# Representing Mental Spaces and Dynamics of Natural Language Semantics

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**Abstract**

Building systems with the robustness of human reasoning capabilities requires inspirations from cognitive science. The primary objective of this study is to investigate the possibility of representing some basic principles of cognitive semantics' Mental Spaces Theory such as domain construction, reality status of domains and their elements, and mental attitudes in a knowledge representation framework for the purpose of developing cognitively plausible knowledge representation systems. The model used as the basis of representation is the extended version of conventional semantic networks, namely Multi-Layered Extended Semantic Networks (MultiNet). The data used in this study have been selected from English expressions and have been represented in MWR, MultiNet's knowledge representation software. Results obtained from analysis of represented data and their comparison to principles of mental spaces theory shows that theoretical constructs of mental spaces theory such as domain construction, reality status of domains and their elements, and mental attitudes can be formally represented in the MultiNet framework.

**Keywords**: Knowledge representation, mental spaces, semantic networks, conitive semantics.

## 1. Introduction

In a daily conversation, we talk about a variety of objects, events, states of affairs, situations, etc. Interesting above all is the fact that none of these conversational elements have to necessarily be real. We may talk about yesterday's car accident (a real event), admire Hercules Poirot (a fictional detective), and even make a seemingly contradictory judgment that both *Poirot is a Belgian detective* and *in reality, Poirot is not Belgian* are true! How could it be that an entity can have a variable "reality status"? All of these facts can be accounted for by Mental Spaces Theory (MST), a cognitive linguistic approach to meaning construction in natural language [7]. According to Fauconnier [5, p. 351], "mental spaces are very partial assemblies constructed as we think and talk for purpose of local understanding and action." In other words, in the course of talking or thinking we construct spaces in our mind all of which having their own internal structures and being related to each other. Thus an entity can have a variable reality status depending on the mental space to which it belongs. The mental space constructed by the sentence *Poirot is a Belgian detective* is a non-real imaginary story space of which Poirot is an element. But when we say *in reality, Poirot is not Belgian* the constructed space is reality space in which Poirot (the actor, not the character) does not have the fictional nationality.

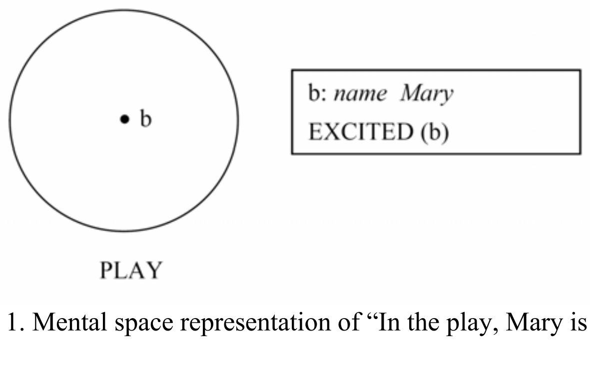


Figure 1. Mental space representation of "In the play, Mary is excited"

Knowledge representation, one of the main concerns of Artificial Intelligence (AI), is "the study of how to put knowledge into a form that a computer can reason with" [18, p. 16]. Natural language semantics as a rich source of knowledge is considered a major challenge to formalization and representation. On the other hand, extracting semantic knowledge of natural language is a crucial task for natural language processing systems if they are to demonstrate a human-like intelligence. In building meaning representation systems, various frameworks with different orientations have been proposed: logic-based (Description Logics [1, 4]; Discourse Representation Theory [11]), network-based (Semantic Networks [17]; Conceptual Dependency Theory [20]; Conceptual Structures [21]), and frame-based (Frame theory [14]) methods of meaning representation are the most discussed ones in the literature.

One of the main problems in classical approaches to knowledge representation [15] is the representation of beliefs about truth, and temporal aspects of knowledge. In response to these difficulties [19], modal logics and the notion of *possible worlds* were introduced to account for epistemic modalities inherent in the natural language. In the thesis of possible worlds [13] it is strongly believed that there are lots of worlds and our world we inhabit is one of those possible worlds.

Possible worlds, however, pose some metaphysical [2, p. 33] and referential [7] problems not to be accounted for easily. In contrast, as Dancygier and Sweetser [3, p. 11] maintains, "mental spaces represent a more general mechanism than possible worlds, referring not only to very partial cognitive 'world' or 'situation' constructions as well as to more complete ones, but also to a variety of non-world-like structures which can be connected and mapped onto other cognitive structures." Implementing mental spaces, as a cognitively motivated parallel to possible worlds, in a cognitive computational framework would tackle the difficulties posed by logic-based methods. As Pereira [16, p. 56] suggests, "From a symbolic AI perspective, a mental space could be represented as a semantic network, graph in which we have nodes identifying concepts (corresponding to the *elements* of a mental space) interconnected by relations. The definitions of mental space still allow many other representations (e.g. cases in Cased-Based Reasoning, memes in Memetics or even the activation pattern of a Neural Network in a given moment) but these would certainly demand more complex computational treatment, especially with regard to the mapping."

This paper aims at investigating the possibility of representing some principal notions of mental spaces – such as domain construction, reality status of domains and their elements, and mental attitudes – in a knowledge representation system. Our proposed framework, the Multilayered Extended Semantic Networks (MultiNet), is a knowledge representation model developed by Hermann Helbig [9, 8]. There are semantic analysis mechanisms built into MultiNet which are hypothesized to show considerable overlap with basic principles of mental spaces. Comparison of MultiNet representations and those of mental spaces theory shows that first steps can be taken to make the outcomes of cognitive semantics research, specially mental spaces theory, realized and pave the way for developing sophisticated and cognitively plausible knowledge representation and reasoning systems.

## 2. Mental Spaces

Mental spaces are highly complex conceptual interconnected networks which are constructed in the course of speaking or thinking. These conceptual networks or domains are formed in the working memory and are expanded as the process of thinking or conceptualization continues.

