

# Web Search Engine as a Bee Hive

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## Abstract

*A new approach to web search that is based on a bee hive metaphor is presented. We proposed a modified model of a bee hive. Our model comprises of a dance floor, an auditorium, and a dispatch room. We have shown that the model is a true model of a bee hive in the sense it simulates several kinds of its typical behaviour. However, more importantly it is a simple model that describes some processes taking place in web search. Our model incorporates also several kinds of uncertainty. The experiments show that uncertainty increases robustness of the search and makes it actually more efficient.*

## 1. Introduction

The world wide web contains a lot of information, some of it undeniably useful. It is definitely not the case, as the popular saying goes, that “everything is on the web”. Nevertheless, the volume of information that is somewhere on the web is growing continuously, opening, by the way, both opportunities and threads. The fact that the information is somewhere on the web does not imply automatically that it is available (i.e., it can be accessed, retrieved or found by search) immediately, or that it will be available with the given methods at all. Role of search, viewed as a more general process, is crucial.

From this more general perspective, there should be left no directions unexplored, if they could only contribute to some improvement of the web searching process. On the other hand, it may be useful to narrow the perspective so that a productive procedure emerges. For example, it may be useful to consider recommending information found on the web, or even more specially recommending a case from a base of cases.

We propose to explore possibilities open by considering behaviour of social insects. Social insects (ants, honey bees, termites, wasps etc.) show a remarkable level of social behaviour. In particular, they communicate, albeit in a very elementary way, with each other. For example, they may communicate regarding the location of

food sources. They even collaborate towards achieving some goal. In particular, they may collaborate regarding bringing the food back once it is found. They distinguish themselves by their organisation skill without any centralised control (Gordon, 1996). The interactions among individuals, between the individuals and the environment along with the behaviours of the individuals themselves allow organisation to emerge.

Among social insects, ants (various species) seem to have gained the biggest popularity as the living creatures that produce a collective behaviour that may serve as a model of solving some real world problem.

Our hypothesis is that the behaviour the particular social insects show is an instructive inspiration to develop a model of searching the web for a source of information. We focus our attention to another kind of social insects, i.e. bees.

## 2. A bee hive

Behaviour of honey bees, *Apis mellifera* has been studied extensively by natural scientists, e.g. sociobiologists and behavioural physiologists. One of their aims has been, from our perspective, to formulate a model of bees' behaviour, specifically of their collective nectar source selection. Basically, there are various approaches possible: e.g., to build a simulation model, or an analytical model expressed using differential equations. A mathematical model of (Camazine, Sneyd, 1991) has proven to be especially inspiring. A very elaborated model has later been presented by (de Vries, Biesmeijer, 1998).

Honey bees are social insects who live in colonies. Bees collect food (nectar) from sources distanced up to 10 km from the hive. The colony uses simple rules to dispatch bees towards the best nectar source available. In this process of foraging, the bees return with nectar and the information about its source. Since the sources are not constant, but new ones appear here and there from time to time, as well as the existing ones become exhausted, the information about nectar sources is crucial. The colony keeps on adapting itself to the ever changing situation. To

be able to do so, and to maintain a sufficient influx of food, some division of labour force between exploring the surrounding countryside for new sources and exploiting the existing ones is necessary. In other words, there are bees, which go on a foraging mission, but there may be other ones, which are explorers at the given moment.

The foraging bees are able to pass the information they have on the location of the food source they visited onto other bees, and other bees are able to receive that information. Waggle dance plays an important role in the process of communication plays. Many have studied the mechanism of the waggle dance, the information that is communicated and the way it is actually done (von Frisch, 1967). It is hypothesized that distance and direction are encoded in the waggle dance, although they may not be the only types of information that the foraging bees are guided by. Discussions about these topics, no matter how interesting they may be, are clearly outside the scope of this research. We shall assume that the waggle dance is a means of communicating a food source. The dancer lets know not only distance and direction of the food source; duration of dancing is influenced by the quality of the source.

### 3. Bee hive modelling

There have been efforts to develop a model of a bee hive. The theoretical model by (Camazine, Sneyd, 1991) supposes that bees either unload nectar they have just brought from source S, or dance promoting source S, or continue foraging at source S, or observe dancers promoting sources S1, S2,..., or follow a new source from S1, S2,... after observing. Each of the choices can be characterised quantitatively by probabilities.

