \mathcal{A}_{ARG}$.

For example, we can associate relations, such as *smile, read, give*, respectively denoted by the lexemes smile, read, give, etc., with arguments roles:[2] Similarly to relations, each type is associated with a set of argument roles. If a type T has a single argument role, we call it a *unary type*, or a *property type*. In particular, *IND*, *LOC*, *POL*, *PAR*, *TYPE*, are unary types, each with one argument role, that can be declared as filled only by elements of sets corresponding to the types.

[1]The the set-theoretical meta-theory of Situation theory, including representation of $\mathcal{A}_{REL}$, is not the subject of this paper.

[2]The argument role of the object that is read is designated by the "misspelled" notations *read-ed* or *readed*.

Argument Roles and Appropriateness Constraints. The argument roles of both relations and types can be associated with types as constraints for their appropriate filling.

Definition 2 (Argument Roles with Appropriateness Constraints)**.** A set of argument roles is assigned to each of the primitive relations and to each of the primitive types by a function *Args* with its domain and range of values such that $Dom(Args) = (\mathcal{A}_{REL} \cup B_{TYPE})$, and $Range(Args) \subseteq (\mathcal{A}_{ARG} \times TYPE)$, so that for any primitive relation and any type $\gamma \in \mathcal{A}_{REL} \cup B_{TYPE}$ with n-arguments: $Args(\gamma) = \{\langle arg_{i_1}, T_{i_1}\rangle, \dots, \langle arg_{i_n}, T_{i_n}\rangle\}$, where $T_1, \dots, T_n$ are sets of types (basic or complex), which are specific for γ and are called *basic appropriateness constraints of the argument roles* of γ.

Notation 1. Often, we shall use the notation (6):

$$Args(\gamma) = \{T_{i_1} : arg_{i_1}, \dots, T_{i_n} : arg_{i_n}\} \quad (6)$$

The very basic appropriateness constraints can be expressed by associating argument roles with primitive types, $T_{i_1}, \dots, T_{i_n} \in B_{TYPE}$. For example:

$$Args(give) = \{\, IND : giver, \quad (7a)$$
$$IND : receiver, IND : given \} \quad (7b)$$

For any relation or type (which can be primitive or complex), the objects that fill its argument roles are restricted to satisfy the constraints associated with the roles.

Definition 3 (Argument Filling)**.** For any given relation $\gamma \in \mathcal{R}_{REL}$ and for any given type $\gamma \in \mathcal{T}_{type}$ associated with the set of argument roles $Args(\gamma) = \{T_{i_1} : arg_{i_1}, \dots, T_{i_n} : arg_{i_n}\}$, an *argument filling* for γ is any total function θ with $Dom(\gamma) = \{arg_{i_1}, \dots, arg_{i_n}\}$, which is set-theoretically defined by a set of ordered pairs $\theta = \{\langle arg_{i_1}, \xi_1\rangle \dots, \langle arg_{i_n}, \xi_n\rangle\}$, so that its values, $\theta(arg_{i_1}) = \xi_1, \dots, \theta(arg_{i_n}) = \xi_n$, satisfy the appropriateness constraints of the argument roles of γ: $T_{i_1} : \xi_1, \dots, T_{i_n} : \xi_n$.

Infons, State of Affairs (soas), Situations. Next, I shall give a mutually recursive definition of several sets of situational objects:

- the set $\mathcal{I}_{INF}$, the elements of which are called infons, and are basic or complex information units;
- the set $\mathcal{R}_{REL}$ of all primitive and complex relations (complex relations are defined later): $\mathcal{A}_{REL} \subset \mathcal{R}_{REL}$;

- the set $\mathcal{T}_{TYPE}$ of all primitive and complex types: $B_{TYPE} \subset \mathcal{T}_{TYPE}$;
- the collection $\mathcal{S}_{SIT}$ of situations.

The basic informational units are identified by a unique relation, an assignment of its argument roles and a corresponding negative or positive polarity.

Definition 4 (Infons)**.** The set $\mathcal{I}_{INF}$ of all infons:

1. *Basic infon* is every tuple $\langle \gamma, \theta, \tau, i \rangle$, where $\gamma \in \mathcal{R}_{REL}$ is a relation (primitive or complex), $LOC : \tau$ is a space-time location, (i.e., $\tau \in \mathcal{A}_{LOC}$), $POL : i$ is polarity (i.e., $i \in \{0,1\}$), and θ is an argument filling for γ, i.e.:

$$\theta = \{\langle arg_{i_1}, \xi_1 \rangle, \ldots, \langle arg_{i_n}, \xi_n \rangle\} \quad (8)$$

   for some situation-theoretical objects $\xi_1, \ldots, \xi_n$ satisfying the appropriateness constraints of γ.
2. Let $\mathcal{B}\mathcal{I}_{INF}$ be the set of all basic infons. $\mathcal{B}\mathcal{I}_{INF} \subset \mathcal{I}_{INF}$.
3. For representation of conjunctive and disjunctive information, *complex infons* are formed by operators for conjunction and disjunction: $\langle \wedge, \sigma_1, \sigma_2 \rangle \in \mathcal{I}_{INF}$ and $\langle \vee, \sigma_1, \sigma_2 \rangle \in \mathcal{I}_{INF}$.
   Other complex infons are constructed from various situation theoretic objects, which we can add later.

