OBJECT-ORIENTED MODELING OF ATTENTIONAL SYSTEMS

IGOR A. CHIMIR
Odessa State Environmental University,
Ukraine.
chemyr@te.net.ua

WAHEEB A. ABU-DAWWAS
Al-Zaytoonah University,
Jordan.
waheeb@alzaytoonah.edu.jo

MARK A. HORNEY
University of Oregon,
U.S.A.
mhorney@darkwing.edu

ABSTRACT

This paper is devoted to the practical application of some classical hypothesis of Cognitive Psychology explaining the phenomenon of perception and attention. After a brief conceptual discussion of the models the paper proposes formalization by means of the Unified Modeling Language (UML).

KEY WORDS:
Perception, attention, UML, cognitive modeling

INTRODUCTION

The goal of this paper is to revise some well known hypothesis of perception and attention from the point of view of the object-oriented modeling technique. Another goal of this paper is to demonstrate the applicability of modern object-oriented methodology to the area of Cognitive Psychology. Models developed by cognitive psychologists embrace all aspects of human mental activity, from perception, to decision-making processes, and models of emotional states. However, from a pragmatic viewpoint, the models offered by cognitive psychologists seldom can be translated into computer simulations.

Today, the depth and universality of the concepts of object-oriented modeling are so prevalent that we can consider them a general theory for all complex natural and artificial systems [6]. This is becoming practicable with the advent of the Unified Modeling Language (UML), which has acquired the features of a strict and formalized theory with the conception of object-oriented modeling. The attractiveness of UML is in its diagrammatical representation of formal descriptions of systems, and, therefore, its “formulas” are various types of diagrams, which depict various aspects of the system: its structure, its behavior, etc. We believe that the expressive power of UML is enough to build sophisticated “formulas of mind” describing the structure and behavior of psychological phenomenon. Due to space limitations we cannot include basic concepts of UML into the paper. Therefore, we refer readers to other books such as [10].

1. CYCLE OF PERCEPTION

The model of perception offered by Neisser [9] integrates “bottom-up” and “top-down” processes of perception into one cyclically repeated process. According to this model, the main cognitive structure, which determines not only perception, but attention, and categorization as well, is a *set of anticipatory schemata*, within a given cycle/step of perception. The set of anticipatory schemata prepares our mind for perception of the subsequent sensory events and can be considered as a control structure for the processes of perception, attention, and categorization. Thus, a perception is a constructive process because at every step of perception the consciousness forms a new set of anticipatory schemata.

The generating of a new set of anticipatory schemata initiates the process of perceptual exploration of the environment, directed on a search for a sensory event, corresponding to one of the schemata from the set of anticipatory schemata. The purpose of *perceptual exploration* is a search for the sensory event, which is relevant to a schema from the set of anticipatory schemata. This, as a rule, entails motor reactions, such as movements of the head, of the extremities or the whole body. A good example of perceptual exploration is the process of palpation of a coin during its tactile perception. By means of perceptual exploration the correspondence between a sensory event and one of schemata is set up. It is clear that the process of perceptual exploration should include the process of categorization of sensory events. The sensory system sequentially focuses on sensory events, which it then categorizes and compares with schemata from the anticipatory set. Perceptual exploration is complete when a chosen sensory event is perceived. Being perceived, a sensory event becomes the trigger to change the current set of anticipatory schemata into a new one. The set of anticipatory schemata is formed from schemata stored in a long-term memory (i.e. previous perceptual experience) and is a part of a cognitive structure named by Tolman [11] a *cognitive map*.

From this brief description of Neisser’s model of perception it follows that the spatial structure of the perceptual system can be represented by at least the following classes of objects:

- **RelevantSchemata** - The class of sets of anticipatory schemata. At every perceptual step only one object from this class is “working”;
- **CognitiveMap** - The class of Tolman’s cognitive maps;
- **SensoryEvent** - The class of sensory events of the environment.

We will not consider a cognitive map as a simple set of schemata, but rather as a *script of perception* represented by sets of anticipatory schemata and relationships between them. Therefore, instead of the class **CognitiveMap** we will consider the class **PerceptualScript**, and will treat objects from this class as control structures, which control the transition from the current set of anticipatory schemata to the subsequent set of anticipatory schemata. A script receives a perceived sensory event and the current set of anticipatory schemata, and returns the subsequent set of anticipatory schemata.

