# Web information retrieval inspired by social insect behaviour

Anna Bou Ezzeddine*
Institute of Informatics and Software Engineering
Faculty of Informatics and Information Technologies
Slovak University of Technology in Bratislava
Ilkovičova 3, 842 16 Bratislava, Slovakia
ezzeddine@fiit.stuba.sk

## Abstract

This work is focused on retrieving information from Web, which represents the biggest source of information that could be used by human. In the process of retrieving useful information, new approaches have been established by using different principles and theories. Methods of solving problems inspired by nature or biologically are used in Informatics quite frequently. Their potential is confirmed in proposing new and making the well-known methods of solving various kinds of problems more effective. Inspired by social insect's behaviour and building upon an analysis of related works, we proposed in our work an upgrading of a chosen bee hive model used for retrieving information. The implemented model represents a multiagent system, which uses a bee as a thematic agent for retrieving information from Web. In our work we used an adapted model in order to follow (trace) a story that is developing on the Web that represents a new approach in retrieving information. In this case the time of publishing the story is also important according to the event it is related to. In order to retrieve an increased number of documents of higher quality in the process of searching, we proposed a hierarchical interconnection among several bee hive models. The advantage of the proposed solution in searching with the help of bee hive's metaphor compared to conventional searching are higher flexibility, more effective source searching that changes during the time and an opportunity to react dynamically to these changes.

## Categories and Subject Descriptors

H.3.3 [**Information Storage and retrieval**]: Information Search and Retrieval—*Retrieval Models*, [Search process]; H.3.5 [**Online Information Services**]: Web-based Services; I.2.1 [**Artifical Intelligence**]: Applications and Expert Systems

## Keywords

Web information retrieval, bee hive model, multi-agent systems, story tracking, hierarchical structure

## 1. Introduction

The World Wide Web (the Web for short) has impacted on almost every aspect of our lives. It is the biggest and most widely known information source that is easily accessible and searchable. It consists of billions interconnected documents called Web pages, which are authored by millions of people. Since its inception, the Web has dramatically changed our information seeking behaviour. The Web has also become an important channel for conducting businesses and provides convenient means for us to communicate with each other. It is a virtual society.

The World Wide Web is defined as a wide-area hypermedia information retrieval initiative aiming to give universal access to a large universe of documents [9].

In simpler terms, the Web is an Internet-based information network that allows users of one computer to access information stored on another one through the world-wide network called the Internet.

Social insects living in colonies like ants, bees, termites, wasps are known for their organizational skills, without any central organization [5]. The organization of whole colony is affected by an individual interaction between each other, the interaction between an individual and environment and behaviour of individuals themselves [2]. This work deals with Web information retrieval, while the main part is focused on methods inspired by the behaviour of social insects. It is built on the knowledge described in several publications and focuses on the description of the possible improvements of different approaches.

## 2. Methods inspired by the behaviour of social insects

To solve complex problems, scientists have often been inspired by the behaviour of animals which is observed in nature. At first view the behaviour of individuals may seem very primitive, but as a whole, they can simply and very effectively solve complex problems. A frequent example for inspiration is the problem with collecting food

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by ants, bees or fish. If the observed simple rules are later transferred to the algorithm, they create a simple but very effective means for solving various complex problems.

In the field of artificial life, social insects have a key position, mainly due to the relative simplicity of behaviour of individuals in connection with complex collective behaviour. Communities or colonies of social insects are able to develop the means to solve the problems collectively. The complexity of these tasks exceeds the individual's ability. They are able to solve tasks with no central leadership, with absence of the fixed structures given before, despite the existence of significant internal noises.

Intelligent behaviour of social insects is generated through indirect communication among individuals of colony known as the principle of stigmergy. Word stigmergy by [1] was used in 1950 to name types of interactions between social insects, which originated for example during the construction of termite mounds, ant hills by ants, hives by bees.

Stigmergy is a mechanism of spontaneous indirect coordination between individuals of the community. It is a form of self-organization, where the colony creates complex, apparently intelligent structures without any necessity of central planning and management. It supports effective cooperation between the very simple animals, which do not have to have memory and intelligence. This deadline-stigmergy has been later transferred to other fields including science.

In [3] authors deal with the description of self-organization of the bee colony. The colony selects the best source of nectar by using simple rules. The bees fly off to the environment and find food for the colony. When a bee locates food, returns with it to the hive, while bringing the other bees a report of the food source.

Authors in [25] experimentally proved that a decision which a bee makes in process of searching food is based on very limited information obtained from sources visited before. Despite such a simple behaviour of each bee, the colony chooses the best source of food. The source is selected by an extent of dancing for a better source and an abandonment of poor quality source.

