

# ONTOSPREAD: Activation of Concepts in Ontologies through the Spreading Activation algorithm

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**Abstract.** The present article introduces the ONTOSPREAD API for the development, configuration, customization and execution of the Spreading Activation techniques over semantic networks and more specifically over RDF graphs and ontologies arising from the Semantic Web area. These techniques have been used to the efficient exploration and querying of large and heterogenous knowledge bases based on semantic networks in the Information or Document Retrieval domains. ONTOSPREAD implements the double process of activation and spread of concepts in ontologies, implicit graph structures, applying different restrictions of the original model like weight degradation according to the distance or others coming from the extension of these techniques like the converging paths reward. The main application of Spreading Activation lies in two different areas of interest to digital libraries: 1) construction of hybrid semantic search engines 2) ranking of information resources according to an input set of weighted resources. These techniques provide a whole framework to ease the information access, a common required features in the exploitation of new and existing digital libraries. Finally, in this work an evaluation methodology and an example using the Galen ontology are provided to validate the goodness, the improvement and the capabilities of this framework applied to digital libraries.

## 1 Introduction

The improvements in digitization lead us to a new environment in which digital libraries and archives are designed and used in a new way. This situation implies new challenges in the digital formats, storage (information is continuously growing) and information retrieval models. Following the recommendations of the European Commission [10] the digital libraries are a key factor to bring out the full economic and cultural potential of Europe's cultural and scientific heritage through the Internet. The online presence of material from different cultures and in different languages will make it easier for citizens to appreciate their own

cultural heritage as well as the heritage of other European countries. Besides its fundamental cultural value, cultural material is an important resource for new added value services. That is why more sophisticated software tools and methods are needed to meet the expectations of users easing the information retrieval of these large datasets and overcoming the classical problems of information overloading.

Initiatives like Semantic Web and Linked Data [22] tries to define vocabularies and ontologies enabling the data interoperability and sharing that enable by means of the Web infrastructure the access to the contents across different platforms and applications. The development of tools using these common data formats and models is largely implemented and representative to digital libraries but some algorithms and methods are not yet promoted to work with them in a standard way preventing the improvement and effectiveness of information access.

In this sense Spreading Activation technique (hereafter SA) introduced by [9], in the field of psycho linguistics and semantic priming, propose a model in which all relevant information is mapped on a graph as nodes with a certain "activation value". Relations between two concepts are represented by a weighted edge. If a node is activated their activation value is spread to their neighbor nodes. This technique was adopted by the computer science community and applied to the resolution of different problems, see Sect. 3. In the field of digital libraries this technique can ease the information access providing a connectionist method to retrieve data like brain can do. Although SA is widely used, more specifically in recent years have been successfully applied to ontologies, a common and standard API is missing and each third party interested in their application must to implement its own version [32] of SA.

Taking into account this new information realm and the leading features of putting together the SA and the Semantic Web technologies, new enriched services of searching, matchmaking, recommendation or contextualization can be implemented to fulfill the requirements of access information in digital libraries of different trending scopes like e-procurement, legal document databases [5], e-tourism or e-health.

## 1.1 Main Contributions

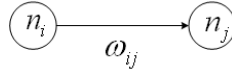
The proposed work aims to afford a framework for SA to ease the configuration, customization and execution of them over semantic networks and more specifically over RDF graphs and ontologies. It is relevant to digital libraries access and interoperability due to the fact that this technique provides a set of proven algorithms for retrieving and recommending information resources in large knowledge bases. Following the specific contributions of this work are listed:

- Study and revision of the classical constrained SA.
- Study and definition of new restrictions for SA applied to ontologies and RDF graphs.

- Implementation of a whole and extensible framework (called ONTOSPREAD API). to customize and perform the SA based on good practices in software programming.
- Outlining of a methodology to configure and refine the execution of SA.
- An example of configuration and refinement applying SA over a well-known ontology, the Galen ontology.

