Web Agent Design Based on Computational Memory and Brain Research

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1 Introduction

The World Wide Web in its current form presents its users with constant learning experience. We consider this learning experience as being of strong autobiographical nature. Users interact with the web mainly to learn something new *on any issue* and are very privileged in this in comparison with the previous generations. WWW has turned into shared repository of useful and valuable information, which is capable of extending the individual knowledge horizon to unlimited scale. This is largely due to the smart way the agents on the web are being built, reflecting facets of the smart manner human cognition performs. In a way, the web is an unprecedented cognitive medium where knowledge from brain studies, cognitive science and information extraction can meet to develop new interfaces and agents capable of augmenting human inclination to learn on a lifetime scale.

Application area of information extraction based on applying a brain-computation metaphor is the Semantic Web, where software agents are built to analyze, restructure, process and store the information that currently displays in human-readable form in the browser window. The software agents, assisting user search requests, can browse, retrieve, transform and display in structured and focused way the contents of thousands of HTML pages which otherwise users would have viewed one by one [Kushmerick et al., 1997, Kushmerick, 2002, Finn & Kushmerick, 2003, Dimitrova, & Kushmerick, 2003, Dimitrova et al., 2003, Karger et al., 2003, Hogue & Karger, 2004, Dobrev et al., 2004, Ringsletter at al., 2006, Stein & zu Eissen, 2008, Argamon et al., 2008]. These smart web agents have to be flexible, adapt to the human way of perceiving information, learn and forget the unnecessary items, and *foresee future user requests* in order to be helpful in the dynamic semi-structured and under-determined knowledge environment of the World Wide Web.

The search, retrieval, analysis and remembering of web knowledge involve hierarchies of cognitive mechanisms on the part of the users in order to produce efficient knowledge extraction strategies [Nakache & Metais, 2005, Dimitrova, 2008]. The underlying optimization mechanisms of human learning are not fully understood; yet focusing on human performance in different cognitive environments like the web can give *ideas* how to make artificial agents more human-like, since the user and the agent goals to find the needed knowledge during the search *coincide essentially* on the web.

In this chapter an approach to combine knowledge from computational memory and brain research with information extraction studies for the design of web agents is described. In developing the agent to adapt to users' search preferences, a neuro-cognitive model of human episodic memory is employed. Our work relates to the models of [Gorski & Laird, 2009, Derbinski & Gorski, 2010, Pearson, et al., 2007, Barakova & Lorens, 2005, Nehaniv & Dautenhahn, 1998], yet focuses on more *experiential*, rather than rational agent knowledge formation. Our studies aim at showing 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.

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, for example, the situation is different in terms of the cognitive functions and memorizing strategies that are involved, including their *autobiographical* elements. We have previously investigated the elements of the search path that have been stored by an agent for subsequent retrieval of the search goal [Dimitrova et. al, 2004]. We have also investigated the *nature of the search goal* for a learner on the web and the utility of a neuro-cognitive agent for assisting user knowledge search [Dimitrova et al, 2007].

We have focused on a group of studies of the function of the hippocampus and related cortical areas in the brain, on the phenomenology of episodic memory and on its contribution to the formation of human autobiographical memory in web search. 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 [O'Keefe & Recce, 1993, McClelland et al., 1995, Skaggs et al., 1996, Yamaguchi et al., 2002, Yamaguchi, 2003, Yamaguchi et al., 2004, Wagatsuma & Yamaguchi, 2006, Wagatsuma & Yamaguchi, 2007, Wagatsuma, 2009]. In this chapter we present the potential of theta phase coding in the brain for modeling human memory as *autobiographical experience* and its application to web agent design. Our aim is investigating cognitive phenomena and computational algorithms applying to the intersection of three independent research areas – information extraction research (IER), human memory modeling (HMM) and computational brain research (CBR) (Figure 1).

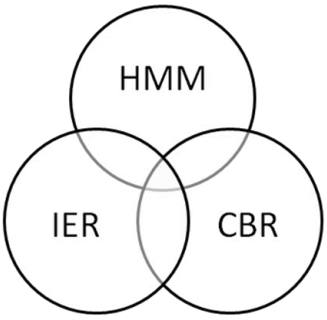


Figure 1: Overlap of three research areas - information extraction research (IER), human memory modeling (HMM) and computational brain research (CBR).

The triple overlap of these areas of research we address as *modeling the autobiographical experience* with the present-day World Wide Web, which requires novel approach to agent design to assist the users in their goals for search of timely, relevant, useful and trustful new knowledge.

We have based our investigations on the following assumptions: 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 can be modeled by cognitive neuroscience based memory models. Our third assumption is that this can be revealed by design of new methodologies for investigating user browsing behavior and subsequent retrieval of the memorized search path in parallel with agent behavior. Such methodologies can, in a way, also help resolve long-standing issues of the empirical investigations of human cognition.

2 Modeling the Autobiographical Web Experience

Autobiographical memory is responsible for remembering the significant events in one's biography [Conway, 1996, Conway, 2001]. It 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.

It has been shown in a longitudinal study that users largely revisit target sites by using search engines and almost never by storing or remembering the exact location as URL or hyperlink [Weinreich et al., 2006]. For memorizing the search process and the result (the search goal) they use mnemonics – like typing in the project acronym (*semantic memory* cue) – or idiosyncratic/personal mnemonics like the name of university next to a city visited before (*episodic memory* cue) and so on. In our observations, user memory for the initial search has *never been complete* in terms of the previously visited sites. Users rely on memorizing *essential fragments of the search episodes* rather than on the exact *search path* retrieval. We have also encountered evidence of that episodic memory of web search can be accounted for by the "first-person approach" of J. Gardiner [Gardiner, 2001]. These observations have helped formulate the *meaningful-fragment retrieval* hypothesis in user-web interaction.

2.1 A Point of Theoretical Departure

A useful model for analysis of the manifestation of probabilistic processes in memory retrieval has been proposed by G.V. Jones [Jones, 1987]. The model is illustrated by Venn diagrams similar to the presented in Figure 1. According to the degree of overlap, three kinds of relations among the probabilistic processes can be outlined: *independence*, *exclusivity* and *redundancy*. Whenever the area of joint manifestation of any two processes is equal to the product of their separate probabilities, these two processes are considered *independent*. In the case of three processes, it is possible that one of the observed processes is contained within another, which violates the independence assumption and is the *redundancy* case. A special case of independence is *exclusivity* – a total lack of overlap of the observed probabilities of process manifestation. When three processes are considered, it is possible that one of them is *independent* in its relations to the other two, whereas these two are being *exclusive* of each other (Figure 2).

The model is proposed for cases when separate measures of the involved processes are included in the experimental design, as well as separate experimental measures of the *joint manifestation* of these processes. By comparing the different theoretical values for the overlapping areas with the experimental

data of the joint manifestation of the processes, the most probable relation among them can be identified – one of *independence*, *exclusivity* or *redundancy*. The model has been useful to describe the exclusivity of retrieval form semantic and from autobiographical memory [Maylor et al, 2001], the redundant nature of the unconscious and conscious memory processing [Jacoby et al., 1994] and the non-redundancy of episodic and semantic retrieval [Jones, 1982, Dimitrova, 1996].

