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Various Ways to Recall Cross-modality Perceptual Information in Cognitive Machine

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Abstract:
As human, we actively stimulate our memory via variety of recalls for information across different modalities in our brains. The variety of recalls enriches our crossmodal recall mechanism and equip our cognitive system to retrieve information for different needs. Inspired by our cognitive capabilities, this paper formulates, implement and examine different ways in performing crossmodal associative recall of perceptual information in machine cognition. Simulations with different cases and scenarios are conducted and examined on the recalls. Results show that different recalls possess their own features and properties which are useful to equip cognitive machine with variety of cognitive recall capabilities for different purposes.

Keywords: Machine perception, machine cognition, associative memory, information retrieval, associative recall, multimodal perception, computational model, cognitive system

1. Introduction

Machine cognition aims to equip computer systems with the cognitive capabilities as what human can have, including the mental process of acquiring, understanding and reasoning through senses, experiences, and thoughts. While machine perception is a sub-area focusing on enabling a machine to perceive the environment by sensory means and represent knowledge as humans and animals are capable of. Variety of sensing modalities such as sight, sound, touch and smell are jointly utilized in machine perception to interpret the sensory data. The process of perception involves making useful models of the environment from a confusing mass of sensory input data [1]. With machine perception, raw sensory input information gathered from the world can be processed and expressed in a form resembling brain representation as what human do for environmental features to relate themselves to the world around them. The perceived situations are subjectively interpreted impressions of the world and grounded to the individual embodiments to facilitate reasoning and meaningful actions in the world. Undoubtedly, machine perception would be very favorable to any artificial being such as agent, robot, or personal electronic assistant.

In ideal environment setup which are well controlled and structured with finite and well-defined possible occurring situations, the observation and interpretation of the input conditions generally do not incur a serious problem to machine. Nevertheless, it is not the case in many real-world environments which are not well defined and controlled, comprising almost infinite number of possible occurring objects, events, and scenarios [2, 3]. Hence, machine perception is required for more robust interpretation and subsequently, reasoning and action. Example applications include social interaction with humans, space exploration, monitoring of environmental condition etc. They are in general very useful in performing tasks that are tedious and hazardous to human but difficult, if not impossible, to automate without perceptual ability.

Incoming information sensed from the environment may not be completely available all the time. It might be scattered and partially complete, like jigsaw puzzle with missing pieces. In order to fill the gaps of missing pieces to form more complete picture and understanding on the scenario, recalling the required perceptual information from memory is essential. The recalled percept can be cued with sensed percept or percept coactive in the memory. Hence, priming and recalling perceptual information is one of the essential functions in cognitive machine for deeper and more thorough understanding on input information to better facilitate reasoning, decision making and problem solving, especially in less defined environments. It mimics cognition in human brain that derives information from sensor data, associate different patterns in the existing memory to create knowledge [4].

In cognitive machine, the functional component in learning and remembering the relationships between items and recalling the items among one another is associative memory (AM). In biological systems the hippocampus is thought to be an associative memory "convergence zone," binding together the multimodal elements of an experienced event into a single engram [5]. Our brains are able to remember, integrate and represent information from multiple sensory modalities [6, 7, 8, 9, 10, 11]. The crossmodal integration is structured such that items can be represented both as a whole as well as a set of crossmodal details [10]. In artificial model, an associative memory is a category of neural network that enables recalling output pattern given a set of input patterns. Several models of AMs are described in [12, 13, 14, 15, 16, 17, 18, 19, 20]. The connectionist approach of modifying the weight of connections between neurons as the fundamental mechanism underlying associative learning and memory was mainly inspired from Hebb's theory of cell assemblies [21].

In human cognition, perception, associative memory formation and recall of perceptual information are closely interlinked among multiple modalities. That is, any perceived object does not have any meaning if an individual fails to recall and relate it to different percept modalities in corresponding memory. Haikonen [22, 23, 24, 25] presented associative neuron modules that are able to perform associative learning and recall of percept over different sensory modalities such as visual, audio, haptic, gaze direction, motors etc. The modules are associatively cross-connected among different modalities so that percepts from individual modules can be globally broadcast allowing cross-associative operations. They are based loosely on ideas about the architecture of the brain and on the emulation of cognitive functions by modular nonnumeric associative neural networks.