In [27] authors discuss modeling of collective food gathering by bees. Individual-oriented model is constructed to simulate the collective behaviour of real bees during collecting food. Each bee follows the same set of rules of conduct. Intention of the drafters was to create a simulation model, which is going to achieve similar results to those which were published in [25].

The mathematical model which represents the dynamic interaction between bees in the process of carrying food from two sources is described in [4].

On the basis of the mathematical model of [4] there was devised in [10] and presented in [11],[12] a prototype of multi-agent recommender system, using the metaphor of social insect colony behaviour - honey bee dancing. The authors were inspired by [24] and [23] but used different approaches to solve the problem. This issue was discussed also in [13].

## 3. Bee hive metaphor

Modifications and improvements of the referred system [12] were presented in [19]. The authors noticed a deficiency of the model [12] in the way a bee is initially assigned a food source. They introduced a dispatch room into the model and the model has been further parametrized by initial distribution of bees. Resulting from these modifications, they achieved a decrease in the number of bees needed and reduced a probability of abandomning a lasting source of quality.

The model [19] uses a set number of bees to find the best sources by evaluating them and using social interaction to agree upon the best of the sources. The mechanism of interaction is shown in Fig. 1.

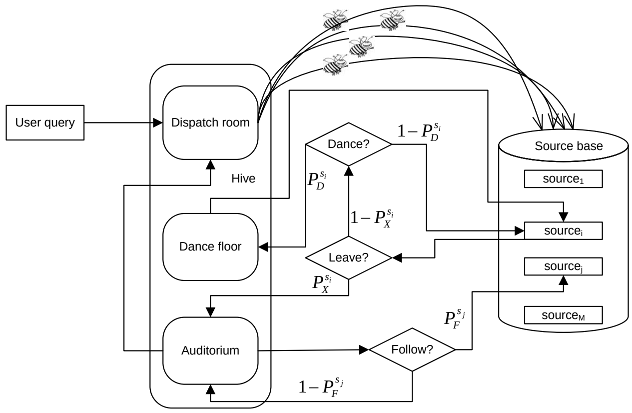


**Figure 1: Model of bee community behaviour by [19]**

Model parameters:

- the total number of bees in a model *N (BIOR+BISB)*;
- initial distribution of bees:*BIOR* represents the number of bees in the auditorium, *BISB* number of bees that fly off into the resource base;
- maximum dancing time for a food source *MDT*, particular dancing time is dependent on the quality of the source ($MDT * quality$);
- maximum time that a bee spends in the observatory *OT*, is fixed, but the bee before ending of this time may be seduced by another bee;
- information noise *NOISE*, accuracy in exchanging information between a dancing bee and an observing bee;
- evaluating error of the source quality *ERR*.

### 3.1 Mechanisms of the model

When a user inputs a search query, the bees leave the dispatch room and they are randomly assigned to the sources. After a bee has collected enough food it returns to the hive. She makes a decision, whether she is going to stay with the source, or abandon it. The probability of staying with the source is equal to the quality of the visited source, if expressed as a number within <0, 1>.

If a bee decides to stay with the source, she makes another decision, whether to forage further, or to start dancing for the source. Again, the probability of deciding to dance is equal to the quality of the source. If the bee decides to start dancing for the source, it moves to the dance floor and starts dancing. The length of a dance depends on a set parameter of the model called 'maximum dancing time' and quality of the source. The better the source is, the longer the bee dances. The bees that decide not to dance return to the same sources they visited before and continue foraging.

If a bee decides to leave the source, she moves into the auditorium to observe the dancing bees, for a set amount of time that depends on a set parameter of the model called observation time. She then considers the sources being propagated at the dance floor by the dancing bees. The chance of choosing a propagated source is equal to the number of bees dancing for the source in the total number of bees. If a bee fails to choose from the propagated sources within the observation time, she transfers into the dispatch room and israndomly assigned to some source. This is important, because if we have fewer bees than sources, we will need a mechanism to find and subsequently propagate those initially unassigned sources.

### 3.2 Experiments with model

We continued with experiments using the modified model [20], [21]. We have made several experiments with the parameters of the model, searching for relevant information in the documents database, calculating PageRank websites. We presented the model extending in [17].

Inspired by the model [22] and papers by [26], [8], [6] we successfully used designed model in stochastic optimalization of mathematical functions [16],[18]. This issue is beyond the scope of this work, therefore we do not present detailed results.

### 3.3 Model parameters

Bee hive model is based on the probability of bees transferring into certain states (dancing, observing, collecting bee). The search results which we receive by this model are to a large extent influenced by the way the model parameters are adjusted.

#### 3.3.1 Parameters N, MDT and OT

We have implemented a graphical user interface to test the suitability of parameters settings $N$, $MDT$, $OT$. We can draw the following conclusions from the test results.