The authors experimented with the model. Their experiment aimed at investigating how colonies choose among nectar sources (Seeley, 1991). In the vicinity of a colony, there were placed two nectar sources, one of them 400 m to the north, the other one 400 m to the south. 12 bees were trained to fly to the north source, 15 other bees to the south source. The sources were of different quality. The south one was better (sugar concentration of 2.5 units) than the north one (1.0 units) initially. At noon, however, the sources were swapped. Next morning, the sources were swapped again, and at noon once again. Empirical observation showed that number of bees foraging for the better source was increasing in time, whereas number of bees foraging for the worse source remained low. After the quality reversal, the trends reversed, too. Simulation experiments with the model yielded a degree of similarity with the empirical observations (Fig. 1).

Some years later, de Vries and Biesmeijer (1998) attempted to build a different simulation model that would as a minimum give experimental results similar to the original empirical experience of (Seeley, 1991). However, their ambitions went beyond that. The simulation model

allows to study rules, according to which bees behave. Indeed, they succeeded to formulate a set of rules. Their concept of forager bee is more refined. A potential forager bee is initially „unemployed“. She does not know about nectar sources outside. Sooner or later, she will fly out for a nectar source. She can fly out „spontaneously“ as an explorer (scout) i.e. not having a definite destination. Or she can visit dance floor, observe waggle dance performers and become a recruit. Then, she starts foraging having stored approximate positional information in her memory, whereas the scout starts without it.

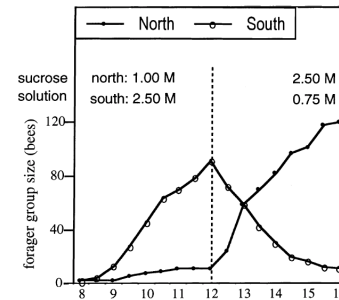


Fig. 1. Result of the experiment aimed at investigating how colonies choose among nectar sources (Seeley, 1991)

Their model has been successful in faithfully simulating some kinds of collective foraging behaviours. Their range is largely determined by the set of rules. If the authors extended it, the range might become larger. In order to model bee hive foraging patterns of behaviour more comprehensively, several other extensions could be proposed.

We have developed another model that allows to simulate some foraging behaviours of a bee hive. However, since our aim has been to create a model that would bring some new ideas to methods of searching the web in a general sense, we shall introduce it in the next section.

### 4. Bee hive metaphor

Honey bees behave in a very interesting way achieving remarkable results, viewing them from the problem solving perspective. To consider bees in this context is a relatively new idea (Tovey, 2004; Lorenzi, 2005).

One of the earliest mentions actually dates back to 1986, when Bullock, Dey and Reilly (1986) suggested in a short note a bee hive model for heterogeneous knowledge in expert system, replacing blackboard by a more de-centralised scratchpad. Dornhaus (1999) studied methods of multi-agent modelling using as an example a bee recruitment. In a conference poster by Schultz (2002), bee foraging has been applied to enhance the collaborative process of filtering information.

One of the most recent projects by Lorenzi et al. (2005) makes use of the bee hive metaphor in a case-based recommender system. Their idea is to use bee dance to retrieve the most similar case to the user's query. They adopted model of Camazine and Sneyd (1991) and combined it with case-based reasoning. Case corresponds to a nectar source. Case base is a set of nectar sources. In a standard case-based recommender, a user query is compared with all cases in the case base. The most similar is returned to the user. In their recommender, bees decide on abandoning or continuing to visit the case depending how similar is the query to the visited case. In other words, the probability of abandoning the source decreases with greater similarity between the query and the case. Bees start foraging randomly and after some time, a case with the clearly highest number of bees emerges.

### 5. Modified bee hive model

Let us now proceed to presenting our model of a colony of bees living in a hive. Its rationale is the following. We want to explore possibilities of defining the process of searching, retrieving etc. information in a way that is similar to the process of searching, bringing etc. food to the bee hive. Intentionally, this is a rather broad formulation, since we want to research in various directions, not making assumptions from the start what will be the best one, if any. First thing to do was to devise a model of a bee hive, that would both be consistent with the biological original and suitable for experimenting in information retrieval.

Therefore, there are two aims regarding our model: it should model behaviour of biological bee hive and it should model information retrieval. However, our main objective is a possible contribution to information retrieval. We shall devise a bee hive model, but we do not obviously aim at a contribution to research in biology. It will suffice if our model exhibits a degree of similarity with the bees' foraging behaviour. One of the properties of our model should be simplicity.

