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A Membrane Systems Explanation of Semantic Change*

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Abstract

An application of membrane systems to natural languages study is presented. Specifically, we show how *semantic change* can be explained by using a new variant of membrane systems: Dynamic Meaning Membrane Systems (DMMS). By using DMMS, we explain the three basic types of changes in meaning -this is, *broadening*, *narrowing* and *shift*. Finally, we relate the membrane systems' application to language evolution with the suggested application of the so-called *cultural grammar systems* to the same topic. Collaboration between the two frameworks may provide a useful formalism that, due to its naturalness and simplicity, might offer interesting results in a discipline traditionally far away from any formalization.

1 Introduction

An application of membrane systems to natural languages study is presented. Specifically, in this paper, we show how *semantic change* can be explained by using a new variant of membrane systems. An initial application of membrane systems to linguistics was introduced in [2]. The most important intuition for translating this natural computing model to natural languages is that membranes can be understood as *contexts*. Contexts may be different words, persons, social groups, historical periods, languages. They can accept, reject, or produce changes in elements they have inside.

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At the same time, contexts/membranes and their rules evolve, that is, change, appear, vanish, etc. All these features make of membrane systems an attractive model to deal with natural language.

If there is something obvious is that languages change. Languages are continuously in flux. Changes in languages will occur in all realms of linguistic organization: the pronunciation, the sound system, the morphology, the lexicon, the semantics, the syntax. A language can change so much as to become a different language or evolve into several different languages. Related languages, which belong to the same group or family, were once the same language. This is, they are derived, due to the operation of 'linguistic change' over long periods of time, from a single, earlier ancestor language. Taking into account that every dimension of language evolves, it is necessary to study language change at different levels. In this paper we will concentrate only on *semantic change*. It has been said that semantics is most easily and radically affected by change than phonology, morphology and syntax. Paradoxically, even though being the dimension of language that changes most easily, semantic evolution is the area of historical linguistics that is least well understood. However, in the literature of diachronic linguistics, taxonomies of semantic change can be found as well as generalities about the mechanics of meaning evolution. For a general introduction to historical linguistics, see [11, 6, 15, 14, 8, 17, 1].

In this paper we will try to approach semantic change in a completely new way. We will provide a *membrane system model* to explain semantic change and we will suggest the possibility of combining this framework with an already defined variant of eco-grammar systems, the so-called *cultural grammar systems* ([9], [10]). Collaboration between the two frameworks may provide a useful formalism that, due to its naturalness and simplicity, might offer interesting results in a discipline traditionally far away from any formalization.

In what follows, we first introduce Linguistic Membrane Systems (LMS) as a general framework that can be used to model in terms of membrane systems different linguistic issues. By modifying some definitions of LMS we obtain Dynamic Meaning Membrane Systems (DMMS), a dynamic model for semantics that can be used in the explanation of semantic change in natural language. By using DMMS, we explain the three basic types of changes in meaning -this is, *broadening, narrowing and shift.* We conclude the paper by briefly relating the membrane systems' application to language evolution with the suggested application of the so-called *cultural grammar systems* to the same topic (cf. [9, 10]).

2 Linguistic Membrane Systems

As generative devices for formal languages, membrane systems do not take into account the problem of meaning in their output. In the initial formalization, membranes are aseptic contexts, this is, contexts which do not have anything to do with the derivation carried out in the system. However, in linguistics contexts matter. Therefore, if membrane systems have to be applied to linguistics, the first required adaptation is to make them able to deal with meaning. Thus, we need to introduce several new notions in order to define Linguistic Membrane Systems (LMS). One of the first notions we need is the notion of the *domain* of a membrane. The domain is to be understood as the set of words, statements, ideas and elements a membrane is able to work with in a given state of the computation. The domain is an active context. During computation a membrane receives some elements which are accepted by its domain and some which are not. We have to explain what to do with elements that are not part of the configuration of the membrane. Another interesting feature is the fact of working with several alphabets, this can be used as a tool for explaining adaptation of a linguistic element from a context to another one. In what follows we will define one by one all those useful concepts for the application of membrane systems to linguistics:

- **Alphabets**: A LMS has one or more *alphabets*, which can change or evolve during the computation. Each alphabet evolves independently.
- **Domains**: The *domain* D of a membrane is the definition of the symbols it accepts. Domains are related to one or more alphabets (for example, the domain DM_n can be the union of two alphabets, $V_m \cup V_j$). The domain of the skin membrane[1] is the union of the domains of its internal membranes. Several membranes of the same system can have the same domain.
- **Adaptation of elements which are not in the domain**:
  - *Function of transposition.* The function h, called function of *transposition*, establishes a correspondence between symbols placed in different membranes. For instance, the function $h(M_n \leftrightarrow M_m)$ establishes the correspondence between symbols belonging to the membrane M_n and symbols belonging to the membrane M_m. The rules of this function have the following form: $h(M_n \leftrightarrow M_m) = \{a_{in_{M_n}} \leftrightarrow \alpha_{in_{M_m}}, \ldots, b_{in_{M_n}} \leftrightarrow \beta_{in_{M_m}}\}$. They are called *rules of transposition.* Sometimes, transposition rules have the symbol "$\rightarrow$" instead of "$\leftrightarrow$". They are *non-returning transposition rules.*
  - *Non-adapted symbols.* The subscript $_i$ attached to an element in a membrane means that this element is not accepted by the domain of the membrane which it belongs to. If a is not included in the domain of M_m and the rule $h(M_n \leftrightarrow M_m) = a_{in_{M_n}} \leftrightarrow \alpha_{in_{M_m}}$ does not exist, then $a_{in_{M_m}} = a_i$. Elements marked with $_i$ are not taken into account as output of the membrane system when computation stops.

