Managing Conversational Streams By Explorative Mind-Maps

Jayanta Poray, Christoph Schommer
Department of Computer Science and Communication
University Luxembourg
6, Rue Coudenhove-Kalergi, L-1359 Luxembourg
Email: {jayanta.poray, christoph.schommer}@uni.lu

***Abstract*—In this paper, we introduce an explorative but adaptive-associative information management system in the presence of a natural conversation. We take advantage of these explorative mind-maps, which have been demonstrated in [10] and which are altogether a management framework that emerges automatically from the data input stream it gets. An explorative mind-map is a non-verificative but dynamic system that basis on the natural paradigm: it changes its complexity continuously and fosters symbolic cells according to internal activation states. Generally, the structure mirrors a mental state where the oblivion of associated facts arrive once the stimulation decreases. As a special case, immortal mind-maps may be taken with respect to conversation streams, where the "die off" and the "forget" of a stimulated input may be disregarded but exploited. Considering two mind-maps $A_{1,2}$ and $B_{1,2}$ for two conversational partners *A* and *B*, then a mind-map $*_1$ represents the self-conversation and $*_2$ the conversational stream of the conversational partner. If we merge these mind-maps, we may apply the out-coming results for the computation of trust.**

***Index Terms*—Cognitive Systems, Brain Informatics, Bio-inspired Learning, Adaptive Information Management, Trustworthiness.**

I. PROBLEM STATEMENT

Assume that *Alice* and *Bob* talk to each other by a natural conversation. Then both *Alice* and *Bob* receive a conversational signals from the conversational partner. Both independently then decide about its relevance: textual patterns inside the conversational streams become extracted or even not, they are summarised and kept in mind - or even handled as noise. If both *Alice* and *Bob* store conversational signals, then both will know something more about the conversing partner. And, *Alice* surely estimates a certain belief about *Bob* and her own believes with respect to the subject of the conversation (and vice versa).

With respect to the question on how *Alice* and *Bob* manage these signals, we understand the corresponding management system as an associative and flexible structure that emerges from the input it gets. We call this structure an explorative *mind-map* (Chapter II; Figures 1 and 3). Assume that *Alice* and *Bob* own such individual mind-maps that foster on their mental status and on the other's conversed input (Figure 1). Then, both *Alice* and *Bob* store temporal patterns inside their own mental images about the conversational partner and are able to merge their own mind-maps (representing what they think and believe) with the own mind-map representing the conversing partner.

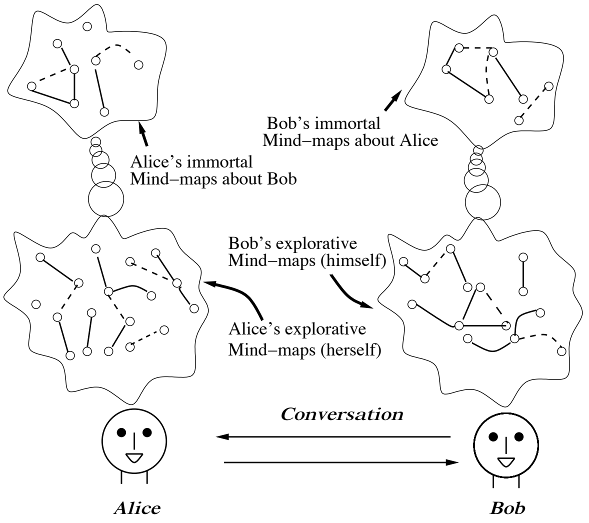

Fig. 1. A sample conversation between *Alice* and *Bob* : both share their own (immortal) mind-map as well as a mind-map about the conversing partner.

Our challenge is now to find a suitable way to merge the mind-maps and to come up with a consistent and reliable mind-map structure. Furthermore, explorative mind-maps include a *forget* factor and therefore risk that parts of the mind-map get lost if they are not activated regularly. At a first glance, this is a disadvantage, since a conversed content should be present all the time and may not forgotten. In case that an important information occurs at the beginning of a conversation but is never communicated again, then this would consequently lead to a decrease of connections and cells, and finally to a forget of this content. Redundant information is kept out and regarded as noise, but a strict consideration of each stream input is generally seen as infeasible. Moreover, there exists always a certain capacity and limitation regarding the harvesting of information.