Notation 2. Often, in this paper, we use the traditional linear notation of basic infons:

$$\ll \gamma, arg_{i_1} : \xi_1, \ldots, arg_{i_n} : \xi_n, LOC : \tau; i \gg \quad (9a)$$

$$\ll \gamma, \xi_1, \ldots, \xi_n, \tau; i \gg \quad (9b)$$

Note 1. The notation (9a) does not assume any innate order over the argument roles of γ. On the other hand, in case that γ has more than one argument roles, the notation (9b), e.g. as in (10b), (10d), makes sense only by having some agreement about an order over the argument roles of γ.

Example 1.1.

$$\ll book, arg : b, Loc : l; 1 \gg \quad (10a)$$

$$\ll book, b, l; 1 \gg \quad (10b)$$

$$\ll read, reader : a, readed : b, l; 1 \gg \quad (10c)$$

$$\ll read, a, b, l; 1 \gg \quad (10d)$$

Definition 5 (States of affairs, events, situations)**.** We define the following complex situational objects:

1. *State of affairs (soa)* is any set of infons that have the same location component.
2. An *event (course of event, coa)* is any set of infons.
3. A *situation* is any set of infons.

Basic Parameters. For each of the basic types IND, LOC, REL, POL, SIT, situation theory that has a collection (a set) of *basic (primitive) parameters*:

$$\mathcal{P}_{IND} = \{\dot{a}, \dot{b}, \dot{c}, \ldots\}, \quad (11a)$$

$$\mathcal{P}_{REL} = \{\dot{r_0}, \dot{r_1}, \ldots\}, \quad (11b)$$

$$\mathcal{P}_{LOC} = \{\dot{l_0}, \dot{l_1}, \ldots\}, \quad (11c)$$

$$\mathcal{P}_{POL} = \{\dot{i_0}, \dot{i_1}, \ldots\}, \quad (11d)$$

$$\mathcal{P}_{SIT} = \{\dot{s_0}, \dot{s_1}, \ldots\}. \quad (11e)$$

Basic parameters are also called *indeterminates*. here we follow the original Situation Theory, by denoting specific basic parameters by dots. Often, we shall use "meta-variables" for basic parameters and the type shall be either explicitly stated or understood, e.g., typically, x is any parameter of type IND.

Infons, states of affairs, and situations, in which some of the argument roles, including the space-time location and polarity components, are filled by parameters, are called, respectively, *parametric infons*, *parametric soas*, and *parametric situations*.

Example 1.2.

$$\ll read, reader : \dot{a}, readed : \dot{b}, \dot{l}; 1 \gg \quad (12a)$$

$$\ll read, reader : a, readed : \dot{b}, \dot{l}; 1 \gg \quad (12b)$$

$$\ll read, a, b, l; \dot{i} \gg \quad (12c)$$

2 SITUATED PROPOSITIONS, CONSTRAINTS AND PARAMETERS

In the considered version of situation theory, we use a specialized primitive type $PROP \in B_{TYPE}$, with two argument roles: a type $\mathbb{T} \in \mathcal{T}_{TYPE}$, and an appropriate argument filling θ for $\mathbb{T}$. I will use the type $PROP$ for constructing abstract objects (set-theoretic tuples) to model the abstract notion of a proposition, which states that some given objects are of some given type, in the following way:

Definition 6 (Propositions)**.** *Proposition* is any tuple $\langle PROP, \mathbb{T}, \theta \rangle$, where $\mathbb{T} \in \mathcal{T}_{TYPE}$ is a type that is associated with a set of argument roles

$$Args(\mathbb{T}) = \{T_{i_1} : arg_{i_1}, \ldots, T_{i_n} : arg_{i_n}\} \quad (13)$$

and θ is an argument filling for $\mathbb{T}$, i.e.:

$$\theta = \{\langle arg_{i_1}, \xi_1 \rangle, \ldots, \langle arg_{i_n}, \xi_n \rangle\} \quad (14)$$

for some objects $\xi_1, \ldots, \xi_n$ such that θ satisfy the appropriateness constraints of $\mathbb{T}$:

$$T_{i_1} : \xi_1, \ldots, T_{i_n} : \xi_n. \quad (15)$$

Notation 3. We use the notation $(\mathbb{T}, \theta)$ for $\langle PROP, \mathbb{T}, \theta \rangle$.

When a proposition $\langle PROP, \mathbb{T}, \theta \rangle$ is true, we say that the objects $\xi_1, \ldots, \xi_n$ are of type $\mathbb{T}$ with respect to the argument role filling θ, and we write $\mathbb{T} : \theta$, or, in case it is clear which roles are filled by which objects, $\mathbb{T} : \xi_1, \ldots, \xi_n$. I.e., propositions are the result of filling up the argument roles of a type with appropriate objects. We shall use a special kind of propositions defined by Definition 7, based on the primitive type $\models$. The type $\models$, pronounced "support", has two argument roles, one that can be filled by any object that is of the type *SIT* of situations, and the other can be filled by any object that is of the type *INF* of inforns. I.e.:

$$Args(\models) = \{ \langle arg_{sit}, SIT \rangle, \langle arg_{infon}, INF \rangle \} \quad (16a)$$
$$\equiv \{ SIT : arg_{sit}, INF : arg_{infon} \} \quad (16b)$$

Definition 7 (Situated Propositions)**.** *Situated proposition* is a situation-theoretical object

$$\langle PROP, \models, s, \sigma \rangle \quad (17)$$

where $s \in \mathcal{P}_{SIT}$ and $\sigma \in \mathcal{I}_{INF}$.