One of the most interesting points of the theoretical formalization of membrane systems is the concept of *evolution*: the system evolves. Notice that this is a very important feature in order to fulfill our goal because natural languages –as membrane systems– are constantly evolving. However, we need to construct systems able to change in any configuration and this is the case of LMS where not only membranes evolve, but alphabets, domains and rules evolve as well, as shown in what follows:

[1]In a membrane structure –understood as a hierarchical arrangement of membranes– the *skin membrane* is the one that separates the system from its environment.

- Evolution of *alphabets:*

  1. Addition of some symbols: for example, for $V_1 = \{1, 2, 3\}$, the rule $ADD\ \{4\}\ TO\ V_1$ increases the alphabet so as $V_1 = \{1, 2, 3, 4\}$.
  2. Deletion of some symbols: for example, for $V_1 = \{1, 2, 3\}$, the rule $DEL\ \{3\}\ FROM\ V_1$ decreases the alphabet so as $V_1 = \{1, 2\}$.

- Processes for the evolution of *domains*, which are called *variable domains*:

  1. Addition of new symbols to the alphabets belonging to the domain. For example, for $V_1 = \{1, 2, 3\}$ and $D_{M_n} = V_1$, the rule $ADD\ \{4\}\ TO\ V_1$ increases the domain.
  2. Deletion of some symbols from the alphabets belonging to the domain. For example, for $V_1 = \{1, 2, 3\}$ and $D_{M_n} = V_1$, the rule $DEL\ \{3\}\ FROM\ V_1$ decreases the domain.
  3. Addition of new alphabets to the domain. For example, for $V_1 = \{1, 2, 3\}$, $V_2 = \{a, b, c\}$ and $D_{M_n} = V_1$, the rule $ADD\ V_2\ TO\ D_{M_n}$ has as a result $D_{M_n} = V_1 \cup V_2$.
  4. Deletion of some alphabets from the domain. $DEL\ V_1\ FROM\ D_{M_n}$, applied to $D_{M_n} = V_1 \cup V_2$, has as a result $D_{M_n} = V_2$.

3 Dynamic Meaning Membrane Systems

3.1 Some Semantic Definitions

Croft points out in [5] that it is possible to give two different definitions of meaning, based on "*the distinction between a language as a population of utterances produced by a speech community, and a grammar as an individual speakers knowledge about the conventions of the speech community*". Such definitions are the following:

- The **community's meaning** of a linguistic form -a lingueme- is the lineage of replication of its use, in their full encyclopedic, contextual value.

- The **individual's meaning** of a lingueme is a mental structure that emerges from the individual's exposure to (necessarily partial) lineages of the community's meaning, including of course the use of the lingueme by that same individual.

In order to adapt semantic definitions to Dynamic Meaning Membrane Systems (DMMS) we take the notion of lingueme referred to in the above definitions. *Lingueme* is a linguistic unit, an utterance. No matter if it is a word, a sentence or a discourse. A lingueme, in the first state, has no meaning. From the concept of lingueme we infer another concept, *semanteme*, which is a semantic unit. The process of meaning assignment is given by the application of a semanteme to a lingueme. Such application is called *convention*.

Since linguemes and semantemes will be two notions that we will use in the definition of DMMS, we have to define the following two alphabets:

- $V = \{a, .., z\}$, the set of linguemes.
- $\Sigma = \{\alpha, .., \omega\}$, the set of semantemes.

And finally, we formally define the concepts of *individual meaning* and *community's meaning* as follows:

- The *individual's meaning*, I, of an utterance is an application of the function $F(\Sigma \to V)$, this is the application of a semanteme to a lingueme. The individual's meaning of a lingueme a in membrane M_m, $I(a)M_m$ is given by the function $F(\Sigma \overset{a}{\to} V)M_m$.
- The *community's meaning*, K, of an utterance is the composition of individual meanings in each step of the computation of a system. In each step, community's meaning of an utterance a is $K(a) = \bigcup_{i+1}^{m} I(a)M_i$.

3.2 Defining DMMS

Definitions of membrane systems can be found in [12] and [13]. We will modify now some definitions of LMS –introduced in section 2– in order to obtain a DMMS:

Statement 1 *In DMMS every membrane is an output membrane, except the skin membrane.*

Statement 2 Semantic domain $\mathcal{D}$ *of a membrane* M_1 *is a set over* Σ *associated to the membrane in every state of the computation. It is the set of semantemes this membrane accepts.*

Statement 3 Linguistic domain $\mathcal{E}$ *of a membrane* M_1 *is a set over* V *associated to the membrane in every state of the computation. It is the set of linguemes this membrane accepts.*

Statement 4 *A* membrane M_n, *in a DMMS, is defined in each state by means of two items: a) its semantic domain,* $\mathcal{D}$, *and b) its linguistic domain,* $\mathcal{E}$. *Thus,* $M_n = (\mathcal{D}M_n, \mathcal{E}M_n)$.

Statement 5 *The function h applied to a membrane* M_n *establishes a correspondence between elements of* $\mathcal{E}$ *and* $\mathcal{D}$ *associated to this membrane. For instance, the function* $h(\mathcal{D}M_n \to \mathcal{E}M_n)$ *establishes the correspondence between semantemes and linguemes belonging to the membrane* M_n. *The rules of this function, called transposition rules, have the following form:* $hM_n(\mathcal{D} \to \mathcal{E}) = \{\alpha \to a, \ldots, \pi \to m\}$. *Non-injective functions are allowed.*

Statement 6 *The subscript* $_i$ *attached to an element in a membrane* M_n *means that there is not a transposition rule for this element in* $h(M_n)$. *When computation finishes, every lingueme will be converted in the corresponding semanteme, following transposition rules. Elements marked with* $_i$ *are not taken into account as output of the membrane system when computation stops, this is, they disappear.*

Statement 7 *For a given skin membrane* M_s*,* $\mathcal{D}M_s$ *is* $\bigcup(\mathcal{D}M_a, .., \mathcal{D}M_n)$ $\forall\ M_a, .., M_n \in \mu$

Domains associated to each membrane can evolve. If they do it, they are called *variable domains.* The processes for changing domains are the following four:

1. *New semantemes are added to the domain.*
   For example, for $\mathcal{D}M_n = \{\alpha, \beta\}$, the rule $ADD\ \{\gamma\}\ TO\ \mathcal{D}M_n$ increases the domain, being $\mathcal{D}M_n = \{\alpha, \beta, \gamma\}$.

