The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

EpistemeBase: a Semantic Memory System for Task Planning under Uncertainties

Xiaofeng Xiong[1,2], Ying Hu[1,2] and Jianwei Zhang[3]

Abstract— **Tasks planning under uncertainties is one of fundamental skills for enabling autonomous robots to make proper manipulations in the complex environment. But owing to inexpressive representations, autonomous robots hardly conduct efficient tasks planning, especially in unknown conditions. The application of semantic knowledge in task planning is critically required in artificial intelligence research.**

In this paper, we focus on two topics: semantic knowledge representations and parallel planning for uncertainties. Firstly, a semantic memory system which is called EpistemeBase is proposed for indoor tasks planning, it includes five parallel agents: *Assertion*, *Plan*, *Anticipation*, *Behaviour* and *Effect*. Its framework is an evolving process, which consists of *Datum*, *Information*, *Knowledge* and *Intelligence*. Secondly, the same task planning is synchronously represented by five paralleled agents. This paralleled structure can well accelerate the process of tasks planning as well as better handle it under uncertainties. Finally, the experiment of tasks planning is conducted for measuring the reaction time of planning and uncertainties by using the EpistemeBase and the Open Mind Common Sense (OMCS) respectively.

I. INTRODUCTION

The semantic memory refers to the memory of meanings, understanding, and other concept-based knowledge. It can provide knowledge about objects for indoor autonomous planning. However, unpredictable situations have been handicaps for the autonomy of robots in changed indoor surroundings. For solving it, robots should not only be endowed with several common skills, but also be equipped with a large amount of knowledge. Even accomplishing seemingly simple task requires robots to understand that the table cannot be tilted, to give an example [1]. In addition to the knowledge base, few people will deny the fact that robots are not able to effectively plan tasks without capabilities of knowledge processing [2]. These capacities include finding analogies and paths between two objects. In general, constructing a semantic memory system with vast amounts of knowledge is necessary for the autonomous manipulations of robots. Memory is essential to any social handling of unknown situations [3]. To our knowledge, little research has been conducted on building such a semantic memory system for robots.

This work was supported by the Knowledge Innovation Project (Project No.KGCXZ-YW-128 and Project No.KGCXZ-YW-166), Natural Science Foundation of China (Project No.50875176) and Concentration of Innovation Resources Program of Shenzhen City (Project No.ZYC200903250122A).

Xiaofeng Xiong is with Shenzhen Institutes of Advanced Technology[1], Chinese Academy of Sciences, China and The Chinese University of Hong Kong[2], Shatin, HongKong xf.xiong@sub.siat.ac.cn

Ying Hu is with Shenzhen Institutes of Advanced Technology[1], Chinese Academy of Sciences, China and The Chinese University of Hong Kong[2], Shatin, HongKong ying.hu@siat.ac.cn

Jianwei Zhang is with the Faculty of University of Hamburg[3], Germany zhang@informatik.uni-hamburg.de

The EpistemeBase is presented for autonomous robots in this study, which is a semantic memory system. This system not only has a large amount of semantic knowledge, but also conducts autonomous planning with high-level thinking. First, the EpistemeBase is composed of hierarchical structures including low-level semantic relations and high-level thinking [4]. Low-level semantic relations include several kinds of semantic relations while *Assertion*, *Plan*, *Anticipation*, *Behaviour* and *Effect* are major agents of high-level thinking. Namely, high-level thinking not only provides a specific account of why the robot has to do things and what the robot gains from failures, but also predicts the subsequent human intentions. Second, the abilities of learning and reasoning from general experiences facilitate indoor self-planning. Robots are able to conduct the proper actions with these abilities, especially in unpredictable conditions. According to the functions accomplished above, this semantic memory system mainly consists of information processing, knowledge representation and intelligence reasoning.

II. RELATED WORK

The Cyc project [5], started in 1984 by Doug Lenat, concentrates upon formatting common sense knowledge into a logical framework. OpenCyc is an open source version of the Cyc technology, which is composed of the complete general knowledge base and a common sense reasoning engine. As of 2005, it contains the full set of (non-proprietary) Cyc terms as well as millions of assertions. However, because the process of representation by its own language CycL is quite complicated, it is difficult to apply to a robotic knowledge base with limited sources. Moreover, all ambiguities in the text need to be changed into completely explicit logical formulations required by CycL. However, a knowledge database need not necessarily be logically consistent [6].

