Cognition Inspired Object Oriented Knowledge Warehouse Architecture

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***Abstract*—An adaptive knowledge system needs massive knowledge. But massive knowledge can handicap the speed of searching and reasoning. Good structure can considerably enhance the expressive power and efficiency of a knowledge system. Inspired by the structure of human memory and data warehouse, object-oriented warehouse architecture of knowledge based on the 3-World model was advanced after exploring the essence of knowledge and cognition. Great amount of conceptual and nonconceptual knowledge can be well handled with this architecture. System using the architecture can be more adaptable with different tasks.**

***Index Terms*—knowledge warehouse, knowledge representation, knowledge structure, cognition, 3-World model**

I. INTRODUCTION

Sufficient knowledge is essential to the building of an adaptive knowledge system [1]. But great amount of knowledge can handicap the reasoning and application. For the sake of efficient application of knowledge, an efficient storage structure must be established. Data warehouse can store large amount of data. Queries and analysis can be efficiently applied on a data warehouse. The structure of data warehouses can be reference of the construction of an efficient knowledge warehouse.

On the other hand, common sense is critical as the context of comprehension and reasoning. A great deal of work is done to establish a knowledge system with plenty of knowledge and common sense [3][4]. But only limited applications can be run on such knowledge environments. Fortunately, human's cognition and memory provides important reference to knowledge and its structure.

According the analysis of human memory and cognition, three types of knowledge were distinguished by the level of cognition in the paper. These knowledge types were modeled into three correlated worlds. The 3-Worlds model and operations on them were introduced as the core of the warehouse architecture of knowledge. Various AI task can be carried out on this architecture. Other ways to improve the efficiency were also mentioned.

In this paper, the essence of knowledge is analyzed according human cognition and related work first. Then 3-World theory of knowledge warehouse structure is advanced based on the analysis. Based on the theory, the common sense and concept cluster is further discussed and the architecture is advanced. At last the problem solving process on this archietecture is discussed.

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II. RELATED WORK

A. General Knowledge System with Rich Description

P. J. Hayses claimed that concepts should be described by plenty axioms in a good knowledge system [1]. Plenty axioms can be used to describe concepts in details and relate it to other concepts. But it's a difficult problem to establish such a huge knowledge system.

Many scientists tried to build a knowledge system can be used to solve general artificial intelligence problems [21]. But this is an impossible task without a general definition of knowledge and its structure.

B. Large Scale Knowledge and CYC

CYC [3][4] is a large project started science 1984. It advanced the idea to build a large scale knowledge system which can solve various artificial intelligent problems. The system maintains a large knowledgebase with common sense. With the reference of common sense, the system can solve natural problems. For example, because a mountain can't fly so the sentence "Fred saw the mountains flying over Zurich." Must means "Fred saw mountains when he was flying over Zurich." rather than "Mountains flew over Zurich, and Fred saw them."

Reasoning and applications are established in CYC based on semantic of natural language. It's a great progress to use common sense to solve ambiguous in natural language understanding. But why is common sense so adaptable? What is the definition of common sense? What's the application domain of a piece of

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common sense? These are all problems about the structure of knowledge.

C. Other Applications of knowledge systems

There are other AI application systems based on semantics such as WordNet [12]. These systems only serve as references of lexical semantic. They can be used as a semantic dictionary, but context is not built in such systems. Reasoning on these systems is quite limited.

D. Data Warehouse and Knowledge Warehouse

Data warehouse is advanced for mass data storage and decision support. Search is optimized in warehouse data while update is not concerned as core factor. Hierarchical dimension is introduced for better OLAP analysis. The concept data cube is introduced in data warehouse to describe data limited by regions of dimensions.

Knowledge warehouse have been advanced as a massive storage of knowledge several years before. But most of previous work concentrated on knowledge warehouse's role in a knowledge system [5].

E. Previous Work on Knowledge Representation Structure

Some work had been done on knowledge structure before the work of this paper. A 2-layered model is advanced in the paper [13]. Some other works are done about knowledge acquisition and some enhances on knowledge structure.

F. Over scope

Various types of knowledge structures have been advanced for different applications. But most of them were advance based on symbols and symbolic semantic dictionary. An adaptable knowledge structure with rich semantics is needed for the solution of general artificial intelligence problems.