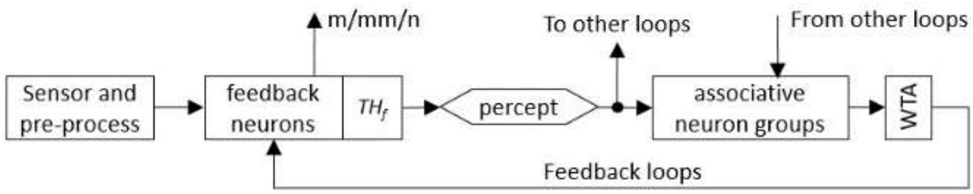
As human, we actively stimulate our memory for information across different modalities. There are variety of ways to perform our recalls. We can recall information freely without specified objective or focus. We can focus our recall related to particular subject or matter of interest. We can even divert our recall from current subject or matter of interest and consider others as the alternative and so on. Sometimes we just focus on one subject while other times, on multiple subjects. Our receptiveness to new idea or information in the recall may also vary from time to time. The variety enriches our crossmodal recall mechanism and equip our cognitive system to retrieve information for different needs. Existing research work on implementing and examining variety of cognitive recalls as mentioned above is hardly found. Thus, this paper takes a step to formulate, implement and examine different ways in performing associative recall of percept, loosely based on the idea of human recall process, in cognitive machine. The work is conducted on the basis of associative recall of perceptual information among different percept modalities, which considers Haikonen's associative neuron modules [22, 23, 24, 25] as the framework.

This paper is organized as follow. Section 2 gives brief overview of Haikonen's associative perception loop as framework for the paper. The perception loops are integrated in Section 3 to facilitate different ways of associative recall of percept among different modalities. It is an adapted architecture comprising array of perception loops and control signals required to facilitate the implementation of different recalls. Other signals and functional blocks unrelated to the scope of the paper are omitted for better focus of the paper. Section 4 formulates different possible ways of recalling perceptual information among different percept modalities, mimicking human recall process. The simulation case studies and results are reported and discussed in Section 5 while conclusions are drawn in Section 6.

2. Associative Perception Loop

Haikonen [22, 23, 24, 25] presented perception loop as the basic neuron modules that performs the cognitive functions of sensory perception, establishment of inner representations; inner imagery, inner speech short term working memory etc. The loop consists of basic elements, namely feedback neurons, association neuron groups and a related WTA (Winner-Takes-All) neurons as depicted in Figure 1.

Figure 1: Associative Perception Loop



Pre-process accesses information about its environment and its own physical states via sensory inputs and convert to distributed signal representations [26]. Each of these signals represents a small fraction or feature of the total information available from that sensor. The representations are able to connect to each other and one representation can be evoked by another. These signals have the point-of-origin meaning same as the sensory attribute signals, which in turn are in causal connection to the sensed external world.

The feedback neuron groups consist of one neuron for each input signal. Each feedback neuron has one input signal from pre-process and another from the output signal of the WTA. The inherent meaning of the signal from pre-process and WTA are the same for the feedback neuron. The output signal array after the threshold **TH_f** of the feedback neuron group is called percept, which will be adopted throughout the paper. It is broadcasted as associative inputs to other neuron loops. We can view percepts as subgroup of attributes defining the contextual state of the cognitive system. Percepts may be the pre-processed input signal array from sensory input, signal array primed by the feedback signal array, or the combination of both. In visual sensory modality for example, these signals represent visual attributes or features of a sensed image of the external entity.

The associative neuron groups consist of array of non-numeric associative neurons [22, 23, 24, 25]. Each associative neuron has one main distributed signal input s, a synaptic learning fixation threshold control input $\mathbf{TH}_s$ and the output signal so, match m, mismatch mm and novelty n. The point-of-origin meanings of the s and so signals are the same. Synaptic learning is correlative and depends on repeated s and a_i signal from other modalities coincidences via modified Hebbian learning. Each coincidence increases the respective synaptic strength. When the so-called learning fixation threshold is achieved, the synaptic weight turns to one and the associative connection between the main signal s and the associative signal a_i is established. The synaptic strength modifications realize learning and long-term memory. After learning, a number of these associated ai signals may evoke the output so alone (associative evocation or inner imagery) and they may amplify the output if the main signal s is present (priming function). The in-loop associative neuron groups facilitate associative cross-connections of the respective distributed signal in the modality to other modalities.

In the beginning the loop is in unlearned state, there is no feedback in the loop due to no associative cross-connection of the distributed signal with other modalities. Only the sensed distributed signal representation passes through the feedback neurons and become the percept in the loop. After going through learning where the distributed signal is associated with other distributed signals from different modalities via synaptic weights, feedback signals can be generated via priming from the associative inputs from other modalities. This results in the output percept as a nonlinear sum of the sensed signals and the feedback.