In comparison to the Cyc project, the ConceptNet is a semantic network of common sense knowledge that includes 1.6 million edges connecting more than 300,000 nodes. Nodes are semi-constructed fragments, correlated by an ontology of eighteen semantic relations [7]. Its knowledge representation can be described as a semantic resource that is structurally similar to WordNet [8], but whose domain of texts is widely the same as Cyc. The ConceptNet obtain knowledge from the public rather than manually handcrafting the common sense knowledge. However, it only focuses on various sets of semantic relationships between concepts instead of the human like thinking, this character limits its applications on other AI fields, such as the human-robot interaction and tasks planning. Furthermore, the knowledge representation in the ConceptNet is too ambiguous to solve problems, especially the tasks planning. Karl Popper claimed that ”all life is problem solving” [9].

III. ROBOTIC MEMORY SYSTEM

The scenario of setting a cup on the table is chosen for well explaining the framework of EpistemeBase, it is a typical instance of task planning for an indoor mobile robot.

A. System Overview

As shown in Fig. 1, the image data can be obtained by using the binocular vision and sensors array in the perception unit, and these data can be processed by three modules in the robot memory unit. These modules include information processing, knowledge representation and intelligence reasoning. First, the grounding between object and symbolic name is executed in the information processing, and properties of the symbolic name will be recorded as specific knowledge in a knowledge pool. Second, the concept base generalizes and classifies hundreds of thousands of kinds of commonsense knowledge by several kinds of semantic relations. Finally, the intelligence reasoning not only finds paths from one concept to another, but also makes the analogy between concepts. It is the essential ability for robots to handle unknown situations.

This framework is an evolving mental process which includs *Datum*, *Information*, *Knowledge* and *Intelligence*. The *Datum* are sets of sensory data about the environment by the perception unit, and they are transformed into *Information* through anchoring between objects and their symbolic name. But the *Information* merely symbolizes objects and describes their properties rather than building the semantic relationship between objects. And the common sense described by these semantic relationships makes up the *Knowledge*, yet robots only possessing the *Knowledge* can hardly handle uncertainties. So the *Intelligence* with reasoning is indispensable for autonomous robots.

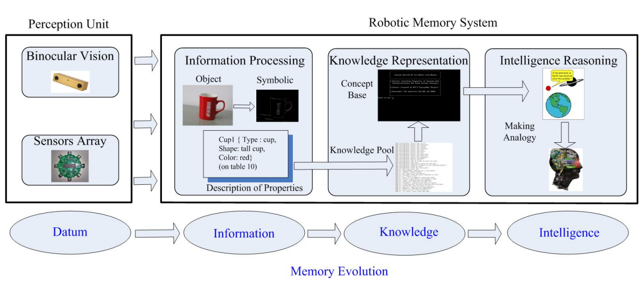


Fig. 1. Robotic memory system

B. Information Processing

Symbolizations of objects and properties of descriptions are conducted in this module (shown in Fig. 2). The perception unit provides the environmental data by using binocular vision unit and the sensor array. First, objects are recognized by the binocular vision unit and are divided into groups like ’Cup 1’or ’table 10’. And the sensor array also offers attributive data about objects, such as colours and spatial coordinates. So the link between a respective object and its symbolic name is created. Second, properties of corresponding objects are used for annotating the symbolic name, for example ’cup 1’ Type: cup, Shape: tall, Colour: red, Position: on the table 10. All these properties are recorded as knowledge in the knowledge pool.

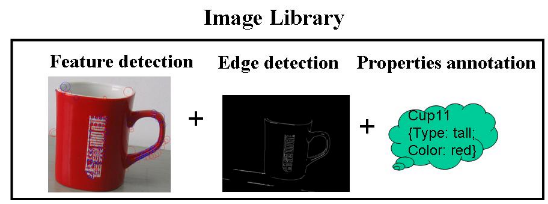


Fig. 2. Implementation of information processing

The implementation of information processing is mainly grounded on the SIFT for the recognition of objects. The SIFT (Scale-Invariant Feature Transform) is a feature recognition algorithm developed by David G. Lowe [10]. The information processing using the SIFT algorithm is accomplished in three phases. Features are first detected by the SIFT [11], matched with features and shapes of objects in an image library, and finally annotated by properties of objects in the knowledge pool. In these phases, the image library can be iteratively constructed by trainings on input images.

$$I_{\mathbf{n}} = (F_{\mathbf{n}}, E_{\mathbf{n}}, P_{\mathbf{n}}), O_{\mathbf{n}} = S(O_{\mathbf{n-1}}, I_{\mathbf{n}}) \tag{1}$$

where n is the iterative times, I_n are parameters of input image, F_n is a matrix of feature points, E_n is a matrix of geometric points, and P_n is a set of sign function; S is the iterative function, O_n is a feature matrix of objects.