Notation 4. We use the notation $(s \models \sigma)$ and say "the proposition that σ holds in the situation s" or "the proposition that the situation s supports the infon σ".

Example 2.1.

$$(s \models \ll book, arg : b, Loc : l; 1 \gg \wedge \quad (18a)$$
$$\ll read, reader : x, readed : b, Loc : l; 1 \gg) \quad (18b)$$

Situation theory uses an abstraction operator, which recalls the λ-abstraction in functional λ-calculi, but, in situation theory, abstraction operator is different and does not define functions. In situation theory, the abstraction operator results in complex types, with abstract argument roles.

Definition 8 (Complex Types and Appropriateness Constraints)**.** Let Θ be a given proposition and $\{\xi_1, \ldots, \xi_n\}$ be a set of parameters that occur in Θ. Let, for each $i \in \{1, \ldots, n\}$, T_i be the union of all the appropriateness constraints of all the argument roles that occur in Θ and ξ_i fills up.

Then the object $\lambda\{\xi_1, \ldots, \xi_n\}\Theta \in \mathcal{T}_{TYPE}$, i.e., $\lambda\{\xi_1, \ldots, \xi_n\}\Theta$ is a *complex type*, with abstract argument roles denoted by $[\xi_1], \ldots, [\xi_n]$ and corresponding *appropriateness constraints* associated in the following way:

$$Args(\lambda\{\xi_1, \ldots, \xi_n\}\Theta) \quad (19a)$$
$$= \{T_1 : [\xi_1], \ldots, T_n : [\xi_n]\} \quad (19b)$$

The type $\lambda\{\xi_1, \ldots, \xi_n\}\Theta$, where Θ is a proposition, is alternatively denoted by

$$[\xi_1, \ldots, \xi_n \mid \Theta(\xi)] \quad (20a)$$
$$[T_1 : \xi_1, \ldots, T_n : \xi_n \mid \Theta(\xi)]. \quad (20b)$$

Sometimes, we shall use a mixture of λ and bracketed notation, for discriminating between the types of the abstracted away parameters.

Example 2.2. The situation-theoretical object (21) is the type of situations and locations where the specific individual a walks; (22) is the type of individuals that walk in a specific situation s and a specific location l; (23a)–(23c) is the type of individuals that read a specific book b, in a specific situation s and a specific location l; (24a)–(24c) is the type of situations, locations and individuals, where the individual reads a specific book b:

$$\lambda\dot{s}, \dot{l}\, (\dot{s} \models \ll walk, walker : a, Loc : \dot{l}; 1 \gg) \quad (21)$$

$$\lambda x\, (s \models \ll walk, walker : x, Loc : l; 1 \gg) \quad (22)$$

$$\lambda x\, (s \models \quad (23a)$$
$$\ll read, reader : x, readed : b, Loc : l; 1 \gg \wedge \quad (23b)$$
$$\ll book, arg : b, Loc : l; 1 \gg) \quad (23c)$$

$$\lambda\dot{s}, \dot{l}, x\, (\dot{s} \models \quad (24a)$$
$$\ll read, reader : x, readed : b, Loc : \dot{l}; 1 \gg \wedge \quad (24b)$$
$$\ll book, arg : b, Loc : \dot{l}; 1 \gg) \quad (24c)$$

Notation 5. For given object α and a set of appropriateness constraints T, we write $T : \alpha$ iff α satisfies all the constraints in T.

Property 1. *Let Θ be a given proposition and $\{\xi_1, \ldots, \xi_n\}$ be a set of parameters that occur in Θ. Let, for each $i \in \{1, \ldots, n\}$, T_i be the union of all the appropriateness constraints of all the argument roles that occur in Θ and ξ_i fills up. Given that $\alpha_1, \ldots, \alpha_n$ are objects that satisfy appropriateness constraints $T_1 : \alpha_1, \ldots, T_n : \alpha_n$, we have:*

1. *by Definition 8, $\lambda\{\xi_1, \ldots, \xi_n\}\Theta \in \mathcal{T}_{TYPE}$ is a complex type with argument roles* (19a)–(19b)*.*
2. *Let θ be the total function that is set-theoretically defined by the set of ordered pairs $\theta = \{\langle [\xi_1], \alpha_1 \rangle \ldots, \langle [\xi_n], \alpha_n \rangle\}$,*
   - *(a) by Definition 3, θ is an argument filling for the type $\lambda\{\xi_1, \ldots, \xi_n\}\Theta$.*
   - *(b) by Definition 6: $(\lambda\{\xi_1, \ldots, \xi_n\}\Theta : \theta)$ is a proposition, i.e., the proposition that the objects from the argument the filling θ are of the complex type $\lambda\{\xi_1, \ldots, \xi_n\}\Theta$, i.e.:*

$$\langle PROP, \lambda\{\xi_1, \ldots, \xi_n\}\Theta, \theta \rangle \quad (25a)$$
$$\equiv (\lambda\{\xi_1, \ldots, \xi_n\}\Theta : \theta) \quad (25b)$$

Abstractions over individuals in propositions result in *complex types of individuals*. In general, for any given proposition Θ and a parameter ξ for an individual, i.e., $IND : \xi$, which occurs in Θ, the situation-theoretical object $\lambda\{\xi_1\}\,\Theta \in \mathcal{T}_{TYPE}$ is a complex type, that is the type of the individuals for which the proposition $\Theta(\xi_1)$ is true.