2. *Some semantemes are deleted from the domain.*
   For example, for $\mathcal{D}M_n = \{\alpha, \beta, \gamma\}$, the rule $DEL\ \{\beta\}\ FROM\ \mathcal{D}M_n$ decreases the domain, being $\mathcal{D}M_n = \{\alpha, \gamma\}$. When a semanteme is deleted for a domain, any rule containing it disappears.

3. *New linguemes are added to the domain.*
   For example, for $\mathcal{E}M_n = \{a, b\}$, the rule $ADD\ \{c\}\ TO\ \mathcal{E}M_n$ increases the domain, being $\mathcal{E}M_n = \{a, b, c\}$.

4. *Some linguemes are deleted from the domain.*
   For example, for $\mathcal{E}M_n = \{a, b, c\}$, the rule $DEL\ \{b\}\ FROM\ \mathcal{E}M_n$ decreases the domain, being $\mathcal{E}M_n = \{a, c\}$. When a lingueme is deleted for a domain, any rule containing it disappears.

Now, starting by the configuration given in Figure 1, we define some **rules with membranes:**

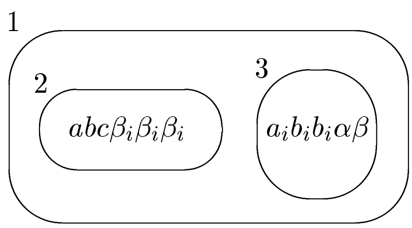

Figure 1: Basic Configuration.

1. **Deletion** is the operation by means of which a membrane M_n is dissolved and its elements go to the immediately external membrane. These elements will be accepted or rejected according to the definition of the new membrane. The rule for deleting membrane M_n is written as δM_n.

   Example 1 *Let* Π *be a membrane system with three membranes,* $[_1\ [_2\ ]_2\ [_3\ ]_3\ ]_1$*, where* $V_1 = \{a, b, c, d\}$*,* $V_2 = \{\alpha, \beta\}$*,* $\mathcal{D}M_2 = V_1$*,* $\mathcal{D}M_3 = V_2$*,* $\mathcal{D}M_1 = \mathcal{D}M_2 \cup \mathcal{D}M_3$*.*

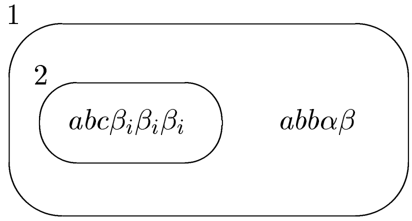

Figure 2: Deletion.

Assume that after some evolution steps the configuration reached is as shown in Figure 1. In this moment, the rule δM_3 is applied, with the result shown in Figure 2.

2. **Expansion** is the operation by means of which a membrane M_n can be expanded to other adjacent or external membranes using the rule ψM_n TO M_m, M_k. That means that membranes M_m and M_k are dissolved in M_n and their elements must be reformulated following the definition of M_n.

   Example 2 *By applying the rule ψM_3 TO M_2 to the system in the previous example, we obtain the situation in Figure 3.*

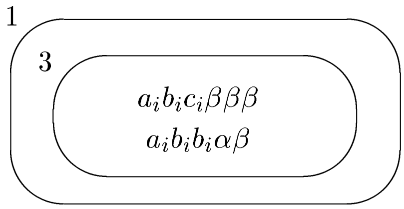

Figure 3: Expansion.

3. **Absorption** is the operation by means of which a membrane M_n disappears dissolved in another adjacent or external membrane M_m. Its elements must be reformulated according to the definition of M_m. The rule is ϕM_n IN $_m$.

   Example 3 *If we apply ϕM_3 IN M_2 to Π, the result is the system in Figure 4.*

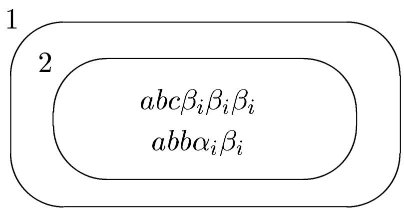

Figure 4: Absorption.

4. **Erasing** is the operation by means of which, given a membrane M_n, it can completely disappear with all its elements. The rule is χM_n.

   Example 4 *If we apply* χM_3 *to* Π*, the result is the system in Figure 5.*

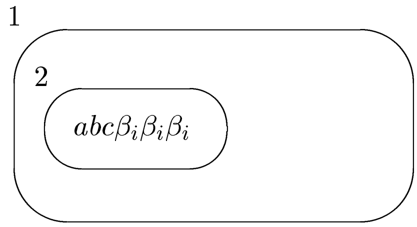

Figure 5: Erasing.

5. **Fusion** is the operation by means of which, given two membranes M_n, M_m, they joint creating M_z in such a way that $\mathcal{D}M_z = \mathcal{D}M_n \cup \mathcal{D}M_m$, $\mathcal{E}_z = \mathcal{E}_n \cup \mathcal{E}_m$. The rule is $M_m \nu M_n$.