We have to distinguish the process of categorization of the current sensory event from the process of its identification with one of the schemata from the set of anticipatory schemata. The task of categorization presupposes that for a certain object – represented by its properties (attributes) and behavior (operations) – it is necessary to define the class to which this object belongs. Let the operation recognition(**out** eventType) be responsible for the process of recognizing sensory events. This operation returns the value of the attribute eventType. Let the class **SensoryEvent** be a container for the operation recognition and the attribute eventType.

In the process of identification, the type of categorized sensory event is sequentially compared to schemata from the anticipatory set of schemata. Identification is complete when the type of sensory event is equal to one of the anticipatory schemata. Figure 1 depicts a UML class diagram modeling the spatial structure of Neisser’s cycle of perception in accordance with speculations given above.

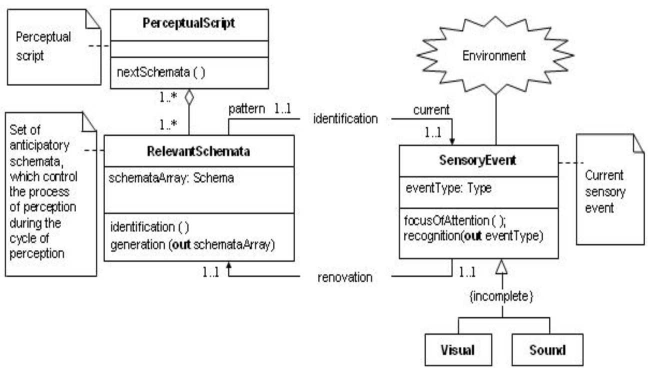

Figure. 1. Spatial structure of Neisser’s cycle of perception.

The class **RelevantSchemata** models a fragment of a perceptual script, which controls the process of perception on given perceptual step. The distinguishing feature of the class **SensoryEvent** is that it produces the sequence of sensory events in accordance with a rule “one event at a time”, using the procedures of focusing attention (operation focusOfAttention) and categorization (operation recognition(**out** eventType)). Thus, objects of the class **SensoryEvent** are responsible for the selection and categorization of sensory events, whereas their identification is realized by objects of the class **RelevantSchemata** by means of the operation identification. Determination of the subsequent set of anticipatory schemata is realized by the operation nextSchemata of the class **PerceptualScript**.

There are two associations, named identification and renovation, between the classes **SensoryEvent** and **RelevantSchemata**. The relationship identification models the fact that during the process of perception the current sensory event is identified with one of the schema from the set of anticipatory schemata; and the relationship renovation models the fact that after the process of identification the current set of anticipatory schemata is renewed. In the relationship identification, objects of the class **SensoryEvent** play the role of a current event, whereas objects of the class **RelevantSchemata** play the role of a pattern. Expression 1..1 means that this relationship permits the link of only one object from class **RelevantSchemata** (one set of anticipatory schemata) with one object from class **SensoryEvent** (one sensory event).

The relationship aggregation between the classes **RelevantSchemata** and **PerceptualScript**, models the fact that the object of the class **RelevantSchemata** is a part of the object of class **PerceptualScript**. The subclasses **Visual** and **Sound** model the multimodal nature of a sensory event, which includes visual and sound components. This set of subclasses is incomplete because a sensory event can include other components, for example an olfactory component.

The formal representation of the structure of Neisser’s cycle of perception in the form of the UML class diagram – depicted in Figure 1 – does not take into account some peculiarities of its original description [9]. Simple introspection allows us to conclude that one sensory event must correspond to several sets of anticipatory schemata from different perceptual scripts. For example, if we observe somebody’s a smile then depending on the context we expect to perceive: (a) a shape of teeth; (c) relation to a certain event (a smile can be polite or offensive).

Apparently our consciousness uses several perceptual scripts, which differ from each other by the goal of the perception. We can model the goal-oriented character of the perceptual script by an attribute describing the goal of a perception in the class **PerceptualScript**.