We then come up with a model compromise and design each person's own mind-map including the continuously forgetful states. With respect to the information collection of the conversed person, however, and since conversations are generally not being that intensive, we favour *immortal mind-maps*, but additionally come up with the occasional application of *cleaning*, which occurs in case that the mind-map reaches its highest capacity. For example, cells and connections, which do not have a necessary strength, are automatically removed. The advantage of this approach is that both all information is recorded and and the natural example remains assured.

II. ARCHITECTURE OF A MIND-MAP

In this chapter, we describe the fundamental architecture of explorative mind-maps. We accent that explorative mind-maps rely on the natural principle on sensations and the corresponding propagation of stimuli to a final destination in order to process streams of symbolic data.

A. Explorative mind-maps

Explorative mind-maps share a principle through an associative architecture that incrementally processes accepted symbolic stimuli to a consistent informational structure. This is similar to the natural paradigm, especially connectionist approaches like [4], [5], [9], but on contrast to a verifying processing of a user's thoughts, the explorative mind-maps are built from the bottom up, meaning that a mind-map's existence exclusively depend on each other by incoming signals. Explorative mind-maps share a sub-symbolic architecture that is composed of interacting entity cells. As mentioned above for the natural principle, these cells foster on a processing of symbolic data streams and a stimulation/inhibition-principle of adjacent connections. The activation of such a connectionist architecture bases on a dynamic construction of cell structures during the processing of the input stream.

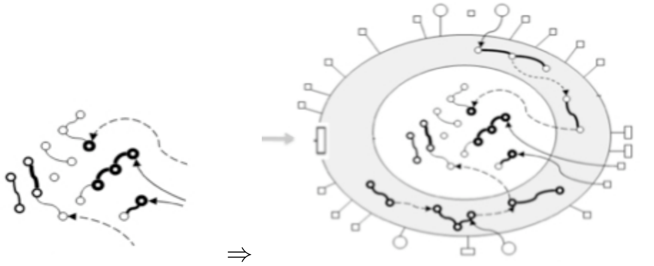

Fig. 2. A clump of conversational cells (left) that become established during the conversation and that are finally sent to explorative mind map (right). At first, it is placed to the *short term* memory (grey area) but possibly being sent to the *long term* (inner core) memory.

In Figure 3 we observe a mini-network (clump of cells) contains three patterns, namely *A, B* and *C*. In a filtration phase the cells A and C enter inside the *short-term memory* and finally merge with the *long-term memory*, where the unused pattern *B* kick-out from the mind-map. The bottom-up process of merging cells together (see section III) starts with a stimulation phase, where a stimulating stream data is absorbed by receptor (input) cells i_k, which then decompose the stream to its entities. For example, a text stream is decomposed to its word entities, transactional streams to item entities, and so on. Using filter cells f_k, exactly those receptor cells i_k are inhibited if they do not address a semantic interest. In the mini-network phase, the collections of entities, which occur at such a specific time-point, form a *mini-network* with fully connected entity cells e_k. A *mind-map merger* starts once the mini-network is established: here, the mini-network is sent to the mind-map and is merged with the existing entity cell in the mind-map (initially, the mind-map is empty). In this regard, the specified merge references an action of mini-network and entity cells - that share a same representation - to a unique entity cell e_k. The activation status of an entity cell is then increased in case it has been merged. If two adjacent entity cells e_k and e_l of the mind-map are activated by the mini-network at the same time, their connection weight $\omega(e_k, e_l)$ is increased by the Hebbian learn rate ϕ. If two adjacent entity cells e_k and e_l remain inactivated, a fragment δ decreases their connection weight. The association becomes forgotten if the connection is below the activation threshold ϵ_{min}. The mind-map may degenerate if due to less intensive stimuli. In a final phase, the communication with the outside, especially the informing about the actual state with regard to contents, is realised. This is to be done either on demand - the user explicitly sends a request - or unsolicited.