In the natural language, linguistic expressions serve as triggers in setting up mental spaces, the levels at which meaning is also constructed. "These domains are not part of the language itself, or its grammars; they are not hidden levels of linguistic representation, but language does not come without them" [7].

Mental spaces, according to Fauconnier [6], are internally structured by frames and cognitive models and externally are linked by "connectors" that relate mental spaces to one another. New elements are added to spaces by linguistic and also non-linguistic expressions.

The followings are some of the linguistic devices used in constructing and linking mental spaces [6, p. 40]:

- **Space builders.** A space builder is a grammatical expression that either opens a new space or shifts focus to an existing spaces. Spaces builders take on a variety of grammatical forms, such as prepositional phrases, adverbials, subject-verb complexes, etc.; for example, *in 1929, in that story, actually, in reality, in Susan's opinion, Susan believes…, Max hopes…, if it rains….*

- **Names** and **descriptions.** Names (*Max, Napoleon,* etc.) and descriptions (*the mailman, a vicious snake, some boys who were tired,* etc.) either set up new elements or point to existing elements in the discourse construction.

In meaning construction there are also information about how elements of the spaces are related. As an example we will consider mental space analysis of sentence (1):

(1) In the play, Mary is excited.

The space builder in example (1) is the phrase *in the play,* which sets up a mental space. In Figure 1 the mental space is diagrammed by means of a circle and define a label ("PLAY") to show that the mental space represents the world inside the play. In this example, the name *Mary* introduces a new element into the mental space which is labeled *b*. The expression *excited* in the sentence, assigns a the property "EXCITED" to the element *b.* This information is included in the 'box' next to the mental space.

### 3. Meaning Representation in MultiNet

MultiNet is a knowledge representation framework (see [8]) developed by the Hermann Helbig and his colleagues at IICS[1] of University of Hagen. Its core design and functionality is based on the notion of semantic networks. In this model concepts are represented with nodes in the network. They are the smallest units of representation connected to one another by means of explicitly defined relations and functions. A very brief overview of representational means in MultiNet has been presented in the following subsections.

#### 3.1. Concepts

One of the distinguishing features of MultiNet is its commitment to the Cognitive Adequacy requirement. According this requirement [9], semantic representations and knowledge representations should be centered around concepts. Concepts[2] are represented by nodes in the graphical representation of the network. Every node belongs to a specific sort defined by the MultiNet's ontology of sorts (Figure 2).

[1] Intelligent Information and Communication Systems group

[2] Following MultiNet convention, concepts are represented by the font concept in the text and multiword concepts are put in angled brackets: <multi-word concepts>.

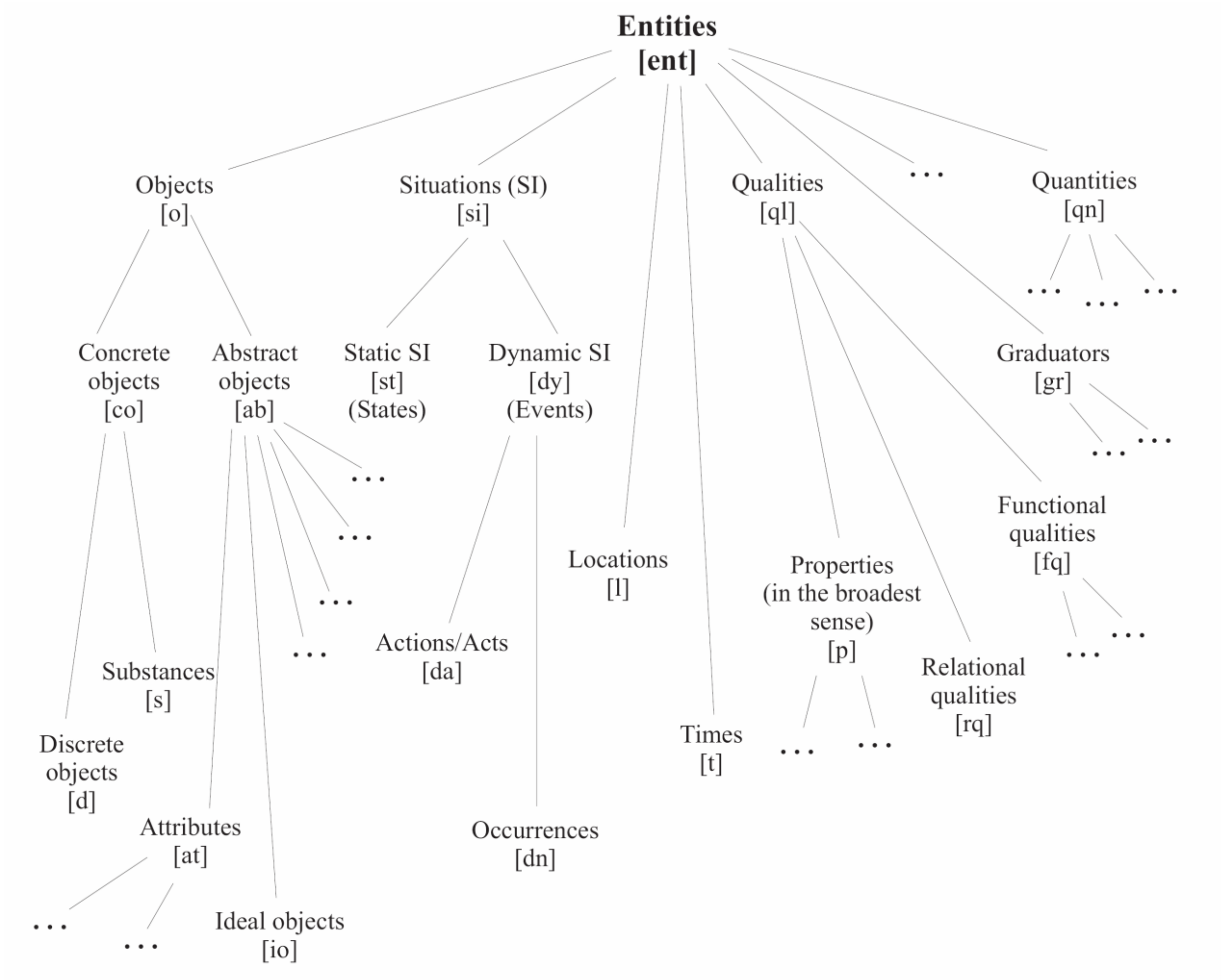


Figure 1. The upper ontology of sorts in MultiNet (after Helbig [17])