An object of class **RelevantSchemata**, which works on a certain cycle of perception, is a "product" of current cycle of perception, but at the same time it is a product of all previous cycles in which this object was used. From cycle to cycle a schema evolves, and this evolution Piaget in his theory of cognitive development called a schema *accommodation* [2]. As a schema is an element of a more complex cognitive structure, namely a script of perception (**PerceptualScript**), it is clear that the process of accommodation is inherent in the script. In some sense schemata and perceptual scripts "keep" the history of the development of a subject's consciousness. We can account the accommodation features of schema and script by including the operations schemaAccomodation and scriptAccomodation into corresponding classes.

The problem of modeling the accommodation of schemata and scripts is very close to the problem of differentiation of schemata and scripts on: (1) innate/genetic, and (2) acquired in the process of development of the organism. Using other words we can say that our model must account for the typology of classes **RelevantSchemata** and **PerceptualScript.** Figure 2 depicts the structure of Neisser's cycle of perception, which takes into account some details of its original description.

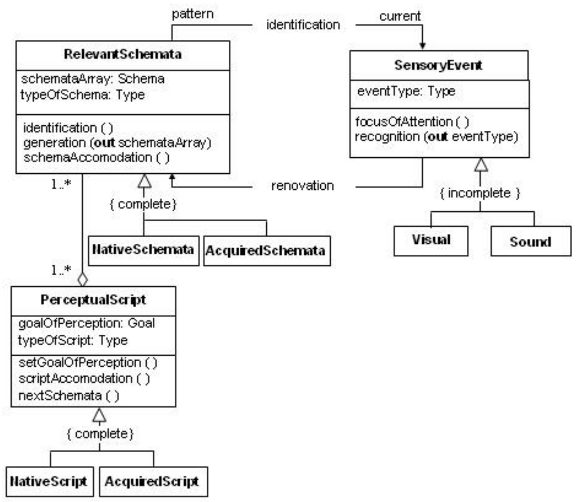

Figure 2 More accurate structure of Neisser's cycle of perception

In the model depicted in Figure 2, the typology of classes **RelevantSchemata** and **PerceptualScript** is modeled by the relationship generalization. Each of these classes has the status of a super-class and falls into two subclasses: **NativeSchemata/NativeScript** (innate schemata or script) and **AcquiredSchemata/AcquiredScript** (acquired schemata or script). The set of subclasses characterized as a complete set, which means that among anticipatory schemata and perceptual scripts there can be only innate or acquired and no other. We also added some attributes and operations into classes **RelevantSchemata** and **PerceptualScript** to specify their properties and behavior. Attributes typeOfSchema and typeOfScript characterize types of schema and scripts respectively and can take values native or acquired. Operations schemaAccomodation and scriptAccomodation model the ability of accommodation for schemata and scripts. In the class **PerceptualScript** we added the attribute goalOfPerception and the corresponding operation setGoalOfPerception, which model the goal-oriented nature of the script.

2. SENSORY EVENT AND ITS INFORMATION STRUCTURE

Let's define a *sensory event* as a fragment of the environment, which can be categorized unambiguously in the post-sensory processing. The sensory event concept is wider than the concept of external stimulus, because sensory event does not refer to a concrete sensory modality. Stimuli can be visual, auditory, tactile, etc. Sensory event pre-supposes integration of several external stimuli. We focus our attention on objects and events in the environment rather than on sensory inputs. However, in some particular cases – quite often in psychological experiments – a sensory event can be represented by a single sensory modality.

It is useful to distinguish two classes of sensory events: *routine sensory events* and *suspicious sensory events*. Such classification is essential because we know from experiments when a certain event (which belongs to the class of suspicious events) occurs, an organism automatically focuses attention on this event and interrupts the process of perception of routine events. An example of a suspicious event is the 400 cps signal in Cherry's [5] experiments on dichotic listening tasks. In this experiment, the subject always detected the 400 cps signal, which was randomly transmitted to the left ear despite the fact that his/her attention was focused on perception of the text, transmitted to the right ear. It is clear that the border between routine and suspicious events is fuzzy and the classification depends on the context. For instance, as mentioned in Cherry's experiment, only few subjects were able to detect messages transmitted to their left ear by a high pitch woman's voice.