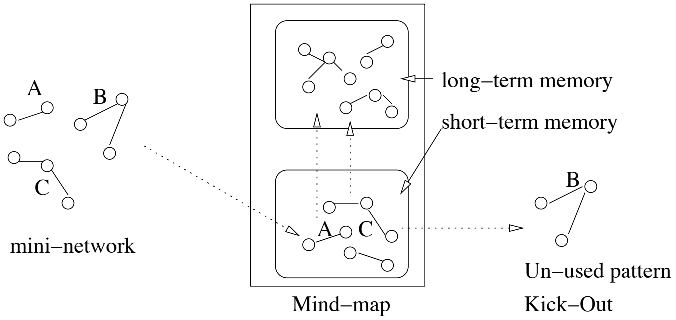

Fig. 3. The architectural design of an explorative mind-map with *mini-network*, *short-term* and *long-term* memory.

Insofar, the consequence of the brief descriptions above is not only that explorative mind-maps are non-deterministic regarding its size, appearance, and communication but that explorative mind-maps stand for a life-cycle process that depends on the intensity of incoming stimulations and the activity inside the mind-map. Before the corresponding mini-networks arrive on the left side, they become firstly assigned to the receptor cells, become then filtered, and finally being put to the mini-network structure. This mini-network is sent to the inner core - which represents the mind-map management system - and then merged with the mind-map itself (inner area). An extension to the explorative mind-maps are *cognitive mind-maps*, which we call as to be explorative like the mind-maps described above but that additionally use temporal mining components to detect temporal changes inside the *skeletons*. As a consequence, both the *short term memory* and the *long-term memory* may benefit from such an additional information. Also, the mind-map becomes more artificially human, meaning that a temporal analysis of data streams can be seen as an intellectual (artificial) intelligence. On the other side, an alternative to explorative mind-maps are *immortal mind-maps*. In contrast to the given mind-maps, they do never support a slightly decrease of activations or cells (in the sense of forgetting something) but simply remain present once they have occurred.

B. Short-Term and Long-Term Memory

The mind-map is managed by two types of memories. The *short-term memory* stands – in analogy to the human example – for a physical and mental place of storing/managing entities like impressions, word associations, etc. In the evolutionary beginning, it is empty but will grow up to a certain size the more and more it receives an input. And indeed, our explorative mind-map model fosters the *short-term memory* as the place where collections of entity cells as well as *skeletons* of cells (see section II-D) may be stored (in case that they are interesting and worth). The *Short-Term Memory* has a limited capacity χ, a temperature τ within an interval $[\epsilon_{min},\ldots,\epsilon_{max}]$, and the transfer parameter ν_p to send longer–established (or worth) cell-based patterns to the *Long-Term Memory* (*long-term memory*). The *long-term memory* is similar to the *short-term memory* but is more a static place (once a *skeleton* is there, it is rather impossible to get rid of it), being a communication platform with the external environment (users, other systems).

C. Mind-map Threshold Factors

A unit is a pattern that is constructed with both the entity cells and the associated connections. Such units change from time to time with their inherent *charge* (activation value). The total amount of charge in some time slice is the measure of *energy* for a pattern. Moreover, we consider the capacity χ as a binary variable that directly depends on a set of binary *boundary thresholds* parameters C_1, C_2, and C_3 with

$$C_1 = \begin{cases} 1 & \text{if} \quad \theta_{min} \leq n \leq \theta_{max} \\ 0 & \text{else} \end{cases} \tag{1}$$

$$C_2 = \begin{cases} 1 & \text{if} \quad \zeta_{min} \leq m \leq \zeta_{max} \\ 0 & \text{else} \end{cases} \tag{2}$$

$$C_3 = \begin{cases} 1 & \text{if} \quad \epsilon_{min} \leq \tau \leq \epsilon_{max} \\ 0 & \text{else} \end{cases} \tag{3}$$

where n is the number of patterns inside a mind-map and m the number of units inside a pattern. The complexity τ $(= \frac{|e_i|}{|c_i|})$ is defined as the ratio between the number of entity cells (e_i) and the number of their associated connections (c_i). If the number of connections is higher than the number of entity cells, then the temperature τ of the mind-map will be significantly higher as well. This is a symptom of complex patterns. These types of patterns need to be simplified for maintain the healthy state of the mind-map. With this, we define the capacity as

$$\chi = \prod_{i=1}^{3} C_i \tag{4}$$

If $\chi = 0$, then the capacity reaches its maximum limit. Operations are applicable only if χ switches to 1.