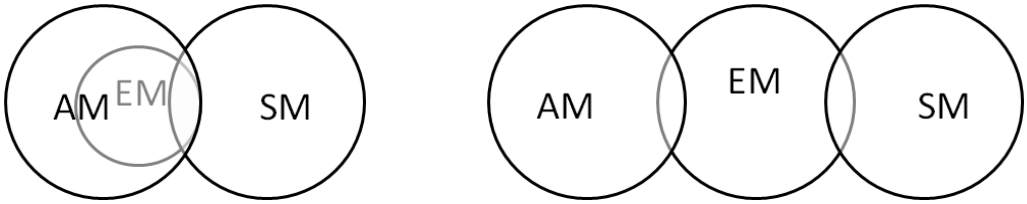


Figure 2: Possible interrelations of three memory systems – episodic (EM), autobiographical (AM) and semantic (SM) – redundancy (left) and exclusivity (right).

Our current hypothesis is that episodic memory is *central* to both semantic and autobiographical memory formation processes, being *exclusive* of each other, and will be elaborated throughout the rest of the chapter (Figure 2 - right). The special emphasis is on evidence from neuro-cognitive studies of episodic memory and on the specific adaptation mechanisms needed by an agent in order to cognitively support users of the web.

2.1.1 Can Diverse Theories of Memory Systems Meet on the Web?

Our long-term goal is to design smart agents supporting user *autobiographical experiences with the Web*. For this reason we have turned to theories of memory that can provide operational definitions reinstating the mechanisms of *acquiring new knowledge* from complex - artificially created - dynamic cognitive environments.

E. Tulving coined the term *episodic memory* following studies of processes involved in remembering lists of pairs of words. He noticed that context is spontaneously integrated within the learning situation so that the strongest links among the studied items were not the ones that are semantically closest, but the ones that were *contextually* present during the learning of an item. Tulving argued that at retrieval of a studied item subjects reinstated mentally the context of the learning situation first instead of retrieving the semantically closest word. If subjects were presented with pairs of words like "train-BLACK", they were more likely to recall the word "BLACK" as studied with the cue "train", rather than to remember having previously studied "BLACK" after cued with the semantic cue "white" [Thomson & Tulving, 1970]. The process of contextualizing the learning situation as vivid, autonoetic, conscious experience of a moment in *one's past* of studying lists of pairs of words was called by Tulving *episodic memory* [Tulving, 1983].

We use Tulving's definition of *episodic memory* ("episodic retrieval mode" or REMO) from a recent brain research study employing Positron Emission Tomography (PET) [Lepage et al., 2000]: "REMO refers to a neurocognitive set, or state, in which one mentally holds in the background of focal attention a segment of one's personal past, treats incoming and on-line information as "retrieval cues" for particular events in the past, refrains from task-irrelevant processing, and becomes consciously aware of the product of successful ecphory (recovery of stored information), should it occur, as a remembered event. …

REMO guides item-related processes … that operate on individual stimulus events within the task", [Lepage et al., 2000, p. 506].

The definition of *semantic memory* that we have employed for our agent is the one of Tulving: "a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meanings and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of the symbols, concepts, and relations" [Tulving, 1972, p. 392]. We have also followed [Thompson-Schill, 2003] in separating it from the encyclopedic knowledge for operational purposes since in an artificial cognitive system maintaining relations among entities is the challenging computational aspect, not just storing them as facts.

It has been known from brain research that the hippocampus in the mammalian brain is central to the formation of episodic memory, its connections to the cortical areas and participation in memory retrieval [McClelland et al., 1995, Mizuhara et al, 2004]. By employing complex hippocampal activations, rats develop sophisticated cognitive maps, guiding their skilled navigation in semi-structured environments. Web *navigation* resembles robot path finding in complex environments to a large extent. Human navigation in real and abstract environments employs path search, optimization and remembering similar to other mammals and robots, and can be reinstated in artificial agents. The context of the learning situation, however, according to Tulving's theory, is much more complicated. It integrates in the human episodic memory, apart from the traversed paths and their perceptual signifiers, a constellation of symbolic and autonoetic processing which is unavailable to the mammalian brain. This makes the navigational metaphor of user web search incomplete and calls for new agents of more humane stance.

The complexity of processing at item retrieval following episodic memory tasks was revealed in a study of G.V. Jones [Jones, 1982]. The item-context integration of unrelated words like "liar-TRAIN", "time-RADIATION", "raw-PEACE", "wed-MORNING" or "loop-SWIMMING" was much weaker at retrieval in a control condition, than when augmented by a strong semantic cue, provided by the backward reading of the cue item. Subjects from the experiment condition were revealed the secret that if they read the cue backward, this could help them remember the studied item. The added cues of "rail" and "emit" produced reliably higher number of recalls of "TRAIN" and "RADIATION" by the subjects who had been unaware at study that the cues were heteropalindromes and could be used as semantic learning cues [Jones, 1980]. Jones proposed the "dual route to memory" theory to account for these findings [Jones, 1982]. His experiments were replicated and reliably confirmed by the experimental data, involving a comparative condition where the heteropalindromes were replaced with other words with similar natural-language frequency norms, like "gym-TRAIN" and "beam-SWIMMING" [Dimitrova, 1996]. By applying the probabilistic model of Jones for the estimates of *independence*, *exclusivity* and *redundancy*, the existence was shown of *direct access retrieval processes* as well as *generate-recognize processes* at recall of items from the studied lists of word pairs (episodic retrieval task) that were either independent or exclusive of each other, but not redundant.

An account of processing within episodic memory is proposed based on these studies in [Dimitrova, 1996]. Two types of processing take place at item retrieval from the episodic memory system: *deliberate direct access* De (consciously controlled retrieval), involving clear recollection of an unusual combination of high natural-language frequency words like "gym-TRAIN" as well as *incongruous item generation* Ge (automatic retrieval), involving increase of the familiarity level of low frequency words like "RADIATION". The existence of processes of conscious recollection and automatic processing in episodic learning is supported by the findings of [Jacoby et al., 1994] that conscious and unconscious influences of memory are redundant – conscious processing is contained within the unconscious

influences in memory tasks. Therefore, episodic memory is more than just declarative memory system and involves *procedural aspects* of learning [see also Gardiner, 2001].

Semantic memory participated in episodic retrieval via the following processes: congruous item generation Gs (consciously controlled retrieval), involving generate-recognize processes of retrieving "SWIMMING" to the cue "pool", and involuntary direct access Ds (automatic retrieval) to gestalt-like semantic phrases like "MORNING dew" (see Table 1).

	Consciously controlled retrieval	**Automatic retrieval**
Episodic system	Deliberate direct access D_E	Incongruous item generation G_E
Semantic system	Congruous item generation G_S	Involuntary direct access D_S

Table 1: Episodic-semantic relation in retrieval from memory.

The complexity of processing of episodic memory has also been revealed by numerous neuro-cognitive EEG and fMRI studies [Lepage et al, 2000, Klimesch et al., 2001, Allman et al., 2002, Luo & Niki, 2003, Mai et al., 2004, Mizuhara et al., 2004].