Let's call the information image of the sensory event, a *sensory segment*. There are two classes of sensory segments: *routine sensory segments* and *suspicious sensory segments*. The sequence of sensory segments, which is relevant to the flow of the sensory events, fills up a limited capacity sensory buffer. It is convenient to represent this sequence of sensory segments by a *queue of sensory segments*. Such representation is quite reasonable because sensory segments come into the buffer and leave the buffer only sequentially. A specific feature of the sensory buffer is the decay of sensory segments during a certain period. The UML class diagram in Figure 3 depicts the sensory system's main classes and relationships.

The class **QueueOfSS** models information in the sensory buffer and is an ordered – in the form of queue – aggregate of instances of the **SensorySegment** class. The class **QueueOfSS** is defined as an abstract class, because it is a generalization of a complete set of subclasses, **RoutineSS** and **SuspiciousSS**. The abstract class **SensorySegment** includes the attributes decayCycle and operation decay(decayCycle), which are modelling the phenomenon of information decay in the buffer and which are inherited by both subclasses.

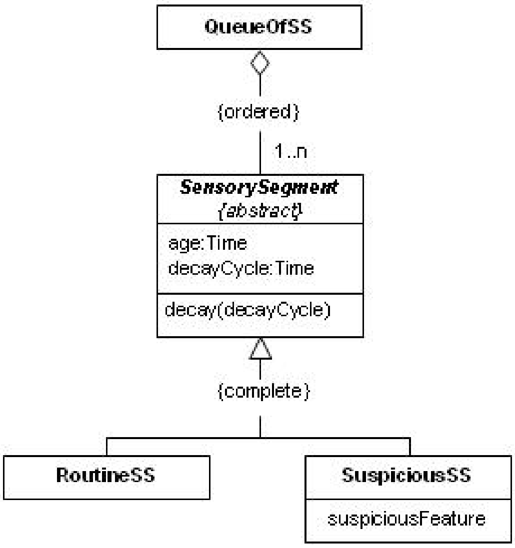

Figure 3. Classes and queue of sensory segments.

The value of the attribute decayCycle defines the duration of decay and the operation decay(decayCycle) realizes the process of decay. The attribute age in **SensorySegment** models the current "age" of the sensory segment. The value of this attribute is within the range "0 < age < decayCycle". The class of suspicious sensory segments is characterized by a certain feature of suspicious, which models by suspiciousFeature attribute.

3. FILTER-ORIENTED HYPOTHESIS OF ATTENTION

The filter models of attention offered by Broadbent [3,4] and Treisman [12,13] presuppose an analogy between psychological and technical filters. However, there is an essential distinction. The technical filter has information inputs and outputs. Part of the input signal substantially attenuates and does not reach the output. According to Neisser's hypothesis, perception is a cyclical process without input and output. Therefore, psychological filtration is not a simple "cutting-off" of a part of sensory information, instead, an impossibility of its perception due to the absence of needed tools (e.g. sensors and/or schemata) in the structure of the cycle of perception. For instance, we are unable to percept information in the form of modulated infrared radiation, not because we are filtering it out but because a human does not have the relevant sensors. We do not percept an unknown language not because we are filtering it out but because we do not have relevant schemata in our long-term memory.

Despite Neisser's critique of the whole class of filter models, a part of the paper is devoted to Broadbent and Treisman's filter models of attention. In addition, as it was mentioned earlier, our goal is a unified description of these models. In other words, authors do not discuss the question of adequacy of the class of filter models of attention to the real mechanism of attention but instead they are trying to find a practical implementation.

Data, obtained from experiments directed on study of the ability of a human to focus attention on the process of perception of auditory sensory events (experiments on *dichotic listening* task), were first generalized in the hypothesis offered by Broadbent [3,4]. According to this hypothesis, a human being's central system of information processing has limited capacity and, therefore, a filter is needed to protect it from information overfilling. Information carried by sensory events in the form of sensory segments initially enters the sensory buffer from which it sequentially selects and recognizes. Broadbent associated the process of selection with the process of filtration according to the rule "all or nothing."

If we take into account the structure of information in the sensory system depicted in Figure 3 and the cyclical nature of the process of perception, according to Neisser's hypothesis, then the functioning of attentional mechanism, can be described in the following way: sensory segments are sequentially picked out from the queue of sensory segments, categorized and compared with the set of schemata, which the organism has anticipated on a given cycle of perception. The maximum "proximity" of one of anticipatory schemata with its recognized sensory segment defines the subsequent set of anticipatory schemata.