- Dancing time affects the speed of convergence to the promoted source. By increasing of $MDT$ parameter, the number of bees promoting the source changes slowly.
- Observation period of dancing bees affects the rate of convergence to the appropriate source. By increasing the parameter $OT$ bees more converge to the one and look less for new sources. (Increasing $OT$ increases the probability of following the dancing bees, thus following sources that have already been found.)
- Reducing of dancing time and dancing observation causes improvement in quality of search. We get satisfactory search results in terms $MDT = 2$, $OT = 2$, with a smaller number of bees (30), too. Decreasing $OT$ is for quality of search more important than reducing $MDT$.
- There is a high convergence of bees to a limited number of sources in the model. Increasing the parameter $N$ (100) makes an increase in the quality of the sources, but not the amount of promoted sources at the end of search.
- Increasing the number of bees does not replace the need for the recommended parameter settings $MDT = 2$ and $OT = 2$. Even with higher numbers of bees (100), improved search results in different $MDT$, $OT$ set points are not guaranteed.
- By setting of appropriate values of parameters $MDT$ and $OT$ the probability of obtaining the highest quality sources increases. The values of these parameters do not provide a balanced promotion of sources according to their quality.

Fig. 2 shows relatively fast promotion of the finest source ($m1z80$ 98 %), but also a substantial suppression of sources ($m1z74$ 96 %) and ($m1z64$ 95 %), whose quality was only marginally lower. In this search model parameters have these values: $N = 30$, $MDT = 2$, $0T = 2$, 10000 sources.

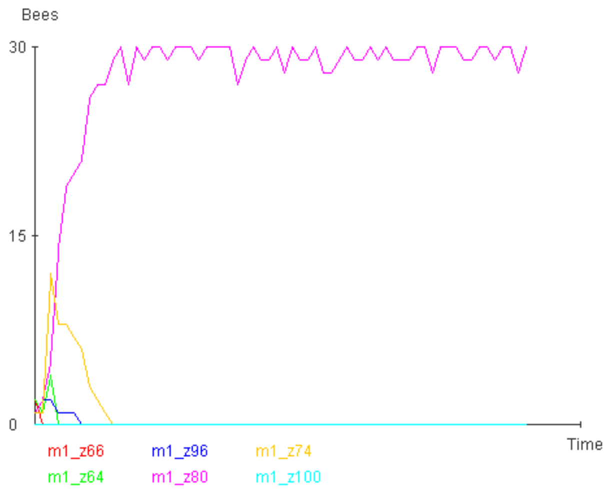


**Figure 2: Experiment: Enforcement of the finest source.**

The aim of our changes is to make bees promoting the sources steadily according to their quality during the search. In this way we ensure an equal distribution of bees and searching around the sources according to the source quality.

#### 3.3.2 Parameter suitability source

Introducing the parameter named suitability is a way to reduce the convergence to a single source and distribute sources for bees according to their quality. Bees visit various sources according to the suitability. Suitability of source $i$ (DESIRE $D_i$) is the value from the interval $< 0, 1 >$ and it is calculated according to equation 1:

$$D_i = Q_i - k * \frac{(DBQ_i)^2}{(N)^2} \quad (1)$$

where $Q_i$ is the quality of source $i$, $DBQ_i$ is the number of bees dancing for the source $i$, $i \in < 1, M >$, where $M$ is the number of sources, $N$ the number of all bees.

By simulation of the adjusted model, we found that assigning a constant $k$ of 0.5 will achieve even distribution of bees and promotion of appropriate sources according to their quality. After the proposed adjustments the bees were evenly distibuted between several sources.

Suitability of the proposal of that change in the model is demonstrated in Fig. 3.

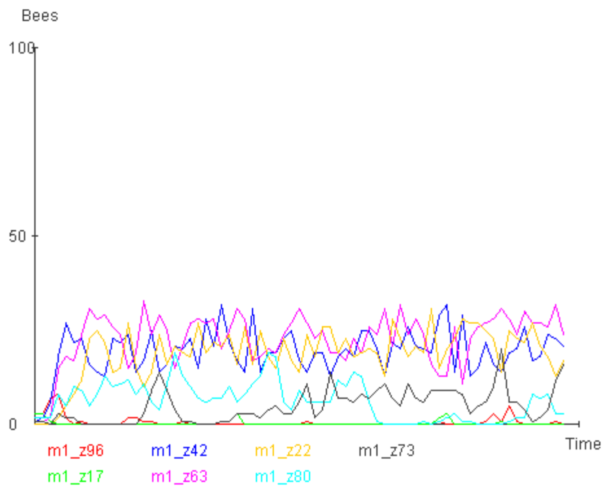


**Figure 3: Experiment: Equitable distribution of bees between multiple sources of food.**

We found a high degree of convergence to a very limited group of sources (1-2) while testing the initial model. By setting the parameters $MDT$ and $OT$ to 2 suitably, we found a high probability of finding the best sources by using not a high number of bees (30).