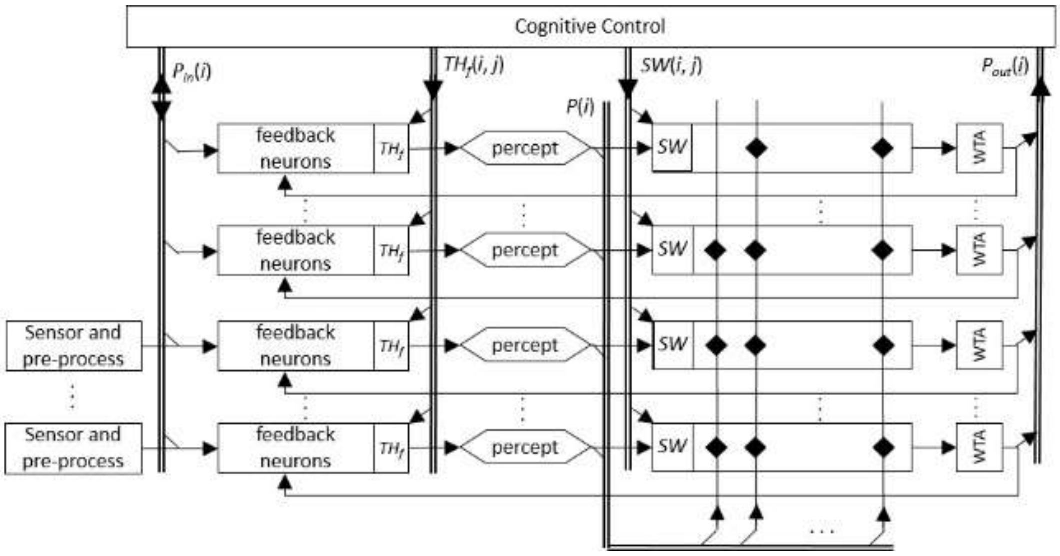
3. Multimodality Associative Model for Perceptual Recall

The dynamics of percept presented in previous section exhibit the bottom-up reactive behavior in cognition as the switching from one percept to another in the modality is primarily triggered by the sensory inputs, although the final outcome of percept in the modality can be the combined effects of sensed percept and "imagined" percept primed by associative inputs from other modalities.

To address the need of top-down control of recalling perceptual information for continuous monitoring, evaluating and supervising mental process even in the absence or insignificant sensory stimuli, it comes naturally that the control of recall in perception loop allows access from higher cognitive level to guild and influence the recall process. Here the active percept is referred to the dominating percept that won competition over other percept in the same modality and gain the influence to prime its associated percept in other modalities. It is in line with the neural firing study in [27] that neocortex neurons exhibit sustained coactivity to retain active contents in brains at any point in time. In this paper the basic perception loop module in [22, 23, 24, 25] is adopted with control signals, such as threshold control **TH** and switch control **SW**, as depicted in Figure 2 to formulate various types of perception recall. Besides percept **P** in the loop, there are also input percept $\mathbf{P}_{in}$ and output percept $\mathbf{P}_{out}$ at the input and output of the loops. The model proposed in Figure 2 is a general model focusing on how the recall of percept information among modalities can be controlled in the mental process for continuous and progressive cognitive 'thinking'.

In Figure 2, percept can be sensory, which has direct connection with the physical sensory inputs and pre-process. It can be also an abstract or concept which has significant meaning but is not directly connected to the sensory inputs and pre-process. However, when the abstract percept has formed cross-connection with sensory percept, it is considered "grounded" to physical world and embodiment. Sensory percept can be internal or external, where internal sensory percept focuses on the internal situation or states of embodiment (within agent) while external percept features external situations or state (agent's environment).

Figure 2: Cognitive Model for Perception Recall



Before we proceed, lets further define some notations in the model. Q represents the number of percept modalities. $Q = Q_A + Q_S$ where Q_A is the number of abstract modalities and Q_S the number of sensory modalities. J_i is the number of percepts in modality i. **P**$_{in}$(i) is the input percept in modality i, which can be from the sensor and pre-process, or output from cognitive control. **P**(i) is the dominating percept output from the feedback neurons in modality i. **pv**(i, **dom**(i)) is the signal value of dominating percept **dom**(i) in modality i. **P**$_{out}$(i) is the output dominating percept index in modality i.

4. Ways of Recalling Crossmodal Percepts

There are various ways of recalling percepts over different modalities. Firstly, the neural prohibitive approach using thresholds **TH**$_f$ in feedback neurons is considered and formulated. Let **TH**$_f$(i, j) be the threshold signal in feedback neuron for percept j in modality i. When **TH**$_f$(i, j) = 0, signal can pass through the threshold, i.e. output equals input and 1 otherwise, i.e. output equals 0. With the threshold controls, the following ways of recalling percept information can be achieved.

4.1. Free Recall

In free recall, there is no any explicit percept of interest in the recall. The recall begins from the current active percept and the recall flow naturally along the way. Any active percept is allowed to prime other percept and at the same time be dominated by its competing percept of higher intensity. The competition on the cross association priming on each other is open and free from external intervention. The formulation of threshold, $\mathbf{TH}_f(i, j)$ for each percept j in each modality i is given below:

$$\mathbf{TH}_f(i,j) = 0 \ \forall \ i,j \qquad (1)$$

4.2. Exclusive Recall of Modality

The recall is focusing on modality i* of interest and the formulation of threshold, $\mathbf{TH}_f(i, j)$ is:

$$\mathbf{TH}_f\,(i,j) = \begin{cases} 0, & i = i^* \\ 1, & \text{else} \end{cases} \qquad (2)$$

It exclusively allows any percept within the focused modality i* to prime for other modalities while blocking other modalities in the priming process. The recalled percept will be exclusively influenced from the focused modality. However, it does not guarantee that the initially coactive percept in the focused modality will sustain after the recall in the case of multifocus modality. It may be dominated by percept primed by other focused modality, depending on the associative priming process.