It is structured as a hierarchical tree of objects, which are related to a large amount of shapes and key points. Namely, an object is composed of several models under different views and consists of many key points; on the other hand, each model only corresponds with an unique object, and some set of key points merely belong to a single model.

C. Knowledge Representation

The knowledge representation in the EpistemeBase is inspired by the ConceptNet [12]. But in contrast to the ConceptNet, the EpistemeBase not only focuses on several kinds of semantic relations between concepts, but also generalizes high-level thinking from these semantic relations. Moreover, thinking is a mental process according to theories in Neuropsychology claim. Thinking allows beings to model the world and to deal with it through their objectives, plans, ends and desires [13]. Thus, the high-level thinking of the EpistemeBase can be divided into five agents: *Assertion*, *Plan*, *Anticipation*, *Behaviour* and *Effect*, their generalizations are shown in Table I. Explanatorily, the agent is a unique kind of high-level knowledge representation or cognitive process [14].

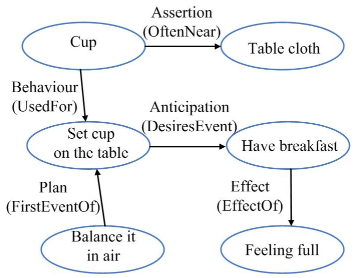


Fig. 3. Excerpt of the EpistemeBase‘s semantic relations

TABLE I
HIGH LEVEL THINKING

Agent	Semantic Relations
Assertion	*IsA, PropertyOf, PartOf, MadeOf, LocationOf, OftenNear*
Plan	*EventRequiresObject, FirstSubeventOf, LastSubeventOf, SubeventOf*
Anticipation	*DesiresEvent, DesiresNotEvent, EventForGoalEvent, PostEventOf*
Behaviour	*Do, UsedFor*
Effect	*EffectOf, EffectOfIsState*

Fig. 3 shows an excerpt of the EpistemeBase’s semantic network. Let the status of each semantic nodes is negative or positive,

$$N = (n = (n_{\mathbf{1}}, n_{\mathbf{2}}, \cdots, n_{\mathbf{j}}), n_{\mathbf{i}} = -1or + 1(_{\mathbf{i} \leq \mathbf{j}})) \quad (2)$$

so overall interactions of other nodes on ni is yi,

$$y_{\mathbf{i}} = sgn(\sum_{k=1}^{N} a_{\mathbf{k}} n_{\mathbf{k}} - \theta_{\mathbf{i}}), a_{\mathbf{k}} = (s_{\mathbf{1}}, s_{\mathbf{2}}, \cdots, s_{\mathbf{j}})^T \quad (3)$$

where $a_{\mathbf{k}}$ is a vector of semantic relations for each agent, $n_{\mathbf{k}}$ is the status of interactive nodes on $n_{\mathbf{i}}$, $\theta_{\mathbf{i}}$is the threshold of $n_{\mathbf{i}}$, $s_{\mathbf{j}}$ is the interactive weight on $n_{\mathbf{i}}$.

These five agents have their own definitions here. *Assertion* is composed of vast amounts of the basic knowledge for robotic manipulation, for example, the cup is a container, and beverages are always located in the refrigerator. Besides, it seems that there are some similarities between the *anticipation* and the *effect* because both of them are about future possibilities, but they differ from each other in essence. The *effect* is objective while the anticipation is subjective. For instance, you are going to eat breakfast to allay your hunger, this is your subjective thinking. Actually, you do not eat your fill if there is not enough food. But there is no doubt that eating breakfast can ease the feeling of hunger to some extent, this is the Objectivity [15]. The *Plan* is an agent for arranging the event, several forms are used for representing planning of events, such as sub events, the prerequisite event and last events. For example, the prerequisite of buying a house is finding a house for sale. The last agent is *Behaviour*. It can provide many paths of solving the problem for the *Plan*. For example, you are able to use the cup to hold the milk.