There are seven attributes (layers) that characterize concept nodes in a multi-dimensional space. A very brief definition for each, adopted from [9], has been given below:

- FACT: This attribute describes the "Facticity" of an entity, i.e. whether it is really existing (value: *real*), not existing (value: *nonreal*), or hypothetically imagined (value: *hypo*).
- GENER: the "degree of generality" indicates whether a conceptual entity is generic (value: *ge*) or specific (value: *sp*).
- QUANT: The intentional "quantification" represents the quantitative aspect of a conceptual entity.
- REFER: This attribute specifies the "determination of reference", i.e. whether there is s determined object of reference (value: *det*) or not (value: *indet*).
- CARD: The "cardinality" as characterization of a multitude at preextensional level is the counterpart of the attribute QUANT at the intensional level; it characterizes the number of elements in a set.
- ETYPE: This attribute characterizes the "type of extensionality" of an entity with values: *nil* – no extension, 0 – individual which is no set, 1 – entity with a set of elements from type [ETYPE 0] as extension, 2 – entity with a set of elements from type [ETYPE 1] as extension.
- VARIA: The "variability" describes whether an object is conceptually varying (value: *var*) – a so-called parametrized object – or not (value: *con*).

Concepts need to be connected to one another in order to make realization of situations possible. These connections are established by a set of built-in relations and functions.

### 3.2. Relations

MultiNet has a total number of 89 relations for maintaining the conceptual dependencies between nodes. 16 relations are C-role (Cognitive Role) and they are those relations that describe the relationships between the main participants of a situation. As an example consider the sentence *Peter finished the discussion.*, semantic representation of which is given in Figure 3.

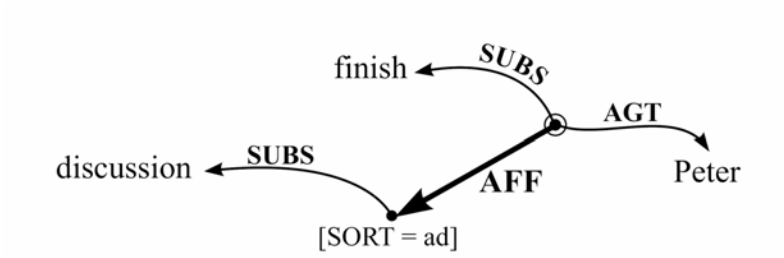


Figure 2. Semantic representation of the sentence Peter finished the discussion in MultiNet after Helbig [8, p. 447]. Semantic frame of the verb finish requires two C-roles: AGT (agent) and AFF (affected). The relation SUBS indicates that the situational concepts finish and discussion are subordinate to their relevant generic concepts.

In Figure 3, semantic frame of the concept Finish realized in the form of the verb *finish* requires two C-roles: An agent represented by the relation AGT, and an affected entity represented by the relation AFF. Here agent is *Peter* and the affected entity is an abstract object ([SORT = ad] means the concept is a dynamic abstraction). The following hierarchy in MultiNet ontology leads to the sort [ad]:

Entities [ent] > objects [o] > abstract objects [ab] > abstractions from situations [abs] > dynamic abstraction [ad].

The relation SUBS indicates that our concept in this particular situation is subordinated to its relevant generic concept.

Now the basic concepts of MST and MultiNet framework have been introduced and we are ready to see if MultiNet is capable of formally representing or simulating basic mechanisms of mental spaces.

## 4. Mental Spaces and Their Computer Modelling

As mentioned previously, MultiNet is a knowledge representation framework for representing semantic content of natural language expressions. It is not a framework for implementing MST. This section will discuss the MultiNet's potentiality in capturing and representing MST's basic principles in the construction of domains, their truth, and reality status of their elements.

### 4.1. Method

In the process of building mental spaces, some natural language expressions (space builders) play the primary role in setting up spaces. In order to make a systematic analysis for the purpose of this paper, space builders (taken from English expressions) were classified into three classes considering theirs grammatical form [6]: Prepositional phrase space builders (PPSB) like *in that story…*, subject-verb space builders (SVSB) like *he believes…*, and conditional space builders (CNSB) like *if it rains….*

In MultiNet, the representational means corresponding to space builders – which were formally classified into three categories – were searched for in MultiNet relations based on definitions provided for them [8]. After a careful comparison, the three categorized space builders were found to be best comparable with MultiNet relations presented in Table 1. To test this resemblance, some simple English sentences containing space builders of the classified three types were constructed and their MST and MultiNet representations were compared.

Table 1**.** Mental spaces builders and their corresponding relations in MultiNet.

| **Mental space builders** | **MultiNet relations** |
|---|---|
| PPSB | CTXT<br>(Restricting context) |
| SVSB[3] | MCONT<br>(Mental content) |
| CNSB | COND<br>(Conditional relation) |

### 4.2. Types of Space Builders

In this part, the aforementioned three types of space builders will be elaborated with an example.

#### *4.2.1. Prepositional Phrase Space Builders*

Prepositional Phrase Space Builders' (PPSBs) main role is to explicitly restrict the description of a situation to a particular context. As a simple example, consider the sentence in (2):

(2) In the film, John is riding a unicorn.