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4.3. Open Recall of Percept

While the previous recall set focus at the modality level, this recall set the specific focus at percept level. Here, j* denotes the focused percept in the recall while the modality where percept j* resides is i*. In modality i*, it only allows percept j* to pass through while blocking the rest. However, for modalities other than i*, they are allowed to pass through the threshold. The effect of recall encourages inference of the specific percept j* with percept in other modalities in the priming process.

$$\mathbf{TH}_f(i,j) = \begin{cases} 0, & i = i^* \text{ AND } j = j^* \\ 1, & i = i^* \text{ AND } j \neq j^* \\ 0 & i \neq i^* \end{cases} \qquad (3)$$

As other competing percept in modality i* is prohibited, only the focused percept j* is allowed through the recall and stay effective to influence the priming in other modalities. As the recall is open to other modalities, the active percept in other modalities are also allowed in cross-associative priming.

4.4. Exclusive Recall of Percept

Unlike the open recall, this recall only allows the focused percept j* in modality i* to affect the recall and blocks all other percept in the priming, including the ones in modality i* or other modalities as given in the formulation below:

$$\mathbf{TH}_f(i,j) = \begin{cases} 0, & i = i^* \text{ AND } j = j^* \\ 1, & \text{else} \end{cases} \quad (4)$$

As the name implies, it is to exclusively recall the percept that has direct association with the focused percept and not others. The recall is very confined and specific, which is useful for very strict deductive reasoning requiring strong associations.

4.5. Open Recall of Alternative Percept

This recall works exactly in the opposite way of the previous recall. It allows all active percept, except percept j* of interest, to jointly affect the priming as given in the below formulation:

$$\mathbf{TH}_f(i,j) = \begin{cases} 1, & i = i^* \text{ AND } j = j^* \\ 0, & \text{else} \end{cases} \quad (5)$$

The purpose is to exclude percept i* and consider the alternative percept having non-zero signal value in the same modality i*. The alternative percept will emerge as dominated percept in the modality at the same time join percept in other modalities in open cross-priming for recalled percept. The recall is suitable to be applied in the divergent reasoning to consider alternative outcome or answer different from the one currently coactive in mind.

4.6. Exclusive Recall of Alternative Percept

Unlike its open recall counterpart, the recall only allows other percept in the same modality i* of percept j* of interest to pass the thresholds. Percept j* of interest as well as percept in other modalities are prohibited in the recall, as depicted below:

$$\mathbf{TH}_f(i,j) = \begin{cases} 1, & i = i^* \text{ AND } j = j^* \\ 0, & i = i^* \text{ AND } j \neq j^* \\ 1, & i \neq i^* \end{cases} \quad (6)$$

4.7. Open Recall of Other Modality

The recall behavior is about similar to Eq 5 except that the alternative is at the modality level. It diverts the attention away from the current modality i* of interest to take part in the recall. The formulation is given by:

$$\mathbf{TH}_f(i,j) = \begin{cases} 1, & i = i^* \\ 0, & \text{else} \end{cases} \quad (7)$$

Intuitively, the recall serves the purpose of "Let's stop on this topic and look into something else".

4.8. Suspended Recall

The recall blocks all percept in the recall as defined below:

$$\mathbf{TH}_f(i,j) = 1 \ \forall\ i,j \quad (8)$$

The purpose is simply to discontinue the recall and clear the active percept. This recall can be applied before performing a drastic switch to attain totally different mental contents.

4.9. Multifocus Recall

The formulations of $\mathbf{TH}_f$ in previous section are specifically defined to focus on single percept or modality. To extend the formulations for multifocus percepts or modalities, $\mathbf{TH}_f$ formulations can be compounded via multifocus operation $\otimes$ as shown below:

$$\mathbf{TH}_f(i,j) = \mathbf{TH}_f^{f_1}(i,j) \otimes \mathbf{TH}_f^{f_2}(i,j) \ldots \otimes \mathbf{TH}_f^{f_k}(i,j) \ \forall\ i,j \quad (9)$$

where $\mathbf{TH}_f^{f_1}, \mathbf{TH}_f^{f_2}, \ldots, \mathbf{TH}_f^{f_k}$ are the threshold controls for the focused subjects, f_1, f_2, … f_k, which can either be a percept or an entire modality. The $\otimes$ operation for each way of recall can be formulated in below and listed in Table 1.

$$\otimes := \begin{cases} \text{OR}, & \boldsymbol{TH}_f(i,:) = 1\ \forall i \neq i^* \\ \text{AND}, & \boldsymbol{TH}_f(i,:) = 0\ \forall i \neq i^* \end{cases} \quad (10)$$

Table 1: Types of multifocus operation for perceptual recalls

	Ways of Recall	**Multifocus Operation ($\otimes$)**
1	Free Recall	-
2	Exclusive Recall of Modality	AND
3	Open Recall of Percept	OR
4	Exclusive Recall of Percept	AND
5	Open Recall of Alternative Percept	OR
6	Exclusive Recall of Alternative Percept	AND
7	Open Recall of Other Modality	OR
8	Suspended Recall	-