The appearance of a suspicious event is detected immediately, and the detector interrupts the process of routine perception, and the attentional mechanism switches to the suspicious event. Experimental research supports the existence of a mechanism of fast detection of suspicious events, and this mechanism acts besides a relatively slow channel of categorization [8]. Presumably, every sensory receptor organ has a subsequent detector of suspicious event's feature. The job of a suspicious event detector is to permanently compare physical characteristics of sensory segments with stored suspicious event's feature (suspiciousFeature). When organism detects a suspicious event, it changes the goal and starts to percept a new flow of sensory events, which begins from uncovered suspicious sensory event. Figure 4 depicts the structure of attentional system in accordance with Broadbent's hypothesis of attention.

As Broadbent's model is a generalization of data obtained from experiments on dichotic listening tasks, the structure of the attentional system in figure 4 depicts the case of focused auditory attention. Classes of sensory segments' queues **RightQueueOfSS** and **LeftQueueOfSS** are relevant to sensory events for the right and left ears correspondingly. Figure 4 depicts the structure of class **RightQueueOfSS** only. The structure of class **LeftQueueOfSS** is identical.

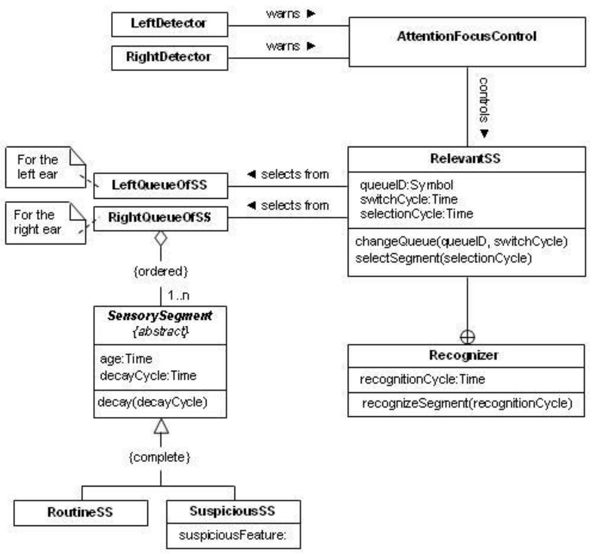

Figure 4. The structure of an attentional system in accordance with Broadbent's hypothesis

The structure of the system of focused attention depicted in Figure 4 presupposes that the class **RelevantSS**, which models a relevant sensory segment and it's processing by the Broadbent's filter, is an inner class and is an element of the class **Recognizer**, which models the phenomenon of categorization. Class **RelevantSS** is able to switch from the queue of the right ear sensory segments to the queue of the left ear sensory segments by means of the operation changeQueue. The operation has some arguments: the identifier of the sensory segments queue (queueID), and the duration of switching (switchCycle). Class **RelevantSS** can also choose a segment from the queue and transmit it to the class **Recognizer**, by operation selectSegment. The operation has a single argument selectionCycle, which defines the duration of the selection process. However, the class **RelevantSS** is unable to make a decision on which of two queues it has to focus attention. Class **RelevantSS** receives this information in the form of messages from the class **AttentionFocusControl**. Class **AttentionFocusControl** makes a decision on which of input flows it has to focus attention, based on information regarding suspicious event detected by one of detectors of suspicious events.

There are two detectors: **RightDetector** and **LeftDetector**, which correspond to the right and left ears. The suspicious event's feature is discovered by a detector, which sends a message to the class **AttentionFocusControl**. This class in turn transmits a message to the filter, which command to interrupt the processing of the flow of routine events (entering the right ear, for instance) and to start the processing of suspicious event (entered the left ear, for instance). Switching of the focus of attention from the flow of routine events to the suspicious event is realized by the operation changeQueue.

Treisman [12,13] also generalizes her model on the entire sensory system although the most part of experimental data on which she bases the model are obtained from experiments on dichotic listening tasks. The main assumption, which Traisman has made regarding the attentional system and which distinguishes her model from Broadbent's one, is that the process of filtration does not work according to the rule "all or nothing" but as an attenuator, which varies the ratio between the signal and the noise for the levels of intensity of the flows of sensory events.