Modification of the model by using the parameter suitability of source allows us to obtain a wider range of results. Adjustment consists of the introduction of variable assessments of individual sources, based on the number of bees involved in collecting and dancing for the source. In this way, we ensure the distribution of all the bees throughout all time of searching for more sources evenly.

## 4. Web Search

In [7] authors present a comprehensive overview of the current state of algorithms simulating bee swarm intelligence. Different ways of using bee colony in information systems are described in detail. As stated in [7], the priority of our research is Web searching, i.e. on-line searching inspired by the bee swarm behaviour.

We applied our model successfully to the domain of online Web crawling. The aim was to appoint the agents to download the quality pages and to use these pages in system for tracking the evolving story (e. g in the newspapers).

The bees acted as crawlers, their environment was the Internet and their food sources were Web pages. Outside the hive, the bees moved from page to page using the hyper-links searching for new quality pages. Due to their decision making and communication in the hive the bees were able to focus on the more promising sites but kept the ability to react dynamically on the changes in their environment.

Fig. 4 displays behaviour outside the hive bee colony.

When a bee flies outside the hive to the Web page, she estimates its quality and with the probability $q$ she stays with the current page, with probability $1 - q$ she follows one of the links on the page to visit a new source. Then she flies back to the hive with her current source with probability $q$ or stays outside the hive and searches for better sources with the complementary probability. The bee cannot stay outside the hive forever, therefore we used the concept of energy. Every time the bee visits some source, the energy will increment by the quality of the source and decrement by a specified parameter. If the bee has no more energy ($energy <= 0$) she shall return to the hive.

The model has been applied to the problem of tracking a developing story dynamically [15], [14] with a considerable success. The bees have been able to follow a developing story on the Web on-line, recommending Web pages containing very relevant material (news, commentaries etc.) as they were emerging.

### 4.1 Quality calculation

The quality calculation is divided into three components. Each of them can reach their maximal value given by the parameters. The sum of these parameters should be equal to 1.

The count quality component counts the query occurences $n$ on the page and using the $Q_{COUNT}$ parameter calculates the quality according to the following formula:

$$q_{count} = \frac{-1}{2(n + \frac{1}{2Q_{COUNT}})} + Q_{COUNT} \qquad (2)$$

The header quality searches all pages headers and page title for query occurence.It then chooses the minimal header number (for case of $< title >$ it was 0 ..., $< h_6 >$ it was 6) and calculates the quality according to the formula:

$$q_{header} = Q_{HEADER} - h * \frac{Q_{HEADER}}{HEADER_{MAX} + 1} \qquad (3)$$

where $Q_{HEADER}$ is the maximal value allowed for header quality, $h$ is the minimal header number and $HEADER_{MAX}$ is the maximal header number we want to take into account.

The Flesch readability index is an integer indicating how difficult is to understand the document. It is computed according to the formula:

$$FI = 206.835 - (1.015 * ASL) - (84.6 * ASW) \qquad (4)$$

where $ASL$ is average sentence length (syllables/words), $ASW$ is average number of syllables per word (words/sentences). We compute Flesch's readability index only in the case if at least one of the two before mentioned qualities was of a non zero quality. The source obtains this partial quality if Flesch's readability index was from the interval $< 0, 50 >$.

### 4.2 Web story

According to A. N. Whitehead, the founder of symbolic logic, an event is defined as something that happens. Event - a story is an essential element of (physical and mental) events, which can be observed in a period of time. In this interval, it is possible to track the creation, qualitative changes and in the case where the whole event happened in the past, also extinction of events. Tracking the developing story is a new approach of information searching