D. Skeletons

In the context of pattern formation process the *skeletons* are the higher-activated clump of entity cells that occur temporally or frequently and that consist of entity cells sharing a strong activity; *skeletons* have been stable over a period of time or are recurrent in a sense that they occur again after being lost. As mentioned in section II-B, the *skeletons* are sent to the *short-term memory* and/or *long-term memory*. As for the natural example, *skeletons* may be *impressions* or *notices*, which are to be discovered: depending on its state and temporal eligibility, existing *skeletons* may stay inside the *short-term memory* or be sent to the *long-term memory*. And, once being in the *long-term memory*, *skeletons* can be communicated to the external ad may become applied: for example, a knowledge center that contains content of a high relevance.

The process of identifying such *skeletons* is a comprehensive task that will be continuously done by e.g. sequential pattern algorithms, which accepts a sequence candidate in case it merges the frequency threshold. To send such a sequence to the *short-term memory*, some parameters must be taken into account:

- *Density*: how dense is the sequence in respect to the time? If it is stable or recurrent with at most a certain time gap γ, then it is accepted; otherwise, it is not.
- *Size*: how large is the sequence? Often, sequences of length $l_s \leq 3$ may occur, which are probably necessary but even not expressive enough.
- *Balance*: the activation balance π of all participating cells may differ, probably, in a too divergent way. Therefore, homogeneous sequences could probably be accepted, whereas heterogeneous patterns stay outside.

E. Membranes

It may appear that entity cells are sometimes unlike to themselves although they contain the same subject. This may occur – for example – in the presence of speeches when words refer to different meanings (ambiguity). For example, although the content of an entity cell e_i = {*ball*} is – at first glance – identical to another entity cell e_j = {*ball*}, the meaning of it may be different since *ball* both stands for *dance evening* and a *seating*. Figure 4 represents the situation, where the entity cell *A* tries to get merged with the already existing entity cell *A*. To enrich each entity cell and to avoid a wrongly merge in general, we protect each cell by a *membrane*. The membrane is a “coat of logic” that controls the correct similarity among the cells (see chapter III). The membrane of a cell is *permeable* in case that both associated entity cells refer to the same meaning (otherwise not).

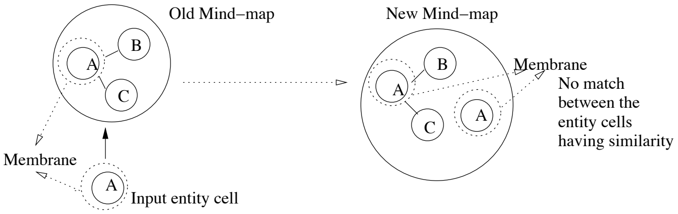

Fig. 4. Identical entity cells that are protected by membranes.

F. Cold and Overheating

A merge of cells, *skeletons*, and/or mind-maps leads us to one fundamental problem: an *uncontrolled complexity* of a mind-map *M* in the presence of a given mind-map capacity χ. With *uncontrolled complexity* we refer to two situations where in the first case a too low number of cells and/or *skeleton* exist and in the second the number of cells and *skeletons* exceeds the given capacity limit. We call these two situations a *cold* and *overheating* of the mind-map. Given a set *E* of entity cells e_k, then a mind-map *M* is *healthy* in case that the *temperature* τ inside the mind-map *M* is within a normal range:

$$\epsilon_{min} \leq \tau \leq \epsilon_{max} \tag{5}$$

The mind-map *M* is called to be *diseased* in case that the *temperature* τ is either too low (cold) or too high (overheated):

$$\tau \leq \epsilon_{min} \vee \tau \geq \epsilon_{max} \tag{6}$$

Keeping mind-maps into a diseased state yields to a mind-map of non-operating cells (this is both for entity cells e_k, filter cells e_k, and receptor cells i_k). Any merge can not take place because the adaptors remain frozen or fluid. As a matter of self-regulation, counteractions are available: *fever* in the sense of increasing the mind-map temperature and *cooling* in the sense of decreasing the mind-map temperature. With this, each mind-map ends in a consistent (healthy) state through this self-regulation process by *fever* and *cooling*.