4.10. Recall with Receptiveness to Change

As human, sometimes we tend to stay with our status quo unless the change is unavoidable – less receptive to change. At other times, we are receptive or even looking forward to change for new possibilities and better outcomes in responding to a situation. In the cognitive model presented in Figure 2, the receptiveness for new percept in the recall can be controlled via the SW signals. Let **SW**(i, j) be the input switch in associative neurons for percept j in modality i, the output signal **so**(i, j) of associative neurons is given by:

$$\mathbf{so}(i,j) = \left(1 - \mathbf{SW}(i,j)\right)\mathbf{pv}(i,j) + \mathbf{sa}(i,j) \quad (11)$$

where **pv**(i, j) is the current signal intensity of percept i in modality j, while **sa**(i, j) the respective associatively evoked output signal given that:

$$\mathbf{sa}(i,j) = \sum_{p,q} \mathbf{w}(i,j,p,q) \blacklozenge \mathbf{pv}(p,q) \quad (12)$$

w(i, j, p, q) is the associative weight on percept i of modality j from percept p of modality q. ◆is a computational operation for cross-connection from associative inputs from other modalities. In this paper, the multiplication operator is applied.

Setting SW to 1 (fully open) will make associative neurons receptive to new percept primed by other modalities while at the same time impulsive, distractive and forgetful. Contrarily, setting it to 0 (fully closed) results in stabilized priming process but increases resistance (less receptive) to change. For generalization, the intermediate results can be achieved with value between 0 and 1.

5. Simulation and Experimental Results

In this section, the cognitive model in Figure 2 is simulated to examine and demonstrate the features of the cognitive recall methods mentioned in Section 4. A scenario of social robot interacting with user is considered as case study in this simulation. For ease of illustration, the cognitive model in the robot embodiment is setup with a few modalities of robot's percept related to interaction experience with a user. They are user emotion (UserEmo), user posture (UserPos), object (Object) presented by user, user request (UserReq) to robot, reward or punishment received (RewardPunish) with the respective percepts in each modality are listed in Table 2. The model can be scaled up to arbitrary number of modalities and percepts in the modalities to suite the applications. In this example, "Unknown" and "Nil" percepts are also included, which is optional, for the case where the sensory information of the percept is unavailable for cross-association.

Table 2: Modalities and Percepts in Case Study

UserEmo	UserPos	Object	UserReq	RewardPunish
Unknown	Nil	Nil	Nil	Nil
Happy	Pos1	Red	Play song	Reward
Unhappy	Pos2	Green	Tell story	Punish
	Pos3	Blue	Dance	

The model starts with unlearned condition, then goes through associative learning with each experience captured as a learning instance in each row of Table 3. For example, learning instance 1 implies that when user is having "Pos1" posture as a body language and presenting "Red" object, user tends to reward the robot. Another example of learning instance 7 implies that user tends to request robot to "Play song" when the user is happy. The learning instances are considered as past experiences perceived by the robot over a period of interaction with a user. Different users may portray different sets of experiences for the model. The experiences are then captured by the model in the form of associative representations of percept across different modalities implying the robot's perceptual experiences with the user.

Table 3: Robot's perceptual experiences with the user

Learning Instance	UserEmo	UserPos	Object	UserReq	RewardPunish
1		Pos1	Red		Reward
2		Pos1	Green		Reward
3		Pos2	Green		Punish
4		Pos2	Blue		Punish
5	Happy	Pos1	Red		
6	Unhappy	Pos2	Green		
7	Happy			Play song	
8	Unhappy			Tell story	

After associative learning and representation of perceptual experiences with user, the following sections demonstrate and discuss different recall methods can be adopted for a cognitive machine.

5.1. Free Recall

Having learnt the perceptual experiences in Table 3, $\mathbf{TH}_f$ is set according to Eq 1 for free recall. In the simulation, the recall starts with initial percept "Blue" and "Reward" in "Object" and "RewardPunish" modalities, respectively. The recall process was executed over 5 recall cycles to confirm the end recall results is achieved. The settings of Initial percepts and $\mathbf{TH}_f$ as well as the simulated recall results obtained are populated in Table 4.

Table 4: Simulation for Free Recall

	UserEmo	UserPos	Object	UserReq	RewardPunish
P			Blue		Reward
P_{in}	-	-	-	-	-
TH_f	0 for all	0 for all	0 for all	0 for all	0 for all
Cycle 1		Pos2	Blue		Punish
Cycle 2	Unhappy	Pos2	Green		Punish
Cycle 3	Unhappy	Pos2	Green	Tell story	Punish
:	:	:	:	:	:

The initial percepts of "Blue" and "Reward" are not in line with each other in the perceptual experience. Results show that recall process may take a few cycles in the cross-modality priming process to compete among one another before settling down to the winning percepts. The priming process in this example can be broken down into the following stages:

i) "Blue" primes "Punish" and "Pos2".
ii) "Punish" and "Pos2" prime "Unhappy" and "Green".
iii) "Unhappy" primes "Tell story".