We took an initial inspiration from the model of Lorenzi et al. (2005) who in turn were inspired by Camazine and Sneyd (1991). Our model of the bee hive comprises of a dance floor, auditorium, and dispatch room. We enriched their model by introducing a dispatch room (Fig. 2).

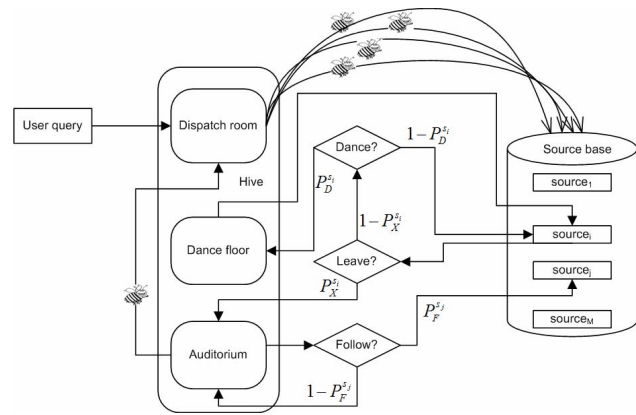


Fig. 2. The bee hive comprises of the *dance floor*, *auditorium* and *dispatch room*

The dispatch room brings additional flexibility to the model. It is an explicit reflection of the hypothesis that some bees in the auditorium may not be ready to follow any one of the advertised sources. They may either not become enthusiastic for any dancer within some reasonable time, or there may not be any dancers to observe within some reasonable time. Therefore, they simply decide better to go foraging blindly than run into a danger of starving in the auditorium. Moreover, bees take off from the dispatch room initially, when a new query arrives.

The model is flexible due to several its attributes which are parameterised. Parameters of our model are the following:

- overall number of bees – in the initial state, it consists of bees in the auditorium (BIOR, bees in the observing room), and those which start foraging (BISB, bees in the source base),
- initial distribution of bees between observers (BIOR) and foragers (BISB),
- maximal time allotted for dancing for a source (maximal dancing time MDT),
- maximal time a bee can spend in the auditorium (observing time OT).

It should be noted that the time a particular bee dances depends on a quality of the source (it equals  $MDT \cdot \text{quality}$ ). The observing time, on the other hand, is either the maximal one or is shorter if the particular bee was attracted by some dancer before the maximal observing time elapsed.

The process of searching for the best source starts when a user query arrives. In response to that, BISB bees take off from the dispatch room randomly, i.e. each of them is sent to a randomly chosen source. Each bee, having visited the source, evaluates it with respect to the user query. The quality  $Q$  of a source is defined as a measure how much the source matches the query.

Having returned to the hive, the bee decides if she abandons the source she just visited (depicted as the selection diamond *Leave?*). The model defines a

probability  $P_X^{s_i}$  ( $P_X^{s_i} = 1 - Q$ ) that the bee abandons the source. The probability of not abandoning the source is obviously  $1 - P_X^{s_i}$ . If the bee decides to abandon the source, she immediately enters the auditorium.

If the bee stays with the source, she has again two options. She can either try to attract some fellow bees for the source or she can take off for another visit to the source (depicted as the selection diamond *Dance*?). The model defines a probability  $P_D^{s_i}$  ( $P_D^{s_i} = 1 - P_X^{s_i}$ ) that the bee goes dancing for the source. The probability of not going to dance is obviously  $1 - P_D^{s_i}$ . In that case she flies to the source. If the bee decides to dance for a source, she immediately enters the dance floor. The better the source quality, the longer she dances for her source. However, the dancing time cannot be longer than MDT. After the bee completes her dancing engagement, she flies to the source which she was trying to advertise by dancing.