3 RESTRICTED PARAMETERS AND PARAMETER ASSIGNMENTS

Any basic parameter x of type τ (i.e., $\tau : x$) can be properly assigned only to a situation theoretic object of type τ. Complex restricted parameters can be properly assigned only to objects that satisfy the constraints associated with the restricted parameters. Associating basic parameters with types has constraining effect. Thus, parameter assignments of both basic and restricted parameters are constrained.

Definition 9 (Consistent Types)**.** For any finite set T of types:

1. T is *consistent* iff there is at least one situation theoretic object that is of each of the types in T.
2. A type τ is *compatible* with T iff the set $\{\tau\} \cup T$ is consistent.

Definition 10 (Parameters)**.** Basic (11a)–(11e) and restricted parameters are parameters.

Restricted Parameters.

1. Let T be a finite (and consistent) set of types. If x is a fresh parameter of type τ, i.e., $\tau : x$, and τ is compatible with the set T of types, then $x^{\{\tau\} \cup T}$ is a parameter of type $\{\tau\} \cup T$. We say that $x^{\{\tau\} \cup T}$ is a *parameter restricted by* $\{\tau\} \cup T$.
2. Let ξ be a parameter and $\Theta(\xi)$ a proposition. Let T be the set of all types associated with all the argument roles in $\Theta(\xi)$ that are filled by ξ[3]. (I.e., $\lambda\xi\,\Theta(\xi)$ is a type and T is the set of the appropriateness constraints of its argument role.) If the set T of types is consistent, and x is a fresh parameter of type τ, i.e., $\tau : x$, such that τ is compatible with T, then $x^{\lambda\xi\,\Theta(\xi)}$ is also a parameter of type τ. We say that $x^{\lambda\xi\,\Theta(\xi)}$ is a *parameter restricted by* $\lambda\xi\,\Theta(\xi)$.
   With the alternative denotation of the complex type $[\xi \mid \Theta(\xi)]$, the restricted parameter $x^{\lambda\xi\,\Theta(\xi)}$ is denoted by $x^{[\xi \mid \Theta(\xi)]}$.

[3]Note that ξ may fill more than one argument role in $\Theta(\xi)$.

For any situation theoretic object $\gamma(x^r)$, in which the restricted parameter x^r is a constituent, we can "connect" some or all of the parameters in it to objects by a parameter assignment function.

A parameter assignment c is defined on x^T, where T is a set of consistent types, only if the proposition $(c(x^T) : \tau)$ is true for each type $\tau \in T$.

A parameter assignment c is defined on $x^{[\xi \mid \Theta(\xi)]}$ only if the proposition $(c(x^{[\xi \mid \Theta(\xi)]}) : [\xi \mid \Theta(\xi)])$ is true; i.e., only if there is a parameter assignment c' for $\Theta(\xi)$, such that $c'(\xi) = c(x^{[\xi \mid \Theta(\xi)]})$ and the proposition $c'(\Theta(\xi))$ is true.

4 BIOLOGICAL BASIS OF SITUATION THEORY

Restricted parameters represent generic patterns, "blueprints", that can be instantiated, i.e., realised, by specific objects that satisfy the corresponding restrictions and are of respective types. In nature, biological entities carry blueprints that are restricted according to shared features, e.g., of species. Parameter assignments represent specific realisations of the generic components in specific instances.

We take a stand that human cognitive abilities and faculties, that are universal for humans, are expressed by innate brain capacities for some fundamental operations:

- perception and recognition of entities, smells, sounds, etc., that are located in three-dimensional space, in time, and situated in environments
- perception and recognition of properties and relations, primitive and complex, "possessed" by entities, in space, time, and situated in environments
- human brain faculties associate properties and relations with abstract and specific objects, by argument roles and argument role assignments
- recognition of abstract patterns, i.e., of types and parametric objects
- pattern construction via primitive abstract types and abstraction over parametric objects
- pattern construction via restrictions over parameters
- pattern matching i.e., an entity o is of type τ, $\tau : x$.

Restricted parameters reflect innate human faculty for development and attainment of concepts of objects that have some properties and are in relations to other kinds of objects, not necessarily referring to specific objects in the reality. A youngster or an adult person can get an idea what an object with certain properties could be, without having seen any such objects, in reality or in other ways depicted. Such concepts are not necessarily expressed by or associated with language.

5 LINGUISTIC CONTEXTS AND AGENTS

Human language is used in contexts, that can be spoken, written, pictural, virtual, in reasoning, “in the mind”, or combining any of these ways of usage. Language can be used by speakers that know its abstract linguistic meanings and how the abstract linguistic meanings can be “connected”, i.e., assigned to specific interpretations. Abstract linguistic meanings, taken out of any context of use, carry semantical information, which is partial, parametric and sometimes ambiguous. I.e., normally, abstract linguistic meanings, out of context, have structure with parametric constituents and abstractions over parameters. When used in specific contexts, the abstract linguistic meanings are assigned to specific interpretations, by the speakers and listeners. The interpretations in context can still be parametric and partial. Ambiguities are typically resolved by speakers’ and listeners’s who interprete depending on their perspectives.

