Object Modeling of Filter-Oriented Systems of Attention: Possibilities of Integration

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Abstract: *This paper introduces theoretical results of research oriented on development object-oriented models of filter systems of attention. The diagrammatical language UML is used as a means of modeling of attentional systems. Two filter-oriented hypothesis of focused attention offered by Broadbent and Treisman were chosen as prototypes. The paper includes: UML model of the structure of information in the sensory system, the classification of existing models of attention, and two UML models of the phenomenon of attention based on Broadbent's and Treisman's hypothesis respectively. The study revealed that from the point of view of OO modeling, the model based on Broadbent's hypothesis can be considered as a basic class, whereas the model based on Treisman's hypothesis is its enhancement. Both UML models were used to explain results of some key experiments on dichotic listening tasks.*

Keywords: *Cognitive model, models of attention, object-oriented modeling, unified modeling language.*

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1. Introduction

This paper depicts some theoretical investigations in the area of computer modeling of cognitive information processes [15]. One of the most important cognitive processes is a process of selection of sensory events by means of the mechanism of attention. An attentional system, situated between the sensory system and the system of decision-making, is the integral part of human mind and intelligence. A number of experiments, oriented on investigation of attention, have generated a series of models explaining the phenomenon [2, 3, 7, 9, 12, 13]. These models vary in their relation to general conception of attentional mechanism (attention is a filter and attention is a resource), sensory modality (auditory and visual attention), concentration of attention (focused and divided attention), etc. Lack of a single and unified model of attention or at least a limited set of unified models cause difficulties for shifting investigations of attention into the area of applications and also practical implementation of computer simulators of attention into applied systems of artificial intelligence. The goal of our research is the unification of models of attention for a class of filter models. As a method of achieving the goal, we use object-oriented modeling of systems in the environment of Unified Modeling Language (UML) [1]. The idea of unified description of systems is in the heart of UML and therefore this language is in good correspondence with the idea of given research. UML has an advantage in comparison with other methods of modeling: models represented in UML notation are in fact ready to use specifications of computer programs.

2. Sensory Event and its Information Structure

Ability of a sensory system of a human to generate information exceeds ability of central neural system to categorize external stimuli and make relevant decisions. Attentional system adjusts productivity of the central part with the volume of information produced by the sensory system. Therefore, the sensory system quite often includes attentional system as one of its structural element.

Let's define *sensory event* as a fragment of the environment, which can be categorized unambiguously (can be compared with one of schemata in the long-term memory) 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. For example, the car is a result of categorization of a sensory event, which is formed by visual, auditory, and might be tactile sensory organs. 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, organism automatically focuses attention on this event and interrupts the process of perception for routine event. Example of suspicious event is a 400 cps signal in Cherry's experiments on dichotic listening task [4]. 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, 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*. It is clear that 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. Let's 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. Specific feature of the sensory buffer is the decay of sensory segments during a certain period. UML class diagram in Figure 1 depicts sensory system's main classes and relationships.

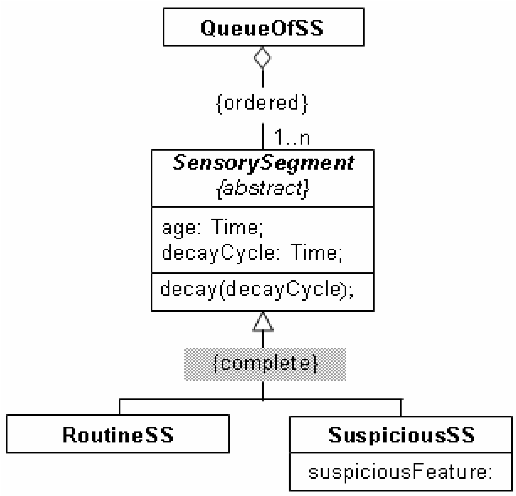

Figure 1. Classes and queue of sensory segments. Where RoutineSS: Class of routine sensory segments, SuspiciousSS: Class of suspicious sensory segments, and QueueOfSS: Queue of sensory segments.