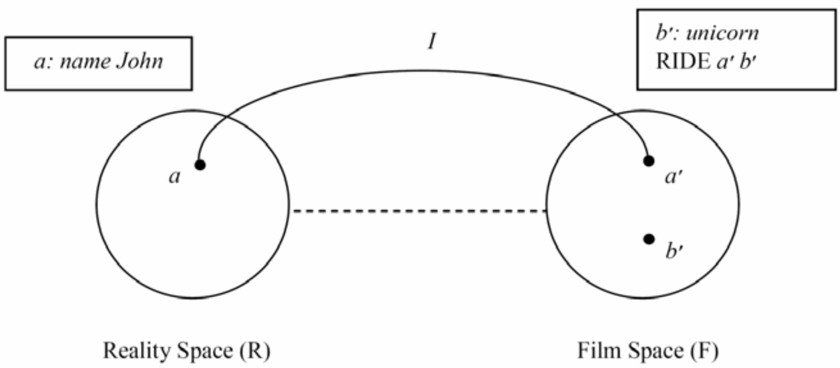


Figure 4. The mental spaces set up by the first interpretation of the sentence in the film, John is riding a unicorn.

In the sentence (2), the prepositional phrase *in the film* is a space builder; it constructs a fictional space relative to the *reality space.* Here, sentence (2) can be interpreted in two different ways:

- *First interpretation:* The reality space (let's call it R) contains an element *a* associated with the proper name *John.* The noun phrase *a unicorn* introduces an element *b′* to the film space (call it F). *I* is the connector linking *a* in the space B to *a′* in the space F (Figure 4). Since the elements of both mental spaces are co-referential, this connector is an *identity connector.* The rectangles represent the internal structure of the spaces next to them. The dashed line indicates that the space F is set up in relation to R and that it is subordinate to R in discourse.

[3] Scope of the SVSBs (subject-verb complexes) in this study is limited to verbs characterizing mental processes.

- *Second interpretation:* The proper name *John* exists only in film space without having a counterpart in base space. Therefore, the second interpretation of the sentence is: John is a film character who is riding a unicorn in the film (Figure 5).

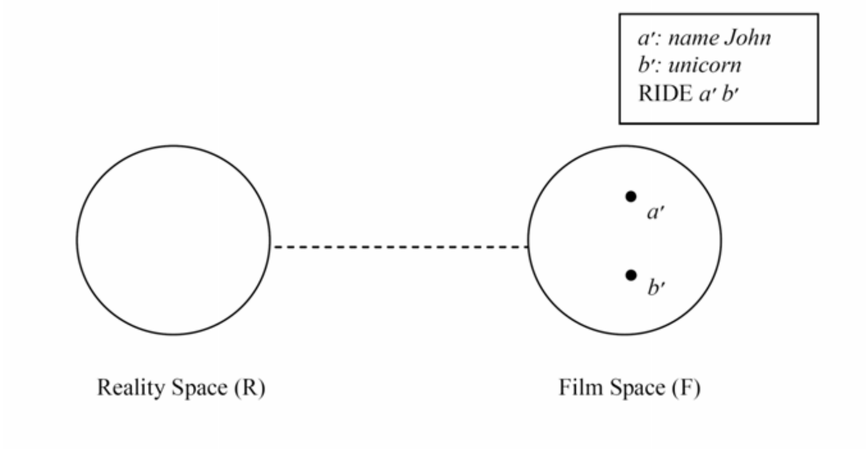


Figure 5. The mental spaces set up by the second interpretation of the sentence in the film, John is riding a unicorn.

### *4.2.2. Subject-Verb Space Builders*

Subject-Verb Space Builders (SVSBs) are the second type of our classified space builders. The verbal position of SVSBs can be filled with a variety of verbs among which are mental or psychological verbs such as *think, believe, suspect,* etc. representing mental attitudes. For example, consider the sentence in (3):

(3) Mary thinks that John smokes.

The proper nouns *Mary* and *John* setup a base space (B). By the help of background knowledge and activated frames we know that they are names of female and male humans. Not having access to the previous discourse, we also consider their existence presupposed. The SVSB *Mary thinks that* sets up a belief space (L) relative to space B (Figure 6). The identity connector maintains the referential link between elements *a* and *a′* both referring to the same person.

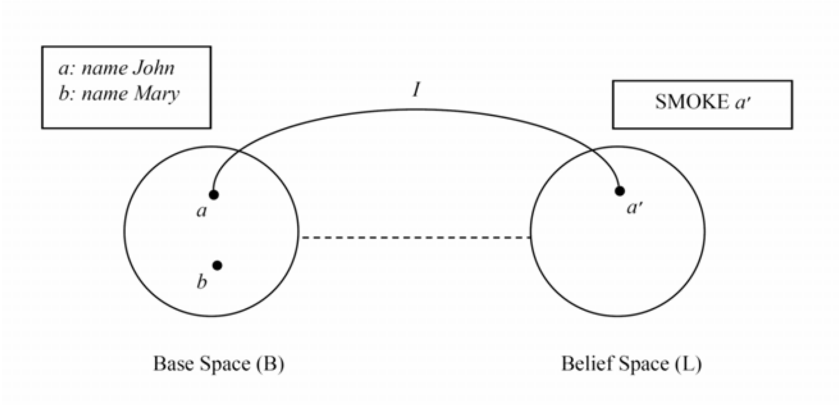


Figure 6. The mental spaces set up by the sentence Mary thinks that John smokes.

### 4.2.3. Conditional Space Builders

The third type of space builders, according to our classification, are those involving Conditional Space Builders (CNSBs) like *if it rains…, if something goes wrong…. if* element sets up a hypothetical space in which the situation described may or may not come true. Consider the example in (4):

(4) If John buys the car, he will drive to Berlin.

In the sentence (4) there are three proper names which constitute elements of the base space or reality space (R). The CNSB *if* sets up the hypothetical space (H) with elements identical to those of reality space (Figure 7). Every space's internal structure is presented in the boxes next to them.

In the next part, we will see how MultiNet's built-in meaning representation mechanisms are capable of representing the basic principles of mental space building outlined above.

