Design of Web Agents Inspired by Brain Research

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Abstract. The paper presents an approach to combine knowledge from memory and brain sciences with information retrieval research in the design of Web agents. An information retrieval agent for classification of Web pages based on genre features is used. In developing the agent to adapt to users' search preferences, a neuro-cognitive model of human episodic memory is employed. Our studies show that neuro-realistic models, capable of abstraction of meaningful fragments of knowledge, rather than snapshots of the retrieved Web pages, are closer to the human way of interacting with the Web and can be used for optimization of agent performance.

Keywords: information retrieval, Web genre, theta phase precession theory, episodic memory.

1 Introduction

Usable Web agents have to be adaptive to the demands of the users as well as to the constant dynamic change of Web knowledge. In a way, Web agents have to mimic the natural flow of human memory processing - to filter useful information and remember meaningful facts - in the context of the unceasing flow of new knowledge from the resources on the Web. It is becoming essential that Web agents are able to predict future knowledge needs of the diversity of Web users based on their own – the agents' – experience [1], [2].

It has been proposed that artificial agents – as an agent subgroup – have autobiography – in terms of the ability of "story-telling", i.e. reconstruction of their own past [1]. The framework is applied to autonomous robot behavior. Web agents are similar to autonomous robots in many ways – in terms of learning, remembering, planning, and decision-making. In this paper we outline a distinction between the navigational (automatic) and the autobiographical (cognitive) aspects of Web browsing on the part of the user, which makes the navigational analogy between the artificial and the human agents' performance incomplete.

Design of Web agents is also concerned with identifying lexical or linguistic features of Web genre (not just topic relevance) like, for example, expertise, detail, subjectivity, etc. that can be captured by automatically scanning/tokenizing html

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scripts and extracting meaningful information [3], [4], [5]. In order to make the process more efficient and sufficiently fast, a lot of heuristically based knowledge is employed. In some cases, these heuristics are grounded in long-tradition research areas like rule-based reasoning, neural networks, linguistics and cognitive science. Our aim is to relate the derived heuristics closer to insights from recent memory and brain modeling studies.

In the present study we have focused on the phenomenology of episodic memory, and on *one* facet of its contribution to the formation of human autobiographical memory in Web context – the extraction of meaningful fragments from the search episodes and its relevance to optimization of Web agent performance. The theta phase precession theory of hippocampal memory is chosen among related models for its account of complex cognitive phenomena like object-context integration, single-trial learning and time-space contextualization [6], [7]. The employed neuro-realistic model is capable of abstraction of meaningful fragments of knowledge, rather than snapshots of the retrieved Web pages, which makes it closer to the human way of interacting with the Web and is appropriate for information retrieval optimization.

2 Information Retrieval Studies based on Cognitive Heuristics

One application area of the information retrieval studies and information extraction algorithms dealing with a variety of stylistic and genre features is the Semantic Web, where software agents are built to analyze, restructure, transform and display the information, which currently exists in human-readable form. The algorithms used for discovering regularities in the html script that are meaningful from a user-viewer perspective and capable of extracting structural and semantic meaning from the text are called *wrappers*. The term *wrapper* is first proposed in [8] and, by definition, is a set of "relatively simple information extraction procedures for semi-structured resources like texts". Since the amount of regularities is enormous and constantly changing in the Web pages, a wrapper is a *learner* and in many cases learning is based on exposing to examples to extract the inner data or linguistic/text model. Structural meaning is conveyed by domain ontologies, which can be both designer-given and user-modified. The process of wrapper construction is called *wrapper induction*, which can be either handcrafted or automatically learned [9]. Semantic meaning is not limited to semantic structure only and can account for the diversity of user styles, preferences, attitudes, experiences, etc. [3], [10]. Being on the server side and used for server performance optimization via collecting and processing user requests, wrapper performance and evolution as a learning algorithm is based on the dynamics of the regularities in the page content as well as on the multiple user interactions with the Web.

In earlier work we designed a Java-servlet (a wrapper to a search engine) to diagnose the level of expertise and detail of a corpus of on-line available Web pages, employing cognitive science based heuristics [4], [11]. One application area of these studies is search for cardiological knowledge on the Web. Currently, we have implemented a MatLab GUI version of the wrapper to test the neurologically inspired algorithm of remembering the significant *fragments* of the retrieved pages during

Web search. The idea is that the evolution of the meaningful *fragment* search for the current user can facilitate the definition of the needed expert level of the text by the agent.