G. Pattern Transfer Rate

The transfer of the temporal patterns to the *short-term memory* and from the *short-term memory* to the *long-term memory* depends on several conditions: *temperature* τ, *Energy* η, a d *Capacity* χ. If the mind-map is healthy ($\epsilon_{min} \leq \tau \leq \epsilon_{max}$) then the memories keep in their active state of pattern transfer. But when the temperature exceeds ϵ_{max} or falls below ϵ_{min}, then the transfer process stops until it refresh to the healthy state. During healthy state the best *skeletons* are sent to the *short-term memory* and/or *long-term memory*, respectively. The energy η_p inside the pattern p can be counted as the total amount of its inherent activation value, where m is the number of entity cells and their associated connections and a_i the corresponding activation value:

$$\eta_p = \sum_{i=1}^{m} a_i \tag{7}$$

This energy level can be considered as the most influencing factor to identify the healthy pattens, present inside the *short-term memory*. The patterns, having minimum energy threshold (η_p^{min}) are eligible to enter into the *long-term memory*. Also the best candidates among the healthy patterns normally contain high energy. These best patterns are separately distinguished as *skeletons*, where η_p^s is the *skeleton* energy threshold:

$$\eta_p^s > \eta_p^{min} \tag{8}$$

The volume of mind-map measures by the number of patterns and the corresponding entity cells with their connections. The goal is to consistent growth of the mind-map with the healthy patterns. In this regard, the capacity (χ) of the mind-map is taken into consideration, which is a combined factor of mind-map parameters, including the volume and the temperature. The transfer of the healthy patterns from *short-term memory* to *long-term memory* is influenced by the capacity with the observed threshold parameters.

We come with the transfer rate ν_p (from *short-term memory* to *long-term memory*) for the pattern p, which depends on its energy (η_p) along with the current state of capacity (χ) of the mind-map:

$$\nu_p = \chi \times \eta_p \tag{9}$$

If $\chi = 0$ then the transfer rate $\nu_p = 0$ as well. However, if $\chi = 1$, then a gradual value will become assigned to ν_p. Furthermore, when the mind-map is in a healthy state (i.e., $\chi = 1$) the overall Transfer Rate ν could be computed as the sum of all transfer rates for n patterns.

$$\nu = \sum_{p=1}^{n} \nu_p \tag{10}$$

In case of a diseased mind-map state, the transfer stops.

III. MERGE FUNCTIONS

A first idea is that a conversation among partners depend on the number of entity cells that are in the mind-maps M_p and M_{pq}^*. In that context, M_p is the self mind-maps for the person p, whereas M_{pq}^* is the mind-map of the person p about the conversing partner q. The similarity of these two mind-maps is then the result of counting the corresponding entity cells contain the same information. A similarity is then given, if the final number of common entity cells reaches a certain threshold value. Furthermore, an improved version of this approach has been to take the activation status (and the corresponding connection status) into account. The similarity between the two mind-maps M_p and M_{pq}^* is then not only the pure number of common entity cells but moreover a weighted sum.

In general all the entity cells inside these two mind-maps are not often important or interesting to a person. Depending upon the conversational situations, some entity cells (and their associations) could be highly important - some remain negligible. We therefore consider the individual *parallel universe*, which is again categorised into the corresponding *self-relevance* ρ^{M_p} and *outer-relevance* $\rho^{M^*_{pq}}$. Some relevance values are dynamic and may change over time. In general when the natural conversations are not influenced by some special situations, all the relevances (temporal patterns) are merged with the similar priority. Here, inside the mind-maps these special situations are defined by the *highly activated entity cells (*skeletons*)*, which can also be considered as the the permanent impression (memory) about some events. Therefore the overall parallel universe does not exist in the beginning of the mind-maps life cycle, but gradually matures with various cognition capabilities - like these non-specified and specified mental representations and their corresponding merging situations.