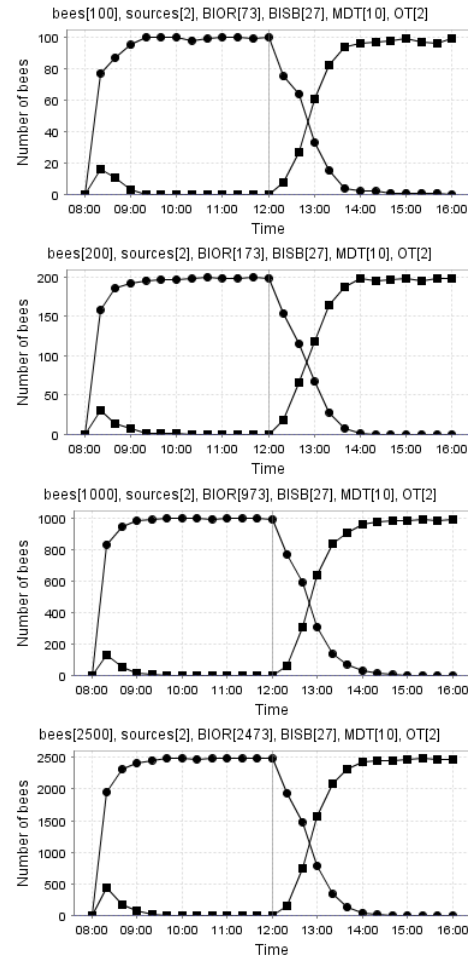
Bees in auditorium observe dancing bees. They try to make a decision which dancer to follow for a source. An observing bee chooses a source by choosing randomly some dancer. Let us assume this dancer advertises a source  $s_j$ . She will fly to this source with a probability

$P_F^{s_j}$ . The model defines the probability  $P_F^{s_j}$  as the number of bees dancing for the source  $s_j$  divided by the number of all dancers. The probability that the bee will not fly to the source  $s_j$  is  $1 - P_F^{s_j}$ . In that case, the bee will choose randomly another dancer.

If the bee does not choose a source within the allotted time, she moves from the auditorium to the dispatch room. From it, she flies to a randomly assigned source. The whole process repeats as described here.

The model just described here is a simplification of models studied by biologists. Still, we hypothesize that it is, at least in some respect, a model of a bee hive. So we do not attempt to model all the aspects of a bee hive's behaviour, having in mind our main goal of developing a model of web search. We tried to perform a similar experiment as the one published by (Seeley, 1991), because this experiment has been used in the literature as a kind of test bed for bee hive models.

In this experiment, our model does not describe uncertainty that experiences a bee when she flies towards a source. For the time being, let us accept the results that show the principal similarity with the experiment, abstracting from the steepness of the curves etc.



**Fig. 3.** From 8 am, bees forage for two sources. The one in the *north* (depicted by a rectangle) is initially worse, the one in the *south* (depicted by a circle) is better. At high noon, the sources are swapped. The bees react accordingly

Some bees have been “trained” initially. They knew, when taking off from the dispatch room, where to fly: 12 bees were trained to fly to the north source, 15 other bees to the south source, totalling 27 bees in the source base. In our experiment, the bees were able to attract other bees to join then foraging for both sources. Soon, however, the better source prevailed. After the sources were swapped at high noon, the bees were able to redirect their mission targets. This is in full conformance with the original experiment.

We present results of our experiments with different numbers of bees in the hive. The basic trend is in all experiments the same. Higher number of bees makes the behaviour smoother.

## 6. Modelling information retrieval

We hypothesise that the bee hive metaphor could prove useful in devising methods of web search, and in particular, of information retrieval from web. We investigate several possible directions of research, including a possible contribution to information recommendation or filtering. At this stage, we wish to present results that may shed some additional light into these considerations, stimulating at the same time further discussion.

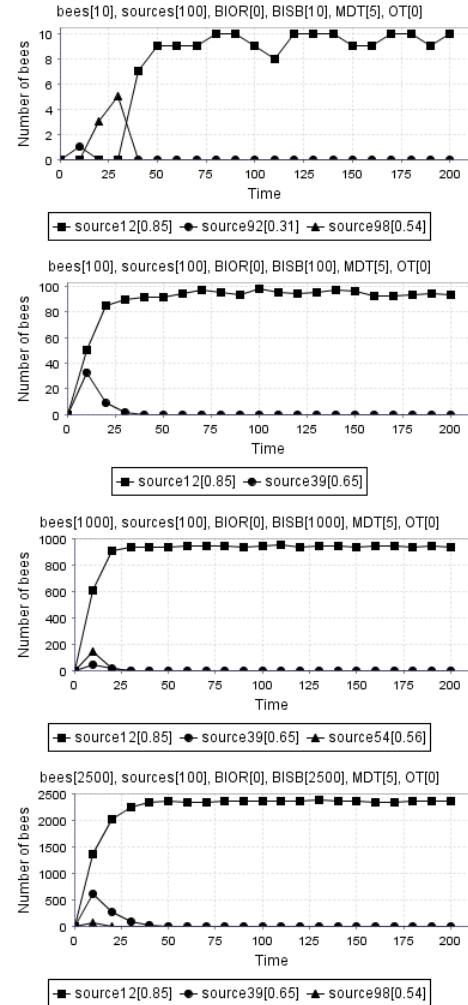
Documents on the web have usually several attributes. Some of them can have only one out of two values, some can have value from an interval of real numbers. This is a fairly general assumption, although we definitely do not claim it covers all possible cases. Let us assume, for the simplicity sake, that the binary valued attributes can be either 0 or 1 and the value 1 is the one matching the user query. Let us further assume that the real valued attributes can have value from the interval  $[0,1]$  and higher value better matches the user query.