Partiality of information about the objects designated by language parts is by introducing primitive and complex, i.e., restricted, parameters. The restriction r over a parameter x^r represents a constraint $r : a$ that is necessary for an object a to be associated with the parameter x^r in a larger piece of information $\gamma(x^r)$. The assignment of an object a to x^r in $\gamma(x^r)$ results in the instantiation $\gamma(a)$. The constraint r itself is not per-se a part of $\gamma(a)$, but is an additional, necessary-constraint information, satisfied by a, i.e., a is of type r, $r : a$. A speaker-agent uses the restriction r to designate the object a, by assigning it to x^r. The listener-agent identifies the object a filling the arguments in $\gamma(a)$, by the constraint $r : a$.

5.1 Linguistic Utterance Components

In this paper, we follow a tradition of using the technical notion of an *utterance*, as a situation type representing minimal components of context, which are crucial for association of linguistic meanings with potentials for specific interpretations in specific contexts, i.e., in “utterances” of expressions, by speakers addressing listeners. Depending on the areas of applications of situation theory, linguistic contexts can be extended. The context (discourse) components include, as a minimum, the following kinds of information:

1. *Pure linguistic information:* The expression uttered are presented by a syntax-semantics interface structure, which determines its abstract linguistic meaning. The authors of this paper support the view that the syntax-semantics interface In human language is innate faculty of brain physiology. Computational approaches to language processing would be more intelligent and adequate by taking such a perspective.
2. *Broad-linguistic information by utterance components:* the “speaker” agent that delivers the expression, for example by an utterance; the listener agent(s) that are addressed interpreters; the time and the space location of the utterance; the speaker’s references that assign particular objects to language components; the knowledge and the intentions of the speaker and the listener that contribute to interpretations of abstract linguistic meanings, assigning objects to parameters, and disambiguation. This information can be presented by abstract utterance types, as parametric situation theoretic constructs.
3. *Extra-linguistic utterance information:* language specific word order and word inflection paradigms, end-of-sentence punctuation, speech acts, intra-sentential punctuation, intonation, gesture and other means for expressing speaker’s perspectives, stress, presenting “new” vs. “old” information.

5.2 Some Biological Phenomena of Syntax-semantics Interface

The extra-linguistic information presented by word order and word inflection paradigms present a distinctive biological foundation of communications between humans via human language. The human brain physiology supports multi-dimensional functionality and multi-dimensional mental faculty. I.e., humans comprehend and act in situations, which are parts of the surrounding world, in three-dimensional space and time continuity, discrete and continuous. On the other side, speech production is linearised by limitations of the physiology of vocal tracts. These limitations are present in linear wording of predominantly existing writing systems, for transposing speech on carrying materials. Writing materials typically have been two-dimensional (e.g., strings, plates, paper, screens) and allow two-dimensional representation of syntactic structure.

Tree-structure representations of syntactic structures of the linear wording of language expressions were introduced and acknowledged by theoretical and computational linguistics. Such tree-structure analyses represent syntax-semantics interfaces, where semantic counterparts, i.e., language utterances describe situations and informational units that consist of multi-dimensional objects. In particular, primitive and complex relations and properties in situation theory have arguments that are not by necessarily ordered: they are sets. This is a distinctive feature of situation-theoretical objects that reflects information in nature and is biologically motivated. Argument assignments are associated with relations by indexing functions.

The features of linear encoding and tree-structure analyses of multi-dimensional structures are transposed into artificial languages, such as formal languages in computational theories and programming languages.

5.3 Situated Linguistic Agents

Denotations of human language expressions in specific contexts may depend on reference acts. A *linguistic reference act* is an event consisting of at least the following components: a language expression, an object (real or abstract) referred to, which is called the referent of the expression, and an utterance situation (or a broader discourse). The *utterance situation* consists of subcomponents such as the speaker, the speaker's reference function, the space-time location of the utterance, and the listener. The speaker's act of reference can be modeled by a function defined on language units with values the objects referred to. The reference function itself is dependent on the utterance. By using situation theoretical objects with restricted parameters, the utterance components can be modeled by situation-theoretical objects as follows, see also (Loukanova, 2001; Loukanova, 2002b; Loukanova, 2002a).

The proposition expressing who is the speaker x, who is the listener y, what is the space-time location, and which is the expression α uttered in an utterance situation u, i.e., a minimum of context information is expressed by the situated proposition (26):

$$pu(u,l,x,y,\alpha) \equiv (u \models \ll tells, x, y, \alpha, l; 1 \gg) \quad (26)$$

Then, (27) is an abstract type of an utterance situation.

$$ru(l,x,y,\alpha) \equiv [u \mid pu(u,l,x,y,\alpha)] \quad (27)$$

The type (28) is the type of a speaker agent in an utterance situation u.