Class *QueueOfSS* models information in the sensory buffer and is an ordered – in the form of queue – aggregate of instances of the *SensorySegment* class. Class *QueueOfSS* is defined as an abstract class because it is a generalization of a complete set of subclasses, *RoutineSS* and *SuspiciousSS*. Abstract class *SensorySegment* includes attribute decayCycle and non-abstract operation decay (decayCycle), which are modeling the phenomenon of information decay in the buffer and which are inherited by both subclasses. 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". Class of suspicious sensory segments is characterized by a certain feature of suspicious, which models by suspicious Feature attribute. As it follows from experiments [2, 4] the feature of suspicious could be a stimulus with "suspiciously" high or "suspiciously" low intensity; for instance, loud or high pitch sound, for the auditory stimulus or quick movement of the object in the field of vision for the visual stimulus.

3. Classes of Filter Models of Attention

Attentional system is a system, which constrains sensory information involving into subsequent conscious perception. Narrowed and selective application of mechanism of attention is called *focused attention*. Quite often, investigation of the phenomenon of attention is oriented on the study of the ability of mind to share mechanism of attention between several sensory events. Such application of attention is called *divided attention*.

Focused and divided attentions are basic classes of attention, however there are also other classes. Firstly, attention can be directed on the inner world or on the external environment. In the case where mechanism of attention is directed on the external environment, it operates with sensory segments. When mechanism of attention is directed on the inner world, it operates with schemata from the long-term memory. Most of researches of phenomenon of attention are oriented on the study of the external attention. Secondly, attention can be considered for different sensory modalities: Visual, auditory, tactile, etc. Most researches are oriented on the study of visual and auditory attention. Class diagram in Figure 2 depicts classification of models of focused auditory attention.

As we can see in Figure 2, the class of models of focused auditory attention (*FocusedAuditoryAttention*) falls into a complete set of subclasses: *FilterOriented* (models of filter attention) and *CapacityOriented* (models of capacity attention). Accordingly, the class of models of filter attention falls into a complete set of subclasses: *EarlyFiltration* (models of early filtration) and *LateFiltration* (models of late filtration). Models of late filtration are represented by class *Deutch & DeutchModel* (model offered by Deutsch and Deutsch [8]), whereas models of early filtration are represented by basic class (model offered by Broadbent [2, 3]) and its enhancement (model offered by Treisman [12, 13]).

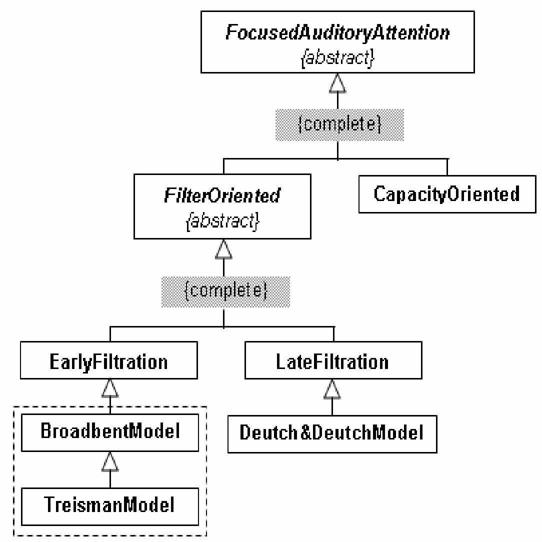

Figure 2. Classes of focused auditory attention. Where dotted line marks out models described in the paper.

Filter models of attention offered by Broadbent (class *BroadbentModel*) and Treisman (class *TreismanModel*) pre-suppose an analogy between psychological and technical filters. However, there is an essential distinction. Technical filter has information input and output. Part of the input signal substantially attenuates and does not reach the output. According to the Neisser's hypothesis, perception is a cyclical process without input and output [11]. 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 relevant sensors. We do not percept 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, the remaining 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.

4. Basic Model of Focused Attention: Broadbent's Hypothesis

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) was first generalized in the hypothesis offered by Broadbent [2, 3]. 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." He formulated his hypotheses in the form of principles, which are so general that pretended not only to explain the results of experiments on dichotic listening task but can also be considered as general principles of information processing by humans.

Articles [6, 14] include: Broadbent's principles, the description of transformation of these principles into concepts of the object-oriented theory of modeling, and spatial structure of Broadbent's model of attention in the form of UML class diagram. Therefore, the model presented below is considered as further development of results obtained in [6, 14].

If we take this into account, i.e. the structure of information in the sensory system depicted in Figure 1 and the cyclical nature of the process of perception, according to Neisser's hypothesis [11], then the functioning of attentional mechanism, can be described in the following way: Sensory segments sequentially picked out from the queue of sensory segments, categorize and compare with the set of schemata, which organism is anticipated on a given cycle of perception. Maximum "proximity" of one of anticipatory schemata with recognized sensory segment defines the subsequent set of anticipatory schemata.