The exclusivity-of-processing framework is applied to studies of retrieval from the semantic and autobiographical memory systems in [Maylor et al, 2001]. A hypothesis is tested that our cognitive system may perform in a simultaneous manner when items from two categories are being retrieved. An exclusivity estimate would predict a boundary level at test below which (in terms of time) or above which (in terms of item production) would suggest parallel retrieval of categories from memory, or, conversely – serial, subsequent retrieval from each category. The results confirm the exclusivity assumption – within each memory system, categories are retrieved one at a time. Retrieval from semantic memory involved recalling item associates of categories like "colors or buildings" and from autobiographical memory - recalling personal events with "flowers or tickets" in the study of [Maylor et al, 2001]. The main relevant to the present context finding is that both systems - semantic memory and autobiographical memory - perform in principally the same way.

Since episodic memory strongly participates in the formation of semantic memories, on the one hand, and in the formation of autobiographical memories, on the other, we forward the idea that episodic memory is central to the others, whereas the semantic and autobiographical memory systems can be considered *exclusive* (Figure 2). In terms of the cited above study: "Consider memory as a process of pattern completion over a distributed network of processing units. Superadditivity among multiple retrieval cues may correspond to the fixing of several parts of a pattern and hence may facilitate filling in the rest of the pattern. But the search for multiple targets is analogous to the attempt to complete two patterns at once, which will not be possible if the patterns are distributed over the same processing units" [Maylor et al, 2001, p. 1194]. The exclusivity assumption is understood here in a similar way, meaning that memorizing life events, as well as acquiring new knowledge, obey complex, yet similar, learning mechanisms, mediated via episodic memory, that are participating equivalently in user-web interaction.

2.1.2 Optimization Function of Episodic Memory

The *cognitive function of episodic memory* is to set the context of the learning task – sensually, perceptually and emotionally influenced, underlying the acquisition of new and the restructuring of old knowledge – semantic knowledge (relations), encyclopedic knowledge (facts) and autobiographical knowledge (events). Within this scheme of relations of episodic memory with the other types of memory, we assert that the relation episodic-semantic memory and the relation episodic-autobiographical memory as learning mechanisms are exclusive of each other, yet performing similarly to generate the individual, both experiential and rational, knowledge of the world/web (Figure 3).

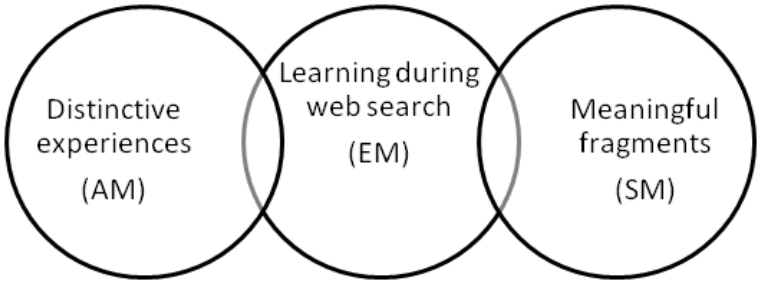


Figure 3: Components of user autobiographical experience with the web.

The main idea of the proposed agent design framework is depicted in Figure 3. The process of learning during web search relies heavily on the mechanisms of episodic memory where remembering and subsequent retrieval of the episodes of web search depend on the appropriate contextual cues. These can be meaningful, idiosyncratic, semantic or orthographic. The search path is followed at retrieval to the extent, defined by whether the search attempt has produced either meaningful or personally *distinctive* result (new, interesting or attractive for the browsing user). If the users try to remember their previous searches – their memories are composed of the encountered meaningful fragments, but not on remembering the exact successions of the viewed pages. The agent has to be able to detect when meaningful encounter is being made, which is the challenging algorithmic part. Table 2 presents the proposed framework of the relation between the episodic and autobiographical memory systems for the design of an agent, supporting autobiographical experiences with the web.

	Consciously controlled retrieval	**Automatic retrieval**
Episodic system	Deliberate direct access D_E	Incongruous item generation G_E
Autobiographical system	Meaningful fragments of knowledge G_A	Distinctive personal experiences D_A

Table 2: Episodic-autobiographical relation of web-search retrieval from memory.

The *optimization function of episodic memory*, therefore, apart from handling the truth validity of one's own recollections, is in having a complex idea of one's navigation – physical, perceptual and conceptual – to prevent from repeating already traversed trajectories as soon as a cognitive demand is felt. The question "Where are my glasses?" triggers a recursive process of memory search first, before traversing physically all possible places where I might have left them. In web search recollection is composed of the meaningful fragments of knowledge encountered during the search process, but not on attempts to reinstate the traversed links one by one.

2.1.3 Design of Agents with Human-Like Memories

In [Gorski & Laird, 2009] an agent was designed to explore the various ways episodic memory optimizes agent performance. One way is to rely on the contents of the episodic memory module. Another – more interesting – was performance optimization via the algorithmic existence of such a module, without the look-up in its contents. The study was performed within the "Two Well World" framework. Consider, for example, a world, consisting of two wells, a shelter and an agent that can be in one of two possible states – thirsty or not thirsty. The two wells can be either full with water or empty. Whenever one is full – the other well is empty. Well states may be of different probability – from completely random to largely dependent on the previous state. A decision-making agent was designed that either uses episodic memory or not. Depending on its own state – thirsty or not – it may either seek for water from the wells or shelter if not thirsty. One way is to look up in the contents of the episodic memory module to see what has been stored. Yet a useful learning strategy for the agent is the meta-knowledge that most recently it has used episodic memory. So, if the most recent decision was based on using EM, the agent would go straight to the alternative to the previously used well or the shelter. In all cases the agent learned to perform better in comparison with the cases of decision-making without EM or of baseline (random) state generation.

Human attitudes towards "virtual humans with human autobiographies" have also been investigated in [Bickmore et al, 2009]. In a study of interaction with an agent, reporting events in first-person, users enjoyed the interaction more than with an agent, reporting events in third-person. The *autobiographical attitude* of an agent is better enjoyed by the users than some reportage-style agent behavior [see also Vanderelst et al., 2009].

2.2 Episodic Learning via Theta Phase Coding in the Brain

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. Although theta rhythmic activity has been most characteristic of the hippocampal neural activity and associated with spatial navigation, it has recently been also found in cortical areas during mental calculation tasks [e.g. Mizuhara et al., 2004]. 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 regular, stable theta oscillation is observed in the hippocampus between 8-10 Hz of the local field potential (LFP). The predominant view of the spatial representation in the rat hippocampus is the cognitive map theory [O'Keefe & Nadel, 1978]. According to this theory, any given

set of cells that act selectively according to the rat's place field represents an external map. These cell sets are called cell assemblies, and each individual cell within an assembly that fires at a specific location, corresponding to a unique point in the environment, is called a *place cell*. O'Keefe & Recce observed a phenomenon of systematic *acceleration* of the firing phase, relative to theta rhythm, as the animal traversed the cell field and called it "theta phase precession" [O'Keefe & Recce, 1993]. Skaggs et al. have shown that this phenomenon is a property of the place cell assemblies [Skaggs et al., 1996]. Place cells activate in sequence according to the position and movement of the rat. Initial firing of a single place cell occurs at a specific phase in the LFP. Every time the cycle advances, the firing phase shifts forward. Cells that start activity near the beginning of a phase complete their cycles before those cells that start later. This maintains *phase precession* during activity. Throughout a theta rhythm cycle, the firing order of place cells is consistent with the running direction around the animal current position. As a result, the duration of the temporal sequence is compressed ten-fold and embedded in the cycle of the theta rhythm [Wagatsuma & Yamaguchi, 2007].