D. Intelligence Reasoning

Reasoning is the cognitive process of looking for reasons, beliefs, conclusions, actions or feelings. Analogy is one of several approaches for reasoning, which is a cognitive process of transferring information from a particular subject (source) to another subject (target) [16]. For people, making an analogy is critical to learn new knowledge and handle the uncertainty [17]. Some AI projects have done little in the way of analogical reasoning because they lack open-source software and a large enough base of concepts and are difficult to use. We believe that the knowledge base from OMCS and general experiences enable analogical reasoning to some degree.

However, the EpistemeBase can record general experiences from robotic manipulations while ConceptNet only acquires knowledge from the Internet. On the other hand, the EpistemeBase also updates its knowledge base from the OMCS project. In the EpistemeBase, two Concept nodes are connected analogically with semantic relations. For example, robots do not even know whether the cup can hold the milk in the process of setting a cup on the table. Therefore they probably get stuck by the ’Subevent(pour milk)’ which is an unknown situation for planning. So robots with the ability of analogy would make some analogies (shown as Fig. 4) between ’cup’ and ’milk’. First, ’cup’ and ’milk’ are backdated to their upper concepts by semantic relations, such as ’IsA(cup, container)’ and ’IsA(milk, liquid)’. Second, the semantic relation ’UsedFor(container, hold liquid)’ connects ’container’ with ’liquid’. So the conclusion can be made that the cup can be used for holding liquid.

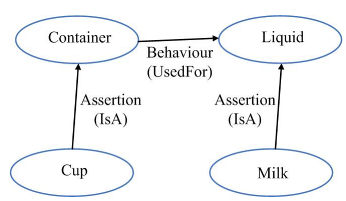


Fig. 4. Making analogies between ’cup’ and ’milk’

IV. INDOOR TASK PLANNING UNDER CERTAINTIES

Planning is one of the most common applications for indoor manipulations. Generally, the process of planning would be divided into several sub events (shown as Fig. 5). But perpendicular representation of planning cannot deal with uncertainties efficiently, for example, the cup would still fall from the tilted table if the robot has no idea of common sense like 'The cup will fall from the tilted table'. Therefore robots can hardly conduct efficient planning with serial representation.

The EpistemeBase is a knowledge base with low-level relations and high-level thinking. It cannot only record common sense by semantic properties of concepts, but also finds analogies and paths between concepts. On the other hand, with its high-level thinking the EpistemeBase can represent the same thing by paralleled agents, which are comprised of *Assertion*, *Plan*, *Anticipation*, *Behaviour* and *Effect*.

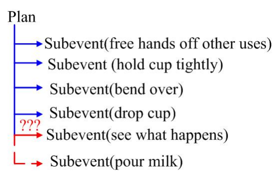


Fig. 5. The common process of planning

Different from perpendicular representation, multiple representations can endow robots with high-level thinking. The EpistemeBase can serve this need. There are several agents for representing knowledge in the EpistemeBase. All agents write the same thing simultaneously in different ways. Endowed with the EpistemeBase, robots are able to obtain basic knowledge for events, plan events, anticipate events, know how to solve a problem and understand objective effects of events.

For instance, the robot is prepared to set a cup on the table but does not know whether the table is flat. First, the robot plans the event, which is represented by sub events (shown in Fig. 6), prerequisite events and the last events. Secondly, the agent *Plan* will automatically turn (dashed shown in Fig. 6) to the agent *Anticipation* when the agent *Plan* cannot handle unknown conditions, such as the cup falls from the tilted table. Certainly, assertions and behaviours are also necessary for planning the event, such as 'the table should be flat' and 'the cup can be used for holding liquid'.

In the EpistemeBase, two Concept nodes are connected analogically with semantic relations. For instance, since robots do not even know whether the cup can hold the milk, they need analogically effecting conceptual reasoning . The

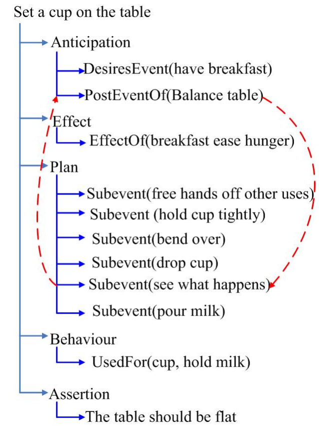


Fig. 6. The planning of setting a cup on the table

analogous results for this uncertainty in the EpistemeBase are shown in Fig. 7.