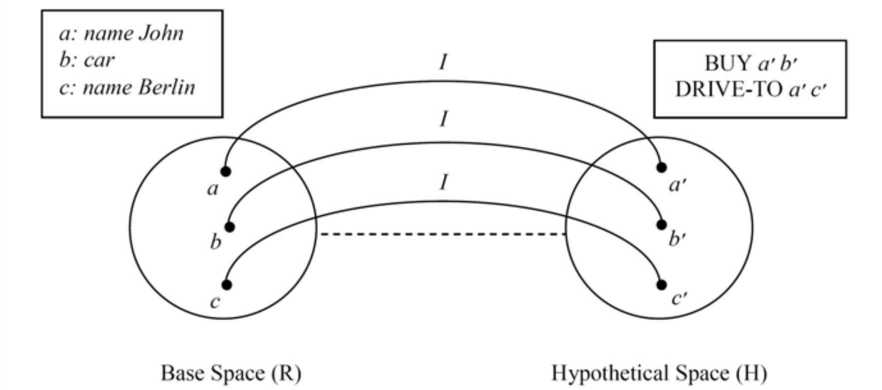


Figure 7. The mental spaces set up by the sentence If John buys the car, he will drive to Berlin.

### 4.3. Analysis of MultiNet Representation

This part will present MultiNet representations of different mental spaces discussed previously. MultiNet has a graphical representation environment called MWR (abbreviated from the German "MultiNet Wissens Repräsentation" which is translated into English as MultiNet Knowledge Representation) which has a powerful and user-friendly facilities for making networks out of concept nodes and relational dependencies.

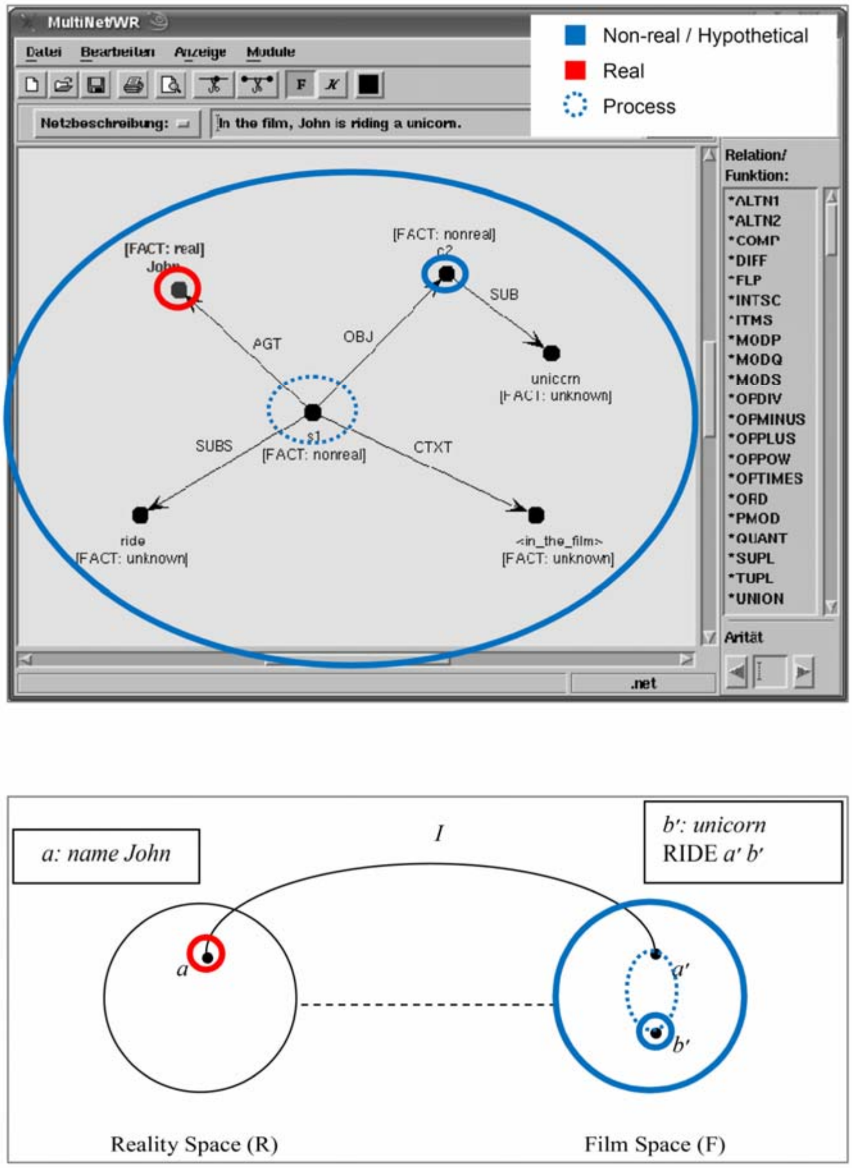


Figure 8. Comparison of MultiNet and MST representations.
Top: Representing first interpretation of the sentence in the film, John is riding a unicorn in MultiNet. Bottom: Corresponding mental space representation (color markings added for illustration).

#### *4.3.1. CTXT: Restricting Context*

According to Helbig [8, p. 40], “[The] relation [CTXT] restricts the whole conceptual capsule and its content to ‘a certain world’ (world view) or a certain context.” Here the phrase ‘a certain world’ can be interpreted as equivalent to a new space in MST which is set up relevant to its base space. For clarification, consider the sentence in (2) given below as (5):

(5) In the film, John is riding a unicorn.