There is no control at all in free recall and percept may prime directly or indirectly associated percept over a number of recall cycles. Also, there is no guarantee that the initial percept can be preserved until the end. It may be dominated by other competing percept, depending on which one win the priming competition. In this case, "Reward" is dominated by "Punish" after "Blue" has won in the priming competition and take over to prime its associated percept in other modalities. Free recall can be applied to recall loosely associated percept in more relaxed, unguided and explorative reasoning before narrowing down the focus on specific modality or percept.

5.2. Exclusive Recall of Modality

To demonstrate the exclusive recall of modality, let's take a look at the below recall scenario where "Object" is the focused modality. In the following discussions, "*" implies that a percept or modality is the subject of interest in the recall. **TH_f** formulation in Eq 2 is applied for Exclusive Recall of Modality. **TH_f** for all percepts in the focused "Object" modality are "0" while percepts in all other modalities are "1". Table 5 shows the setup and recall results in the simulation.

Table 5: Simulation for Exclusive Recall of Modality

	UserEmo	UserPos	Object*	UserReq	RewardPunish
P			Blue		Reward
P_{in}	-	-	-	-	-
TH_f	1 for all	1 for all	0 for all	1 for all	1 for all
Cycle 1		Pos2	Blue		Punish
Cycle 2		Pos2	Blue		Punish
:		:	:		:

In contrast with free recall, only the focused modality (i.e. percepts in "Object" modality) is allowed to prime its associative percept while other modalities are prohibited. Thus, the current percept in "Object" modality, which is "Blue" in this case, remains in the recall and continues to prime the rest of modalities. As the results, "Reward" disappears in this case as it is prohibited from priming and is dominated by "Punish", which is primed by "Blue". As the recall's focus is at modality level, it does not guarantee that an initial percept in the modality will be preserved. In brief, exclusive recall of modality can be used to focus the recall at modality level (specific area or domain, but not specific object) with no interference from other unfocused modalities.

5.3. Open Recall of Percept

Open recall of percept follows the $\mathbf{TH_f}$ formulation in Eq 3 where only the unfocused percepts in the same modality of the focused one are blocked while percepts in other modalities are not blocked. In the below demonstration, "Pos1" is chosen as the focused percept, thus is labelled "*". The recall begins with the focused percept and "Blue" percept. The initial setups together with the simulated recall result are summarized in Table 6.

Table 6: Simulation for Open Recall of Percept

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos1*	Blue		
$\mathbf{P_{in}}$	-	-	-	-	-
$\mathbf{TH_f}$	0 for all	0 for "Pos1" 1 for others	0 for all	0 for all	0 for all
Cycle 1	Happy	Pos2	Blue		Punish
Cycle 2	Happy	Pos1*	Green	Play song	Reward
Cycle 3	Happy	Pos1*	Red	Play song	Reward
Cycle 4	Happy	Pos1*	Red	Play song	Reward
:	:	:	:	:	:

As shown in the simulation, besides "Pos1" percept in "UserPos" is not blocked in the recall, percepts in other modalities are also not blocked. Thus, the recall allows percepts in other modalities to give influence in the recall. In this example, "Pos1" is initially dominated by "Pos2" in cycle 1 due to the open competition from "Blue". However, only "Pos1" is unblocked and allowed to stay in the focused modality. It leads to the percept in favor of "Pos1", i.e. "Happy", start to affect and call up "Pos1" in the next cycle. Subsequently, "Pos1" starts to prime its associated percepts in the rest of modalities. Finally, we see that "Pos1*" recalls "Happy" and "Red" in stage one while "Happy" recalls "Play Song" in the stage two and so forth. In short, open recall of percept behaves quite similar to free recall in terms of allowing open priming from other modalities except that it has additional control to focus on a specific percept to ensure the focused percept will not disappear and continue its influence in the recall process.

5.4. Exclusive Recall of Percept

Table 7 shows the case study for exclusive recall of percept. The input percept of "Tell story", which is different from the focused percept (Play song), is included to demonstrate the recall feature. As expected in exclusive recall, "Play song" retains in the recall and not distracted by the input percept. It is noted that, only the focused percept is allowed to prime its directly associated percept, which is "Happy", in the recall.

Table 7: Simulation for Exclusive Recall of Percept

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P	Unhappy	Pos1	Blue	Play song*	Punish
P_{in}	-	-	-	Tell story	-
TH_f	1 for all	1 for all	1 for all	0 for "Play song" 1 for others	1 for all
Cycle 1	Happy			Play song*	
Cycle 2	Happy			Play song*	
:	:			:	

Besides ensuring the focused percept can be retained, the recall exclusively attains to the focused percept. It will not be interfered even by the input percept. It restricts the priming of percept having direct or strong association with the focused percept only. This type of recall is useful in highly focused attention for strict deduction and inference for percept that has strong relation with the focused one.