   Example 5 *If we apply* $M_2 \nu M_3$ *to* Π*, the result is the system in Figure 6.*

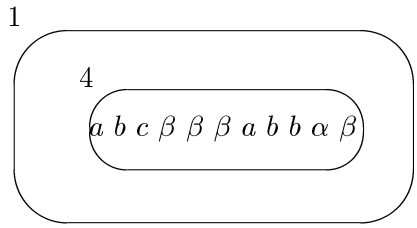

Figure 6: Fusion.

Above we have introduced rules that can be applied to membranes. Now, we refer to possible **relations among membranes**. Given two membranes M_1, M_2, we call the relation between them:

- **Nesting**, when one is inside the other. It is denoted by $M_1 \subset M_2$.
- **Sibling**, when they are adjacent or they are inside adjacent membranes and they have the same depth. It is denoted by $M_1 \approx M_2$.
- **Command**, they are not nested and they do not have the same depth. It is denoted by $M_1 \wedge M_2$.

Membranes in a system are related by what we call *communication channels*. This is, they can be communicated among them or not. There are three states of communication:

- **Connexion**: Two membranes are connected when the communication channel between them is open. It is denoted by $\odot$. A membrane is *connected* when it has the relation of connexion with every membrane in the system. A system is called *supra-connected* when every communication channel is open.
- **Isolation**: Two membranes are isolated when the communication channel between them is closed. It is denoted by $\oslash$. A membrane is *isolated* when the communication with every membrane in the system is closed. A system is called *supra-isolated* when every communication channel is closed.
- **Inhibition**: Two membranes are related by inhibition when the communication between them is closed and it cannot be opened. It is denoted by $\otimes$. A membrane is inhibited when every communication channel is closed to it, and it cannot be opened. A system is *supra-inhibited* when every membrane in it is inhibited. An inhibited system cannot work. It is not a system.

There are some properties of connexion which can be established depending on the relation between membranes:

- Two nested membranes are connected by definition.
- If a membrane is connected to a sibling membrane, then it is connected to any membrane nested to it.
- If a membrane is isolated with respect to a sibling membrane, then it is isolated from any membrane nested to it.
- If a membrane M_1 is connected to a membrane M_2, and M_2 is connected to M_3, then there is a way of communication between M_1 and M_3, even if $M_1 \oslash M_3$.

During the process of computation some specific rules can break the initial relation among membranes described above.

Example 6 *We have a membrane system with the following structure:*

$$\mu = [_S\ [_1\ [_2\ ]_2\ ]_1\ [_3\ ]_3[_4\ ]_4\ ]_S,$$

where:

- $M_2 \subset M_1$,
- $M_1 \oslash M_3$,
- $M_1 \odot M_4$,
- $M_3 \odot M_4$.

This system is represented as shown in Figure 7.

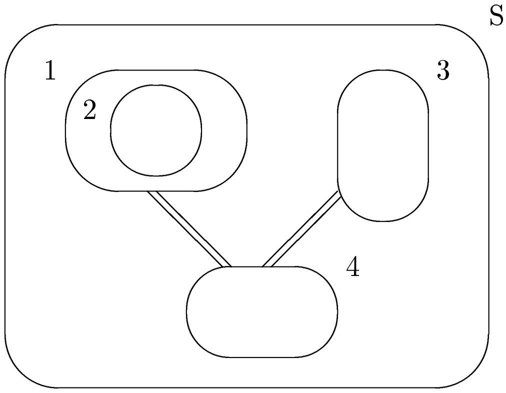

Figure 7: Example.

4 Explaining Semantic Change with DMMS

4.1 Generalities about Semantic Change

Language change can, and should, be studied at different levels. Even though no component of natural language is totally immune to change, they show a distinct level of susceptibility to change. In general, it has been said that semantics is most easily and radically affected by change than phonology, morphology and syntax, in that specific order. This is, it seems that there is less resistance to change in the semantics that in other areas of the grammar, so that meaning changes relatively quickly and easily.

According to [15], semantic change is so ubiquitous that hardly a word in the dictionary lacks earlier meanings more or less different from the present-day sense(s). However, semantic change seems to be the area of diachronic linguistics that is least well understood, perhaps because semantics has for a long time been the weak point in synchronic language study. In contrast with this, phonological change has been fairly intensively studied in the world's languages and grammatical change, even being less well studied than phonology, it is an area that is receiving a lot of attention from linguists at the present. Anyway, it is not difficult to find in the historical linguistics literature lots of observations about the kinds of semantic changes that take place in natural languages as well as about the aspects of language that allow semantic change to occur. It is precisely on these aspects in which we will concentrate on in this section. For more information about semantic change see [11, 6, 15, 1].

There seem to be different aspects of language in general, and meaning in particular, which allow semantic change to occur. Two of this aspects are the following (cfr. [11]):

1. *Polysemy*: words are typically polysemic each has various meanings or covers a whole range of shades of meaning. This flexibility is necessary since words are used in a wide variety of contexts by many different speakers, who may vary in the meaning they wish to convey. Words can lose or gain meanings

relatively easily due to this elasticity, and they do not have to lose an earlier sense to gain a new one.

2. *Arbitrariness of the linguistic sign*: they sign is bipartite, made up of a signifier and a signified. These two components are arbitrarily linked. Arbitrariness allows us to regard the signifier and the signified as essentially independent, either may therefore change with time.

Following [6], we can establish the following taxonomy of semantic evolution that considers three basic types of changes in meaning. Notice that the classification below refers to the evolution of meaning (signifier). However, according to the arbitrariness of the linguistic sign we have said that signifier and signified are independent and they may change also independently. Later we will briefly consider possible changes in the signifier, but now we are only interested on the following typology of semantic change, this is changes that affect the *signified* of a word:

- **Broadening, extension or generalization**. The term *broadening* is used to refer to a change in meaning that results in a word acquiring additional meanings to those that it originally had, while still retaining those original meanings as part of the new meaning. So, it refers to the increase of the number of contexts in which a word can be used, paradoxically reducing the amount of information conveyed about each one.