A. *Merging Entity Cells*

So far, several alternatives have been identified, which do either use an a-priori knowledge or demand an ex-posteriori information. A first (and in our opinion the most appropriate) approach is to randomize each relevance value, which has the advantage that a-priori less/no efforts must be investigated. The belief that more important entity cells adapt to a higher relevance value (and less interesting entity cells to lower relevance values) can not be dismissed. The idea of initially differ between entity cells only considers for some specific events. Therefore in a simplistic approach, we firstly consider all entity cells with *equal priority*. Then the merge function $\mu(M_p, M^*_{pq}, t)$ is as follows:

$$\mu(M_p, M^*_{pq}, t) = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{|\rho^{M_p}(e_i, t) \cap \rho^{M^*_{pq}}(e_j, t)|}{|\rho^{M^*_{pq}}(e_j, t)|} \tag{11}$$

B. *Merging* skeletons *and Entity Cells*

The grade of accordance among conversational partners may certainly depend on the number of entity cells that are in the immortal mind-maps M_p and M^*_{pq}, respectively, and a merge over weighted cells inside these mind-maps might eventually demonstrate how trustworthy a person is. However, these structures might be worthless or even less interesting in case that longer established *skeletons* exist in one of the memories. This observation follows the natural example, where a decision is partially influenced by recent events, ideals, and even longer established facts. With this, the following merge function $\mu^{'} betweenM_p$ and M^*_{pq} is an alternative to the previously defined function. Now, the self structural *skeletons* (s_i), which exist inside the memory of the mind-maps, are considered. The time t has been removed as such a parameter is senseless within immortal mind-maps.

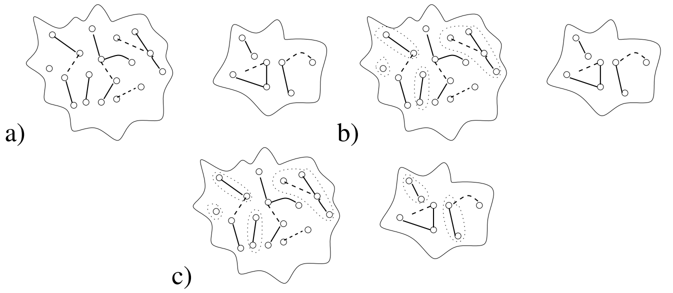

Fig. 5. Merge processes between a) entity cells, b) entity cells and *skeletons*, and c) *skeletons* and *skeletons*.

$$\mu^{'}(M_p, M^*_{pq}) = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{|\rho^{M_p}(s_i) \cap \rho^{M^*_{pq}}(e_j)|}{|\rho^{M^*_{pq}}(e_j)|} \tag{12}$$

C. *Merging* skeletons

A third merge function $\mu^{''}$ concerns with longer established structures and not with recent events. For example, if *Alice* talks to *Bob*, then it is likely that *Alice* knows already *Bob*. It is therefore less of interest, what exactly *Bob* says. However, there might be some indication that *Bob* 's comments may influence Alice's mind-map with respect to *Bob*. The merge function is then

$$\mu^{''}(M_p, M^*_{pq}) = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{|\rho^{M_p}(s_i) \cap \rho^{M^*_{pq}}(s_j)|}{|\rho^{M^*_{pq}}(s_j)|} \tag{13}$$

$\mu^{''}$ is not a time varying function as time has no influence for already structured *skeletons* (s_i and s_j) inside the mind-maps.

Figure 5 describes the merge for these functions. In a), we merge both inner cores of *Alice*'s mind-maps (herself, left side) and her mind-maps about *Bob* (right side), whereas b) represents the situation about strong temporal impression of *Alice*'s mind-maps in the form of memory (rounded dotted shapes on the left side - *skeletons*) vs. the *Alice*'s immortal mind-maps about *Bob* (right side), and c) the situation about the *Alice*'s own strong beliefs (rounded dots on the left side) vs. the *Alice*'s strong impressions about *Bob* (rounded dots on the right side).