$$rsp(u,l,y,\alpha) \equiv [x \mid pu(u,l,x,y,\alpha)] \quad (28)$$

The type of an individual to be a listener agent in an utterance situation u is (29):

$$rlst(u,l,x,\alpha) \equiv [y \mid pu(u,l,x,y,\alpha)] \quad (29)$$

The type of an object to be the utterance (or discourse) space-time location is given by (30):

$$rdl(u,x,y,\alpha) \equiv [l \mid pu(u,l,x,y,\alpha)] \quad (30)$$

The type (31) is a type for the *referent agent* i.e., of the objects to be referred to by an expression α in an utterance situation.

$$r_\alpha(u,l,x,y,s_{res}) = [z \mid q(u,l,x,y,z,\alpha)] \quad (31)$$

where $q(u,l,x,y,z,\alpha)$ is a proposition such as (32a) or (33a).

$$q(u,l,x,y,z,\alpha) \equiv \quad (32a)$$
$$(u^{ru(l,x,y,\alpha)} \models \quad (32b)$$
$$\ll refers\text{-}to, x^{rsp(u,l,y,\alpha)}, z, \alpha, l^{rdl(u,x,y,\alpha)}; 1 \gg) \quad (32c)$$

The proposition (32a), i.e., (32b)–(32c) asserts that the speaker x^{rsp} refers to z by using the expression α, in the location $l^{rdl(u,x,y,\alpha)}$. More elaborate representation of the names can be expressed by the following version of the proposition $q(u,l,x,z,\alpha)$:

$$q'(u,l,x,y,z,\alpha,s_{res}) \equiv \quad (33a)$$
$$(u^{ru(l,x,y,\alpha)} \models \quad (33b)$$
$$\ll refers\text{-}to, x^{rsp(u,l,y,\alpha)}, z, \alpha, l^{rdl(u,x,y,\alpha)}; 1 \gg \quad (33c)$$
$$\wedge \ll believes, x^{rsp(u,l,y,\alpha)}, \quad (33d)$$
$$(s_{res} \models \ll named, \alpha, z; 1 \gg), \quad (33e)$$
$$l^{rdl(u,x,y,\alpha)}; 1 \gg) \quad (33f)$$

The proposition (33a), i.e., (33b)–(33f), asserts that the speaker x^{rsp} refers to z by using the name α and believing that z is named α. In what follows, all the abode restrictions shall be written without explicitly specifying the parameter arguments.

6 NAMING EXPRESSIONS AND SENTENTIAL MEANINGS

In this section, we turn to examples of referential expressions, such as proper names and definite descriptions, for exposition of how Situation Theory can handle such semantic phenomena. Semantics of naming expressions gives essential contributions to semantics of larger, encompassing language constructions, e.g., such as sentences and upward to larger texts. However, it is important how those contributions are handled computationally, where is their proper placement in the semantic representations, all of which should also take into account the context and agent dependency of their semantics.

A distinctive semantic contribution of naming expressions provides means for *potential reference to objects*, by the language users, i.e., "speaker" and "listener" agents in context, e.g., by using sentences, and so forth, up to text discourse. Typically, by utterances of affirmative sentences, speakers describe some situations (not necessarily the same as the utterances) as holding facts (i.e., infons). The objects, which are the referents of name sub-expressions, participate as fillers of arguments roles of semantic relations, in the facts that are stated to hold in the described situations, by utterance situations. Then, it is important not to misplace the additional semantic contribution, however important, of the naming sub-expressions as direct components of the facts (i.e. of the infons) that are directly in the propositional content stated by a sentence utterance, and not directly in the facts of the utterance itself.

E.g., by an utterance u of a sentence like "Maria is reading the book", a speaker may describe a situation s_1 as holding that a specific individual, referred to by the name "Maria", is involved in some activity, i.e., reading a specific book, referred to by the definite description "the book". The described situation s_1 may be part of or the same as u, i.e., $s_1 \subseteq u$. But it is also possible that s_1 is fully disjoint from u, while both are related via the speaker's references in the utterance context. The speaker uses the name and the definite description to identify the participants of the reading fact. By the inflection of the verb lexeme "read", the reading fact is located with respect to the space-time location of the utterance. But these informational pieces are additional, however important, information that is linked to both the facts of the utterance and the facts of the described situation, and they should not be indiscriminately conjoined.

In general, for a given naming expression α, in its abstract referential semantics, its denotation[4] $\mathsf{den}(\alpha) = x^{r_\alpha}$ is given by a restricted parameter, where r_α is like (31), as abstract linguistic meaning that is dependent on potential contexts. Depending on the expression α and applications, r_α may have more or alternative constraints in it, e.g., by (33b)–(33f). Importantly, the object x^{r_α} is parametric and its instantiations are subject to the r_α constraint expressed by the semantics of the name α, as e.g., in (34a)–(35a) and (36a)–(36d).

Potentially, an utterance and speaker's references, given as parametric components, can provide a specific object referred to by the expression α, as instantiation of the restricted parameter x^{r_α}. The restricted parameter x^{r_α} can get linked to specific referent depending on the specific utterance context and the speaker agent. That specific referent, subjected to satisfaction of the constraint r_α, can fill up relation arguments in facts described by a larger expression, in which the name α occurs, e.g., as in (37a)–(37b). However important, and expressed by the semantics of component name α, the restriction r_α, while a direct component of the restricted parameter itself, provides "extra" semantic information, as necessarily linked to the direct semantic content of the larger expression.