III. KNOWLEDGE & COGNITION

A. Knowledge

There are many kinds of knowledge, precise or fussy, monotonic or nonmonotonic, first order or high order. The definition of knowledge varies in different theories and tasks. In the book Knowledge Representation, it's mentioned that natural languages display the widest range of knowledge can be expressed [22]. In fact, there exists knowledge that can't be expressed by language. The definition of knowledge was extended as below:

Definition 1: Knowledge is anything can be perceived or understand by an intelligent body.

B. Conceptual and Nonconceptual Knowledge

In Cussins's paper [6], nonconceptual content is distinguished with conceptual content. Conceptual content is define as the content can be described by features precisely. Nonconceptual content is content which can be used by man but not precisely defined. A great deal of knowledge exists as nonconceptual content in human cognition whether because of impossibility or inconvenience of conceptualization. For example, it's hard to define every detail in riding a bike as concept, but man can deal with such thing conveniently by instinct and simple instructions.

C. Cognition Structure of Knowledge

From the research on cognition psychology, human memory can be divided into long term memory (LTM) and short term memory(STM). Long term memory mainly stores the knowledge extracted and comprehended from the outside world [11]. Short term memory stores perceptional information. Short term memory is limited especially for complex objects [8][9]. Conceptual knowledge is mainly stored in LTM while nonconceptual knowledge mainly stored in STM in a more natural representation.

D. Object-Orientation in Knowledge Representation

The world can be naturally represented in objects and their interactions. Objects are related to each other. Two basic relations are firstly focused. One is inheritance, the other is polymerization. They are frequently used in various knowledge representation methods such as frames, semantic web, and description logic and so on. Although the two relations can't provide rich semantic, they can construct the static structure of an object-oriented world.

More than describe the static structure of the world, object-oriented method can be used to describe the dynamic world intuitively using operations and process. Object oriented method can hold detailed information with rich semantic.

E. Ontology and Knowledge Hierarchy

Ontology is advanced as a philosophy term. It was used to describe concepts in the field of computer science to show the hierarchy inheritance of objects in the world [16]. As shown in Fig1, concepts are hierarchically organized. A concept may inherit from more than one concept. The full hierarchy is called full knowledge hierarchy which has the concept of ontology as its root. It's the unique hierarchy consist of all concepts. Knowledge hierarchy in a knowledge based system is a part of the full knowledge hierarchy.

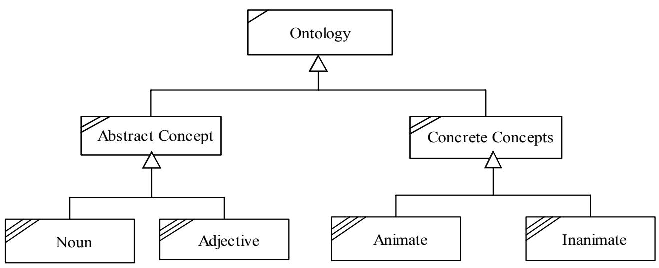

Figure 1. A Hierarchy of Knowledge

F. Dimension and Knowledge Cluster

In Hayses's paper [1], concepts are related to each other. The concepts related with many other concepts can be defined as a knowledge cluster. These clusters may include length, weight and many frequently used metrics. These clusters serve as dimensions in relational database.

A cluster is a concept, so it has the structure of a concept. Operations roll up and drill down can be applied on it.

In this paper, every concept is defined as a knowledge dimension. Dimensions can be arranged or indexed by the frequency of their relation to other concepts.

Whether in a conceptual or nonconceptual world, four dimensions are the basic dimensions. They are the three dimensions represent the position and the dimension represent the time.

IV. 3-WORLDS IN KNOWLEDGE SYSTEMS

A. 3W Model

From the cognition of human, we can imagine the three layer of knowledge. The knowledge in a knowledge base has similar architecture to represent various kinds of knowledge. Fig 2 shows the process of conceptualization and cognition.