The appearance of suspicious event is detected immediately, and detector interrupts the process of routine perception, and the attentional mechanism switches to the suspicious event. Experimental research justifies that there is a mechanism of fast detection of suspicious events, and this mechanism acts besides a relatively slow channel of categorization [10]. Presumably, every sensory receptor organ has a detector of suspicious event's feature. For auditory stimuli, the suspicious event's feature can be a signal with high frequency; for visual stimuli, it can be a fast movement of the bound between light and dark, etc. 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 3 depicts the structure of attentional system in accordance with Broadbent's hypothesis of attention.

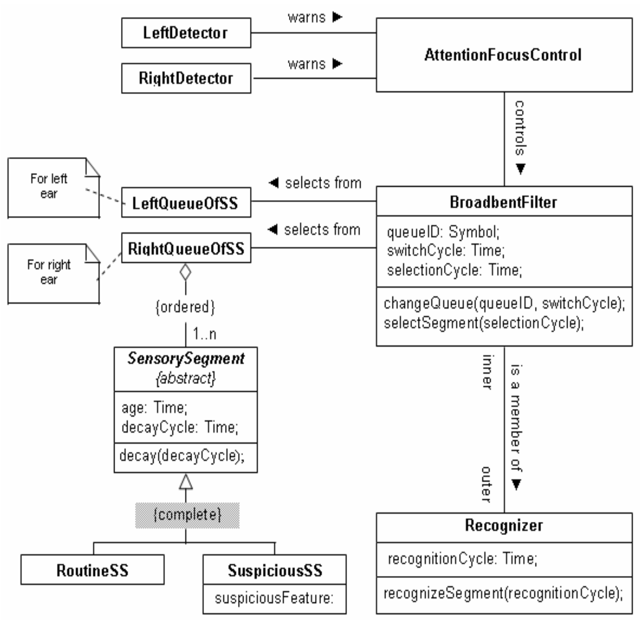

Figure 3. The structure of an attentional system in accordance with Broadbent's hypothesis. Where *BroadbentFilter*: Class, which models Broadbent's filter, *AttentionFocusControl*: Class, which controls the process of filtration, *Recognizer*: Class, which categorizes sensory segments, and *RightDetector and LeftDetector*: Classes of suspicious events detectors.

As the Broadbent's model is a generalization of data obtained from experiments on dichotic listening tasks, the structure of attentional system in Figure 3 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 3 depicts the structure of class *RightQueueOfSS* only. The structure of class *LeftQueueOfSS* is identical. Classes on the left side of the diagram in Figure 3 represent a sensory system whereas classes on the right side in Figure 3 model a post-sensory system.

The structure of the system of focused attention depicted in Figure 3 pre-supposes that class *BroadbentFilter*, which models Broadbent's filter, is an inner class and is an element of the class *Recognizer*, which models the phenomenon of categorization. This fact is described by the association named "is a member of". Class *BroadbentFilter* 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 method changeQueue. The method has some arguments: The identificator of the sensory segments queue (queueID), and the duration of switching (switchCycle). Class *BroadbentFilter* can also choose a segment from the queue and transmit it to the class *Recognizer*, by method selectSegment. The method has a single argument selectionCycle, which defines the duration of the selection process. However, class *BroadbentFilter* is unable to make a decision on which of two queues it has to focus attention. Class *BroadbentFilter* 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 commands 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 method change Queue.

5. Enhancement of the Basic Model: Treisman's Hypothesis

Ann 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. There is a terminological distinction in the description of Treisman's model of attention. She uses the term "input-channel" instead of the term "sensory event". This terminological distinction reflects her point of view on the processes in the sensory system. She operates with continuous information flows rather than with discrete sensory events.

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. Broadbent's filter pre-supposes that only one queue of sensory segments (on which attention is focused) sends information to the system of post-sensory processing, and all other queues are blocked.

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 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 method changeQueue, and in new attribute recognitionTreshold. Treisman's filter instead of switching queues of segments changes their thresholds by the method known as "changeTreshold". Figure 4 depicts a fragment of Treiman's system of attention and includes only revised classes.

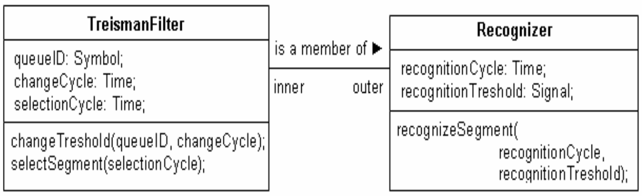

Figure 4. Classes treismanfilter and recognizer of Treisman's model of attention.