## 2 Background

In this section, the theoretical model of *SA* [9,3] is reviewed to illustrate the basic components and the operations performed by SA during their execution, specially the spread of the activation from a node to their adjacent, see Fig. 1. This model is made up of a conceptual network of nodes connected through relations (conceptual graph). Taking into account that nodes represent domain objects or classes and edges relations among them, it is possible to establish a semantic network in which SA can be applied. The process performed by the algorithm is based on a thorough method to go down the graph using an iterative model. Each iteration is comprised of a set of beats, a stepwise method, and the checking of a stop condition. Following the different stages of SA are presented and defined:



**Fig. 1.** Graphical model of *Spreading Activation*

**Preadjustement:** This is the initial and optional stage. It is usually in charge of performing some control strategy over the target semantic network.

**Spreading:** This is the spread stage of the algorithm. Concepts are activated in activation waves. The spreading node activates its neighbor nodes, see Fig. 2.

The calculation of the activation rank  $I_i$  of a node  $n_i$  is defined as follows:

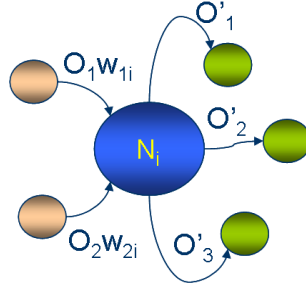
$$I_i = \sum_j O_j \omega_{ji} \quad (1)$$

$I_i$  is the total inputs of the node  $n_i$ ,  $O_j$  is the output of the node  $n_j$  connected to  $n_i$  and  $\omega_{ji}$  is the weight of the relation between  $n_j$  and  $n_i$ . If there is not relation between  $n_j$  and  $n_i$  then  $\omega_{ji} = 0$ .

The activation function  $f$  is used to evaluate the “weight” of a node and decide if the concept is active.

$$N_i = f(I_i) = \begin{cases} 0 & \text{if } I_i < j_i \\ 1 & \text{if } I_i > j_i \end{cases} \quad (2)$$

$N_i$  is 1 if the node has been activated or 0 otherwise.  $j_i$ , the threshold activation value for node  $i$ , depends on the application and it can change from a node to others. The activation rank  $I_i$  of a node  $n_i$  will change while algorithm iterates.



**Fig. 2.** Activation of concepts in *Spreading Activation*

**Postadjustment:** This is the final and optional stage. As well as *Preadjustment* stage, it is used to perform some control strategy in the set of activated concepts.

### 3 Related Work

Since SA was introduced by [9] in the field of psycho linguistics and semantic priming it has been applied to the resolution of problems with regards to the behaviour of the brain using a connectionist method to provide an “intelligent” way to retrieve information and data.

The use of SA was motivated due to the research on graph exploration [27,3,8]. Nevertheless the success of this technique is specially relevant to the fields of Document [12,23,30] and Information Retrieval [11,4,1,21,27].

In recent years and regarding the emerging use of ontologies in the Semantic Web area new applications of SA have appeared to explore concepts [28] and browse taxonomies and graph-based knowledge structures [7,24,13,25]. Other application of this technique lies in the data mining [33] field.

Moreover some scenarios have taken advantage of SA to provide new enriched services of annotation [19,6], tagging [17,18] or recommendation [16,20]. It has been also used in the development of semantic search [31,34] engines based on hybrid approaches [5,29], user query expansion [26] combining metadata and user information or improving web data annotations [19].

## 4 ONTOSPREAD API

### 4.1 Constrained Spreading Activation

One of the leading features of SA techniques are their flexibility to fit to the resolution of different kind of problems. From the configuration point of view some constraints presented in [8] have been customized improving the expected outcomes of the execution according to the domain problem.

**Distance:** nodes far from an activated node should be penalized due to the number of needed steps to reach and activate them.

**Path:** the activation path is built by the activation process from a node to other and this process can be guided according to the weights of relations (edges).

**Multiple outputs (Fan-Out):** nodes “highly connected” can guide to a misleading situation in which activated and spread nodes are not representative, these nodes should be skipped or penalized by the algorithm.