- **Narrowing, restriction or specialization**. Semantic narrowing is the exact opposite of the previous kind of change. We say that narrowing takes place when a word comes to refer to only part of the original meaning. The restriction of meaning paradoxically involves an increase in the information conveyed, since a restricted form is applicable to fewer situations, but tells more about each one.

- **Shift** occurs when a word completely loses its original meaning and acquires a new meaning. Words obviously do not jump randomly from one meaning to another when they undergo semantic shift. They may shift in smaller steps. But, as some original meanings are lost, the points of connection between intermediate semantic stages may also be lost.

The taxonomy we have just presented is the most general (and maybe useful) one about semantic change. In the literature, we can find different subtypes of each of the above three main categories of meaning changes. For example, subtypes of *generalization* are *metonymy*, *metaphorical extension* and *radiation*. A subtype of *narrowing* can be the so-called *contextual specialization*. And finally, subtypes of *shift* can be the phenomena referred to as *melioration*, *pejoration* and *semantic reversal*, etc. Since what we want to offer is a general formal framework for semantic change, we will concentrate in what follows just in the general taxonomy of meaning evolution, this is in the main three types of change: generalization, narrowing and shift.

4.2 Semantic Change from DMMS

Let us consider the above classification of semantic change and look at DMMS features introduced in section 3. Dynamic meaning membrane systems offer two powerful mechanisms that allow us to provide a membrane's explanation of the three above types of semantic change. These two mechanisms are what we have called *variable domains* and *transposition rules.*

The first type of semantic change we have referred to is the so-called **broadening, extension or generalization**. We have said that it consists on a change in meaning that results in a word acquiring additional meanings to those that it originally had, while still retaining those original meanings as part of the new meaning. This can be easily explained in DMMS by postulating the *addition of new semantemes* to the semantic domain of a membrane without adding any new lingueme. Notice that if we add new semantemes, they should be related, via $h(M_n)$, to existing linguemes. If it is the case that such linguemes, to which we associate the new semantemes, already exist in the membrane and they are already related to different semantemes, what we obtain is the extension of meaning. So, by postulating the addition of semantemes to a membrane domain we account for the gain of meaning of a word.

Formally, in DMMS, broadening is explained as follows: Given a semantic domain $\mathcal{D}M_n = \{\alpha, \beta\}$ and a linguistic domain $\mathcal{E}M_n = \{a, b\}$, apply $ADD\ \{\gamma\} TO\ \mathcal{D}M_n$. The result of this rule is the increasing of the semantic domain of M_n that changes to $\mathcal{D}M_n = \{\alpha, \beta, \gamma\}$. Now, if the linguistic domain $\mathcal{E}M_n$ does not suffer any modification, we will have to relate the added semanteme γ to an already existing lingueme, changing in this way transposition rules. The function $h(\mathcal{D}M_n \rightarrow \mathcal{E}M_n)$ establishes the correspondence between semantemes and linguemes belonging to the membrane M_n. If in the first state of computation $hM_n(\mathcal{D} \rightarrow \mathcal{E}) = \{\alpha \rightarrow a, \beta \rightarrow b\}$, now because of the application of $ADD\ \{\gamma\}\ TO\ \mathcal{D}M_n$, we should modify the function: $hM_n(\mathcal{D} \rightarrow \mathcal{E}) = \{\alpha \rightarrow a, \gamma \rightarrow a, \beta \rightarrow b\}$. See Figure 8.

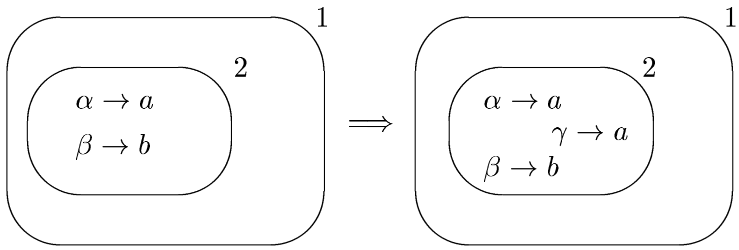

Figure 8: Broadening, Extension, Generalization.

From here, membranes easily explain examples in real life. Let us consider the following two examples:

1. The modern English *dog* derives from the earlier form *dogge*, which was originally a particularly powerful 'breed of dog' that originated in England. This in DMMS is explained as shown in Figure 9.

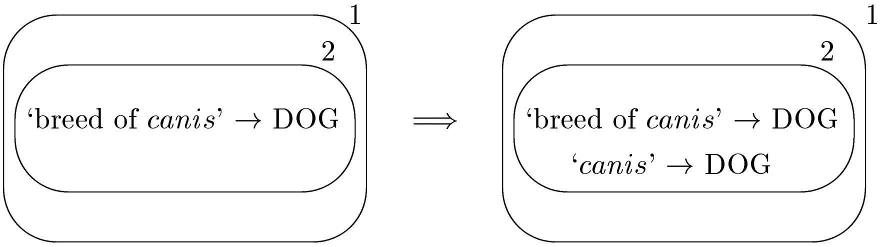

Figure 9: Example of Broadening: *dog.*

2. Let us consider the Latin word *muliere* whose meaning was 'woman'. The Spanish evolution of that Latin word –*mujer*– has acquired an additional meaning to the one that it originally had: *mujer* < *muliere* means both 'woman' and 'wife', thus we can say that an extension of meaning has taken place. This is easily explained by using the DMMS framework as shown in Figure 10.