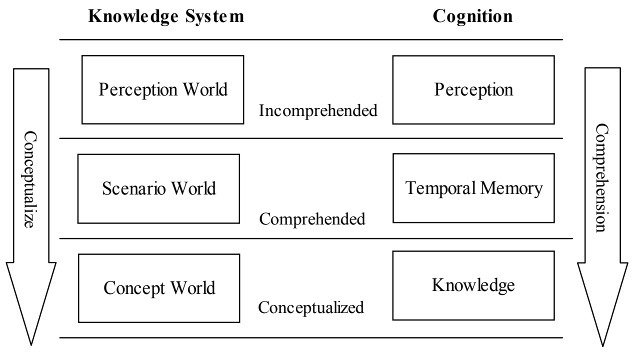

Figure2. Knowledge in Various Stages of Conceptualization and Human Comprehension

As shown in Fig 2, the right part is the process of human cognition. The left part is the conceptualization process of knowledge. Three stages of knowledge representations are concerned in both processes. First, information is perceived by intelligent agents such as sensors of a machine or eyes of a man. Information at this stage is some raw data, these data consists the perception world in the knowledge architecture. Then, information is comprehended with current knowledge, scenarios are established. The scenario world emerges. At last, scenarios are analyzed, and new concepts are gained to the concept world.

B. P-World

P-World consists of a set of raw data such as text, graph and video. It represents the perception of an intelligent body in the real world. Information in this world is what perceived by agents of the intelligent body. Information is stored as blocks in this world. The information blocks are arranged with the temporal and spatial dimensions as well as the agent perceives the block. Fig 3 shows the structure of P-World.

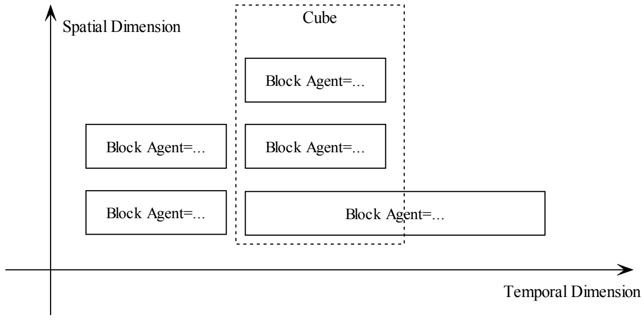

Figure3. Blocks in the P-World

AS shown in Fig 3, information in P-World is mainly nonconceptual content. Such content is angle-dependent. No numeric metric can be provided in this kind of content. The boundary of such content can be represented with symbol sequences.

Definition 2: Let a, b be two point on one dimension. The relationship precedence a < b means a precedes b in the definition of current view. For example, in the temporal view a<b means a happened before b. For two numbers a and b, a < b means a<b.

Definition 3: Let i, j, n be numbers. A symbol sequence is a finite sequence of symbols $S=\{s_1, s_2, \dots, s_n\}$ that $s_i < s_j$ if and only if i<j.

Definition 4: Let D be the value of a dimension, a closed region R is a region limited with bounds. It is recursively defined as below:

- Let be two symbols on a symbol sequence, $s_i < s_j$. $R=\{ D| s_i < D < s_j \}$is a closed region.
- $R=\{D| D=s_j \}$ is also regarded as a closed region represent a point.
- The result of operations $\cap$, $\cup$ of two closed regions is also a close region if it's not empty.

Proposition 1: The subset of a closed region is a closed region.

Proposition 2: Let R1, R2 be two closed regions, R1 $\neq$R2 and R1 is not a subset of R2. The result of the difference R1-R2 which means cut the region of R2 from R1 is also a closed region.

Proof: There are two atomic forms of closed region. The definition of a point $R=\{D| D=s_j\}$ can be transited to the form of $R=\{D| s_{j-1} < D < s_{j+1}\}$. So only the first form should be considered. Let $R1=\{ D| s_i < D < s_j \}$, $R2=\{ D| s_m < D < s_n \}$. If R1$\cap$R2 is an empty set, R1-R2=R1. Else, $R1-R2=\{D| s_i < D < s_m \} \cup \{D| s_n < D < s_j \}$. Each of the two components is rather an empty set or closed region. R1-R2 is a closed region. For the closed region consists of many regions, all the components should be considered separately. The same conclusion can be drawn. On the other hand, the result is a subset of R1.