**Threshold activation:** a node  $n_i$  will be spread *iff* its activation value,  $I_i$ , is greater than a threshold activation constant  $j$ .

The abovementioned theoretical model in Sect.?? is an excellent start point to design an API for SA but from the domain expert point of view some requirements are missing (FIXME: ref) to provide a configurable set of techniques based on SA. That is why a set of extensions are proposed to deal with the specific features of ontologies and RDF graphs.

**Context of activation  $\mathbb{D}_{com}$ :** concepts can be defined in different domains or schemes. The double process of activation and spreading will only be carried out in the context  $\mathbb{D}_{com}$ .

**Definition 1.** Let  $\mathbb{D}_{com}$  an active domain, if a concept  $c_i$  is activated or spread then  $c_i \in \mathbb{D}_{com}$ .

**Minimum activation value  $N_{min}$  :** concepts with an activation value  $N_k$  greater than  $N_{min}$  will only be spread. This constraint comes from the theoretical model of SA.

**Maximum number of spread concepts  $M$  :** the process of activation and spreading will be executed, at the most, until  $M$  concepts had been spread.

**Minimum number of spread concepts  $M_{min}$  :** the process of activation and spreading will be executed, at least,  $M_{min}$  concepts had been spread.

**Time of activation  $t$ :** the process of activation and spreading will be executed, at the most, during  $t$  units of time.

**Output Degradation  $O_j$ :** one of the keypoints to improve and customize the algorithm is to define a function  $h$  that penalizes the output value  $O_j$  of a concept  $c_j$ .

1. Generic customization:  $h$  calculates the output of a concept  $c_j$  according to its degradation level.

$$O_j = h(I_j) \quad (3)$$

Basic case: if  $h_0 = id$ , the output value  $O_j$  takes the level of the activated concept  $c_j$  as its value.

$$O_j = h_0(I_j) = I_j \quad (4)$$

2. Customization using **distance**:  $h_1$  calculates the level activation of the concept  $c_j$  according to the distance from the initial concept  $c_l \in \Phi^3$  that has activated it. The activation value have to decrease if the distance from  $\Phi$  grows thus the algorithm follows a path from  $c_l$  to  $c_j$ :  $I_l > I_j$ . The function  $h_1$  penalizes the output of concepts (decreasing their rank) far from the “activation core” and rewards closed concepts. Thus, let  $d_j$ , where  $d_j = \min\{d_{lj} : \forall n_l \in \Phi\}$ :

$$O_j = h_1(I_j, d_j) = \frac{I_j}{d_j} \quad (5)$$

3. Customization using **beats**: the function  $h_2$  calculates the degradation of the concept using the number of iterations  $k$ :

$$O_j = h_2(I_j, k) = (1 + \frac{I_j}{k}) \exp(-\frac{I_j}{k}). \quad (6)$$

## 4.2 Design of Spreading Activation

The entry point to *SA* techniques is the set of initial concepts ( $Q_{sem}$ ) that will generate a new set of the most relevant concepts ( $Q'_{sem}$ ). Ontologies based on the RDF graph model are a graph where each node  $n_i$  represents a concept  $c_i$  and the edge  $\omega_{ji}$  is the semantic relation between  $c_j$  y  $c_i$ . The final result of the algorithm is a set of sorted pairs  $(n_i, I_i)$  that build  $Q'_{sem}$ , where  $n_i \approx c_i$  and  $I_i \approx w_i$  (the relevance of the concept).

The implementation of *SA*, see Algorithm.4.2, comprises of two sets of concepts that store information about the state of the algorithm: 1)  $\mathbb{D}_{com}$  are all the concepts in the semantic network and 2)  $\Phi^4$  is the set of initial activated concepts,  $c_j^k$  is the spreading concept at the  $k$ -esima iteration (from which other concepts are activated).