The System in Figure 4 consists of the outer class *Recognizer*, which includes inner class *TreismanFilter*. An important characteristic of the class *Recognizer*, which is responsible for categorization, is the threshold of recognition, modeled by the attribute recognitionThreshold. The categorization is realized by the method recognizeSegment, which recognizes only those segments that have level of intensity higher than that of the recognitionTresholds.

Class *TreismanFilter*, after receiving a message from class *AttentionFocusControl* (this class is not shown in Figure 4) with the information which queue is relevant at the moment makes its threshold higher than the recognitionTreshold. This ability of class *TreismanFilter* modeled by method changeTreshold, uses two arguments: Queue's identifier (queueID) and duration of the threshold change (changeCycle**).**

6. Interpretation of Experimental Data

Broabent and Treisman's models of focused attention are offered to explain results obtained in experiments on dichotic listening task. Sensory events for the organ of hearing are sequences of acoustic signals divided by pauses. In dichotic listening task, experiment subjects are placed into artificial environment in which their ears working independently and each ear generates its own queue of sensory segments. Basic technique in experiments on dichotic listening task is called shadowing. Shadowing pre-supposes that the subjects are instructed to repeat messages, attended to one sensory organ (for instance to the right ear) and hence focuses the attention on the queue of sensory events, which are relevant to this organ.

6.1. Cherry's Experiment on Listening to Two Different Text Messages

In [4], there is a description of experiment in which two different and prolonged text messages were transmitted into subject's right and left ears simultaneously. Both messages were recorded by the same voice. Subject was instructed to repeat the message transmitted in the right ear. The experiment demonstrates that the subject was able to recognize all information transmitted in the right ear but had no idea about information transmitted into the left ear.

Artificial environment, in which the subject was placed during the experiment, differs from the real environment and thus, simplifies the task for the attentional system:

- The flow of sensory events is fixed.
- Physical characteristics of all sensory events are identical (all messages were recorded by one voice).
- Suspicious events are excluded.

Results obtained in the experiment can be easily explained in the framework of Broadbent's hypothesis. As the subject could accurately fulfill the shadowing, procedure means that:

1. The categorization took place.
2. The time characteristics of all sequential procedures were agreed. Sensory segment did not stay in the buffer for the time, greater than decayCycle and, hence the following inequation is correct:

$$\text{SelectionCycle} + \text{recognitionCycle} < \text{decayCycle}$$

The system of attention cyclically executed the methods selectSegment and recognizeSegment. Subjects were unable to percept sensory events transmitted to their left ear because:

1. Incessant filtration from the queue of sensory events corresponding to the right ear was realized.
2. The method changeQueue did not execute.
3. The duration of the experiment was much longer than the decayCycle and by the time of its completion.

The queue of sensory segments corresponding to the left ear irretrievably disappeared as a result of the process of natural decay.

Results obtained in the experiment can also be easily explained in the framework of Treisman's hypothesis. Level of intensity for the queue of sensory event corresponding to the right ear was set up higher than the threshold and the permanent filtration from this queue occurred. As the level of intensity for the queue, which is relevant to the left ear, was less than the threshold and there were no suspicious events in it, organism percepted this flow of events as a noise.

6.2. Cherry's Experiment on Recognition Messages From the Irrelevant Flow of Sensory Events

This experiment was directed on investigation of suspicious events' features. Messages transmitted into the right ear of the subjects were passages from newspapers without proper names and without rare words. Subjects were instructed to repeat these messages aloud. In their left ear, the following information was transmitted:

- Text pronounced by a male voice.
- Text pronounced by a high pitch female voice.
- Text pronounced by a male voice but in a reverse order.
- 400 cps signal.

After the experiment, subjects were questioned to find out what they listened by the left ear; all subjects were unable to percept text transmitted to the left ear and pronounced by male voice in normal and reverse order. From the other side in all cases, when a 400 cps signal was transmitted into the left ear, it was percepted. The text pronounced by high pitch female voice was percepted in most cases. The experiment justified the presence of detectors of suspicious events in the attentional system, which interrupts the process of categorization for routine sensory events, transmitted into the right ear and shifted attention to the suspicious event. Hence, we conclude that left ear of subjects received the following flows of sensory events:

1. Suspicious event in the form of 400 cps signal.
2. Routine event in the form of male voice.
3. "Semi-suspicious" event in the form of high pitch female voice.