To show the feature of the above recall, the above case study is repeated with exclusive recall of modality. The simulation results as shown in Table 8. As the focus is at the modality level, the percept in the focused modality can still be distracted by incoming percept, i.e. "Tell story", or percept from other modalities.

Table 8: Simulation for Comparison with Exclusive Recall of Modality

	UserEmo	**UserPos**	**Object**	**UserReq***	**RewardPunish**
P	Unhappy	Pos1	Blue	Play song	Punish
P_{in}	-	-	-	Tell story	-
TH_f	1 for all	1 for all	1 for all	0 for all	1 for all
Cycle 1	Unhappy			Tell story	
Cycle 2	Unhappy			Tell story	
:	:			:	

5.5. Open Recall of Alternative Percept

Instead of maintaining attention on the percept of interest, open recall of alternative percept switches current attention to the alternative. The formulation of $\mathbf{TH}_f$ can be found in Eq 5. The case study with simulation results is given in Table 9. "Red" is the initial focused percept and the cognition model is recalling the alternative, i.e. other than "Red" in the same modality, given the initial percept "Pos2" and "Reward" active in the model. The result shows that 'Green' emerges as the alternative to "Red", which in turn joining "Pos2" to prime "Unhappy", "Tell story" and overwrite "Reward" with "Punish". In short, the recall results in the transition to another set of percepts associative with "Green" and "Pos2". The recall mimics the divergent thinking in phycology in a way to explore alternatives under a given context, which is a set of initially active percepts in the modalities in the model.

Table 9: Simulation for Open Recall of Alternative Percept

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos2	Red*		Reward
$\mathbf{P}_{in}$	-	-	-	-	-
$\mathbf{TH}_f$	0 for all	0 for all	1 for "Red" 0 for others	0 for all	0 for all
Cycle 1	Unhappy	Pos2	Green		Punish
Cycle 2	Unhappy	Pos2	Green	Tell story	Punish
Cycle 3	Unhappy	Pos2	Green	Tell story	Punish
:	:	:	:	:	:

Table 10 compares the above recall feature with a free recall having the same setup. As "Red" is not blocked in the free recall, the three initial percepts are given opportunity to compete and prime their respective associated percept. It turns out in the simulation that "Red" and "Reward" finally won in the competition to recall their associated percepts, i.e. "Happy", "Pos1" and "Play Song". The recall outcome is different from Table 9.

Table 10: Simulation for Comparison with Free Recall

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos2	Red		Reward
$\mathbf{P}_{in}$	-	-	-	-	-
$\mathbf{TH}_f$	0 for all	0 for all	0 for all	0 for all	0 for all
Cycle 1	Unhappy	Pos1	Green		Reward
Cycle 2	Happy	Pos1	Green	Tell story	Reward
Cycle 3	Happy	Pos1	Red	Play song	Reward
Cycle 4	Happy	Pos1	Red	Play song	Reward
:	:	:	:	:	:

5.6. Exclusive Recall of Alternative Percept

For exclusive recall of alternative percept, the $\mathbf{TH}_f$ formulation in Eq 6 is adopted. In this case study, we start with three percepts in "Object" modality, namely "Red", "Blue" and "Green", with signal intensities of 1, 0.8 and 0.2, respectively. Besides the "Object" modality, the initial conditions also comprise "Pos2" and "Reward" as dominating percepts. "Red" percept is selected as the focused percept and hence, is blocked to recall its alternative. All percepts in other modalities are blocked in the exclusive recall as shown in Table 11. With the non-zero intensity of other alternative percept signals, setting the exclusive alternative on 'Red' blocks 'Red' percept to prime, which gives opportunity for the alternative percept, i.e. 'Blue', to take over and prime other percepts – "Pos2", "Punish" and "Unhappy". Unlike the open recall of alternative percept, exclusive recall of alternative percept recalls the alternative of the focused percept and restrict the recall from the alternative only.

Table 11: Simulation for Exclusive Recall of Alternative Percept

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos2	Red*=1 Blue = 0.8 Green = 0.2		Reward
P$_{in}$	-	-	-	-	-
TH$_f$	1 for all	1 for all	1 for "Red" 0 for others	1 for all	1 for all
Cycle 1	Unhappy	Pos2	Blue		Punish
Cycle 2	Unhappy	Pos2	Blue		Punish
:	:	:	:		:

5.7. Open Recall of Other Modalities

Let's consider the open recall of other modality where all other modalities, except the focused one, are not blocked as formulated in Eq 7. Table 12 presents a case study with initial conditions and simulation results. It starts with two initially active percepts, "Happy" and "Blue", which come from different sets of experience conflicting to each other to some extent. In the recall, the entire 'Object' modality is blocked from priming other percepts. This allows active percept (Happy) in other modalities to prime its associated percept. The priming result may even overwrite the original dominant percept (Blue).