Treisman's filter permanently supplies the post-sensory system with information from all queues of sensory segments but the level of only one flow of segments (on which attention is focused) is enough for categorization. Levels of intensity of all other flows are attenuated and these signals can be considered as a background, which masks the information from the relevant or main flow. Treisman uses the term "threshold" as a certain critical level of intensity for signals conveying information of sensory segments. Only those segments, which have the level of intensity that exceeds the threshold, can be categorized. Control of filtration according to Treisman is manipulation with the levels of intensity for sensory segments. When a filter sets the level of intensity higher than the threshold, it makes available categorization for the corresponding segments. Therefore, the general structure of attentional system offered by Treisman is identical to the structure of Broadbent's model of attention. The difference is in the algorithm of operation changeQueue, and in new attribute recognitionTreshold. Treisman's filter instead of switching queues of segments changes their thresholds by the operation changeTreshold.

4. CAPACITY BASED HYPOTHESIS OF ATTENTION

Filter-oriented models of attention explain, primarily, the selective nature of attention, which becomes apparent in the process of perception. However, the phenomenon of attention possesses not only such property as selectiveness and becomes apparent not only in the process of perception. Capacity based hypothesis of attention issues from the assumption that the denotation of attention includes also the ability of a man to solve mental tasks. It can be tasks related to perception, for instance a deliberate selection and categorization of one type of sensory events, or the task of a decision making with subsequent motor reaction. One of the factors of successful solving a mental task is the *amount* of attention allocated to the task.

Berlyne [1] examined the relationship between attention and the degree of arousal of the organism. Kanheman [7] made an assumption that not all types of arousal determine the successfulness of solving the task but only those types, which facilitate a *mental effort*. Kahneman equates such expressions as *pay attention*, *exert effort*, or *invest capacity*. From this point of view attention is a certain mental resource without the availability of which a conscious activity is impossible. One of key assumptions made by Kanheman is the *total amount of attention, which a human can allocate for solving mental tasks is limited for every given moment of time*, and therefore an organism must solve a problem of rational distribution of limited resource of attention between several mental tasks.

Let us assume that at every step of activity of an organism the environment forces the organism to solve a certain mental task. Therefore, it is reasonable to consider an *environment as a constantly working generator of mental tasks*. Let consider a class of mental tasks – **MentalTask**, in which instances are tasks generated by the environment. Attributes of this class **MentalTask** are: a relevant cognitive structure, and information from the sensory system in the form of poly-modal sensory event, which has a type of **SensoryEvent**. We will associate the attribute "relevant cognitive structure", which Kanheman calls a *cognitive structure of a long-term memory*, with a schema in a sense, generally adopted in cognitive psychology. The class of mental tasks falls into two subclasses: tasks, the solving of which are under control of conscious – **VoluntaryControlTask** and tasks, the solving of which is not under conscious control – **InvoluntaryControlTask**.

The selection of the schema and its activation (resource allocation) for tasks from the class **VoluntaryControlTask** realizes in accordance to the "momentary intention" principle. Hence, the momentary intention principle presupposes a schema selection and its activation. Selection of the schema for tasks from the class **InvoluntaryControlTask** is realized in accordance with "enduring dispositions". Hence, the enduring dispositions principle presupposes automatic schema selection without its activation.

Earlier, in the process of formalization of model of focused attention according to Broadbent's hypothesis of attention, we introduced a classification of sensory events, which divides them between two classes: routine and suspicious sensory events. This classification is in good correspondence with Kanheman's proposition to consider two types of selection: voluntary selection (or deliberate selection) and involuntary selection (or automatic selection). We can assume that *involuntary selection take place in the case when a suspicious event is detected*.

One of the distinguishing characteristics of Kanheman's hypothesis of attention is in integration of the concept of attention as a phenomenon related to perception with a concept of attention considered as a resource needed for solving mental tasks. As it is follows from Kanheman's hypothesis an organism uses the mechanism of attention in a twofold way.