**Set  $\mathcal{A}$ :** queue of **activated** concepts (candidates to be spread).

$$\mathcal{A}^0 = \Phi \quad (7)$$

$$\mathcal{A}^k = (\mathcal{A}^{k-1} \cup \{c_i : \forall c_i / \omega_{ji}^k > 0\}) - \{\mathcal{G}^k\} \quad (8)$$

**Set  $\mathcal{G}$ :** set of spread concepts:

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<sup>3</sup> Set of initial concepts.

<sup>4</sup>  $\Phi \equiv Q_{sem}$ .

$$\mathcal{G}^0 = \emptyset \quad (9)$$

$$\mathcal{G}^k = \mathcal{G}^{k-1} \cup \{c_j^k\} \quad (10)$$

The output of the algorithm is the new enriched query  $\mathcal{G}^k = Q'_{sem}$  made up of the set of weighted concepts.

Finally, the calculus of the activation value of a concept  $c_i$  at iteration  $k$ , indicated by  $I_i^k$ , is defined. At 0 iteration the activation value  $c_i$  is calculated as follows:

$$I_i^0 = \begin{cases} 1 & \text{si } c_i \in \Phi \\ 0 & \text{si } c_i \notin \Phi \end{cases} \quad (11)$$

at  $k$  iteration, the activation value of  $c_i$  from element  $c_j^k$  that activates  $c_i$  is calculated as follows:

$$I_i^k = \begin{cases} I_i^{k-1} & \text{si } \omega_{ji}^k = 0 \\ I_i^{k-1} + \omega_{ji}^k I_j^{k-1} & \text{si } \omega_{ji}^k > 0 \end{cases} \quad (12)$$

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**Algorithm 1** *Pseudocode of Spreading Activation*

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**Require:**  $\Phi \neq \emptyset$

**Ensure:**  $\mathcal{G} \neq \emptyset$

$\mathcal{A} \leftarrow \Phi$

$\mathcal{G} \leftarrow \emptyset$

**while**  $\mathcal{A} \neq \emptyset$  **AND**  $\text{card}(\mathcal{G}) < \mathcal{G}_{\min}$  **AND**  $N_k \geq N_{\min}$  **do**

$n_k \leftarrow \text{extract}(\mathcal{A})$

$\mathcal{G} \leftarrow \{n_k\} \cup \mathcal{G}$

**for all**  $n_i/w_{ki} > 0$  **do**

$N_i \leftarrow N_i + w_{ki} N_k$

$\mathcal{A} \leftarrow (\{n_i\} \cup \mathcal{A}) - \mathcal{G}$

**end for**

**end while**

**return**  $\mathcal{G}$

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### 4.3 Improving Spreading Activation

Some improvements in the calculus of the activation value of a concept have been introduced in order to get FIXME. If some paths of activation converge to the same node and the source nodes are different then this node should be important and a reward is applied to the nodes presented in these paths.

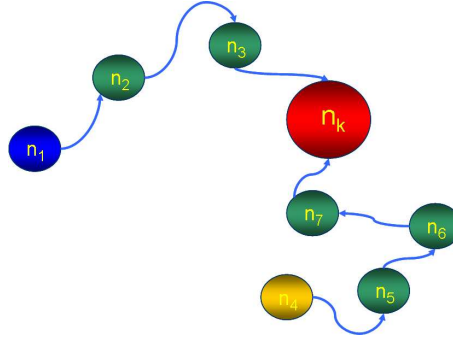
**Definition 2.** Let  $p_i$  the number of paths that start and finish in different nodes of  $\Phi^5$  and they go through the node  $c_i$  and they only contain nodes belonging to  $\mathcal{G}$ . This improvement assigns a new value to the activation value of each node  $c_i$  indicated by  $I_i^*$  and it is calculated by means of the function  $g$ :

$$I_i^* = g(I_i, p_i) \quad (13)$$

In this case, a relaxed reward function has been chosen, Eq. 14, and, it is applied in the *Postadjustment* stage, thus the original semantics and behaviour of *SA* algorithm is not broken.

$$g(x, y) = x(\log(y + 1) + 1) \quad (14)$$

$x$  is the reward constant, it can be defined according to the context and  $y$  is the number of times that a concept  $c_i$  must be rewarded.