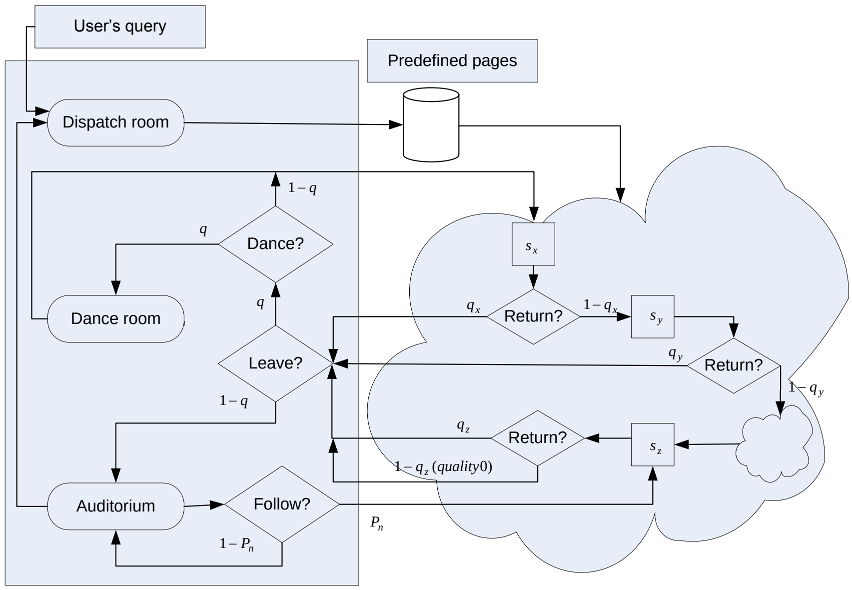


**Figure 4: The behaviour of the bee hive outside the hive [17]**

based on searching, sorting and arranging time information associated with a specific event.

We used the model described above to perform story tracking, an activity performed upon Web on-line. Aim of the on-line search is not to obtain a single piece of information, the aim is to find a relevant set of pages which would form together a story. This should not be a general search engine. Instead, it is supposed to be used on news portals or any other sites containing frequently updated or added information. The best application is for headline stories where new information is being added very often.

Thus our aim was to devise a method implementable on a personal computer that would be capable of supplying documents related to the developing story as they are emerging on the Web for several hours or days. It seems that any such method must include searching the Web. After collecting a set of related documents, it is necessary to filter and cluster the data set. News portals contain mainly articles, annotations, discussions, blogs and symposia. Articles are important from the aspect of information tracing. Information that was found and sorted was classified according to the publication date.

We used the event of earthquake in Haiti that has been widely monitored by media, at the time as a developing story. In our experiment, three news portals represent the start Web pages: www.pravda.sk, www.sme.sk and www.ta3.com. The key words that we looked for were: earthquake and Haiti.

The process of following the story was divided into three parts. The first part is represented by an experiment that took place from $13^{th}$ January 2010 10:00 a.m. to $14^{th}$ January 2010 4:00 p.m.

We used parameters and the settings from the table 1.

In the first part 9327 Web pages were found, out of which 1066 were of non zero quality. Web pages of non zero quality where divided into 5 classes: informative pages,

**Table 1: Parameters used in Web story**

| | |
|---|---|
| Number of bees | 30 |
| Maximal dancing time | 2 |
| Maximal time in auditorium | 2 |
| Default energy | 1 |
| Energy decrement | 0,05 |
| Max. count quality | 0,7 |
| Max. header quality | 0,15 |
| Max. header number | 3 |
| Flesch's readability index | 0,15 |

list of articles, discussions, blogs, graphic contents. Discussions and blogs are irrelevant because they represents only reactions to the event. The list of articles has no informative value, but is important for page discovery.

During the first part of experiment 217 informative pages with a quality higher than 60 percent were found. The most frequently used words on those 217 informative Web pages were: disaster, tragedy, victims, OSN, chaos, help. 13 pages with quality higher than 90 percent were recommended to the user. These Web pages were classified according to the published date extracted from the page.

The second part of the experiment took place $16^{th}$ and $17^{th}$ January 2010 always at the same time: from 8:00 a.m. to 5:00 p.m. 11439 Web pages were found, 1193 with non zero quality. 298 informative Web pages with the quality higher than 60 percent were found. The most frequently used words which occured on the Web pages after $16^{th}$ January 2010 8:00 am were: cadavers, indigence, looting, despair, water, help. Gradually, it was recommended to user 36 informative pages with quality higher than 90 percent during this experiment.

The last part of the experiment took place from $18^{th}$ to $21^{th}$ January 2010, always at the time from 6:00 p.m. to 11:00 p.m. 12576 Web pages were found, out of which 1271 of non zero quality. 327 informative Web pages possesing a quality of above 60 percent were found, 66 Web pages was recommended to user. The most frequently used words on the Web pages after $18^{th}$ January 2010 6:00 p.m. were: water, collections, help, charity, putrefaction, physicians.

When repeating the experiment twice or three times, the algorithm found almost all the Web pages that were marked as relevant by the previous algorithm run, hence supporting a hypothesis that our method based on the modified bee hive model is quite robust.

## 5. Proposing a hierarchy

We contemplated an opportunity of linking several hives to a certain structure by creating a hierarchy, which allows mutual communication not only between individuals in the hive, but also between hives. We hypothesize that an appropriate combination of several hives can improve search results.

We used a regular tree structure, where nodes represent hives and tree leaves represent bees as introduced in [18] and [16]. Each bee is a part of the first level of hive and each hive (except the root hive) is part of some higher level (parent) hive. So, bees are present only at the lowest level.