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, evidently govern this phase precession and it is possible that the rhythmic pattern can appear in the absence of memory to cause memory formation. 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.

2.2.1 A Neuro-realistic Model of Episodic Encoding and Retrieval

A model for the dynamics of the hippocampus is proposed by Y. Yamaguchi, in which synaptic plasticity is produced selectively within the hippocampus in a way that mirrors the temporal pattern, by which cell assemblies are formed, via the interaction between the nerve cell rhythm and the LFP theta rhythm thus allowing the pattern to be sent to the hippocampal nerve circuit [Yamaguchi, 2003].

Traditionally, a phase model is used as a model of a limit cycle with a single variable of the oscillation phase ϕ_i (mod 2π), assuming the amplitude rapidly converging to a unit circle. A phase model is used with saddle-node bifurcation that satisfies not only the oscillation, but also the resting state with excitability. The resting state is given as a stable fixed point in a unit circle where the membrane potential is given by $\cos \phi_i$. An unstable fixed point gives the threshold for *autocatalytic increase of the membrane potential*. Sustained oscillation is given as a rotary motion on the unit circle after the disappearance of the fixed point through collision between the node and the saddle.

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 of the EC to the hippocampal CA3 layer (CA3), the temporal firing pattern, generated in EC, is inherited to CA3 units. It modifies the recurrent synaptic connections among CA3 units in accordance with the Hebbian synaptic plasticity with asymmetric time window (Figure 4).

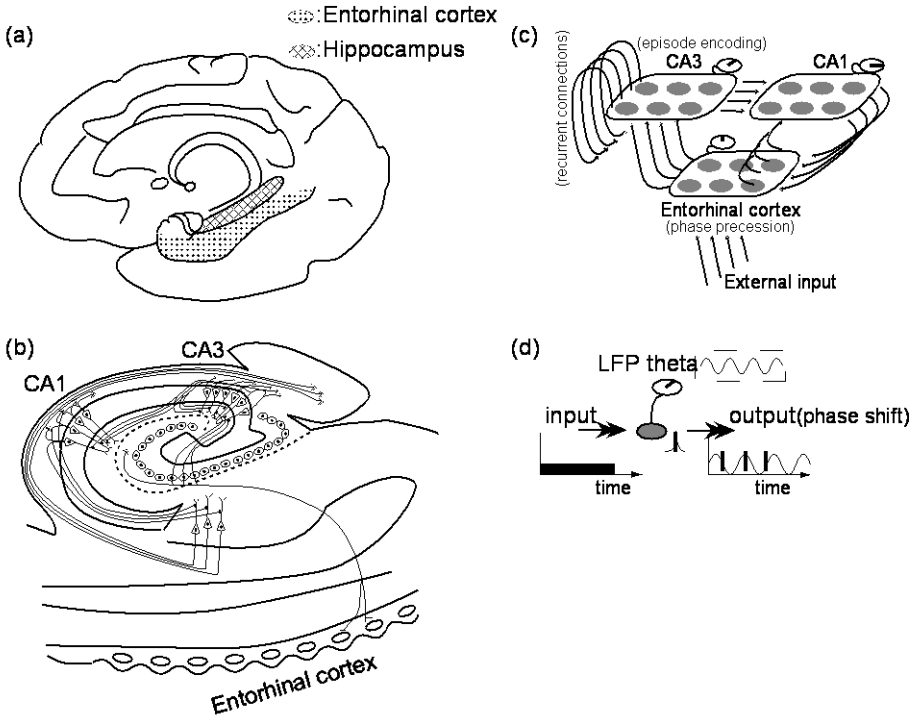


Figure 4: A schematic illustration of the anatomical structure surrounding the hippocampus and the hippocampal LFP oscillation. (a) A section of the human brain. (b) A close up of the anatomy with the hippocampus and the entorhinal cortex. (c) A simplified model of the entorhinal-hippocampal circuit. (d) The important interaction between the LFP theta oscillation and the sensory input, generating the phase advancement.

The asymmetric time window in the plasticity rule was discovered as the enhancement of the synapse when neurons fire with a time delay, ~50ms [Wagatsuma & Yamaguchi, 2007]. However, the time window is not applicable directly to the encoding of temporal sequences in behavioral events, seconds to minutes. 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. This 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 (Figure 5).

2.2.2 Mechanism of Theta Phase Coding

The behavioral inputs are transferred to the firing phase in the entorhinal cortex (EC) and provide the asymmetric connections in the hippocampus. When the rat runs to the right, the phase shift in firing within each theta rhythm cycle occurs in place cells A to C, which are activated sequentially; the phase is arranged in order of firing within one phase cycle. In this way the rat running environment is expressed in compressed form in each theta cycle (Figure 5).

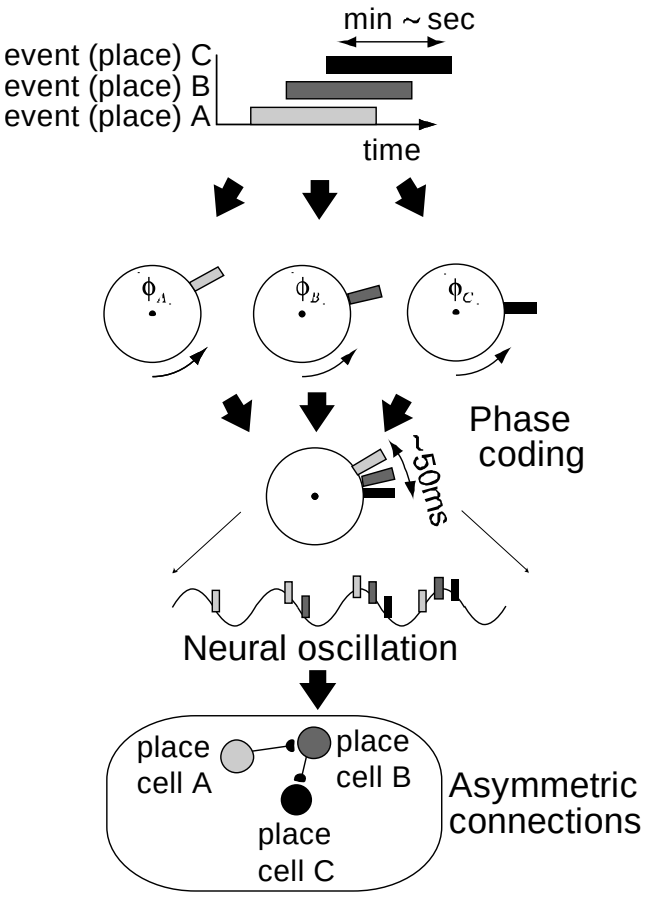


Figure 5: Mechanism of hippocampal encoding of one-time experience by using theta phase coding

After the formation of synaptic connections, being asymmetrically and locally connected, the hippocampal network can replay the spatio-temporal firing pattern, representing the animal past experience, as 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. In this way the rehearsal of the stored patterns has a variety of time scales, basically faster than the original behavioral time scale [Lee &Wilson, 2002].