Example 6.1.

$$r_{\text{MARIA}} \equiv [z \mid (u^{ru(l,x,y,\text{MARIA})} \models \tag{34a}$$

$$\ll \textit{refers-to}, x^{rsp}, z^n, \text{MARIA}, l^{rdl}; 1 \gg)] \tag{34b}$$

where the restricted parameter z is recursively restricted by the type n in (35a)–(35b), which expresses that the object z is named MARIA by x^{rsp} in a resource situation s_0:

$$n = [z \mid (s_0 \models \tag{35a}$$

$$\ll \textit{named}, \text{MARIA}, x^{rsp}, z; 1 \gg) \tag{35b}$$

Example 6.2. The linguistic meaning of a noun phrase (NP) that is a definite description, e.g., "the book", can be expressed by z^d, where d is the type (36a)–(36d), and s_2 and l_2 are parameters for a *resource situation* and its resource *location* for evaluation of the NP THE BOOK. Typically, the resource situation s_2 and some of its component locations l_2 are provided by the references of the speaker agent, and while they might be the same as the utterance situation and some of its immediate component locations, respectively, they might as well be "external" via constraints over parameters.

$$d = [z \mid (s_2 \models \ll \textit{book}, z, l_2; 1 \gg \tag{36a}$$

$$\land \ll \textit{unique}, z, \tag{36b}$$

$$[z \mid (s_2 \models \ll \textit{book}, z, l_2; 1 \gg)], \tag{36c}$$

$$l_2; 1 \gg)] \tag{36d}$$

The abstract, linguistic meaning of a sentence like "Maria is reading the book" can be designated by the following situated propositional type:

Example 6.3.

$$\lambda s_1, s_2, l_1, l_2 (s_1 \models \tag{37a}$$

$$\ll \textit{read}, z^{r_{\text{MARIA}}}, z^d, l_1^{[l \mid l \circ l^{rdl}]}; 1 \gg) \tag{37b}$$

where r_{MARIA} and d are, respectively, the constraints (34a)–(35a) and (36a)–(36d).

[4]We present the denotation function without diverging to more theoretical technicalities, which are subjects to other ongoing and future work.

7 CONCLUSIONS AND FUTURE WORK

Conclusions: Advances in Theory for Applications to New Technologies. This paper is part of broader work on development of computational syntax-semantics interface for human language. Mathematical models of the concepts of linguistic context and agents in context concern fundamentals of syntax-semantics interfaces in natural languages in general. Our specific goal is theoretical development of computational type-theory of information for human language processing based on syntax-semantics interface. We target theory of information that is supported by the role of languages in nature, from the perspective of applications and software engineering in new technologies.

The first part of the paper is presenting ongoing research in theoretical development of situation theory for modelling complex information. One of the primary applications of situation theory is to computational semantics of human languages, for modelling semantic domains and information designated by human language, including linguistic contexts and agents. Human language is notoriously ambiguous and context dependent. While some authors may point that as disadvantageous, these phenomenal features present the core part of language productivity and efficiency, partly because it allows different agents, in different contexts, to express varying information, with familiar expressions. Something more, language expressions, even when considered unambiguous, when out of context, carry partial and parametric information, which is not necessarily and fully instantiated in specific contexts when used by specific agents. In many cases, agents such as language users, speakers, listeners, and readers, appreciate parametric, partial and under-specified information expressed by language even in specific contexts. This presents needs of a theory that models partial, parametric and underspecified information, that also models the context-dependency of language and information. This means that such a theory of information has the capacities to model interrelated context components and language agents in context. Situation theory has been under development for meeting such needs.

Future Work. Recent years have been characterised with new technological advancements across sciences and industries, by involving hardware and software engineering. Well established, classical theories and methodologies may be fully sufficient as the foundations of some of these new technologies. The most challenging technological advances occur concurrently with new developments of their scientific foundations, including new methodologies, and new approaches to mathematical models of the domains, for which the technologies are used and applied.

From this perspective, a new interdisciplinary area is emerging, which conjoins theoretical developments in sub-ares that are often considered and developed separately, but are getting co-involved in the context of new technologies. In particular, the primary sub-areas that are forming foundations of new technology advances involve (1) mathematics of the concepts of computations, e.g., mathematics of algorithms and programs (2) classic and new approaches to computational models of various domains of applications (3) hardware and software engineering (4) computational approaches in life sciences.

A representative of this new interdisciplinary area has been emerging as *Domain Science and Engineering* (DSaE), see (Bjørner, 2012). On its side, our paper represents ongoing research on development of Situation Theory, as a computational theory of information, which contributes to domain science , by modelling domains and domain dependent entities, parts, materials, relations, situations, states, events, etc. Situation theory is information type-theory of domains. We view DSaE approach as a computational realisation, in its domain science, of versions of Situation Theory, depending on areas of applications, specifically for applications in computer software engineering. In its current stage, DSaE encompasses series of versions of Situation Theory that are software implementable. A new line of research is on modelling the concepts of states, events, actions, processes, relations (predicates) in Situation Theory depending on applications.