### 5.1 Bee and hive in a hierarchical hive

Behaviour of a bee in the hive and outside of it is not changed in a hierarchical hive compared behaviour of bee in the original model.

Behaviour of the hive (except for the root one) within its parent hive is very similar to the behaviour of a bee in a hive.

There is a horizontal communication among entities at the same level of hierarchy. Only descendants of one parent can communicate.

Bees communicate only through dance in dance room in their hive, the bee hives by dancing in dance room in their parent hive.

Vertical communication represents communication between the superior and inferior (between bee and hive, hive and its parent hive). In this communication, only directly adjacent entities at different levels (parent, child) can communicate with one another. According to the location of entities in the hierarchy, there are several kinds of communication relations possible, i.e. bee - hive, offspring hive - parent hive, hive - root hive. Vertical communication takes place through abstract bees ($AB$) in the dance room. Actually, these bees do not exist outside the dance room. Number of abstract bees ($db$) promoting source $q_z$ depends on the quality of the source $q_z \in \langle 0.1 \rangle$ and $AB$ parameter.

$$db = q_z * AB \tag{5}$$

Each beehive dance room includes the dancing bees from this hive and the abstract bees, promoting parental hive (except the root one). The source, for which most bees will dance in the dance room, will be evaluated as the best. This source will be promoted by dance between sources on the same level or by abstract bees in their offspring hives.

### 5.2 Story tracking using a hierarchical hive

The event that was tracked was the earthquake in Haiti in 2010.

We used three-level hierarchy (1-2-3-2-10) with 120 bees at the lowest level in this experiment.

The experiment was performed on $27^{th}$ April 2010 from 2:00 to 12:00 p.m. In this experiment, we downloaded 35247 pages of which 2875 have non-zero quality. We performed the same experiment on $28^{th}$ April 2010 at the same time with a beehive without hierarchy to compare searching quality.

We searched 140 sites, which present 86.4% from previously searched sites (162) with a quality higher than 90% while a similar number of pages (35711) was downloaded.

Table 2 shows the total number of pages with quality higher than 90% looked up in different stages.

**Table 2: The number of looked up sites in various stages of the search**

| search | page with quality higher than 90 % |
|---|---|
| 1st search stage | |
| 1st Phase | 13 |
| 2nd Phase | 13+23 |
| 3rd Phase | 13+23+30 |
| 2nd search stage | |
| hierarchical model | 13+23+30+96 |
| basic model | 8+15+25+93 |

When comparing the results of these searches, we found that the original model was not able to find especially earlier published sources. We sought only 8 sources in the first phase (61.54% of sources compared to the hierarchical model), 15 newly discovered sources in the second phase (65.22%), 25 newly discovered sources in the third phase (83.33%), 93 newly discovered sources found in the second stage (96.88%).

It is to be noted that by using a hierarchical model, searching speed does not improve, but we can observe an increase in precision search and discovery of more quality sources.

## 6. Conclusions

The proposed modified model represents a multiagent system which uses a bee as a topical agent for searching information on the Web.

Searching for information from websites by the method using the metaphor of the bee hive is a new look at options and ways to search. The modified model was used to track current events:

- earthquake in Haiti,
- the fall of the Polish government aircraft
- floods in Australia.

Experiments ran for several hours to days, during which we have sought, evaluated and recommended the highest quality sources to the user. The searching was online. The search was not stopped in local extremes. The user has an opportunity to change the quantity and quality of the displayed and recommended sources, which are grouped by quality and date of publication during the search.

We achieved an increase in the amount of searched quality sources by using hierarchical hive.

From the experiments we can conclude the following:

- the method is able to look for Web pages and evaluate the quality of the found Web pages automatically,
- it can collect relevant pages,
- it can reconstruct the story backwards in time,
- it can monitor the story that is developed during the search,
- it provides statistical results about the searching process,
- by means of this method we can obtain the most frequently used words on time distinguishable Web pages.

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## References

[1] E. Bonabeau, G. Thraulaz, J. Deneubourg, S. Aron, and S. Camazine. Self-organization in social insects. *Trends in Ecology and Evolution*, 12:188–193, 1997.

[2] E. Bonabeau, G. Thraulaz, and M. Dorigo. *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, 1999.

[3] S. Camazine, J. Deneubourg, N. Franks, J. Sneyd, G. Theraulaz, and E. Bonabeau. *Self-organization in Biological Systems*. Princeton University Press, 2003.

[4] S. Camazine and J. Sneyd. A model of collective nectar source selection by honey bees: Self-organization through simple rules. *Journal of Theoretical Biology*, 149(4):547–571, 1991.