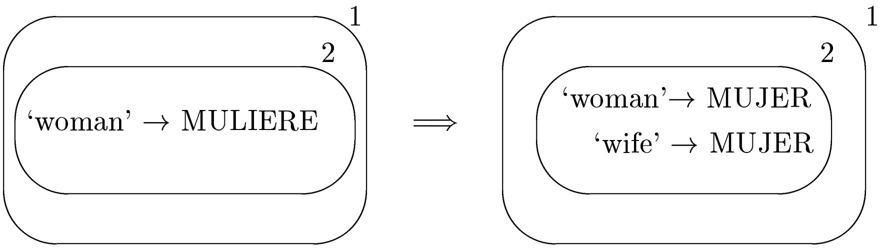

Figure 10: Example of Broadening: *muliere.*

Narrowing, restriction or specialization is the second type of semantic change we have identified in the taxonomy introduced in the above section. Semantic narrowing is the exact opposite of the previous kind of change. Here a word comes to refer to only part of its original meaning. In order to account for *restriction* of meaning in terms of DMMS, what we do is to *delete semantemes* from the domain of a membrane. Notice that using this process we can easily account for the loss of meaning of a word. If a lingueme is related to several semantemes and we delete one of those semantemes from the semantic domain of the membrane, we lose one meaning of this word. So, as it could not be otherwise, deletion of semantemes account for *restriction* of meaning.

Formally, in DMMS, narrowing is explained as follows: Given a semantic domain $\mathcal{D}M_n = \{\alpha, \beta, \gamma\}$ and a linguistic domain $\mathcal{E}M_n = \{a, b\}$, we apply the rule $DEL\ \{\gamma\}\ FROM\ \mathcal{D}M_n$. The result of this rule is the deletion of a semanteme from the semantic domain of M_n that changes to $\mathcal{D}M_n = \{\alpha, \beta\}$. When a semanteme is deleted from a domain, any rule containing it disappears. So, if in the first state of computation the function $hM_n(\mathcal{D} \to \mathcal{E}) = \{\alpha \to a, \gamma \to a, \beta \to b\}$, now because of the application of $DEL\ \{\gamma\}\ FROM\ \mathcal{D}M_n$, we should cancel the transposition rule that contained the deleted semanteme, changing in this way the function to $hM_n(\mathcal{D} \to \mathcal{E}) = \{\alpha \to a, \beta \to b\}$. See Figure 11.

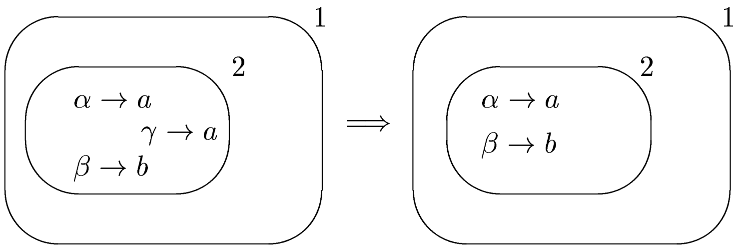

Figure 11: Narrowing, Restriction or Specialization.

This formalization helps to give account of some changes in the meaning of words like the following ones:

1. The word *hound* in English (originally pronounced *hund*) was the generic word for 'any kind of dog' at all. Over the centuries, however, the meaning of *hund* in English has become restricted to just those dogs which are used to chase game in the hunt, such as beagles. This restriction of meaning is formalized as shown in Figure 12.

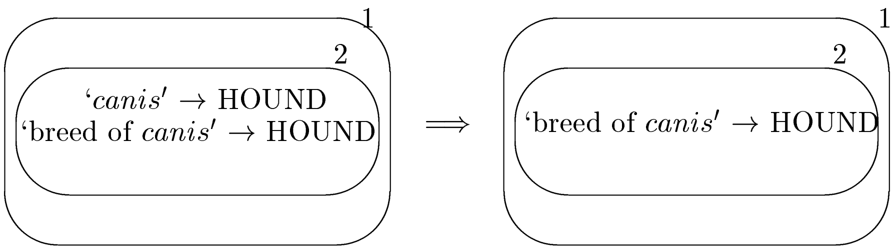

Figure 12: Example of Narrowing: *hound.*

2. The word *meat* originally referred to 'any kind of food' at all (and this original meaning is still reflected in the word *sweetmeats*) though now it only refers to food that derives from the flesh of slaughtered animals. In fact, in modern English, *meat* came to mean 'the flesh of animals as opposed to the flesh of fish'. Figure 13 shows how to explain this restriction of meaning by using DMMS.

The third and last type of semantic change is the so-called **shift**. We have an example of shift whenever a word completely loses its original meaning and acquires a new meaning. So, in order to account for this by using DMMS we have to center on *transposition rules.* In contrast with narrowing and extension, here we will not speak about addition or deletion of semantemes, but we have to postulate *a change in the transposition rule* that relates a given semanteme to a given lingueme. Let us consider that, at a given moment of computation, lingueme a is related to semanteme

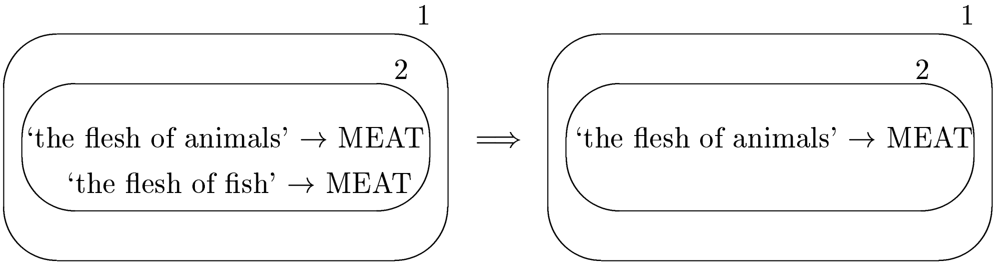

Figure 13: Example of Narrowing: *meat.*

α, we will have a case of shift if, in the next computation step, a will be related not to α anymore but to, for example, β.