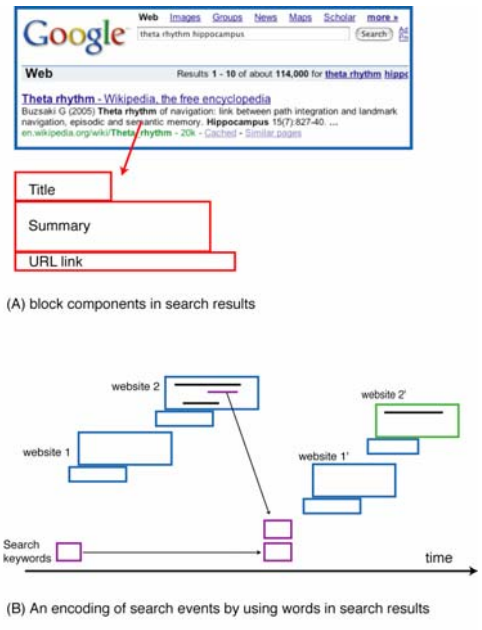

Fig. 1. Fragment extraction and recombination of textual elements as a process of encoding of search events

Figure 1 presents the general idea of wrapper performance (fragment extraction and recombination of textual elements) as a process of encoding of search events. In following the history of interaction, optimization is needed much the way natural cognitive systems perform - learn, abstract, remember and forget. We have used the 'autobiographical memory' metaphor to apply to such kind of Web agents and the theta phase precession theory to model it [6], [7], [12].

3 Theta Phase Coding in the Brain and Episodic Memory

Synaptic connections among nerve cells are widely thought to contribute to the functional selectivity of the nerve assemblies involved in specific cognitive tasks. Rhythmic neural activity is another collective property very frequently observed in the brain. One focus of brain research is how the instantaneous property of rhythmic activity benefits the programming of the brain. Theta rhythmic activity in the rat hippocampus is observed in spatial navigation, and it has recently been also found in cortical areas during mental calculation tasks [12]. Theta phase modulation is a promising candidate for a neural-plasticity correlate of episodic memory tasks

involving hippocampal-cortical relations within a global network of brain computation.

In freely running rats, a stable theta oscillation, 8-10 Hz,[1] is observed in the hippocampus as the local field potential (LFP). According to the cognitive map theory [13], any given set of cells that act selectively according to the rat's spatial location, called *place cells*, represents an external map. O'Keefe and Recce [14] recently discovered a phenomenon of systematic *acceleration* [2] of the firing phase of the cell relative to theta rhythm as the animal traversed the cell's receptive field, called "theta phase precession". In other words, place cells fire not only depending on the position, but also depending on the behavioral context. In every theta cycle, the firing phase shifts in advance, so that cell assemblies in the cycle appear to be a temporal sequence representing the visiting places according to the running direction. As a result, the duration of the behavioral sequence is compressed ten-fold and embedded in the cycle of the theta rhythm [6], [7].

The relevance to learning attracted researchers' interest in phase precession in the rat hippocampus. The basic properties of the rhythm interaction system, known as the entrainment phenomenon, appear to govern this phase precession and it is possible that the rhythmic pattern appears in the absence of memory to cause memory formation [6], [7]. The emergence of rhythmic patterns *in the absence* of memory *to cause* its formation is a plausible candidate for a neural correlate of the formation of complex and durable cognitive effects, governing future behavior i.e. autobiographical memories.

The Theta Phase Model. Traditionally, a phase model is used as a model of a limit cycle with a single variable of oscillation phase, assuming the amplitude converging to a unit circle, with states either the oscillation or the resting. Sustained oscillation is given as a rotary motion on the unit circle in the presence of the external input. To generate the phase precession, the important assumption is a gradual increase of the natural frequency of the phase model during the oscillation state. In the network model of the hippocampus with the phase model description, the stable oscillation of the theta rhythm, a LFP theta unit, and neurons with oscillatory activities are assumed in the entrance of the hippocampus, called the entorhinal cortex (EC). When an input is coming, the neuron starts to fire and sustains its oscillation with the gradual increase of the natural frequency. According to the coupling with the LFP theta unit, the firing phase regularly advances from the late phase to the earlier phase.