Operations in the P-World should be semantically rather than syntactically defined. For example, Let. The

Only with the definition above, P-World can be defined and manipulated. Further definition need to be made as below to describe the P-World:

Definition 5: A block is a continuous piece of information perceived by an intelligent agent. It's the content of the perception.

A block can span a finite region of time and space or span an infinite one. It may be continuous or discrete in any dimension. Blocks can be measured only on the basic dimensions.

Definition 6: A Cube is a region to focus the perception. It's a triplet: *Cube*([Spatial Region], [Temporal Region], [Agent List]). Spatial Region and Temporal Region are two closed regions refer to position in the space and the time. Agent List is related agents in the perception. The operation cube means the creation of a cube.

C. S-World

1) The Structure of S-World

S-World is a comprehended World. It consists of a set of scenarios extracted from P-World with current C-World. A scenario is composed of a set of objects. These objects including objects extracted from P-World with reference to the blocks in the P-World and a process object which describes the interactions of the other objects.

Definition 7: A scenario is a set of objects and concepts organized as a hierarchy in the form of an object. The set of objects are the elements of the scenario.

A scenario can be extracted from a cube or generated from operations. A scenario extracted from P-World is a conceptualized cube, it correspond to a cube in the P-World and some concepts in the C-World. Such a scenario describes things occurred in some time and some space. It includes concepts and objects organized in hierarchies. A process object is stored as an object describing the sequence of the actions.

Objects are the basic element of scenarios. They are the instances of concepts. Concepts are the same as classes in object oriented programming. Semantic of concepts and objects depends on the context, so the applicable domain should be defined in the objects and concepts. An object should be represented in Fig 4:

```
ObjectName extended [Concepts List]
{
   Public: //Elements and operations needed to be accessed by other objects
        ElementType ElementName;
        ¡-
        ReturnedValueType Operation([Parameters List]);
        {//Process of the operation}
         ¡-
         Domain ApplicationDomain;
         Prototype prototype;
    Private: //Transition elements and operations
         ElementType ElementName;
        ¡-
        ReturnedValueType Operation([Parameters List]);
        {//Process of the operation}
         ¡-
}
```

Figure 4. Representation of an Object

The concepts list includes concepts inherited by the object. An object can inherit various concepts. The application domain of an object may be the name of the scenario or a concept in the knowledge hierarchy. For default, it's the direct inherited concept of the object. For example, Tom is the biggest cat in the town the application domain of biggest is the cats in the town. A prototype is adhered to objects sometime. It's the compound of some P-World materials related the object. Objects and concepts should be identical in a scenario.

The representation of a concept is similar to that of an object.

To construct system consists of massive data, efficiency must be considered. For the convenience of knowledge acquisition and application, a copy of the concepts in the C-World is stored in the scenario to organize the objects. Some prototypes should be stored in the scenario too if necessary.

A scenario can be represented as Fig 5:

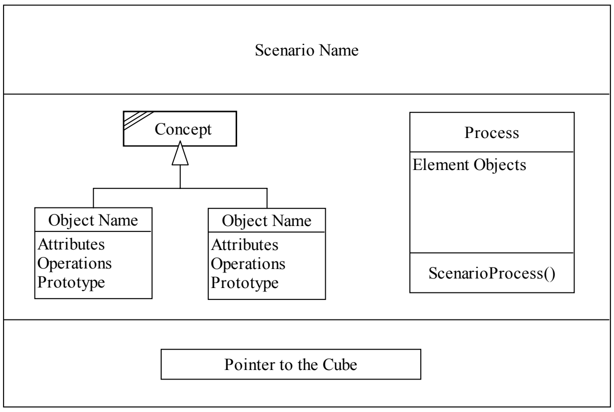

Figure 5. Scenario Extracted from a Cube

As shown in the figure, the scenario is an object. The objects and concepts organized hierarchically and the process object consist the main body of the scenario. A pointer to the cube from which the scenario generated is saved in the scenario for the sake of retrospection.