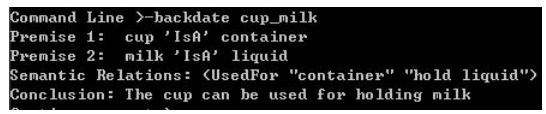


Fig. 7. The analogies between 'cup' and 'milk'

V. EXPERIMENTAL RESULTS

The robot with the EpistemeBase is MRobo (shown in Fig. 8), a household mobile robot with abilities of path planning and telepresence. The MRobo can navigate the whole indoor lab and conduct some manipulations including grasping cups and setting the table.

Fifty common indoor tasks are selected for measuring the efficiencies of OMCS and the EpistemeBase. For example, Experiments on five agents to 'set cup on the table' will be conducted in the following sections. And these experiments focus on the 'concept' layer (shown in Fig. 9), namely, all objects are instanced in the knowledge Pool, such as 'cup 11' and 'table 2'. Then they will be generalized to concepts, such as 'cup' and 'table' in the 'concept' layer.

In this experiment, the agent *Plan* for 'set cup on table' is expressed as multiple methods. They consist of 'EventRequiresObject', 'FirstSubeventOf','LastSubeventOf' and 'SubeventOf '. And we assume that the table which holds the cup is in a state of proper balance. Fig. 10 shows that the 'set cup on table' is divided into the sub events [free hands from other uses, hold cup tightly bent over, drop cup, see what happens, pour milk]. Besides, other semantic relations for the agent *Plan* are used to express the manipulation 'set cup on table'.

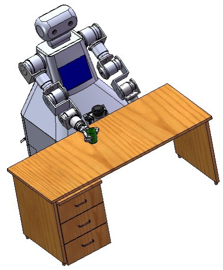


Fig. 8. The MRobo

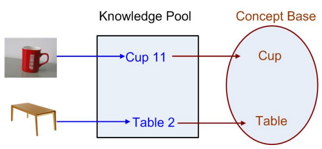


Fig. 9. The generation of concepts

However, the robot would get stuck if the table were out of balance. This is the uncertainty, the agent *Plan* stops at the 'Subevent' of 'see what happens'. What the robot 'sees' is that the cup still falls from the table if it is not equipped with the EpistemeBase, it may even be programmed to repeat past sub events. With the EpistemeBase, the MRobo will automatically switch to other agents for dealing with abnormalities. The 'Subevent' of 'see what happens' turns into the agent *Anticipation*, and then turns into the agent *Plan* again after 'balance table' (shown as Fig. 11).

Among fifty indoor tasks, the experimental results of ten tasks are shown in the TABLE II. There are several kinds of uncertainties, such as 'table is out of balance'. The efficiencies bwtween the EpestemeBase and the OMCS are compared by reaction time for indoor tasks,