Through the anatomical projection the EC to the hippocampal CA3 layer (CA3), the temporal firing pattern generated in EC is inherited to CA3 units and it modifies the recurrent synaptic connections among CA3 units in accordance with the Hebbian synaptic plasticity with asymmetric time window. As a result, in the temporal coding by using theta phase precession, the behavioral sequence is compressed into the temporal sequence of firing phases in the theta cycle, and it makes possible the encoding of behavioral episodes even in one-time experience, because of the time-compression and the repetition of the firing pattern in several theta cycles. After the formation of synaptic connections asymmetrically and locally connected, the

[1] Theta rhythm is 4-10Hz in human, but 8-10 Hz in rat experiments

[2] The firing phase advances from the late phase to the earlier phase in the phase precession

hippocampal network can replay the spatio-temporal firing pattern that represents the animal's past experience, as the memory retrieval. The retrieved activity may cause further synaptic plasticity in other cortical areas for memory consolidation or memory transfer from the hippocampus to the cortex.

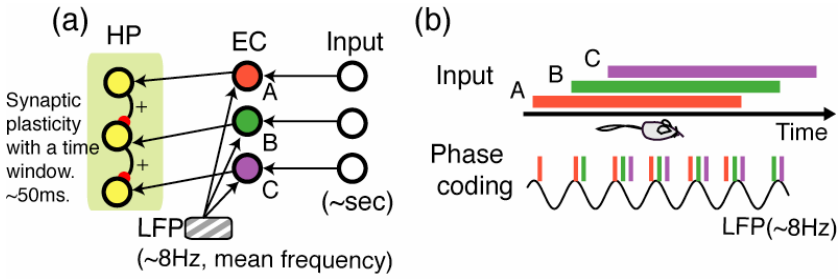

Fig. 2. Model of hippocampal nerve circuit: (a) mechanism of theta phase coding. Behavioral inputs are transferred to the firing phase in the entorhinal cortex (EC) and provide the asymmetric connections in the hippocampus; (b) when the rat runs to the right, the phase shift in firing within each theta rhythm cycle occurs in place cells 1 to 3, which are activated sequentially; the phase is arranged in order of firing within one phase cycle

This phase coding has an important advantage over rate coding in storing temporal sequences of events. The temporal compression of an input sequence into every theta cycle ensures a highly selective synaptic plasticity over the entire time period of an on-going experience, while in rate coding the synaptic selectivity is lost easily when the sequence has a variety of time scales. This precession model bridges the gap between the fixed value of a time interval (several tens of milliseconds) that is recognized by the synapse and the experienced event (seconds). A variety of input time series are translated by the theta rhythm, thereby giving the synapse the proper temporal difference and enabling experienced events to be encoded on the spot.

Relevance to Episodic Memory. Episodic memory as the building element of autobiographical memory has been the focus of intensive and elaborate studies and modeling at various levels of memory and brain research – human, animal, cognitive, neural-physiological, brain-imaging, and so on. In human memory research the term 'episode' has been used both operationally i.e. 'the learning episode' and metaphorically, i.e. 'episodic memory'. Both derive from Tulving's theory [15], [16] and refer, in the first case, to the situation or the environment where learning occurs, and in the second, to the information processing *system* underlying the acquisition of new knowledge - and is therefore stressing its processing complexity. Autobiographical memory, on the other hand, is responsible for remembering the significant events in one's biography [17]. The distinction is also in terms of the different kind (or scale) of information extraction to build the idea/memory of (a fragment of) an episode or an event.

The phenomenon we have aimed to observe in our study is the structure of the episodic trace in terms of stored page (in)completeness, search path memorizing and insight-related experiences that may support optimized future retrieval from memory.