We have performed a series of experiments, out of which we shall present here only two. In both experiments, we assumed that the sources have three attributes. Two of them are binary and one is real. In the first experiment, a bee was able to evaluate the source how close is it to the user query by considering all the three attributes. In the second experiment, we tried to create a situation when some bees will use only the first attribute during foraging, some will use only the second attribute and some will use only the third attribute.

Results of the first experiment are shown in Fig. 4. Bees find the best source and massively forage for it. The sources are (listed in the order of quality): source12[0.85], source39[0.65], source54[0.56], source98[0.54], source43[0.36], source11[0.33], source63[0.33], source87[0.33], source18[0.32], source24[0.32], source92[0.31].

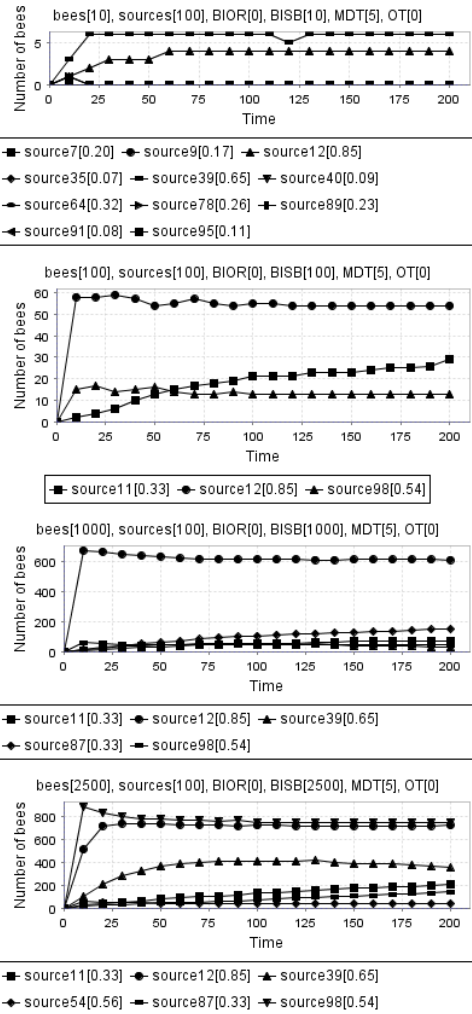
As we can see, bees are more confident in recommending the best source if there are more of them foraging. But even a bee hive with only 10 bees was able to recommend the best source out of 100 candidate sources.

Results of the experiment shown in Fig. 4 are hardly surprising. Indeed, once we have established a basic similarity to the bee hive, as demonstrated in Fig. 3, it should have no difficulty in demonstrating a strongly decisive recommendation of the bees in this experiment, where the only additional difficulty was a slightly more complicated evaluation of the similarity between the query and the source. Still, please note that in the beginning, bees go for various sources and only later unite on the best one. In other words, the bees truly search the space of sources (and are quite good at it). We include this experiment also to have its results available for comparison to the next one.



**Fig. 4.** Various numbers of bees forage for 100 sources. Sources have 3 attributes, bees evaluate all of them

In the second experiment, the sources are (listed in the order of quality, average of the three values is given): source12[0.85], source39[0.65], source54[0.56], source98[0.54], source43[0.36], source11[0.33], source63[0.33], source87[0.33], source18[0.32], source24[0.32], source64[0.32], source92[0.31], source78[0.26], source89[0.23], source7[0.20], source9[0.17], source95[0.11], source40[0.09], source91[0.08], source35[0.07] etc.