[5] D. Gordon. The organization of work in social insect colonies. *Nature*, pages 121–124, 1996.

[6] D. Karaboga. An idea based on honey bee swarm for numerical optimisation. In *Technical Report-TR06*. Erciyes University, Engineering Faculty, Computer Engineering Department, 2005.

[7] D. Karaboga and B. Akay. A survey: algorithms simulating bee swarm intelligence. *Artificial Intelligence Review*, 31:61–85, June 2009.

[8] W. Li-Pei, C. Y. Puan, M. Yoke-Hean, and C. S. Chong. Exploring social behaviour of honey bees searching on the web. In *Bee Colony Optimisation algorithm with Big Valley landscape exploitation for Job Shop Scheduling problems*, pages 2050–2058. Winter Simulation Conference, 2007.

[9] B. Liu. *Web Data Mining: Exploring Hyperlinks,Contents,and Usage Data*. Springer-Verlag, Berlin Heidelberg, 2007.

[10] F. Lorenzi, D. S. dos Santos, and A. Bazzan. *Case-based Recommender Systems: a unifying view*. LNCS/LNAI State-of-the-Art Survey book on Intelligent Techniques in Web Personalization, 2005.

[11] F. Lorenzi, D. S. dos Santos, and A. Bazzan. Case-based recommender systems inspired by social insects. In *In XXV Congresso da Sociedade Brasileira de Computacao*, July 2005.

[12] F. Lorenzi, D. S. dos Santos, and A. Bazzan. Negotiation for task allocation among agents in case-based reccommender systems: a swarm-intelligence approach. In *IJCAI-05 Workshop on Multi-Agent Information Retrieval and Recomander Systems*, pages 23–27. Edinburg, 2005.

[13] F. Lorenzi and F. Ricci. Case-based reasoning and recommender systems. In *Technical report, IRST*, 2004.

[14] P. Navrat and A. BouEzzeddine. Bee hive at work: Following a developing story on the web. In *IFIP Advances in Information and Communication Technology*, volume 331, pages 187–196. Springer Verlag, 2010.

[15] P. Navrat, L. Jastrzembska, and T. Jelinek. Bee hive at work: Story tracking case study. In *Proceedings of the 2009 IEEE/WIC/ACM International Joint Conference on Web Intelligence and Intelligent Agent Technology - Volume 03*, WI-IAT '09, pages 117–120, Washington, DC, USA, 2009. IEEE Computer Society.

[16] P. Návrat, A. BouEzzeddine, L. Jastrzembska, and T. Jelínek. Exploring the bee hive metaphor as a model for problem solving: serach, optimisation, and more. In *Web Intelligence and Intelligent Agents*, pages 429–446. Vukovar : In-Tech, 2010. - ISBN 978-953-7619-85-5., 2010.

[17] P. Návrat, L. Jastrzembska, T. Jelínek, A. BouEzzeddine, and V. Rozinajová. Exploring social behaviour of honey bees searching on the web. In *IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology (Workshops)*, pages 21–25. IEEE Computer Society, Silicon Valley, Los Alamitos USA, 2-5 November 2007.

[18] P. Návrat, T. Jelínek, and L. Jastrzembska. Bee hive at work: A problem solving, optimizing mechanism. In *I World Congress on Nature and Biologically Inspired Computing (NaBIC'09) 8th International Conference on Computer Information Systems and Industrial Management Applications (CISIM2009)*. PSG College of Technology, Coimbatore, India, December 2009.

[19] P. Návrat and M. Kováčik. Web search engine as a bee hive. *IEEE/WIC/ACM International Conference on Web Intelligence*, pages 694–701, 2006.

[20] P. Návrat, M. Kováčik, A. BouEzzeddine, and V. Rozinajová. Information retrieval using honey bees. *Znalosti 2007, University of Technology in Ostrava*, ISBN 978-80-248-1279-3:63–74, Ostrava 2007.

[21] P. Návrat, M. Kováčik, A. BouEzzeddine, and V. Rozinajová. The metaphor of the bee hive - search and recommendations information model. *Cognition and Artificial Life VII*, pages 249–258, Smolenice 2007.

[22] D. Pham, A. Ghanbarzadeh, E. Koc, S. Otri, S. Rahim, and M. Zaidi. The bees algorithm - a novel tool for complex optimisation problems. In *http://conference.iproms.org/the bees algorithm a novel tool for complex optimisation problems.*, 2006.

[23] P. Resnick, N. Iacovou, M. Suchak, P. Bergstrom, and J. Riedl. An open architecture for collaboretive filtering of net news. *In Proceedings ACM Conference on Computer-Supported Cooperative Work*, pages 175–186, 1994.