IV. DISCUSSION

Currently, the explorative mind-map supports the creation of binary patterns, which are associatively connected between two adjacent cells: in case that a signal $\{A, B, C\}$ arrives, a full-connected cell clump made of *A*, *B*, and *C* is sent to the main memory trying to merge it with existing cells. But all results of this merge remain binary. An extension therefore is to understand temporal signals as n-ary patterns: these are formed by several entity cells by an associated connectivity. Here, the formation of the patterns is a bottom-up process that evolves several learning steps. In this regard, the input signals are decomposed to *frames*, where each frame is to be understood as a sub-set of a sentence (a phrase) or even the sentence itself. If at a particular time the overall text input stream is considered as to be the content that is received from the conversational partner, then each sentence can be distinguished by such a *frame*. The filtration (extraction) of individual *frames* influences the entity cells and their connectivity: the cells of a newly filtered frame compare its immediate predecessor frame with the beginner frame of the same content (in an iterative way). On the one hand, this results in novel patterns, and on the other in an update of activation values after each iteration. If there exist no common cells, then obviously more than one patterns will be obtained.

Consider the example of a natural text stream that is received by *Alice*'s conversational partner (*Bob*). It influences the desired pattern formation inside *Alice*'s mind-map concerning *Bob*:

```
Bob: I have a football.
Bob: Footballs are round.
```

There exist two frames: after having processed the first frame, the single entity cell *football* comes out as the main subject. This is filtered with an activation value 1 due to its first occurrence. The second frame owns then two entity cells *football* and *round*, respectively. Here, the connection between these entity cells is the main learning outcome (subject) of this frame. It activates the new pattern with an activation value of 1 with respect to the connection between the entity cells. Let us now assume that in the next communication phase the followoing input signal is quoted by *Bob*:

```
Bob: I have mentioned about round shape.
Bob: Round shapes are very common in the universe.
Bob: For example, shape of most of stars are round.
```

Then, the new n-ary patterns are obtained at the same time. The connectivity is clearly based on the relation among the n-ary pattern; the activation values for the individual n-ary patterns are updated stepwise. Finally the extracted n-ary patterns are merged with the extracted n-ary pattern of its previous content based on the common subject cell *round*. If there are no common cells between two n-ary patterns, then both patterns are kept separately inside the mind-map memory. In this way both *Alice*'s and *Bob*'s own mind-maps have been established. Also when the following continuous conversation between *Alice* and *Bob* takes place then both mind-maps are taken into account:

```
Bob: The sun is shining, what a beautiful day.
Alice: The sun is very hot.
Bob}: This is right, but I like sunny days.
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Bob's affirmation is inherited to *Alice*'s mind-map and the entity cell *day* is activated double and that the connection between *day* and *sunny* has been strengthened.

V. CONCLUSIONS

In this paper, we have concerned with the nature-inspired processing of data input streams through *explorative mind-maps*. In the presence of a natural conversation, the presented model takes advantage of an associative management structure, a consistency of the cell membrane and the temperature inside the mind-map. Moreover, we have shown a merge of existing, but independent, conversational *skeletons* and described the mind-map model in detail and figured out a diverse number of merge functions and transfer rates. So far, we have applied explorative mind-maps in various situations [10], for example as backbone in a intrusion detection system or as query manager in an information retrieval system *SEREBIF*.

With the presented extended model, however, we follow the path of recommending trust in the presence of a conversation. Having two mind-maps M_p and M^*_{pq} for a person p and the minimum number k and l of entity cells, which share the relevance values $\rho^{M_p}(e_i, t)$ and $\rho^{M^*_{pq}}(e_j, t)$, respectively, then a trust function $gtrust()$ may be given as

$$gtrust(M_p, M^*_{pq}, t) = \begin{cases} yes, & \mu(M_p, M^*_{pq}, t) \geq \alpha \\ no, & else \end{cases} \tag{14}$$

The trust threshold α is given individual to each conversing partner. Here the decision on how to trust the conversational partner is binary but also the trust level can be quantified with the measured value μ. With this as well as other with other model-related aspects, we are optimistic to come up with a trust decision system.

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