4 Autobiographical Memory in Web Context

Autobiographical memory includes all that we have ever experienced, but more importantly, all that we have ever *learned*. In this sense, as a significant part of one's daily life, the user-Web interaction is a powerful autobiographical learning experience. We have hypothesized that the process of episodic learning in Web environment is *both* navigational and autobiographical at the same time. Navigation focuses on the optimization of the trajectory (the traversed links) to a desired goal for subsequent reuse of the shortest path to reach the same goal. With using the Web for educational purposes, however, the situation is different in terms of the cognitive functions and memorizing strategies that are involved, including their autobiographical elements. Our first assumption is that the interaction with the present-day Web is an autobiographical experience. Our second assumption is that memorizing *events* in a human-like memory system undergoes constant synthesis principally the same way as any learning process takes place and therefore can be implemented in autonomous agents on the Web.

We use 'episodic memory' in its conceptual meaning – the system of processing episodes of Web search and transforming them into autobiographical events of successful or unsuccessful Web navigation to reach the needed goal. Every Web page viewed by the user is a complex perceptual and semantic stimulus. We assume that what is stored in episodic memory from the rapid viewing of a succession of pages is a set of fragments. The stored fragments are cues for subsequent retrieval. These cues can be perceptual or semantic, random or meaningful to the goal. The theoretical hypothesis is that episodic memory extracts meaningful cues from the fragments of the page-retrieval episodes, rather than random perceptual or semantic cues.

The Search Task. The search task was to reach a significant personal goal from incomplete initial information. We involved two participants in the study in order to monitor the autobiographical elements of the task – a European researcher, browsing for an art gallery (motivated) and a Japanese colleague, invited to find the gallery based on Japanese orthography (neutral). The controlled elements were: a) personal motivation in reaching the goal and b) emotional involvement in terms of *feelings* of anticipation to reach the goal, i.e. anticipation of success. We have aimed to show that the *mechanisms* of event synthesis from fragments of page-retrieval episodes in the episodic memory system are the same for both participants, volunteering to the study.

The Search Goal. The search goal was an example of new concept learning and, for a foreign language speaker, similar to a case of artificial concept learning. The cue concept is composed of two Japanese words 'kurenai-kai' which to a non-Japanese speaker may appear like anagrams. Kurenai-kai is related to traditional Japanese craft arts - Japanese style embroidery. The participants did not know the concept 'kurenai-kai', although it would have been the keyword, retrieving the home page of the needed art gallery. The discovery of the new concept and its remembering was one important element of the observed episodic memory based retrieval.

Procedure. We tested memory of the search process in two steps - each on two subsequent days. The first step was to see if the participants remembered the newly learned concept words to reach the goal the shortest way and the answer was affirmative. The second step tested episodic memory of the actual search process and the remembered search path. The participants were asked to try and recall how they

would have searched the same goal provided they had had forgotten the concept words ‘kurenai-kai’. They copied and pasted their trials to reach the links leading to the needed home page of the art gallery.

Results and Discussion. The presented in section 3 model of episodic memory has been successful in reproducing the behavior of rats in a maze in finding the location of a goal. In a maze behavior starts from random search until the shortest path is found. Moreover, the model is capable of reproducing situations of single-trial learning by composing and maintaining retrievable memories of the search-path cues [6], [7]. Our study of Web search has replicated the mechanism of performance of the proposed memory model based on theta phase precession, and has supported its advantages for implementation in autobiographical Web agents. Table 1 gives a summary of the performed searches by our participants. The Web paths resemble random search until a meaningful path is composed.

Table 1. User performance on Web search with incomplete initial information about the search goal

User	Searches		Time
	Random	Meaningful	Approximate
Motivated	23	3-5	30 min
Neutral	19	3-5	30 min

We have observed that meaningful paths are *composed*, rather than *encountered* that is essential to the understanding of episodic memory. The nature/character of the search was identical in both cases. It started randomly with possible combinations of various cue words and browsing the search engine results until the rewarding (success) combination of cue words was found. The success combination was the same for both users – kurenai-kai – in either English or Japanese orthography. We assume that the ‘event’ of finding meaningful and useful information in terms of the newly learned concept word ‘kurenai-kai’ in one’s autobiographical memory is based on cognitive mechanisms similar to those in learning new concepts in semantic memory [18]. Our results are an illustration to this similarity of processing of knowledge and *events* in human memory in Web search context.