Phase coding has an important advantage over rate coding in storing temporal sequences of events [Sato & Yamaguchi, 2003]. In phase coding by theta phase precession 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. In rate coding the cue for selective synaptic plasticity is restricted to the end points of the sequence. 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) (Figure 6). 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.

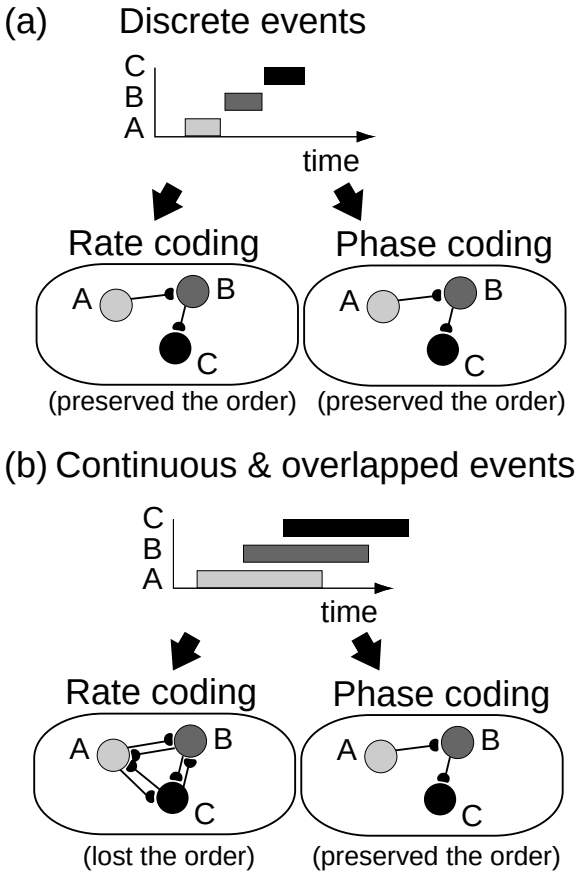


Figure 6: An important advantage of phase coding in comparison with rate coding (see text).

It is demonstrated in [Wagatsuma & Yamguchi, 2004] and [Wagatsuma & Yamaguchi, 2006] how the cognitive map is formed from interacting with the environment as *memory integration process* and how similar but different episodes are encoded as *memory separation process* in the framework of theta phase coding. The key feature is the transformation between time scales of behavioral events and neural activities. It was shown how the neural dynamics bridges the time-scale gap between the external world and the neural process. The compressed representation in theta phase coding is not only useful for the memory encoding of behavioral experiences accompanied with the integration process for the cognitive map formation, but also helpful in the immediate update of awareness of where I am in the current behavioral context.

Support to the idea of anticipation-related hippocampal processing, which is observed in many animal studies [Lisman & Redish, 2009], can be found in the human brain study of Sato and Yamaguchi [Sato and Yamaguchi, 2009] and related to the involvement of emotional information, which is encoded in the amygdala [Phelps, 2004]. In the fMRI study of Smith et al. [Smith et al., 2004], it is shown that the hippocampus is involved in the memorizing and anticipation of emotionally colored events. This confirms the plausibility of the phase coding mechanism for maintaining memories with anticipatory value in the

hippocampus and the neighboring areas, such as the amygdala, responsible for experiencing emotions. Therefore, via including multiple brain areas, the episodic-autobiographical relation is composed of *emotionally-biased* episodes. In daily life, by remembering the past episodes, we associate naturally unrelated, at first glance, items with important facts.

3 Framework for Design of Web Agents by Using Theta Phase Coding

Figure 7 illustrates schematically the composition of the web agent interacting with conventional search engines, helping user find websites and encoding users' experiences of exploring the sites. Through visiting of web sites according to users' interests and motivation for finding a target website, which is based on initially incomplete information, an episodic memory is expected to be formed in the system.

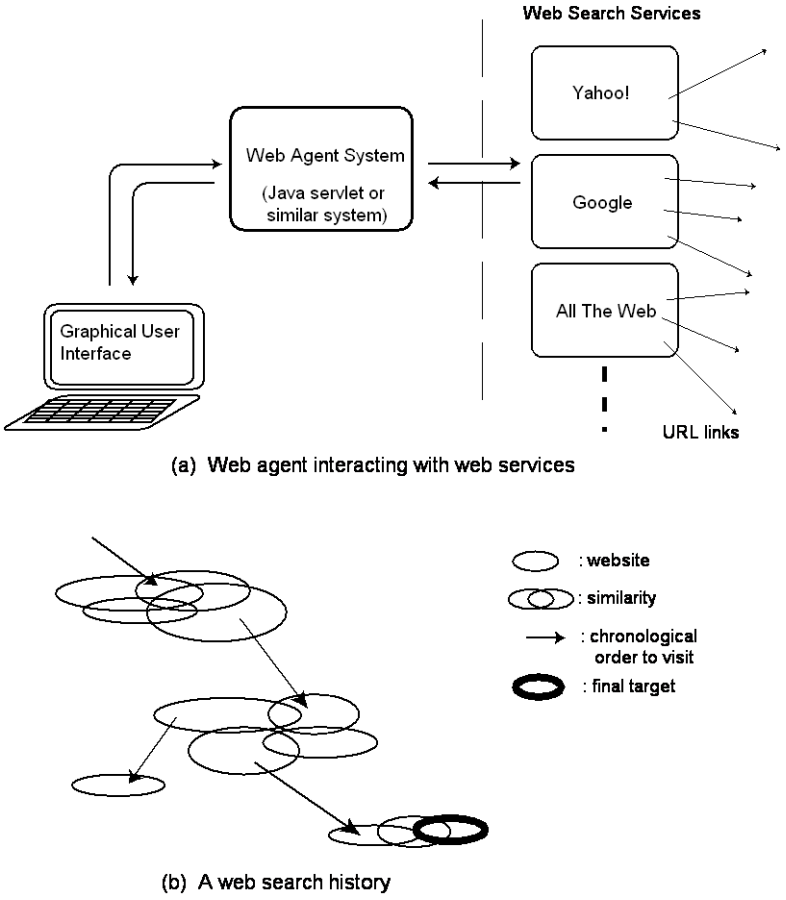


Figure 7: Agent composition (a) and web search history (b).

The background memory system, embedded in the computer and used for web exploration, cannot monitor directly the user's emotional behavior towards the individual contents of the sites. Yet to a certain degree it can be reconstructed during recording of episodic memory, which is formed in temporal

sequences of web exploration by linking similarities between the websites, as footprints. As a first step, we try to design such a system by using similarities between web contents such as words in a page. It is being extended to a system involving the *episodic-autobiographical relation* based on users' interaction behavior analysis as presented in the next section.

3.1 Prototype of the Web Agent

The system is currently built in MATLAB. Interactions with the web are given by the JAVA call functions in MATLAB. The User graphical interface is built as a hybrid system between MATLAB GUI and Internet Explorer (Figure 8). Components that the system can encode are keywords, found website contents, such as page titles, sentences from the web pages and URL links. In the prototype version for encoding of episodic memory from search experiences are used keywords, page titles, sentences, appearing in the search result, and URL links. The agent can be upgraded to a more advanced system by adding background components that emulate the brain memory functions.