Formally, in DMMS, shift is explained as follows: Consider that in the first state of computation we have a semantic domain $\mathcal{D}M_n = \{\alpha, \beta\}$, a linguistic domain $\mathcal{E}M_n = \{a, b\}$, and a function $hM_n(\mathcal{D} \to \mathcal{E}) = \{\alpha \to a, \beta \to b\}$. We will speak of shift if, in the next computation step, we will perform some modification in the transposition rules, in such a way that for a given lingueme the semanteme associated to it in the second step of computation will be different from the one it had associated in the first step. So, we have shift if there is a modification of the initial function, as for example the following one: $hM_n(\mathcal{D} \to \mathcal{E}) = \{\beta \to a, \alpha \to b\}$. See Figure 14.

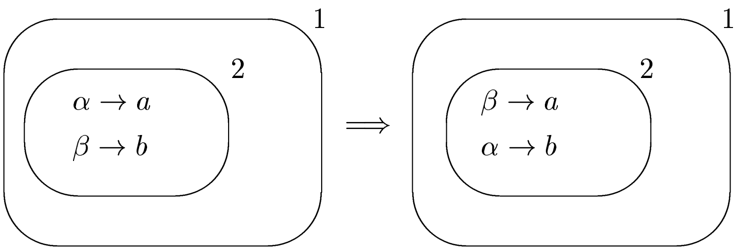

Figure 14: Shift.

Semantics provides a large number of examples of linguistic shift. An example of shift can be the history of the word *silly* in English. This word is cognate with the German word *selig* ‘blessed’, and it is derived from *Seele* ‘soul’. The meaning of the German word represents the original meaning of the word, so there has clearly been a major semantic shift to get from the meaning ‘blessed’ to the meaning in modern English of ‘stupid’ or ‘reckless’. This semantic shift is formalized in DMMS as shown in Figure 15.

From what we have said above, the proposed taxonomy of semantic change can be explain in terms of DMMS as follows:

- **Broadening:** *addition of new semantemes* to the domain of a membrane without addition of linguemes, with the obligation of relating these new semantemes to already existing linguemes (related to other semantemes).

- **Narrowing:** *deletion of semantemes* from the semantic domain of a mem-

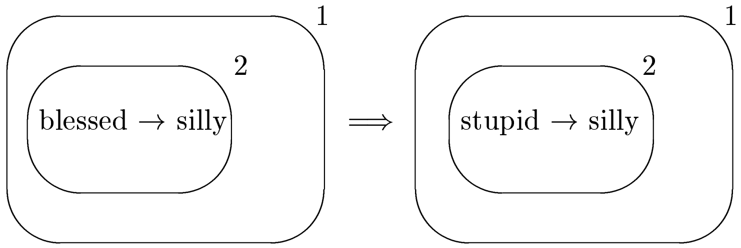

Figure 15: Example of Shift: *silly*.

brane, with the consequent deletion of every rule that contains the deleted semantemes.

- **Shift**: *a change in the transposition rule* that relates a given semanteme to a given lingueme, relating in this way the given lingueme to a different semanteme.

Therefore, by using the process of addition/deletion of semantemes we can explain *extension* and *restriction* of meaning while modification of the transposition can explain *shift* of meaning.

Up to now we have account for semantic change, this is for evolution in the signified of words (*semantemes*, in our terminology). But, not only the signified is allowed to change, in fact, in the previous section, we have said that both signifier and signified can change independently. So, in order to complete the picture of DMMS utility in language change, and even though it is not the topic of this paper, we will briefly refer to the possible DMMS' explanation of the evolution of signifiers of words (*linguemes*, in our terminology). We can use again the idea of *variable domains* and play, now, with *addition/deletion of linguemes*:

1. New linguemes can be added to a membrane domain. The addition of new linguemes can account for the introduction of a new signifier that may then be related to new or already existing meanings (semantemes). In this case $h(M_n)$ associates a new or already existing semanteme to the new introduced lingueme.

2. Some linguemes can be deleted from the domain. This process account for the elimination of a signifier whose meaning should be absorbed by another new or existing lingueme. Notice that in order to describe this fact we just need that $h(M_n)$ associates the semanteme that was associated to the lost lingueme to a different lingueme.

Above we have account separately for the change (evolution) of meaning and for the change (evolution) of signifiers. Notice that, with DMMS, we can also account for the total deletion of a word by using subscript i: all elements marked with a subscript i disappears because there is not a transposition rule for this element in $h(M_n)$ (see page 5). So every word marked will this subscript will stand for total loss of a word.

Summing up, in this section we have tried to account for semantic change by using DMMS. At the end, what we have is that DMMS can account separately for semantic change –understood in terms of addition/deletion of semantemes from a membrane domain– and for lexical (signifier) change –understood as addition/deletion of linguemes.

5 DMMS and GS: Suggestions for the Future

In the above section we have defined in terms of DMMS different types of semantic change. Note that by doing this what we have done is to answer to the question *'what?'*, this is *what does it happen when a semantic change takes place?'.* As we have seen, there are three possible answers to this question in terms of membrane systems: 1) a new semanteme is added to the membrane domain; 2) an existing semanteme is deleted from the membrane domain; 3) or there is a modification in the transposition rule that relates a given lingueme to a given semanteme. But, by just answering to the question *what?* we do not offer a complete view of language (semantic, in this case) change. There are other questions that must be answered if we like to offer a formal framework for evolution in language. Questions such as the following ones:

- *'How do linguistic changes spread through a language community?* Changes in language are interesting when they become general in a community, but obviously innovations does not originate collectively. In fact they have to be uttered for the first time by a single speaker. Some of these novelties will be imitated by other speakers, and then imitated by still others. If the process is sustained, the innovations will spread through the whole speech community. According to [11], if we recognize that there are individual idiolects, shared norms and an idealised linguistic system, we can study language change in all of these areas, and their possible interrelations: that is, an individual or group of individuals may produce a novel pronunciation or other form of speech, which contributes to variation in the speech community; this may be adopted by more speakers, and cause a change in the norms of the community; and finally, it may become the expected, or standard usage, being incorporated into a shared linguistic system of native speakers of the language.