Suspicious event was detected by all subjects, while semi-suspicious event only by those subjects for whom it was definitely suspicious, and for the routine event, the conditions of this experiment were identical to the conditions of the previous one.

6.3. Broadbent's Experiment with Binaural Lists of Digits

Sensory events in this experiment are lists of digits called the binaural lists [3]. In binaural lists, pairs of digits are recorded on the magnetic tape in such a way that both the ears of the subject can listen different digits at the same time. For example, (7 3 4) into the left ear and (2 1 5) into the right ear.

One group of subjects listened to the binaural lists (consisting of three pairs of digits with ½-second interval between pairs). Subjects were instructed to write down all six digits in an arbitrary order. Broadbent discovered that: Almost all binaural lists were written correctly, and as a rule, subjects initially wrote down digits transmitted to one ear and then digits transmitted to another ear. For instance:

If the left ear's sequence is (7 2 3) and the right ear's sequence is (2 1 5) Then
a regular record is 7 2 3 2 1 5
or 2 1 5 7 2 3.

Another group of subjects also listened to binaural lists consisting of three pairs of digits but these subjects were instructed to write down digits in the order of its actual transmission. For instance:

If the left ear's sequence is (7 3 4) and the right ear's sequence is (2 1 5) Then
expected records are 7 2 3 1 4 5
or 2 7 1 3 5 4.

Time intervals between pairs of digits were: 2 seconds; 1½ seconds; 1 second; and ½ second. This group of subjects had demonstrated much more mistakes than the previous one and maximum mistakes occurred between the time intervals of 1 second and ½ second.

Artificial environment, which Broadbent created for his subjects, is similar to the environment in Cherry's experiments because physical characteristics of all sensory events are identical and moreover, suspicious events are excluded. But Broadbent's experiment has essential distinction: Subjects are oriented on switching their attention from one flow of sensory events to another, which in fact is the goal of the experiment.

In the framework of Broadbent's model and in the framework of Treisman's model, the results obtained during the experiment can be explained by "inertial" properties of the filter. Sensory event is a portion of information which system can categorize "at once." In the case of verbal auditory sensory event, the separator between events is a pause. For a small pause (½ second) all three digits percepts as one sensory event. Thus, first group of subjects have solved a problem of categorization of one sensory event. The problem is formulated in such a way that the attentional system needs only one switching between two queues of sensory events. Good results obtained while solving this problem can be explained by the following. The total time, which has been spent by the filter and the system of recognition, is less than the time of natural decay. For Broadbent's model, we can evaluate this case by the following inequation:

$$\text{switchCycle} + 2\,(\text{selectionCycle} + \text{recognitionCycle}) < \text{decayCycle}$$

Second group of subjects received verbal messages with small time interval between them (½ second) and also solved a problem of categorization of only one sensory event. But in this case, the problem was formulated in such a way that the attentional system needed five switching between queues. A number of mistakes mean that the total time of solving a problem was greater than the time of natural decay:

5 switchCycle + 6 (selectionCycle + recognitionCycle) > decayCycle

Finally, the second group of subjects, which received verbal messages with prolong time interval (approximately 2 seconds) solved a problem of categorization of six sensory events. In this case, categorization of one event needed only one switching. This group also demonstrated good results because the total time that the filter and the system of recognition used, was less then the time of decay:

switchCycle + 2 (selectionCycle + recognitionCycle) < decayCycle

7. Conclusion

Research presented in the paper allows us to make the following conclusions. First of all, the diagrammatical modeling by means of UML is rich enough and can be used for accurate description of cognitive models. The adequacy of models described in the paper to the original descriptions of Broadbent's and Treisman's hypothesis, is proved by its good agreement with the results of experiments devoted to the investigation of the phenomenon of attention. Secondly, models represented in the formal system can be easily integrated and combined. For instance, Treisman's filter, which we modeled by class *TreismanFilter* (see Figure 4), is a subclass of class of Broadbent's filters, modeled by class *BroadbentFilter* (see Figure 3). Easiness of integration of cognitive models depicted in UML notation defines the direction of our further research: The development of large-scale models, which integrate attentional and perceptional system from one side and the system of categorization from another side. We also consider as a prospective direction of research, the embedding of the integrated models of attention into the cycle of perception offered by Neisser [5, 11].

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