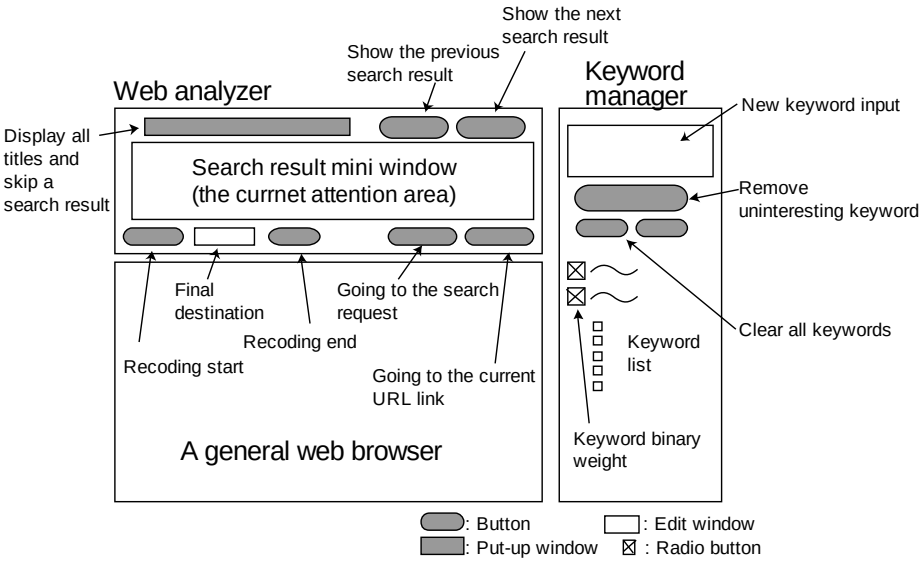


Figure 8: User graphical interface for the learning agent.

An example of how the system works is the user typing in a search word in the keyword manager - the right window. Then, when the user presses the 'Search' button, for example calling Google, the system sends the query to the web search engine through the MATLAB JAVA function. The search results are stored in the system, showing each result in the text window in the Web analyzer - the top window. The user can see the search results one by one, pushing either the 'Previous' or 'Next' button. If the user wants to see the list and skip it, the pop-up window helps jumping to other results. Simultaneously with the search action, the MATLAB application interface calls Internet Explorer to show the search result, as a visualization support. If additional keywords are found in the browser, the user can copy keywords, or a sentence, and paste them into the keyword manager. The user can try iteratively the new search again.

3.2 Recoding Search History

By pressing the 'Start' button, the encoding process starts and every word item that is shown in the window of the Web analyzer is stored sequentially, saved in a set of files, and accompanied with time stamp at which the event happened. The user terminates the recoding by pressing the 'End' button and pasting the destination URL in the Edit window of the analyzer if the target website is found. The conceptual scheme of agent recording the search history is presented in Figure 9.

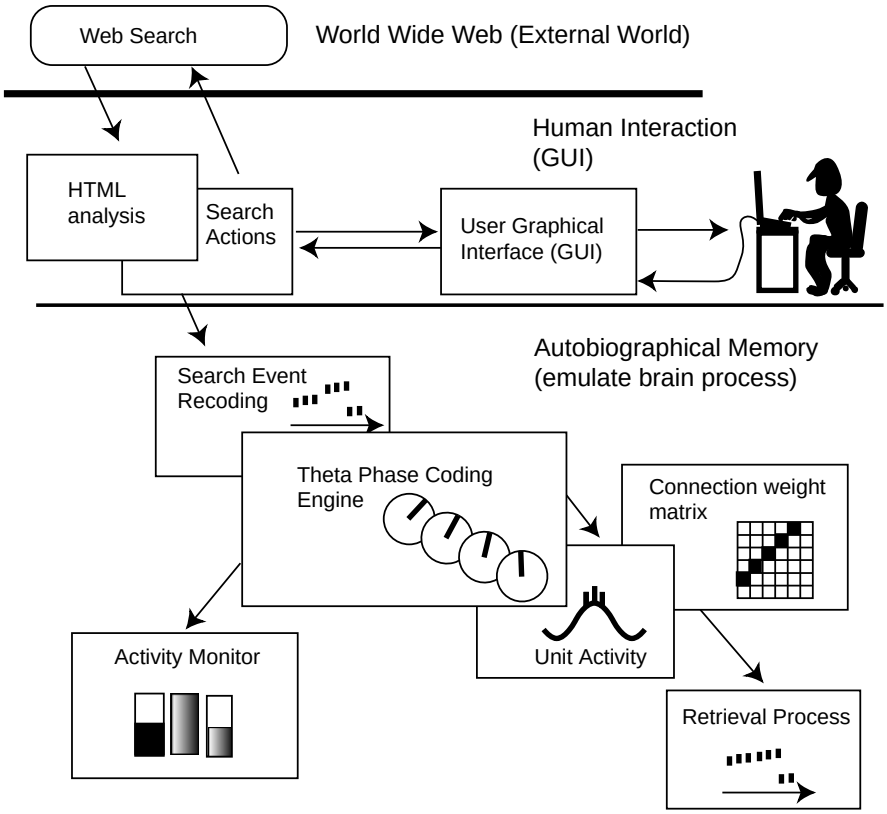


Figure 9: Conceptual scheme of the search history encoding process.

3.3 Visualization of the Episodic Experiences

The formation of episodic memory as an emulation of the brain process with theta phase coding is running as a background process. Similarly to the "Two Well World" agent, it is capable of making use of episodic memory without actually looking into the contents of the memory module or analyzing the semantic meaning of the retrieved fragments. The next step is to augment agent performance with *human-like* memory features in generating autobiographical web knowledge.

The agent obtains the necessary information for episodic memory encoding from the web pages that the user has viewed. As it is shown in Table 3, Gword, TL, and Word are classified and encoded depending on the sentence structure.

The learning path of the agent to the search goal developed in time in the same way as users performed the search [Dimitrova et al., 2007]. The example case was finding a gallery of Japanese craft arts near Tokyo from the initially incomplete information that the gallery is related to an embroidery center in Atlanta.

No	Encoding	Learning during the Iterative Search Process
1.	Gword (keywords used in the SE)	**Web** embroidery center atlanta [Search] Advanced Search Preferences
2.	Search results in the SE	**Web** Results **2** - **31** of about **448,000** for **embroidery center atlanta**. (**0.10** seconds) Crafts : Japanese : Japanese Silk **Embroidery** : Home & Garden ... Needle artist Kazumi Tamura works with her mother Masa, teaching at the Japanese **Embroidery Center** in **Atlanta**. Her grandfather was a master teacher at a ... www.hgtv.com/hgtv/cr_needlework_japanese/ article/0,1789,HGTV_3262_1391776,00.html - 38k - Cached - Similar pages Asian Cultural Experience 10:00 - 7:00, Japanese **Embroidery**, Japanese **Embroidery Center** ... 4:00 - 4:20, Japanese Martial Arts, Aikido **Center** of **Atlanta** ... www.asianculturalexperienceinga.com/calendar2006.php - 39k - Cached - Similar pages Welcome to the Japanese **Embroidery Center** Japanese **Embroidery Center** 2727 Spalding Drive, **Atlanta**, GA 30350 USA Phone: 770.390-0617 Fax: 770/512-7837 e-mail: info@japaneseembroidery.com. About Us ... www.japanese**embroidery**.com/About_Us/about_us.html - 24k - Cached - Similar pages the Japanese **Embroidery** Journal (Kurenai-kai) Japanese **Embroidery Center** 2727 Spalding Drive **Atlanta**, GA 30350. Membership to the Japanese **Embroidery Center** is $40.00 for US residents, and $45.00 for ... www.japanese**embroidery**.com/Membership/ Membership_Form/membership_form.html - 8k - Cached - Similar pages
3.	TL (titles in the SE)	• Crafts : Japanese : Japanese Silk Embroidery : Home & Garden ... • Asian Cultural Experience • Welcome to the Japanese Embroidery Center • the Japanese Embroidery Journal (Kurenai-kai)
4.	Word (incremental keywords)	Crafts, **Japanese**, Silk, **Embroidery**, Home, Garden, Needle, artist, Kazumi, Tamura, Masa, **Center**, **Atlanta**, Asian, Cultural, Experience, Spalding, Drive, USA, Journal, **Kurenai-kai,** Membership, ...