Table 2. The left column represents episodic memory guided retrieval based on a set of meaningful cues and ‘insight’. The right column contains the mappings to the respective initial cues (none of them are identical)

Steps No	Episodic memory guided retrieval	Composition of the retrieval path from meaningful fragments	Snapshots of the search episodes
1		Looking for a matching semantic cue or a useful word phrase /”Embroidery Center in Atlanta”/	

2		Closest match with the 14th search step, but picking up another hyperlink	
3		Remembering that the insightful encounter of 'kurenai-kai' was in the 'links' section	
4		Mapping the 'link' cue with the 17th search step (the 'insight')	
5		The goal site	

Table 2 shows the meaningful cues on which episodic retrieval was based for our motivated participant. The retrieval process is composed of fragments of meaningful information starting from a matching semantic cue, retrieving previous page, remembering the 'insightful' encounter in the links section, taking the remembered abstract cue and finding the goal (5 steps). At 'episodic' retrieval our motivated participant usually started from more personalized information about the people running the art gallery (which was her initial motivation for the search, i.e. element of her autobiography). Our neutral, i.e. native-speaker participant started from more general sites about the Japanese craft arts. However, the essential aspect of their search is reflected in the aforementioned 5 steps. An interesting point to be mentioned is that the retrieval pages never matched exactly the search pages. Our participants mapped the meaningful *cues*, not the *exact* images of the Web pages.

Implementation. Figure 3 gives the temporal evolution of episodic events in the task to try to find 'kurenai-kai' with initial keywords of 'Embroidery Center in Atlanta.' Gword, TL, and Word correspond to the keywords, used in the Google search, the titles of the search results, seen by the user in the system window, and the words in the summary of the search results, respectively, which are automatically stored in the system. For an autonomous agent on the Web the relevance of this study is in the following: Users base subsequent retrieval of the search path on remembering

the ‘events’ of their search, which are the meaningful fragments of knowledge inside the Web pages, not the exact ‘page-retrieval’ episodes.

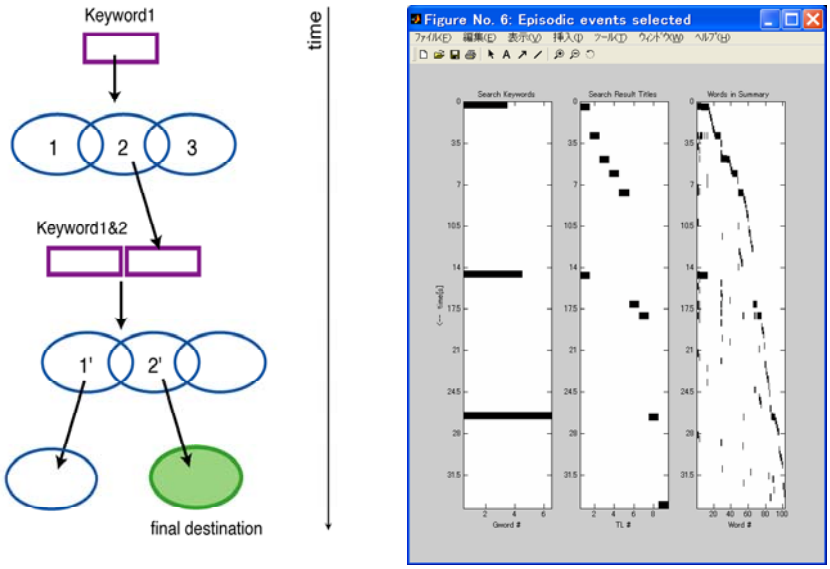

Fig. 3. Temporal evolution of episodic events by the neuro-cognitive agent

We propose that the autonomous Web agent behaves in analogy with the event-based (autobiographical) strategy that Web users are applying for retrieval of useful information, which is some state of knowledge with anticipatory value (useful in the future). Next steps will be tests of the agent for optimized storage of fragments of knowledge from user searches, rather than of snapshots of sequences of Web pages.

5 Conclusions and Future Work

In this paper we presented one approach towards the design of Web agents that are able to mimic the natural flow of human memory processing in complex environments, which is based on new knowledge from brain research. We have tried to demonstrate how the theoretical framework of theta phase coding endows real-time process of memory formation of Web search experiences, and the retrieval process of effective routes to the targets through the experienced sites. The proposed approach focuses on bridging the gap between neuroscience and Web technologies to enlighten the importance of the context-dependence in autobiographic memory.

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