There are three kinds of measured functions for the reaction time,

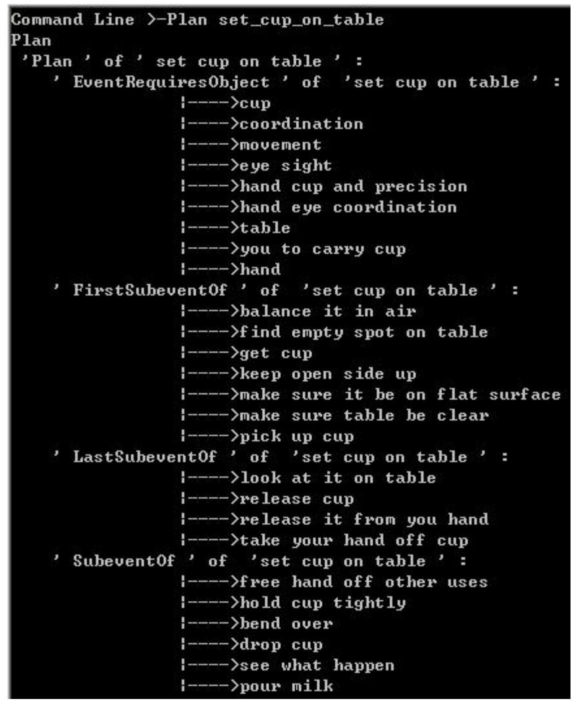
$$Max = \max(T_{\text{j}}) \tag{4}$$

$$Min = \min(T_{\text{j}}) \tag{5}$$

$$Ave = \frac{\sum_{j=0}^{N}(T_j)}{n} \tag{6}$$

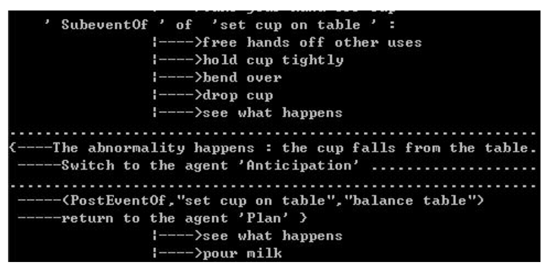
where j is the id of indoor tasks, T_{j} is the reaction time used for planning or uncertainties, *Max* is the maximum of T_{j}, *Min* is the minimum of T_{j}, *Ave* is the average of T_{j} and n is the total number of valid indoor tasks (indoor tasks are invalid when their reaction time is Null here).

According to experimental results shown in TABLE II and TABLE III (Null means infinity), the average reaction time of the EpistemeBase is 9.4 *sec* when that of the OMCS



```
Command Line >-Plan set_cup_on_table
Plan
 'Plan ' of ' set cup on table ' :
    ' EventRequiresObject ' of  'set cup on table ' :
                ¦---->cup
                ¦---->coordination
                ¦---->movement
                ¦---->eye sight
                ¦---->hand cup and precision
                ¦---->hand eye coordination
                ¦---->table
                ¦---->you to carry cup
                ¦---->hand
    ' FirstSubeventOf ' of  'set cup on table ' :
                ¦---->balance it in air
                ¦---->find empty spot on table
                ¦---->get cup
                ¦---->keep open side up
                ¦---->make sure it be on flat surface
                ¦---->make sure table be clear
                ¦---->pick up cup
    ' LastSubeventOf ' of  'set cup on table ' :
                ¦---->look at it on table
                ¦---->release cup
                ¦---->release it from you hand
                ¦---->take your hand off cup
    ' SubeventOf ' of  'set cup on table ' :
                ¦---->free hand off other uses
                ¦---->hold cup tightly
                ¦---->bend over
                ¦---->drop cup
                ¦---->see what happen
                ¦---->pour milk
```

Fig. 10. The agent *Plan* for 'Set cup on table'



```
   ' SubeventOf ' of  'set cup on table ' :
                ¦---->free hands off other uses
                ¦---->hold cup tightly
                ¦---->bend over
                ¦---->drop cup
                ¦---->see what happens
...................................................................
<----The abnormality happens : the cup falls from the table.
 -----Switch to the agent 'Anticipation' ..................
...................................................................
 -----<PostEventOf,"set cup on table","balance table">
 -----return to the agent 'Plan' >
                ¦---->see what happens
                ¦---->pour milk
```

Fig. 11. The agent *Plan* for an uncertainty

is 19.8 *sec*, while both of them are dealing with indoor tasks planning. The reaction time in the EpistemeBase is considerably faster than that in the OMCS, no matter what the measured function is. This is due to the fact that the EpistemeBase stores semantic knowledge through five paralleled agents, while the OMCS uses perpendicular sections. All paralleled agents can be active when the same task is executed. With this character, indoor planning can avoid falling outside predefined conditions which arise with uncertainties. Thus the paralleled structure of the EpistemeBase accelerates the decision processes of indoor planning. Moreover, for handling uncertainties, the average reaction time of the EpistemeBase is 56.8 *Sec* when that of the OMCS is 102.8 *Sec*. The EpistemeBase is more tolerant of uncertainties than

TABLE II
REACTION TIME(UNIT:SEC) FOR PLANNING AND THE UNCERTAINTY

Indoor task	EpistemeBase		OMCS	
	Plan	Uncertainty	Plan	Uncertainty
Clear the floor	11.3	76.2	20.2	148.6
Set cup on the table	10.5	63.8	19.4	128.2
Find an cup	7.5	58.4	14.5	74.3
Clean up	7.8	42.6	15.1	65.7
Recharge batteries	10.8	56.3	24.2	Null
Turn the heater	6.7	31.9	13.7	86.7
Heat food	9.4	54.8	18.6	105.4
Go to refrigerator	12.5	80.5	26.7	114.6
Find a person	7.2	30.7	13.8	60.4
Turn on lights	8.5	43.6	17.3	96.8