Table 3: Extraction of keywords from the search results by the Web analyzer. Words with highest weights during learning from the retrieved pages are in bold.

In 23 steps users were able to find the target site, based on encounters like trying to follow the "kurenai-kai" link in the middle of the iterative search. At recall, however, they remembered the meaningful encounters, but never repeated the exact hyperlink path from the learning episode. The learning by the agent is illustrated in Table 3. Like reading a sentence, the temporal order is encoded directionally in the form of asymmetric connections in the theta phase coding network. By using time records of visited web sites and temporal orders of words in sentences, user's experienced episodes are

reconstructed as a cascade process (Figure 10), which is consistent with the input types for the theta phase coding scheme (Figure 5).

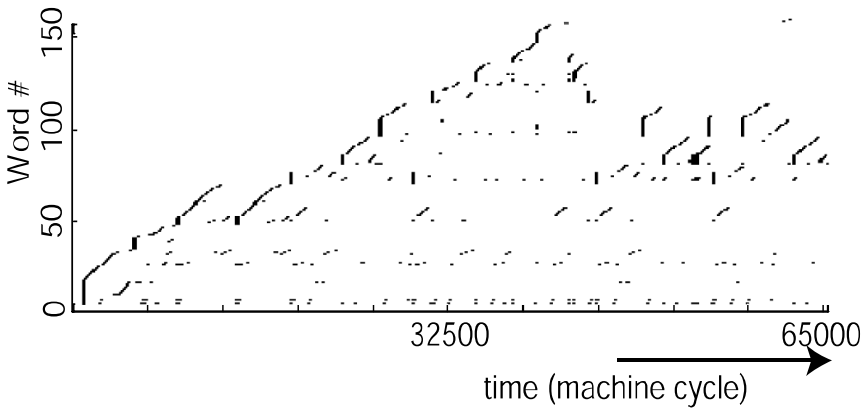


Figure 10: Encoding process of keywords.

The most recent results of our agent performance are presented in the next figures. In the reconstructed temporal sequence, words vary in their visible time length. After the learning process by theta phase coding, the weight matrix, called CA3 connection weight, is formed as a representation of the relationships among the words through the episodic experience.

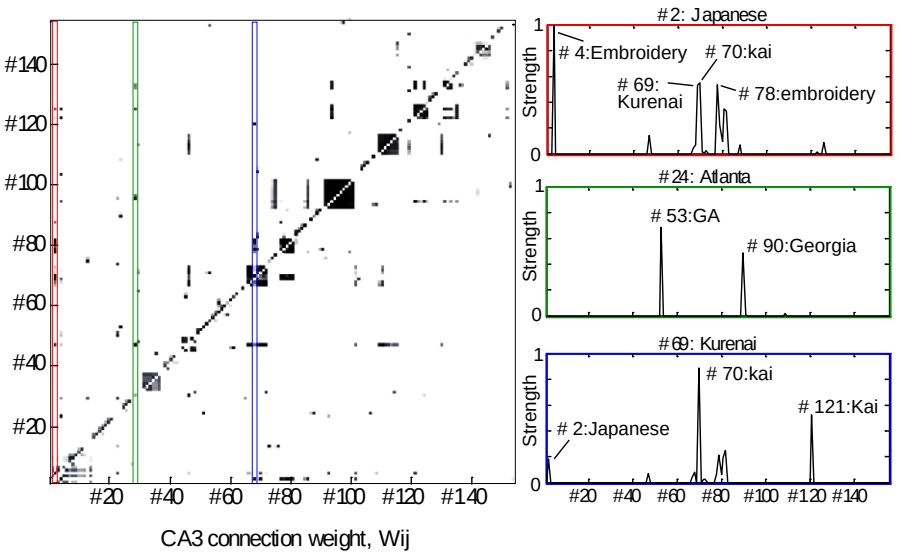


Figure 11: Weight matrix after the learning process.

The left panel of Figure 11 shows the raw matrix pattern, which is visualized as a two dimensional array with the strength of the connections between the words given by their numbers (#word vs. # word). The right panel extracts three sample bars from the matrix, and shows cases of #2 "Japanese," #4 "Embroidery," #69 "Kurenai.",#70 "kai" (top right bar). This represents "Japanese" → "Embroidery," "Japanese" → "Kurenai," "Japanese" → "kai," "Japanese" → "embroidery" connections in the top right, "Atlanta" → "GA", "Atlanta" → "Georgia" in the middle right and "Kurenai" → "kai", "Kurenai" → "Japanese", "Kurenai" → "kai", "Kurenai" → "Kai" in the bottom right bars. Sharp peaks represent strong connections. The middle and bottom cases clearly exhibit the natural sequential structure, suggesting that the theta phase coding algorithms of episodic learning successfully encode temporal sequences of user experiences.

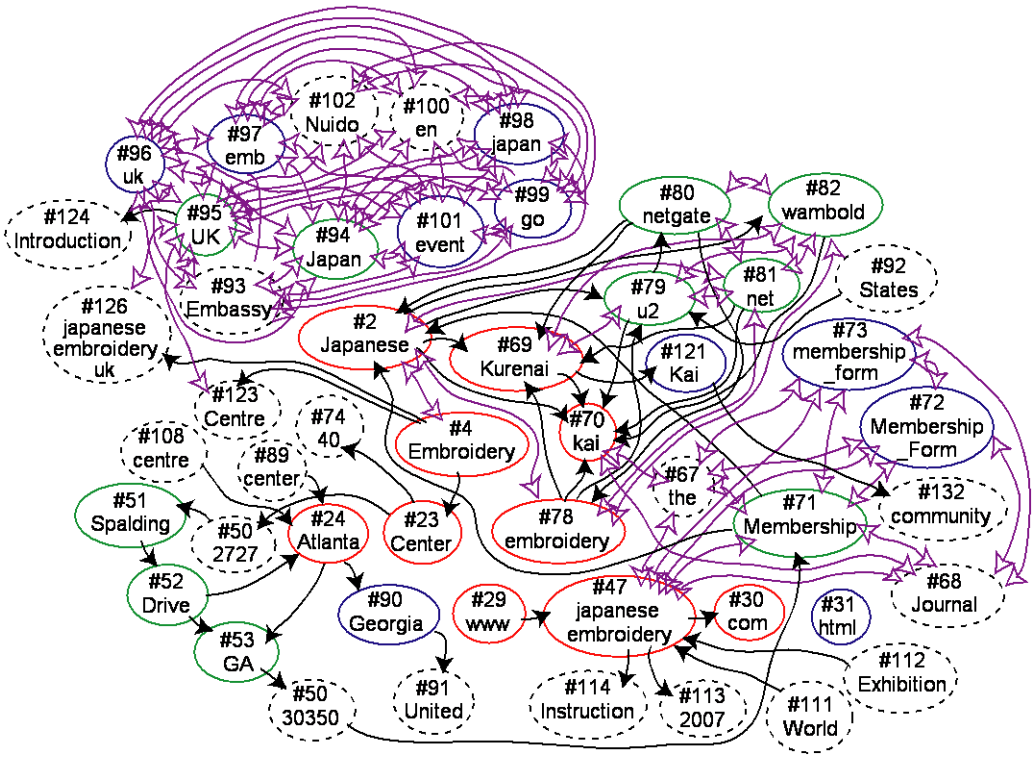


Figure 12: Diagram of words represented in the agent learned matrix by using theta phase coding.