- Attention focuses on those sensory events, which are need for solving mental tasks. In this case attention is working as a selector of sensory events in accordance with the filter-oriented hypothesis of attention.
- Attention focuses on those schemata, which are relevant to a task and must be activated. In this case attention is working as a selector of schemata.

Hence, attention plays the role of a certain "intermediary" between classes: mental tasks, schemata, and sensory events. This allows us to think about attention as a ternary association among following classes: the class of mental tasks (**MentalTask**), the class of sensory events (**SensoryEvent**), and the class of relevant schemata (**RelevantSchemata**).

The class diagram in figure 5 represents the point of view of attention as a ternary relation between classes. To model this relationship we used an association type of relationship, which, in turn, is considered as a class **Attention**. The class **Attention** is a basic class for two subclasses **SensoryEventAttention** and **SchemataAttention**. The class **SensoryEventAttention** is "responsible" for focusing attention on sensory events, which are relevant to the current task, whereas the class **SchemataAttention** is "responsible" for focusing attention on relevant schemata, which must be activated.

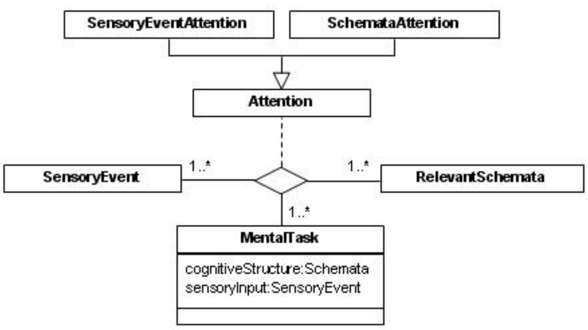

Figure 5. Modeling of attention by a ternary association

Taking into account basic concepts of Kanheman's hypothesis we can represent the class **SchemataAttention** by means of the following attributes and operations. spareCapacity:Capacity – an attribute which models spare resources. totalCapacity:Capacity – an attribute which models common and limited resources. arousal(sources **out** totalCapacity) – an operation which models dependences of common resource from the state of arousal. sources – sources of arousals. evaluationDemands() – an operation which models the principle of evaluation of demands in resource. selectionAndAllocation() – an operation which models selection of resource and its allocation to the task. This operation selects and activates schema and realizes principles of momentary intention and enduring dispositions. Diagrammatical presentation of Kanheman's hypothesis of attention is depicted in figure 6.

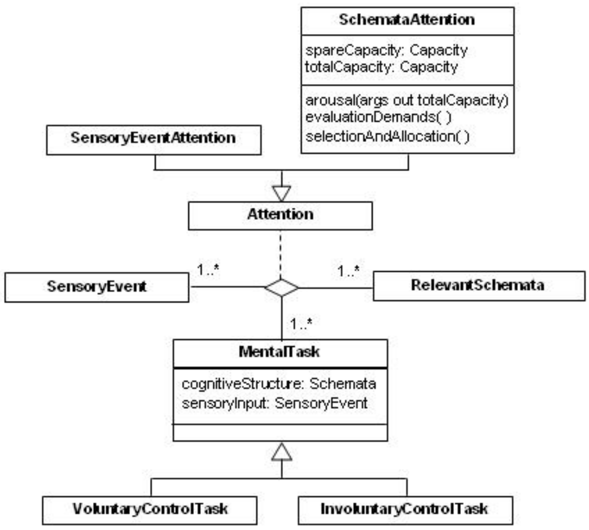

Figure 6. The structure of an attentional system in accordance with Kanheman's hypothesis

CONCLUSION

In this article we have tried not only to familiarize readers with results obtained during their theoretical investigation, but also attract reader's attention to the utility and effectiveness of applying the object-oriented concepts to the area of cognitive modeling. At the moment we continue our investigations in two directions. We are elaborating UML versions of other well known models of cognitive phenomenon and processes. Secondly, we consider class diagrams developed during our research as specifications of computer program systems and use them as a basis for creating computer simulators of cognitive processes. A simulator of the filter-oriented model of attention (in accordance with Broadbent's hypothesis) has allowed us to conduct a series of experiments and obtain some key temporal characteristics of the model: the duration of natural decay of sensory segment in sensory buffer, the duration of switching the filter from the left ear to the right ear, and the duration of categorization.

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