- *'Why do particular changes spread?.* According to [6], language change can be seen as *natural.* If speakers of natural languages let things take their natural course, language will inevitably change in one way or another, given sufficient time. However there are situations in which the deliberate action of speakers can affect the future of a language. In times of rapid social, cultural and technological change, speakers of a language need to add new words to their vocabulary in order to talk about new things. So, some changes take place because a particular language must change in order to meet new demands that its speakers place upon it. As the functional needs of a language change, some aspects of the language may be lost, while others may be added. These kinds of pressures do not generally affect the phonology, or even the grammar, but they can have drastic effects on the vocabulary.

- *'Who makes language change?* There is still a great deal of research and discussion about which social groups introduce linguistic changes. One answer seems to be that a linguistic change may enter a speech community through any social group. Members of the group with most social status, for example, tend to introduce changes into a speech community from neighbouring communities which have greater status and prestige in their eyes.

In order to account, in a formal way, for the above issues we cannot use membrane systems, but it is preferably to resort to grammar systems theory, and in particular to the so-called *cultural grammar systems*, introduced in [9] as a formal-language framework to account for cultural evolution, in general, and language evolution in particular. Cultural grammar systems –represented in Figure 16– offer a simple machinery to account for the dynamics of cultural evolution, pointing out the difference between cultural and genetic change and stressing the role of man in the evolution of culture. Taking into account that language can be seen as a part of culture, we can explain language change by using the model defined for cultural evolution.

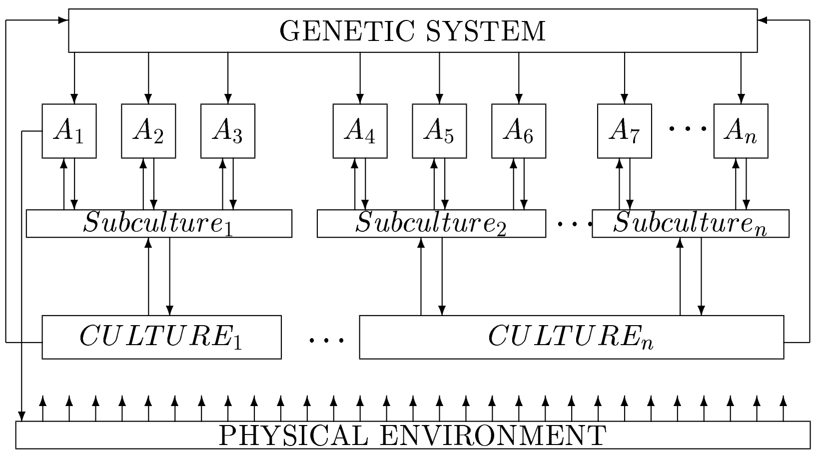

Figure 16: Cultural Grammar Systems.

Lack of space prevent us from present here the formal framework of cultural grammar systems (for formal definitions see [9]) and from describing language change by using the model. We just want to point out that with a cultural grammar system we can formally define *how* a semantic innovation spreads first from a single speaker to the most immediate linguistic community (dialect), and then to the whole linguistic community. We can capture also the idea that speakers and only speakers are *who* change languages. It remains clear in the model that it is not languages that change, but speakers who change them. And last but not least, the model offers an answer to the question *why* semantic change takes place: language changes as far as speaker's necessities change.

The only question that seems to remain unanswered in the grammar systems model is *what* happens when a semantic change takes place. And here is when enters the model we have presented in this paper. We think that there exists a complementarity between DMMS and cultural grammar systems since the former offers a model of *what* happens when a semantic change is implemented, while the latter provides explanation of the reasons, agents and procedure of the evolution of meaning. Taking into account this and considering the fact that in grammar systems we can postulate any mechanism as component of the system, we propose to define cultural grammar systems with dynamic meaning membrane systems as components in order to give a complete formal-language-model of semantic change. We are fully convinced that collaboration between both models –cultural grammar systems and DMMS- may provide a useful formalism that, due to its naturalness and simplicity, might offer interesting results in a discipline traditionally far away from any formalization as linguistic evolution is.

6 Final Remarks

One of the most challenging problems in linguistics is the possibility of dealing with meaning contexts, in order to be able to formalize one of the most important components of human language, which is the semantic module. Semantics cannot be solved in the standard theories of language because of its ambiguity and change. Moreover, the multiplicity of meanings is a constant handicap for developing computation resources applicable to linguistics.

In this paper, we have introduced a very simple model for explaining semantic change in the framework of membranes. Just a few examples have been given, related to very well known phenomena of meaning evolution. The model is based in two important ideas: a) the meaning is defined as a dynamic concept, with two components which are not joint in a consistent way, b) membranes related between them understood as different contexts for a lingueme can give account of semantic processes without involving syntactical or structural changes in it.

It is worthwhile to emphasize the simplicity of the model and the possibility of reaching a computational implementation which can help to solve some practical problems in computer programming.

Moreover, the inclusion of domains in membranes can be combined with other very fruitful concepts of standard theory of membrane systems to integrate syntax and semantics in the same process of language generation.

Finally, we suggest the integration of the model with the one provided by grammar systems, in order to give a whole explanation of the process of semantic change and language evolution.

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