**Fig. 3.** Paths and rewards in *Spreading Activation*

#### 4.4 Refining Spreading Activation

The whole configuration of the algorithm can be made by default but a customization to a particular domain should be performed by a domain expert taking into account the specific issues of this domain and considering it as a new stage of the ontology o graph modelling process.

1. The algorithm is highly coupled to the target ontology and domain. Thus the adjustment and customization of the algorithm should be created or supervised by experts with domain knowledge.
2. The establishment of relation weights among concepts is the key point to customize *SA* techniques.

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<sup>5</sup> The reward is not applied to nodes in  $\Phi$ .



Since *SA* uses weights in relations (or edges) to calculate the activation value of the concepts, different “patterns”, see Table 1, have been identified to manage the direction of the spreading process.

Spread Direction	Definition	Key Relation
Ascending	It seeks for the activation of concepts more generic than the current.	“superclass”
Descending	It seeks for the activation of concepts more specific than the current.	“superclass”
Nominal	It seeks for the activation of instances instead of concepts.	“instance of”
Cross	It seeks for the activation of concepts and instances connected through a certain relation $\mathcal{R}$ .	$\mathcal{R}$

**Table 1.** Patterns of direction control in *SA*.

These control patterns can be put together in order to fit as much as possible the focus and direction of the double process of activation and spreading.

#### 4.5 Design and implementation of ONTOSPREAD API

ONTOSPREAD API is addressed by an open design and the application of best practices on software design [15,2] and development [?,14]. The next basic objects need to implement *SA* techniques have been identified.

- The *Player* class handles the execution of the algorithm in a stepwise way. This is an application of the *Iterator* design pattern to the activation and spreading processes. The state of the algorithm is captured in a separate class, *OntoSpreadState* thus it is possible to serialize the state and back to a previous one.
- The *SA* process comprises of three sub-processes:
  1. *Preadjustment*: *OntoSpreadPreAdjustment*; 2. *Spreading* (activation and spreading) with constraints: *OntoSpreadRun*; and 3. *Postadjustment*: *OntoSpreadPostAdjustment*.

Moreover, the process carries on the information about the knowledge base using the DAO pattern thus the API is independent from the modelling language of the semantic network. Currently, OWL and RDF are supported.

**Fig. 4.** ONTOSPREAD Overview Diagram

#### 4.6 Designing the state of SA

The keypoint to design the algorithm lies in how and where the information will be available at different iterations. Secondly, an unique entry point to the state of the algorithm should be available trying to avoid illegal accesses to the state. This object stores the next information: 1. Spread concepts. 2. Active concepts. 3. Paths of activation. 4. Concept to be spread. 5. Generic swap area (to share information among iterations).

#### 4.7 Designing the restrictions of SA

The extensibility and flexibility of the algorithm is subjected to a good design of the restrictions and to the procedure of their evaluation. The next features and design patterns are used to design and implement the model of restrictions for SA:

- Any restriction can be considered as a simple restriction and can be evaluated to a boolean value.
- Conditions or actions in the algorithm can be comprised of several restrictions.
- The extension points of the algorithm, included through a *Template Method* design pattern, are strategies to carry out an specific action. Each strategy can be subjected to one or several restrictions.
- Each restriction can be simple or comprised of others. *Composite* pattern.
- Each action is an strategy. *Strategy* pattern.
- One strategy implies one restriction (or a set of them) thus the strategy is a client of the *Composite* of restrictions.
- The evaluation of the restrictions to get their value (boolean) is carried out through a *Visitor* pattern that fits perfectly to evaluate and walk in composite objects.
- The evaluation process consists on:

#### ONTOSPREAD supporting tools

#### 4.8 Use Cases and Scenarios

### 5 Evaluation of ONTOSPREAD API

#### 5.1 ONTOPSREAD API in Action

### 6 Conclusions and Future Work

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