**Fig. 5.** Various numbers of bees forage for 100 sources. Sources have 3 attributes, a bee evaluates only one of them

In the second experiment, each bee is capable of evaluating one single attribute. Each source has three attributes so any evaluation made by an individual bee is only a partial one. Some bees contribute to recommendations by evaluating only the first attribute, some only the second attribute and some only the third

attribute. A source with better evaluations in each attribute will be rewarded by higher number of combined bee visits. Objective of our experiment was to see if this hypothesis deserves further attention or it should be rejected.

Results of the experiment are in Fig. 5. Bees were able to recommend the best source in two cases (100, 1000 bees). They nearly missed the best recommendation in the case of 2500 bees. They clearly failed in the case of 10 bees, which however should be attributed more to the low number of foraging bees than to the way of evaluating attributes. Still, results of this experiment cannot be interpreted in any conclusive way. They are more ambiguous than those in the first experiment (cf. Fig. 4). We do not have any definitive explanation for it. It is becoming clear, however, that it is inevitable to enhance the model by incorporating e.g. some kind of impreciseness or uncertainty.

## 7. Introducing uncertainty

There are several sources of uncertainty that can be considered in this context. Let us introduce two kinds of uncertainties into our model. First, we admit that a bee dancer is able to communicate location of a source with some uncertainty (noise) only. Second, we acknowledge that a forager is able to evaluate the quality of a source with some uncertainty (error) only.

We enhanced our model with these two kinds of uncertainties. We developed a tool that implements our model so that we are able to perform various simulation experiments. In Fig. 6, there is depicted a user interface of our tool.

We performed experiments to find out how the uncertainties change capabilities of our model. In the following experiments, we used 1000 bees and 4 sources: source1[0.8], source2[0.5], source3[0.4], source4[0.3]. At time 100 we increased the quality of source4 from 0.3 to 0.85. The source4 has subsequently become the best source around (by a very narrow margin, but nevertheless).

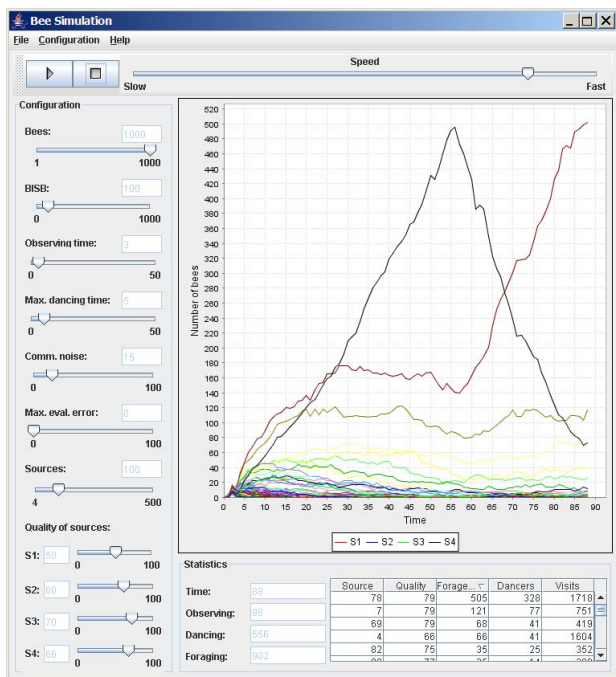


Fig. 6. Tool for simulation experiments with our model - a user interface

In Fig. 7. we show essentially the same experiment as we report in Fig. 3. Now, we have only four sources and after the quality of the source4 has been increased to become the best one in time 100, the bees reacted so that already in time 370, the number of bees foraging for the source4 prevailed.

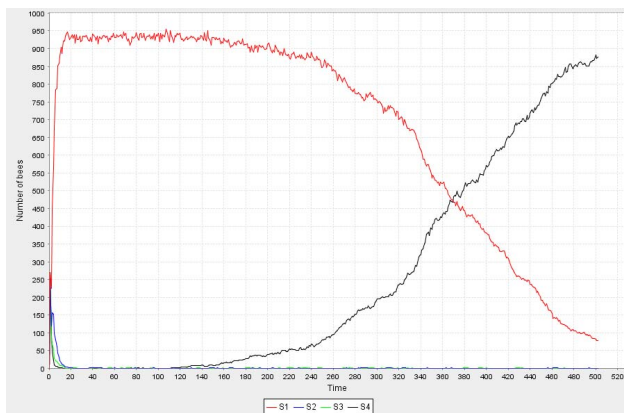


Fig. 7. 1000 bees, 4 sources, source4 made dominant in time 100, no noise, no error

In Fig. 8, we show result of a similar experiment, however after an error of evaluating the source was introduced into the model. The bees evaluate sources with the margin of error of 15%. The bees react more swiftly this time. The number of bees foraging for the source4 prevailed already at time 290.