2) Operations in S-World

As a more conceptualized world, more operations can be defined in S-World. Basic operations in the S-World are defined below:

Rollup is the operation to find the direct parents of a concept or object in a scenario on the relationship of inheritance, polymerization or both. It can be defined as below:

Rollup(Node,[RelationType],Scenario)

The parameter *Node* represents the target node from which to roll up within the scenario. The parameter *RelationType* may be *Inheritance*, *Polymerization* or *Both*. The default value of *RelationType* is *Both.*

Drilldown is the operation to list the direct children of a concept in a scenario on the relationship of inheritance, polymerization or both. It can be defined as below:

Drilldown(Node,[RelationType] ,Scenario)

The parameter *Node* represents the target node from which to roll up. The parameter *RelationType* may be

Inheritance, *Polymerization* or *Both*. The default value of *RelationType* is *Both.*

Projection is the operation to find all the children concepts and instances of a concept in a scenario. It can be defined as below:

Project(Concept, [Scenario])

Selection is the operation to find all concepts and objects fulfills some condition. It can be defined as below:

Select([Condition],[Scenario])

The parameter *Condition* represents the criteria to choose elements. The default value of the parameter is null which means all the objects in the scenario. Let capital letters A, B, C… represent elements such as a class or an object or an attribute. Lowercase letters represent values such as numbers or strings. The parameter *Condition* is an algebra expression recursively defined as below:

- Let θ represents compare operators =, > or <. Expressions in the form of $A\ \theta\ b$ is a condition.
- Let A, B represent elements with numeric values. Lowercase letter a, b ... and x represent numbers. Let θ represents compare operators =, > or <. Let △ be algebra operators such as ＋, －, ×, ÷. Expressions in the form of $aA \triangle\ bB\ \triangle \ldots\ \theta\ x$ is a condition.
- *EXISTS(A)* is an expression which means A is a part of the target elements.
- Let α,β be conditions, θ be logic operators AND, OR, NOT. $\alpha\ \theta\ \beta$ is a condition too.

With the selection and projection operation, concepts and objects can be precisely located.

Join is the operation to join two or more scenarios into one scenario structurally with some templates of concepts and objects. A new scenario is returned by this operation. It can be defined as below:

Join(Scenarios List,[Templates List])

A template should be restriction to some concepts or objects. Objects have the template structure in different scenarios can be regarded as the same object. For example, a template is defined as below:

Cat
{Color='White'}

Using it as the template to join two scenarios means the white cats in the scenarios are regarded as the same object when the two scenarios are joined into one.

D. C-World

C-World is a conceptualized world which consists of generalized concepts. The concepts are arranged with the knowledge hierarchy. It serves as the collection of dimensions. Concepts are organized as a knowledge hierarchy. Some concepts in common use are indexed for better efficiency.

Basic operations in the C-World are defined below:

Rollup is the operation to find the direct parents of a concept in the hierarchy.

Drilldown is the operation to list the direct children of a concept in the hierarchy.

Projection is the operation to find all the children concepts of a concept in the hierarchy.

Selection is the operation to find all concepts that fulfills some condition in the hierarchy.

The definitions of operations in the C-World are similar to the corresponding operations in the S-World. The only difference is that the target is the knowledge hierarchy. Further more, the C-World can be regarded as a special scenario and join with S-World to create a scenario.

E. Uniqueness and Realtions of 3-Worlds

3) Uniqueness and Keys of Elements

Every element must be unique in the 3-World. In different worlds, elements are ensured unique by different methods. Like data models the key of an element is defined below:

Definition: The **key** of an element is the features make an element unique and used as a label to connect with other elements.

Blocks and cubes are the elements of P-World. Blocks are organized according the value of four basic dimension and agents. Unique symbol sequences and agent labels of a block can ensure the uniqueness of a block. They are regarded as the key of the block. For cubes, the definition of spatial and temporal regions and agents can ensure the uniqueness of them. For convenience of reference in the S-World, a cube should have a unique label. The label of a cube is regarded as the key of it.

In the S-World, scenarios should have their distinct names as the key. Objects should be unique in the scenario they belong to. With the unique label of the scenario, they are distinct in the whole S-World by the reference to the scenario name. The key of an object should consist of the name of the object and the scenario. Concepts are duplicated from the C-World. They should be distinct only in the scenario they belong to.

In the C-World, a concept can be distinct only in the concepts inherit or compose the same concept. But for the convenient of reference in the S-World, they should have their distinct name over the whole C-World as their key.