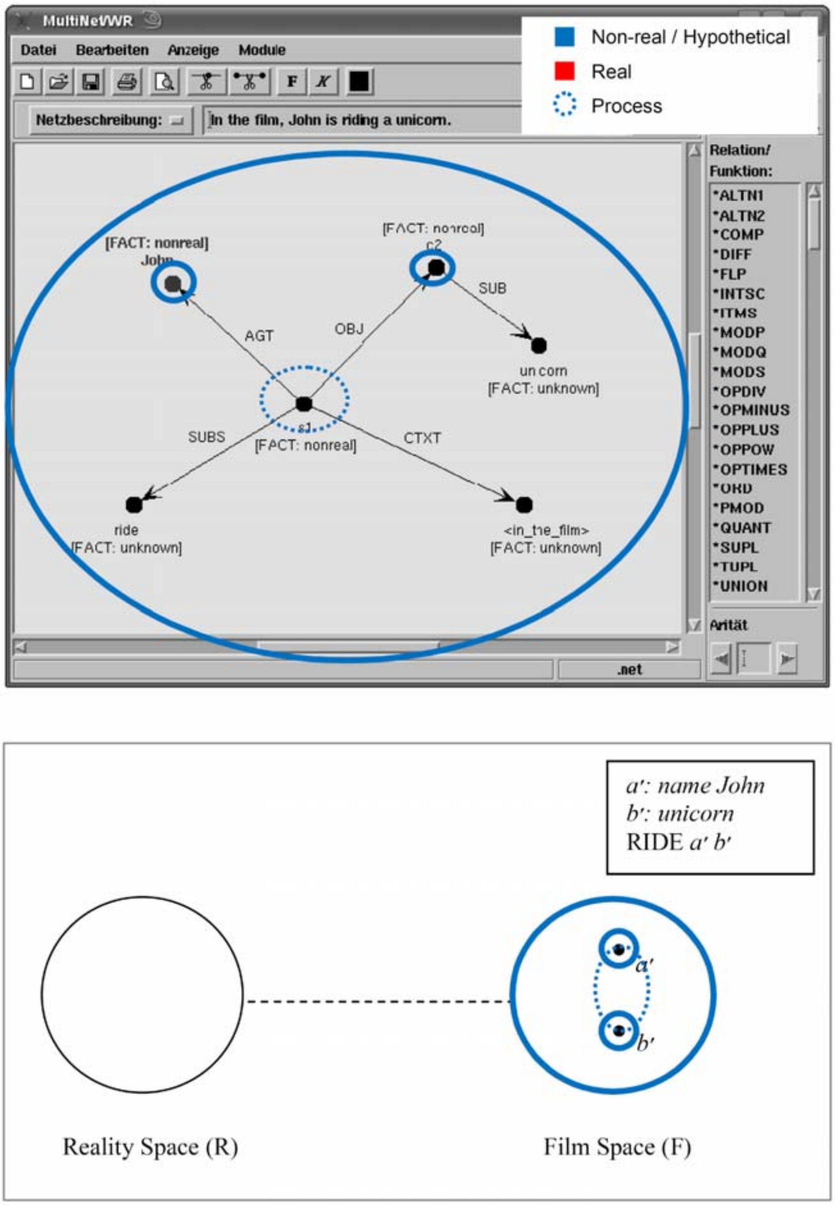


Figure 9. Comparison of MultiNet and MST representations.
Top: Representing first interpretation of the sentence in the film, John is riding a unicorn in MultiNet. Bottom: Corresponding mental space representation (color markings added for illustration).

We saw that the sentence (5) had two interpretations. Their corresponding MultiNet representations should also reflect these two readings.

According to the above definition, the PPSB *in the film* can roughly be taken as equivalent to CTXT relation in MultiNet. The relation CTXT restricts the situation to the film space in which the elements *unicorn* and *John* have different reality status. *Unicorn* is a fictional animal, so it is characterized by the attribute-value [FACT = *nonreal*]. The first interpretation of the sentence in mental spaces, characterized *John* as an element of reality space. In MultiNet this can be achieved by specifying the attribute-value [FACT = *real*] for the concept John. Facticity attribute-value of the attsituation $sv_1$ is also characterized as [FACT = *nonreal*]. So the first reading of the sentence (5) is represented in MultiNet with John having [FACT = *real*] attribute-value (belonging to reality space) and other entities having [FACT = *nonreal*] attribute-value. Figure 8 shows the representation of the first reading of the sentence (5) in MWR. The MultiNet is shown at top of the figure, and the corresponding mental space representation is shown at the bottom side. Blue circles mark hypothetical or nonreal objects and situations and red circles mark real objects and situations. Facticity value for John is *real,* for unicorn it is *nonreal,* and for the process of *riding,* marked with blue broken circle*,* it is non-real as well.

Second interpretation of the sentence (5) can be represented with changing John's Facticity attribute-value from [FACT = *real*] to [FACT = *nonreal*] making the whole situation and its elements non-real (Figure 9).

#### *4.3.2. MCONT: Mental Content*

Helbig [18, p. 507] defines the expression (s MCONT c) as "a specification of the informational or mental content c of a mental or informational process s… By default, the second argument c is assumed to be a hypothetical object or situation."

MCONT relation properties are roughly equivalent to those of subject-verb complexes (SVSBs) of MST. MCONT relation can generally be treated as capturing the idea behind what philosophers call *propositional attitudes* in representational theories of mind [12] or opaque contexts [10] in semantics. For example, consider the sentence in (3) rewritten below as (6) and semantic representation of which is given in Figure 10:

(6) Mary thinks that John smokes.

$Sv_1$ describes a situation in which we have the concept represented by the verb *think* that requires a "mental experiencer" (MEXP). In the frame of the verb *think* there is also another argument specifying the content of thinking process (MCONT) which according to definition is hypothetical ([FACT = *hypo*]) by default. $Sv_2$ centers around the concept smoke which is realized by the verb *smoke* and requires one agent (AGT) argument. Here we suppose that the verb *smoke* is intransitive so the concept smoke needs just one argument. In $sv_2$ the Facticity of the concept John is set to [*real*] implying that *john* exists in reality (base) space and it is just the whole situation $sv_2$ that is hypothetical.