Extensive research have been demonstrating that model-theoretic approaches to computational semantics of human language are highly productive, for an overview see (Loukanova, 2010). In brief, such approaches involve translation of human language into a formal language, which provides computational semantics of the human language. This is desirable for various reasons, in case formal languages are mathematically grounded and equipped with relevant semantics. On the other hand, finding a sufficiently adequate formal language that covers the semantic phenomena of human language, and is also computationally expressive, has been widely open area. It is also important that the formal language supports syntax-semantics interfaces for human language and covers ambiguity and context-dependency (Loukanova, 2010). In this direction, closely related line of research is development of new approach to the fundamentals of computation and algorithms. In particular, new theories of recursion for untyped versions of full recursion (Moschovakis, 1994), and for typed cyclic recursion (Moschovakis, 2006), model the concepts of algorithms, in a novel way that covers fundamental features of mathematics of computation processes. In particular, the formal language and theory of acyclic recursion L_{ar}^{λ} (Moschovakis, 2006) presents a novel approach to modelling the logical concepts of meaning and synonymy, by targeting adequateness of computational semantics of human language. Initial work on the theoretical aspects of computational syntax-semantics interface has covered major syntactical constructions of human language (Loukanova, 2011a) by using L_{ar}^{λ} in Generalized Constraint-Based Lexicalized Grammar (CBLG). Work in that direction is ongoing. Further work is necessary in the following directions:

- mathematical modelling of the domains of semantic structures of L_{ar}^{λ}. E.g., in this direction, we target versions of Situation Semantics.
- developments of type-theory of recursion, in several directions for adequacy depending on applications (Loukanova, 2012). Further work is necessary towards (1) type-theory of full recursion (2) type-theory of recursion with extended type systems, for example with dependent types

Another closely related work involves using versions of Situation Theory and type-theory of algorithms (i.e., of recursion) in large-scale grammatical frameworks for human language. In particular, a highly expressive new grammatical framework (GF) (Ranta, 2004; Ranta, 2011), has been under developments for multi-lingual translations, by targeting universal, typed-directed syntax that covers semantic fundamentals of human-language. We maintain the view that GF, as a new branch of CBLG, is open and highly prospective for further work on syntax-semantics interfaces, e.g., in the lines of the new ideas and approaches presented in this paper.

The new foundational developments, such as Situation Theory and Typed theory of Recursion, target more adequate, reliable and intelligent foundations of technological applications. In the same time, they are part of the ever advancing, scientific understanding of the fundamentals of information and computation.

REFERENCES

Barwise, J. and Perry, J. (1983). *Situations and Attitudes*. Cambridge, MA:MIT press. Republished as (Barwise and Perry, 1999).

Barwise, J. and Perry, J. (1999). *Situations and Attitudes*. The Hume Series. CSLI Publications, Stanford, California.

Bjørner, D. (Spring-Summer 2012). Domain science & engineering. a precursor for requirements engineering. *Being written*.

Loukanova, R. (2001). Russellian and strawsonian definite descriptions in situation semantics. In Gelbukh, A., editor, *Computational Linguistics and Intelligent Text Processing*, volume 2004 of *Lecture Notes in Computer Science*, pages 69–79. Springer Berlin / Heidelberg.

Loukanova, R. (2002a). Generalized quantification in situation semantics. In Gelbukh, A., editor, *Computational Linguistics and Intelligent Text Processing*, volume 2276 of *Lecture Notes in Computer Science*, pages 46–57. Springer Berlin / Heidelberg.

Loukanova, R. (2002b). Quantification and intensionality in situation semantics. In Gelbukh, A., editor, *Computational Linguistics and Intelligent Text Processing*, volume 2276 of *Lecture Notes in Computer Science*, pages 32–45. Springer Berlin / Heidelberg.

Loukanova, R. (2010). Computational syntax-semantics interface. In Bel-Enguix, G. and Jiménez-López, M. D., editors, *Language as a Complex System: Interdisciplinary Approaches*, pages 111–150. Cambridge Scholars Publishing.

Loukanova, R. (2011a). Semantics with the language of acyclic recursion in constraint-based grammar. In Bel-Enguix, G. and Jiménez-López, M. D., editors, *Bio-Inspired Models for Natural and Formal Languages*, pages 103–134. Cambridge Scholars Publishing.

Loukanova, R. (2011b). Situated propositions with constraints and restricted parameters. In Blache, P., Christiansen, H., Dahl, V., and Villadsen, J., editors, *Proceedings of the 6th International Workshop on Constraints and Language Processing*, number 134 in Computer Science Research Reports, pages 44–55, Roskilde University, Denmark.

Loukanova, R. (2012). Semantic information with type theory of acyclic recursion. In Huang, R., Ghorbani, A. A., Pasi, G., Yamaguchi, T., Yen, N. Y., and Jin, B., editors, *AMT*, volume 7669 of *Lecture Notes in Computer Science*, pages 387–398. Springer.

Moschovakis, Y. N. (1994). Sense and denotation as algorithm and value. In Oikkonen, J. and Vaananen, J., editors, *Lecture Notes in Logic*, number 2 in Lecture Notes in Logic, pages 210–249. Springer.

Moschovakis, Y. N. (2006). A logical calculus of meaning and synonymy. *Linguistics and Philosophy*, 29:27–89.

Ranta, A. (2004). Grammatical framework: A type-theoretical grammar formalism. *Journal of Functional Programming*, 14(2):145–189.

Ranta, A. (2011). *Grammatical Framework: Programming with Multilingual Grammars*. CSLI Publications, Stanford.