Figure 12 visualizes the nested structure of the matrix as a diagram of words with nodes (#word) and edges (connections). Red circles indicate words ranked top 1-10 in frequency of occurrence in the visited sites, green circles indicate words ranked 11-20, and blue circles are the last 21-30. Words in dotted circles are outside of the top 30, which are relatively non-frequent words in the visited sites. Purple and black lines represent reciprocal connections (non-directional) and asymmetric connections (directional), respectively. Interestingly, there are reciprocal connections to a certain level but the asymmetric connections are preserved clearly and represent the sequential order of the experienced episodes. The mixture of the two types helps the formation of episodic memories by propagating a collective and

cascaded activity of simulated neurons representing words. Moreover, the agent is developing in the historical time of the web and has learnt about a recent exhibition of Japanese embroidery at the Embassy of Japan in the UK. Our agent performance has acquired *human-like* memory features in generating autobiographical web knowledge.

3.5 Design of Agents to Support User Autobiographical Experiences with the Web

Present day users of search engines exhibit two kinds of behaviors in knowledge search. The first kind of behavior is to strictly follow the hyperlink path and is called web navigation [Kleinberg, 1998]. With the recent optimization of web services and search engine performance in terms of speed and flexibility of information retrieval, it has become common that users copy fragments of text from a page and paste into the search engine dialogue box for a novel search, rather than just relying on the highlighted hyperlinks in the retrieved pages. This process of browsing via iteratively starting new searches based on meaningful fragments encountered during viewing a retrieved page we refer to as *semantic navigation* of the web. The agent is extended with the ability to extract fragments of text, which have been meaningful to the user. This is referred to as the *episodic-semantic memories relation* of our memory model.

Work is currently being carried out on identifying aspects of genres in web pages based on structural, ontological, perceptual or stylistic features presented to the user by browser reading of HTML scripts. One group of studies addresses sentiment analysis [Tang et al, 2009], another – multiplicity of genres in a web page [Santini & Sharoff, 2009], stylistic analysis [Karlgren et al., 1998, Karlgren, J., 1999], or expert level of the text [Dimitrova & Kushmerick, 2003, Goeuriot et al, 2005]. Methodologies include part-of-speech tagging, bag-of-words approach, support-vector-machine classification and many others.

In previous work we employed a natural-language word frequency heuristic to define semantic features of the analyzed text [Dimitrova, 2003, Dimitrova & Kushmerick, 2003]. A thesaurus was compiled taken from the Brown Corpus [Kucera & Francis, 1967] with long English words of low natural language frequency (NLF) norms. The agent used this module to check the NLF norm of each encountered long word in the retrieved document. Based on this heuristic an index was proposed of the expert level of the document – scientific text or popular description. A visualization interface was designed to display retrieved pages as belonging to one of four groups – brief –expert, brief-popular, detailed-expert, detailed-popular. Users could choose which pages to open based on this display, and the agent could infer preferences from the classified pages. Classifications of web genres based on formal characteristics like blogs, personal pages or institutional sites have also been developed [zu Eissen & Stein, 2004, Cheng & Choi, 2009]. Our neuro-cognitive agent implements a *semantic memory* module, similar to the above thesaurus. This module is intended to perform independent analysis of the first hundred of the returned pages by the search engines – for any iteration of the search. The classified along a genre dimension pages are helpful in providing guidance for the semantic navigation. Neuro-cognitively this will reflect the hippocampal cortical relations of general knowledge retrieval like "birds can fly", "Paris is the capital of France", "kurenai-kai is style of Japanese embroidery".

For the episodic-autobiographical relation one particular feature of the autobiographical memory has to be implemented. Autobiographical memory stores remarkable events of *one-time experience*. These can be either of large social scale or of emotional personal significance [Wagenaar, 1986]. The single-trial learning property of the theta phase coding model is especially appropriate for this memory aspect and is elaborated throughout the chapter (e.g. Figure 12).

The discussed in Section 2 theories of episodic memory and learning all agree on the mechanism of learning new knowledge via relative increment of activation of less familiar (distinctive) items in comparison with the more familiar ones. With the process of rehearsal the level of activation decreases in

the regions of the brain where new knowledge is encoded while relative increase of activation in areas responsible for semantic retrieval increases [Posner et al., 1997, Posner & Rothbart, 2005]. For an agent to support user autobiographical experiences with the web a module of independent semantic analysis of *only those pages*, where meaningful fragments have been encountered by the user can be employed.

Experimental studies show that the distinctiveness of an item enhances processing in terms of time and spontaneous rehearsal [Soraci et al, 1994, Lachmann & van Leeuven, 2008]. The encounter of low-frequency words during web search in itself is a *distinctive element* of one's memory. The index of predominance of high or low frequency words in the retrieved meaningful for the user pages, as well as the natural-language frequency norm of the user keywords may turn into useful agent knowledge about the individual user performing web search. Illustration of the complexity of the memory for previous web search and retrieval episodes was user performance when asked to remember the steps of the search path – not just the search goal – these never matched the exact URLs used in the initial search. Moreover, retrieval resembles the "dual-route to memory" experiment of Jones of backward reading of heteropalindromes in recruiting all possible memory resources to produce fast and reliable retrieval strategy [Jones, 1982]. Reinstatement of these aspects of user behavior in web search and memorizing meaningful fragments as *distinctive* personal events is the aim of our current and future work.

4 Conclusions

The chapter presents a theoretical framework for design of web agents on the basis of computational memory and brain research. The framework integrates studies of human memory, brain research and information extraction. The long-term goal is the design of smart agents supporting user autobiographical experiences with the web. The theta phase coding theory is employed to model episodic memory formation based on the dynamics of the neural activations in the brain. A neuro-cognitive agent is described, which implements learning algorithms of theta phase coding applied to modeling web browsing behavior.

The proposed agent is augmented with *episodic-semantic integration* module for support of semantic navigation of the Web as well as with *episodic-autobiographical integration* module to support individual user experiences with the web. The performance of the agent is validated via comparison with web users' search and memory performance and interpreted in relation to information extraction studies of detecting semantic and genre features of web sites. Our agent is developing in the historical time of the web and performs in human-like way in retrieval of autobiographical memories. It is shown that neuro-cognitive agents, 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.

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