In representing the sentence *Mary thinks that John smokes,* Mary and John (marked with red circles) and also the process of thinking (marked with red broken circle) are elements of reality space, and process of smoking (marked with blue broken circle) belongs to Mary's belief space.

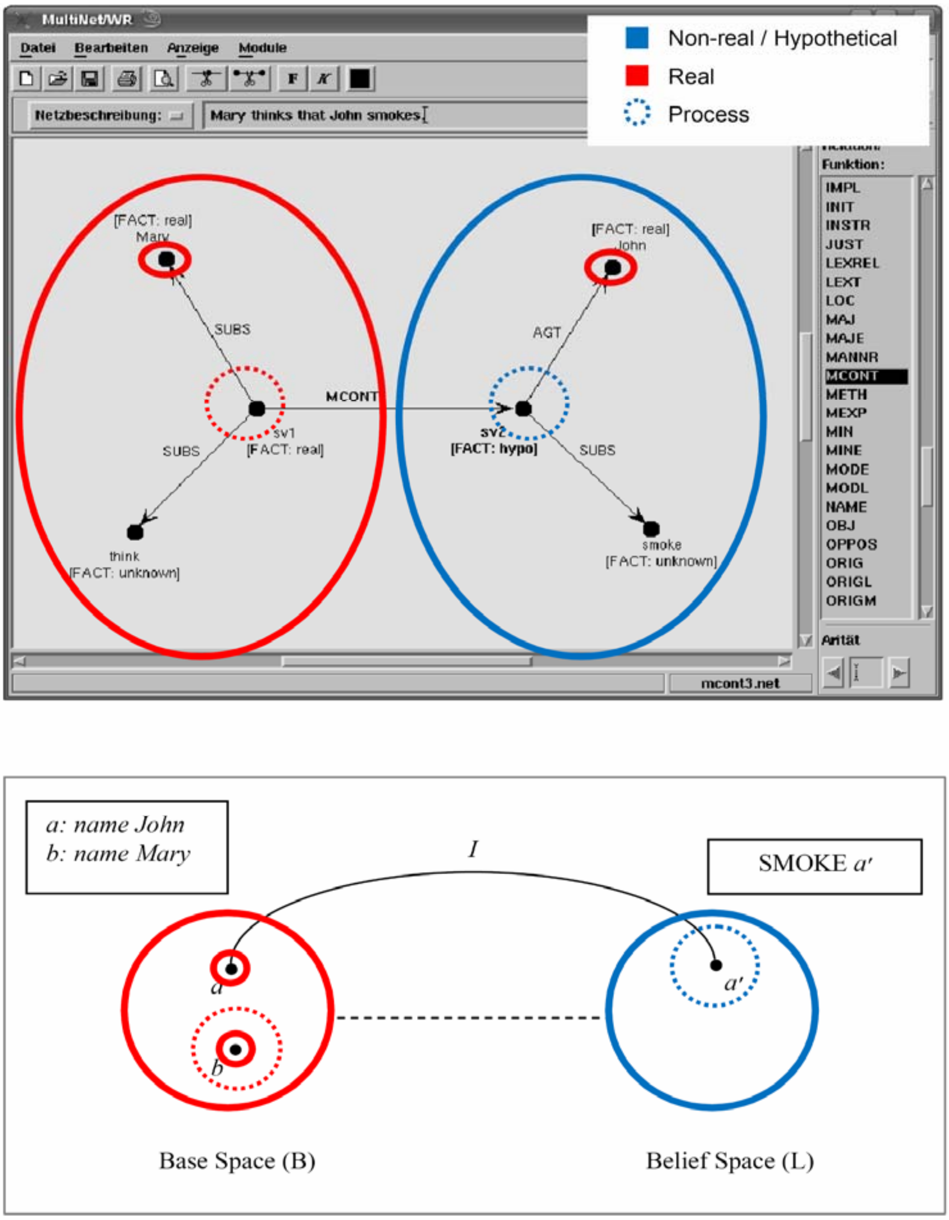


Figure 10. Comparison of MultiNet and MST representations.
Top: Semantic representation of the sentence Mary thinks that John smokes in MWR. Bottom: Corresponding mental space representation (color markings added for illustration).

#### 4.3.3. COND: Conditional Relation

If situation sv1 is said to be a sufficient condition for the situation sv2, the relation COND can be established between the two situations: sv1 COND sv2. This means that sv1 is a trigger for sv2 while both situations are hypothetical (FACT = hypo). In MST's terms we can say both of the situations are set up in a hypothetical space. Consider example (4) given below for convenience as (7):

(7) If John buys the car, he will drive to Berlin.

In the sentence (7) there are two clauses describing two hypothetical situations. These two situations are connected by the relation COND in MultiNet representation (Figure 11).

In the mental spaces constructed by the sentence (7), we saw that the nominals *John, the car, Berlin* all were set up in the base space which are marked with red circles. Similarly in MultiNet's representation these objects' Facticity value is set to *real*: [FACT = *real*]. This means if we take the reality space as our base space, entities having the attribute-value [FACT = *real*] are elements of base space. On the other side, entities or situations having the attribute-value [FACT = *hypo*] belong to the hypothetical space: $sv_1$ and $sv_2$ in our example are hypothetical situations marked with blue broken circles to indicate hypothetical quality of their representative processes.