4) Connect 3 Worlds Together

A scenario can be easily connected to the corresponding cube with the reference of its label.

A scenario can connect with the concept hierarchy in the C-World by the reference or structural join of concepts in the scenario. This can build a lager scenario. With the concepts in the C-World, any scenario in the S-World can be joined together to build an overall scenario for knowledge acquisition and application.

F. Transition Operations Bridge the Three Worlds

As well as the transitions of human cognition, the three worlds can be bridged by some operations. As shown in Fig 6, blocks and cubes are conceptualized to build scenarios using the concepts from C-World. Concepts in C-World are induced from the scenarios in S-World. Concepts and Scenarios can be used to construct P-World elements too.

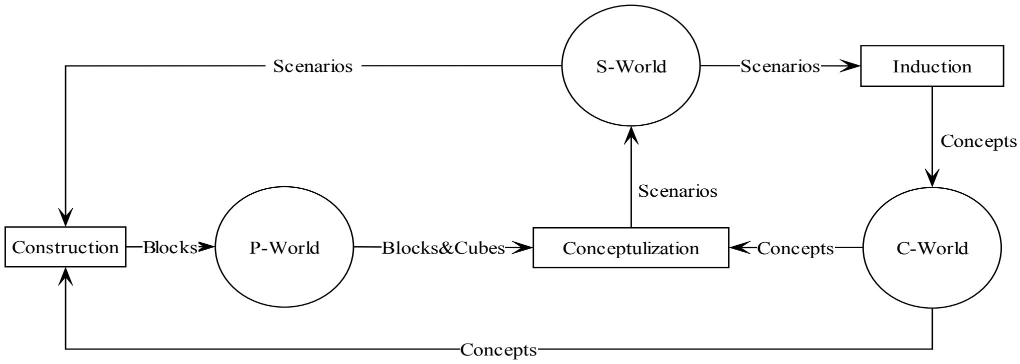

Figure 6. Transition Operations Bridge the Three Worlds

The induction and conceptualization operations concern many complicated operations such as pattern recognition and machine learning.

V. Other Problems about the Warehouse Architecture

The 3W model is the core of the architecture. There are other problems about the efficiency and application of such architecture.

A. *AI tasks in 3-Worlds*

Different AI tasks are performed in different worlds. Multimedia compares can be carried out merely with data in the P-World. Reasoning with concepts should be carried out in the S-World and C-World. Tasks such as media labeling and pattern recognition with concepts can use data in all the three worlds.

Table 1 shows the familiar tasks carried out in different layers of the 3-World model.

TABLE I.
TASKS CARRIED OUT IN THREE WORLDS

Worlds / Tasks	P-World	S-World	C-World
Media Editing	●		
Picture Editing	●		
Text Mining	●	●	
media labeling	●	●	●
Pattern Recognition	●	●	●
Scenario Reasoning		●	●
Semantic Web		●	●
CYC Project		●	●

From the table, media concerned tasks may span their domain to the P-World. Objects concerned tasks may span their domain to the S-World. Concepts concerned tasks may span their domain to the C-World.

B. *Enhance Efficiency in Massive Knowledge*

Good adaptable knowledge architecture needs massive knowledge. Efficiency must be considered. In a data warehouse, redundant are used to save time. Computations with high complexity such as Cartesian product are almost avoided. Indices are created appropriately to enhance the query.

Similar method can be applied in the knowledge. Redundant data such as prototypes and concepts can be stored in S-World to enhance the efficiency. Complex computations such as structural joints should be lessened. Dimensions related to frequently performed tasks are selected as indices to arrange data for better efficiency.

C. *Element type and Metadata*

There are various types of data. These types include concept, object, scenario, cube and many basic element types such as number, character, string, bitmap and so on.

These types are metadata of the system are stored as concepts in the C-World and S-World and can be operated. The operation below means select all scenarios include the concept CAT:

Select(EXISTS(CAT),Project(Scenario))

VI. Problem Solving with the Archietecture

A. *An Example of Problem solving*

Before the discussion of topic of problem solving, let's find how problems are solved by human beings with an example. Let's focus on Fig 7 and answer the question: *What the cat want to do?*

Figure 7. A picture of a cat and a mouse

We can see a cat and a mouse on the picture. The cat is staring at the mouse. Then we know the cat will try to catch the mouse.