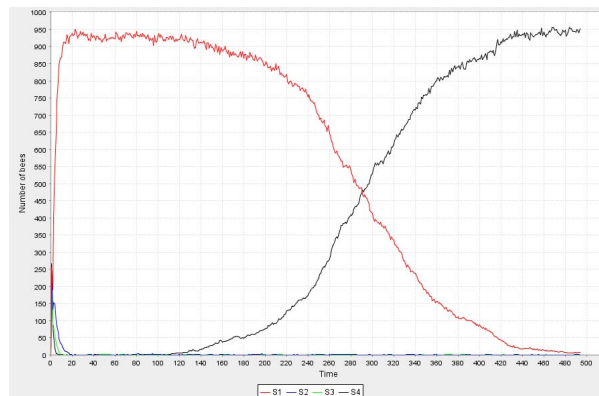


Fig. 8. 1000 bees, 4 sources, source4 made dominant in time 100, no noise, error 15%

In Fig. 9, we show result of another similar experiment, however after a communication noise was introduced into the model. The dancers communicate where the sources are to observers with the uncertainty of 15%. The bees react even more swiftly this time. The number of bees foraging for the source4 prevailed already at time 220.

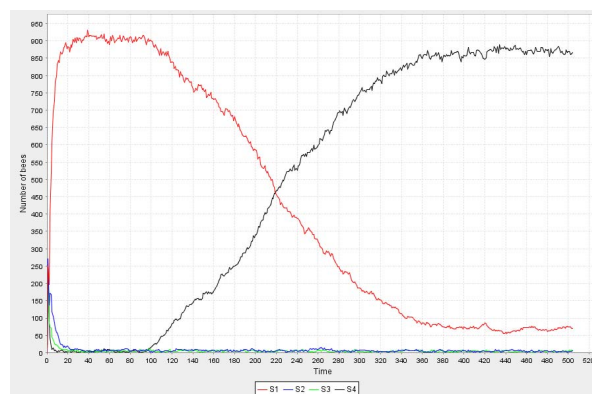


Fig. 9. 1000 bees, 4 sources, source4 made dominant in time 100, noise 15%, no error

## 8. Conclusions and future work

A new approach to web search that is based on a bee hive metaphor was presented. Building on related works especially by Lorenzi et al. (2005), we proposed a modified model of a bee hive. We have shown that the model is a true model of a bee hive in the sense it simulates several kinds of its typical behaviour. However, we have been even more keen to formulate a simple model that would describe some processes taking place in web search. We claim we have such a model, as some of our experiments show.

We are well aware more research is still ahead. However, the bee hive metaphor has received further endorsement. At the same time, to reach a workable model of web search requires not only refinement, but more ideas. The

idea of bee typing according to types of attributes they evaluate is to be elaborated. We have not attempted to introduce any schemas how to combine partial results, although there are obvious candidates such as weighting etc. The model itself can be more refined. Additional parameters, such as initial distribution of foraging directions could be considered. Alternatively to generating initial direction randomly, some kind of memory (individual or collective) could be considered helping to retrieve directions to sources that have been useful in the past in providing information relevant to the current or similar past query.

Some reflection on the very purpose of the model might be desirable, too. We have used the term web search in a rather loose sense. It appears as retrieving information from the web could benefit from this approach. In particular, information recommending and filtering could be modelled by the bees' behaviour. But other possibilities are still open for research.

The bee hive metaphor has been used so far as a basis for a model of recommending information from a given set of sources collected from the web. Besides such an off line application, searching a "frozen" part of the web, it might be worthwhile to attempt to search the "living" web with bees becoming agents. Such a dynamic search, if performed continuously, could open possibility of adaptive recommendation according to changes (disappearances of old documents and appearances of new ones) on the web.

## 9. Acknowledgements

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