Table 12: Simulation for Open Recall of Modalities Other than "Object"

	UserEmo	**UserPos**	**Object***	**UserReq**	**RewardPunish**
P	Happy		Blue		
P$_{in}$	-	-	-	-	-
TH$_f$	0 for all	0 for all	1 for all	0 for all	0 for all
Cycle 1	Happy	Pos1	Red	Play song	
Cycle 2	Happy	Pos1	Red	Play song	Reward
Cycle 3	Happy	Pos1	Red	Play song	Reward
:	:	:	:	:	:

Next, let's examine the same initial condition but the entire "UserEmo" is blocked to consider other modalities in the recall, this time "Blue" in other modality has the opportunity to prime its associated percept and turn into another set of experience.

Table 13: Simulation for Open Recall of Modalities Other than "UserEmo"

	UserEmo*	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P	Happy		Blue		
$\mathbf{P}_{in}$	-	-	-	-	-
$\mathbf{TH}_f$	1 for all	0 for all	0 for all	0 for all	0 for all
Cycle 1		Pos2	Blue		Punish
Cycle 2	Unhappy	Pos2	Blue		Punish
Cycle 3	Unhappy	Pos2	Blue		Punish
:	:	:	:		:

5.8. Multifocus Recall

To demonstrate the multifocus recall, the simulation in Table 7 focusing on single percept, i.e. "Play song", is repeated by adding one more percept, i.e. "Pos1", as another focused percept. The multifocus operation would be "AND" from Table 1 to form the compounded THf settings for exclusive recall of percept. Table 14 illustrates the initial setup as well as the simulated results. Unlike the single focus in the exclusive recall in Table 7 that recalls only the percept associated to the single focused percept, multifocus recall prime the percept associated to multiple focused percept concurrently. When the multiple focused percept has minimum overlap in the sets of associative percepts, the recall results in a set of percepts that is close to union of the sets. In the case where the sets are heavily overlapped, the recall serve to refine the recall towards the intersection of the sets.

Table 14: Simulation for Multifocus Recall

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P	Unhappy	Pos1*	Blue	Play song*	Punish
$\mathbf{P}_{in}$	-	-	-	Tell story	-
$\mathbf{TH}_f$	1 for all	0 for "Pos1" 1 for others	1 for all	0 for "Play song" 1 for others	1 for all
Cycle 1	Happy	Pos1	Green	Play song*	Reward
Cycle 2	Happy	Pos1	Green	Play song*	Reward
:	:	:		:	:

5.9. Recall with Receptiveness to Change

In this section, a setup of free recall starting with "Pos1" and "Punish" percepts are considered. Table 15 simulates the free recall process with "UserPos" modality having receptiveness to change while in Table 16, "RewardPunish" is receptive to change. It can be observed in the former case that the recalled percept are the results of priming from "Punish" as "UserPos" is receptive to change. In contrary, as shown in Table 16, when the "RewardPunish" modality become receptive to change, it is receptive to the priming from "Pos1" percept. While "recall of alternative percept" prohibits the focused percept in the recall, "receptiveness to change" only reduces the resistance to change so that it is receptive to the new percept associative from other modalities. Thus, it may happen to come back to the same percept resulted from the associative inputs when coactive percepts mutually prime each other.

Table 15: Simulation for Free Recall with "UserPos" Receptive to Change

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos1			Punish
P_{in}	-	-	-	-	-
TH_f	0 for all	0 for all	0 for all	0 for all	0 for all
SW	0 for all	1 for all	0 for all	0 for all	0 for all
Cycle 1	Happy	Pos2	Green		Punish
Cycle 2	Unhappy	Pos1	Green	Play_song_A	Punish
Cycle 3	Unhappy	Pos2	Green	Tell_story	Punish
Cycle 4	Unhappy	Pos2	Green	Tell_story	Punish
:	:	:	:	:	:

Table 16: Simulation for Free Recall with "RewardPunish" Receptive to Change

	UserEmo	**UserPos**	**Object**	**UserReq**	**RewardPunish**
P		Pos1			Punish
P_{in}	-	-	-	-	-
TH_f	0 for all	0 for all	0 for all	0 for all	0 for all
SW	0 for all	0 for all	0 for all	0 for all	1 for all
Cycle 1	Happy	Pos2	Green		Reward
Cycle 2	Unhappy	Pos1	Green	Play song	Punish
Cycle 3	Happy	Pos1	Red	Play song	Reward
Cycle 4	Happy	Pos1	Red	Play song	Reward
:	:	:	:	:	:

6. Conclusion

In this paper, the author has presented variety crossmodal perceptual recalls in multimodal machine cognition and perception. Formulations for each type of recall was given, which based on the threshold and switching controls in the crossmodal perceptual system. The formulations can be generalized and adapted to other multimodality associative model with prohibition signals to control the priming of percept in array of modalities and switching to control the feeding of current percept into computing the next associative percept. In this paper, the recalls have been simulated with different case studies and scenario. The simulation results for the recalls have been reported, which successfully demonstrated the feature for each associative recall, which is useful in recalling information in crossmodal cognitive machine. The application scenarios used in the simulations and demonstrations in this paper are admittedly in limited scope but it could be easily scaled up.

7. References

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