This thinking process completed in a blink. Let's see what happened in this process.

First, we see the picture. Then the cat and mouse are recognized. If you have seen the process of a cat catching a mouse recently, you can get the result immediately without considering the details of the concept cat. This is because similar scenarios are stored in the LTM.

The thinking process can be modeled as below:

- First, the picture is perceived, and an image is stored into the P-World.
- Then the scenario is built as Fig 8.

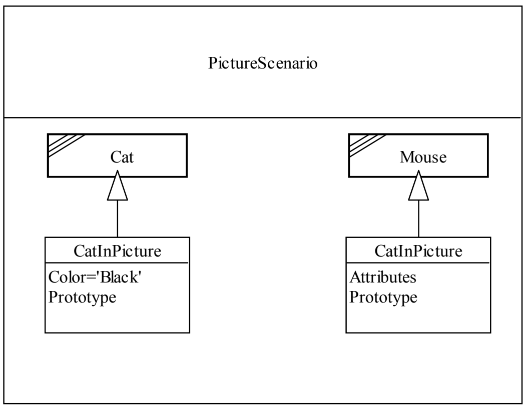

Figure 8. Scenario of Fig 7

- Related scenarios are selected use such an operation:

Select((EXISTS(CAT)) AND (EXISTS(MOUSE)),Project(Scenario))

- A scenario is applied to solve the problem.

B. *Problem Solving*

Problem solving is a topic more general than reasoning. Generally speaking, problem solving is to find the way to meet the requirements input. Human problem solving differs from traditional algorithms in the aspects below:

- Algorithms often try to find all the solutions or the optimized solution while human often find one or a few reasonable solutions.
- Algorithms are required to be convergence and to end in finite time. Human may stop thinking by his will.
- To avoid NP-hard problems, algorithms often based on relatively static knowledge. But human must face the dynamic world.

As in the example mentioned before, the result of the problem solving can be affected by knowledge of the most current events most.

In the background of 3-World model, a frame can rather than a real algorithm can be advanced in Algorithm 1.

Algorithm 1:

```
ProblemSolve(Problem)
{
  While(!TimeOut)
  {
    Scenario ps; //Define the problem scenario
    Scenario TempS[];
    Concept TempC[];
    ps=Conceptualize(Problem);
    //Matching ps with recent scenarios
TempS[]=Select(EXISTS(Concepts in ps), RecentSenarios);
    Evaluate(TempS[]);
    if EXIST TempS[i] satisfies then return TempS[i];
    //Search the C-World
    TempC[]=Project(Concept,ps);
    //Try to construct a problem scenario from C-World
    ps=Reasoning(TempC[],C-World)
    Evaluate(ps);
    if ps satisfies then return ps;
  }
  Return(Can't Be Solved);
}
```

In this frame, similar scenarios in the memory are first analyzed to solve the problem. If no solution is found for the problem, then concepts in the C-World are searched to construct a solution. Since the Reasoning in C-World is complicated and knowledge changes with time, the algorithm ends only when problem is solved or time is out.

VII. Conclusion

Object-oriented warehouse architecture is advanced in this paper. The architecture is adaptable for different tasks. The paper is novel mainly for the advance of the 3-World model as the core of knowledge architecture. Three types of information is manipulated the three worlds respectively. The worlds are bridged with operations, so tasks can deal with different type of data. A frame of problem solving based on the architecture is also defined.

VIII. Discussion and Future Work

Previous related works mainly focus on specific AI tasks. Many works are done to set up a general AI system [21]. Some project constructs a large knowledge base of common sense [3][4]. Some build a semantic dictionary [12]. But none of them can deal with different type of knowledge and AI tasks. It's a great process that various type of knowledge can represent and manipulate in the 3-Worlds. Different AI tasks can be handled with the 3W model.

Different data and tasks can be defined and manipulated in the 3-World. But there are many operations especially the conceptualization operation from the P-World to the S-World is in a black-box. In future work, more details should be defined and described.

Problem solving is complicated. The definition of a general problem solving process can be significant. In this paper a frame is advanced on problem solving. Works are also needed in the research of this field.

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