TABLE III
MEASURED RESULTS (UNIT:SEC) FOR PLANNING AND THE UNCERTAINTY

	Plan			Uncertainty		
	Max	*Min*	*Ave*	*Max*	*Min*	*Ave*
EpistemeBase	12.5	6.7	9.4	80.5	30.7	56.8
OMCS	26.7	13.7	19.8	Null	60.4	102.8

the OMCS owing to representing indoor tasks synchronously. Invalid task planning happens occasionally in the OMCS when it handles uncertainties. Because its semantic structure is out of order for tasks planning, and its storage goes against planning task parallel. Finally, the high-level thinking agents are conducive to understanding the inner meaning of the human thinking. These thinking are correlated. For example, one of anticipations of setting cup on the table is that people possibly want to have breakfast.

VI. CONCLUSION

In this paper, a semantic memory system with five paralleled agents is proposed, which is the EpistemeBase. Endowed with this system, autonomous robots can effect tasks planning and handle uncertainties. The EpistemeBase not only uses several kinds of semantic relations describing knowledge, but also represents knowledge in parallel through different agents. These agents are composed of *Assertion*, *Plan*, *Anticipation*, *Behaviour* and *Effect*. Moreover, the mental memory process applied to robots is presented by four evolving stages, which consists of *Datum*, *Information*, *Knowledge* and *Intelligence*. Furthermore, the EpistemeBase instantiates a machine with multiple representations of tasks planning.

REFERENCES

[1] Moritz Tenorth and Michael Beetz, "Towards practical and grounded knowledge representation systems for autonomous household robots", *Proceedings of the 1st International Workshop on Cognition for Technical Systems*, Muenchen, 2008.

[2] Moritz Tenorth and Michael Beetz, "KnowRob: Knowledge Processing for Autonomous Personal Robots", *IEEE/RSJ International Conference on Intelligent Robots and Systems*, St.Louis, MO, 2009, pp. 4261-4266.

[3] Wan Ching Ho, Mei Yii Lim, Patricia A. Vargas, Sibylle Enz, Kerstin Dautenhahn and Ruth Aylett, "An Initial Memory Model for Virtual and Robot Companions Supporting Migration and Long-term Interaction", *8th IEEE International Symposium on Robot and Human Interactive Communication*, 2009, pp. 277-284.

[4] Hector Levesque and Gerhard Lakemeyer, "Cognitive Robotics", *Handbook of Knowledge Representation*, Elsevier, 2008.

[5] C. Matuszek, J. Cabral, M. Witbrock, and J. DeOliveira, "An introduction to the syntax and content of Cyc", *AAAI Spring Symposium on Formalizing and Compiling Background Knowledge and Its Applications to Knowledge Representation and Question Answering*, 2006, pp. 44-49.

[6] Wade Roush, "Marvin Minsky on Common Sense and Computers That Emote", *MIT Technology Review*, 2006.

[7] Liu H and Singh P, ConceptNet: a practical commonsense reasoning tool-kit, *BT Technology Journal*, vol. 22, 2004, pp. 211-226.

[8] Fellbaum .C, *WordNet: An Electronic Lexical Database*, MIT Press, 1991.

[9] K. R. Popper, *All Life Is Problem Solving*, Routledge, London, 1999.

[10] Lowe D. G, "Local Feature View Clustering for 3D Object Recognition", *IEEE Conference on Computer Vision and Pattern Recognition*, Kauai, Hawaii, 2001, pp. 682-688.

[11] Lowe D. G, Distinctive Image Features from Scale-Invariant Keypoints, *International Journal of Computer Vision*, vol. 80, 2008, pp. 45-57.

[12] Havasi.C, Speer.R and Alonso.J, "ConceptNet 3: a Flexible, Multilingual Semantic Network for Common Sense Knowledge", *Proceedings of Recent Advances in Natural Languges Processing*, 2007.

[13] Harper Douglas, "Etymology of Thought", *Online Etymology Dictionary*, 2009.

[14] Marvin Minsky, *The Emotion Machine*, SIMON and SCHUSTER, 2007.

[15] Megill Allan, *Rethinking Objectivity*, Duke UP, 1994.

[16] Kirwin Christopher, *Reasoning*, Oxford University Press, 1995.

[17] Vickers John, *The Problem of Induction*, The Stanford Encyclopedia of Philosophy, 2009.