[24] J. Schafer, J. Konstan, and J. Riedl. E-commerce recommendation applications. *Data Mining and Knowledge Discovery*, 5(1/2):115–153, 2001.

[25] D. Selley, S. Camazine, and J. Sneyd. Collective decision-marking in honey bees: How colonies choose nectar sources. *Behavioral Ecology and Sociobiology*, 28:277–290, 1991.

[26] D. Teodorovic and M. D. Orco. Bee colony optimisation: Cooperative learning approach to complex transportation problems. In Proc.:16th Mini - EURO Conference and 10th Meeting of EWGT, Poznan 2005.

[27] H. Vreis and J. Biesmeijer. Modelling collective foraging by means of individual behaviour rules in honey-bees. *Behav Ecol Sociobiol*, 44:109–124, November 1998.

## Selected Papers by the Author

P. Návrat, A. Bou Ezzeddine, L. Jastrzembská, T. Jelínek. Exploring the bee hive metaphor as a model for problem solving: serach, optimisation, and more. *In: Web Intelligence and Intelligent Agents. - Vukovar : In-Tech*, 978-953-7619-85-5: 429–446, 2010.

A. Bou Ezzeddine. Web information retrieval inspired by social insect. In *Advanced software design methods. Advanced methods of search, representation and presentation of information. Publishing Slovak University of Technology in Bratislava, FIIT*, 978-80-227-3139-3: 303–329, 2009.

P. Návrat, A. Bou Ezzeddine. Bee hive metaphor for solving problems in artificial intelligence. In *Artificial Intelligence and Cognitive Science II. Publishing Slovak University of Technology in Bratislava*, 978-80-227-3284-0: 381–407, 2010.

M. Barla, M. Bieliková, A. Bou Ezzeddine, T. Kramár, M. Šimko, O. Vozár. On the impact of adaptive test question selection for leatning efficiency. In *Computers & Education*. ISSN 0360-1315, Vol.55, Iss. 2: 846–857, 2010.

P. Návrat, M. Kováčik, A. Bou Ezzeddine, V. Rozinajová. Web search engine working as a bee hive. In *Web Intelligence and Agent Systems: An International Journal*. - ISSN 1570-1263, Vol.6, IOS Press, pages 441–452, 2008.

P. Návrat, T. Taraba, A. Bou Ezzeddine, D. Chudá. Context Search Enhanced by Readability Index. In *IFIP Series, Vol. 276: Artificial Intelligence in Theory and Practice II. IFIP 20th World Computer Congress, TC 12: IFIP AI 2008 Stream, September 7-10, 2008, Milano, Italy - New York : Springer Science+Business Media*, LLC. - ISBN 978-0-387-09694-0: 373–382, 2008.

P. Návrat, A. Bou Ezzeddine. Bee Hive at Work: Following a Developing Story on the Web. In *IFIP Advances in Information and Communication Technology. - : Springer Verlag Vol. 331 Artificial Intelligence in Theory and Practice III : Third IFIP TC 12 International Conference in Articifial Intelligence, IFIP AI 2010, held as part of WCC 2010, Brisbane, Australia*, September 2010, pages 187–196, 2010.

P. Návrat, A. Bou Ezzeddine, L. Slížik. Mining Overall Sentiment in Large Sets of Opinions. In *Advances in Intelligent Web Mastering - 2 : Proceedings of the 6th Atlantic Web Inteligence Conference - AWICt'2009, Prague, CzR. - : Springer Science+Business Media B.V., 2010*, ISBN 978-3-642-10686-6: 167–173, 2010.

P. Návrat, L. Jastrzembská, T. Jelínek, A. Bou Ezzeddine, V. Rozinajová. Exploring Social Behaviour of Honey Bees Searching on the Web. In *IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (Workshops), Silicon Valley, California, USA, 2-5 November 2007. - Los Alamitos, CA 90720-1314 : IEEE Computer Society*, ISBN 0-7695-3028-1: 21–25, 2007.

P. Návrat, M. Kováčik, A. Bou Ezzeddine, V. Rozinajová. Information retrieval using honey bees. In *Znalosti 2007, University of Technology in Ostrava*, ISBN 978-80-248-1279-3: 63–74, 2007.

P. Návrat, M. Kováčik, A. Bou Ezzeddine, V. Rozinajová. The metaphor of the bee hive - search and recommendations information model. Cognition and Artificial Life VII. - Opava: Silesian University In *Cognition and Artificial Life VII. - Opava: Silesian University*, ISBN 978-80-7248-412-6: 249–258, 2007.

P. Návrat, A. Bou Ezzeddine, L. Jastrzembská, T. Jelínek. The Bee Hive At Work: Exploring its Searching and Optimizing Potential. Journal of Universal Computer Science, Vol. 17, 2011, accepted of publication.