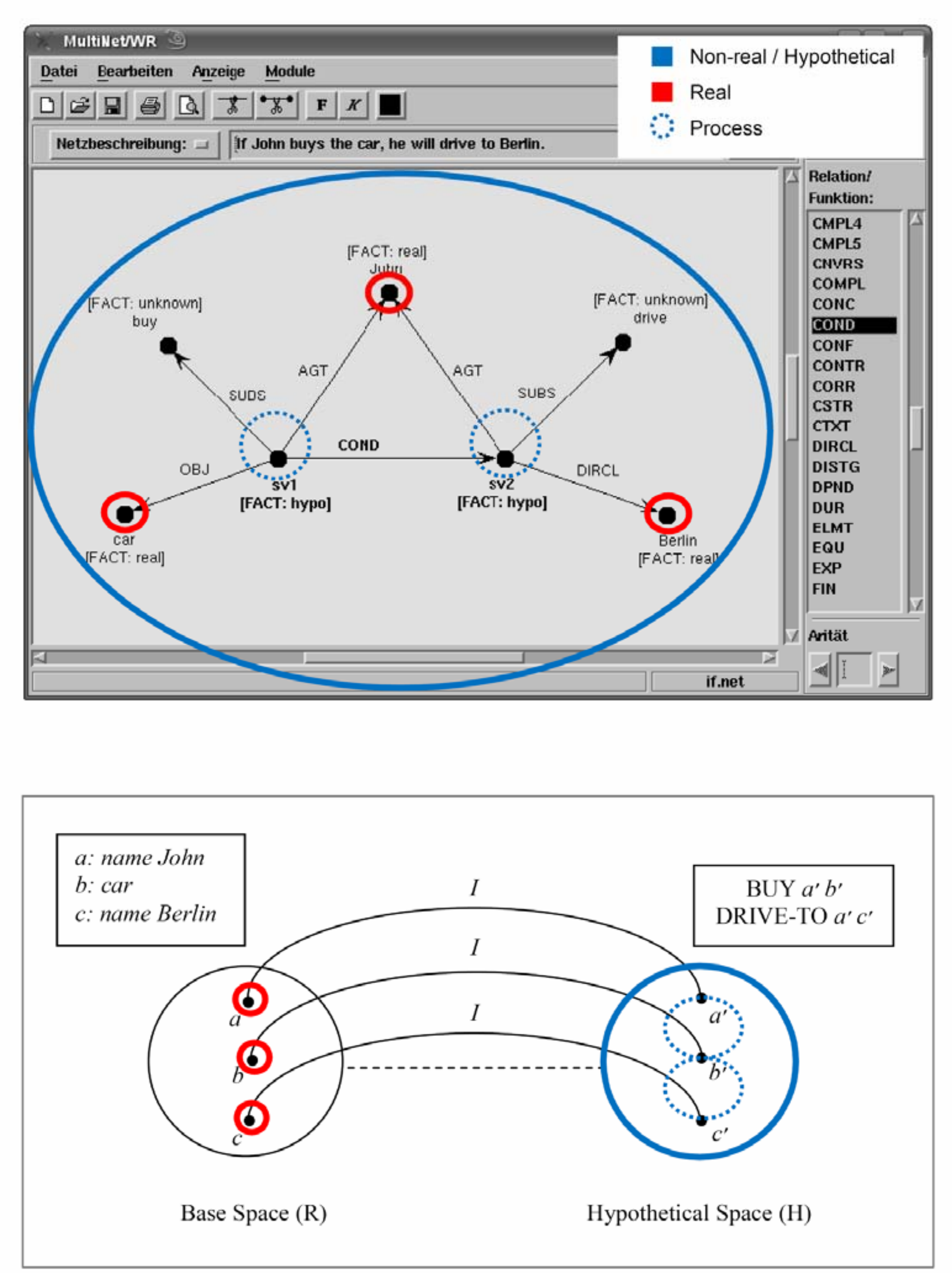


Figure 11. Comparison of MultiNet and MST representations.
Top: Semantic representation of the sentence if John buys the car, he will drive to Berlin in MWR. Bottom: Corresponding mental space representation (color markings added for illustration).

## 5. Concluding Remarks

Mental Spaces is a theory about human knowledge representation and processing. It has proved to be successful in accounting for some cognitive phenomena such as constructing conceptual domains, an entity's variable reality status, and mental attitudes. These phenomena pose serious problems in building automatic knowledge processing and reasoning systems.

In this paper, I tried to establish a connection between meaning representation mechanisms of mental spaces and those of MultiNet, a knowledge representation framework. In building mental spaces, some linguistic expressions, called space builders, act as a trigger to construct mental domains. Some major space builders were formally categorized into three classes: prepositional phrase space builders (PPSBs), subject-verb complexes space builders (SVSBs), and conditional space builders (CNSBs). The correspondence between MST space builders and MultiNet relations can be stated as following points:

In building mental spaces, some linguistic expressions, called space builders, act as a trigger to construct mental domains. Some major space builders were formally categorized into three classes: prepositional phrase space builders (PPSBs), subject-verb complexes space builders (SVSBs), and conditional space builders (CNSBs). The correspondence between MST space builders and MultiNet relations can be stated as following points:

1. PPSBs in MST have their counterpart as CTXT relation in MultiNet. CTXT relation restricts the validity of a situation to a specific context or world.
2. SVSBs (of the type mental processes) in MST have their counterpart as MCONT relation in MultiNet. MCONT's second argument is hypothetical by default implying the situation described by the second argument is constructed in a hypothetical space.
3. CNSBs in MST have their counterpart as COND relation in MultiNet. Both arguments of COND relation are hypothetical by default. Thus the hypothetical situations are set up in a hypothetical space.

Reminding the paper's objectives, this study aimed to investigate formalization of MST's representational concepts such as domain construction, reality status of domains and containing elements, and mental attitudes in a knowledge representation framework. To this end, MultiNet framework provides us with the representational means summarized in table 2.

Table 2**.** MST concepts and corresponding MultiNet representational mechanisms.

| | | **MultiNet** | |
|---|---|---|---|
| | | Relations | Attributes |
| **MST** | Domain construction | CTXT, MCONT, COND | FACT |
| | Reality status of domains and elements | --------- | FACT |
| | Mental attitudes | MCONT | --------- |

Scope of this study was limited to basic constructions and principles. There are still many semantic phenomena not mentioned here, but studied and handled in the MST framework: presuppositions, tense and mood, counterfactuals, etc., are just some of these. This study can be further extended to include the untouched domains.

**6. Acknowlwdgment**

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