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Hidden Markov Model for the Simulation Study of Neural States and Intentionality

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Abstract**—**Hidden Markov Model (HMM) has been used in prediction and determination of states that generate different neural activations as well as mental working conditions. This paper addresses two applications of HMM; one to determine the optimal sequence of states for two neural states: Active (AC) and Inactive (IA) for the three emission (observations) which are for No Working (NW), Waiting (WT) and Working (W) conditions of human beings. Another is for the determination of optimal sequence of intentionality i.e. Believe (B), Desire (D), and Intention (I) as the states and three observational sequences: NW, WT and W. The computational results are encouraging and useful.

Keywords**—**BDI, HMM, neural activation, optimal states, working conditions.

I. INTRODUCTION

INTENTIONALITY has been manifested in various disciplines with different perspectives. From cognitive psychological point of view, it is a matter of mental attitude that encompasses its constituents as believe, desire, preference, choice, intention and commitments etc. From philosophical perspective, it is taken as a state of mental affair in an abroad sense, possessed by any animate being and is displayed in one's actions [5], [6]. In artificial intelligence, it is for the measure and formalizing of the main components of intentionality i.e. Believe (B), Desire (D) and Intention (I) rather than its manifestation [3].

The features of the mental states are either about the object or directed upon them that may or may not exist or have contents that may or may not be true, has been called intentionality. Every mental phenomenon includes something as object within itself [1], [2].

From the above conceptual definitions, it is clear that believe, desire, and intention are the prime components of intentionality. Apart from believe, desire and intention (BDI), we have determined working conditions based on neural activation. The optimal sequences of states are determined for two neural states: Active and Inactive, and for the three observation: No Working, Waiting and Working conditions.

The neural activations are revealed by different working conditions of brain [4]. The BDI can be computed and measured directly [3] or indirectly as in [10]. Based upon certain definitions, we present in this paper, a computational modal of BDI using HMM.

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II. HMM IN NEURAL STATES

A. Hidden Markov Model

HMM consists of three parameters as:

$$\text{HMM } \lambda = (A\ B\ \pi)$$

where A = Transition matrix, a_{ij} = P(state S_j at t+1| state q_i at t); B = N * M Emission matrix where N=number of states in the model and M =number of observation symbols.

$$b_j(k) = P(\text{observation } k \text{ at } t |\ \text{state } q_j \text{ at } t)$$

where A and B are row stochastic in the sense that sum of the elements in a row is one and π = initial states.

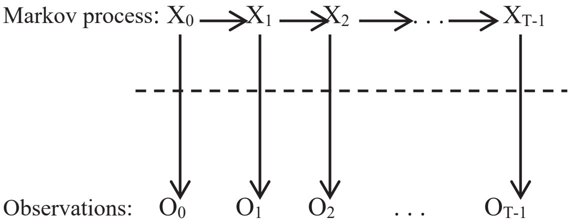

Fig. 1 HMM

HMM (Fig. 1) addresses three problems as:

- Given the model and observation sequences, $O_t = O_1\ O_2\ O_3 \ldots O_T$, the objective is to determine P (O\ λ) efficiently i.e. probability of the observation sequences for the given model, λ.
- To determine the optimal sequences of states for given model, λ and observation sequences, Oi. This is solved efficiently by Viterbi algorithm.
- Estimation: It is to get the maximum P(O| λ) by adjusting (estimating) the parameters of model λ. This problem is solved by Baum-Walch algorithm.

We determine the optimal sequence of states for our study. HMM has been used to study the spatiotemporal pattern of activity in single trials as a sequence of firing rate states. It has been investigated on the evolution of collective activity of neurons called Neuron Ensemble (NE) during single trials of perceptual discrimination task performed by monkey. HMM is used to characterize the NE activity from frontal lobe. The hidden states determine the firing rate of each neuron of the NE. It is done by Baum Walch algorithm to estimate the model parameters A, B and π by gathering the large set of experimental data regarding the firing patterns in the discrimination task [4]. These mental states cannot be measured by any neuro-scientific means and methods directly

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but can be enumerated by physical means indirectly through their effects in action for the cognitive functions. The action with respect to any cognitive function can be represented in three conditions as mentioned earlier. The waiting state is similar to the tri state condition in digital device. In this regard, there is signal in the output terminal of the device; it is neither observable nor measurable. But, it is waiting for a trigger signal to be fetched on one of its terminal to show the latched signal at the output terminal. Analogically, the same situation occurs in the activation condition of human brain physically and abstractly in human mind. In operating systems of a computer, a job is in waiting state, it is waiting for its turn in queue to be brought into execution mode. The tri state in digital circuit, wait state in operating system and an inert state in human mind have the same analogical behavior in their respective domain.

III. Methods

Some concepts of BDI are given below.

Believe: It is the knowledge of an agent about the world. To have the knowledge of the world of an agent is a complex process consisting of acquisition, interaction with prior related knowledge and generation of one's own knowledge to understand the world [7]. It is correlated directly to knowledge as believe, and is considered to be strong believe. We set aside from the believe and knowledge issue for computation in this work. We assume that the agent has high and low level of believe of the world.

Desire: The desire is conceived as the state of world that the agent wishes to bring about. It combines choice, preference and selection of some tasks from a given set of tasks.

Intention: It is what the actions the agent is going to do to achieve the goal [8]. There are two issues regarding intentions, one is intention to and another is intention for.

A. Optimal Values of State

For a generic state sequence of length n, the state equation is given by (1):

$$X = (x0\ x1\ x2\ x3 \ldots xn - 1\ xn) \tag{1}$$

and corresponding observation of length m is given by (2):

$$O = (O0\ O1\ O2\ O3 \ldots Om - 1\ Om) \tag{2}$$

The probability of the state sequence X is given by

$$P(x) = \pi x0\ bx0\ (O0) axo, x1bx1(O1)ax1x2bx2(O2)$$

$$ax2x3bx3\ (O3) \ldots axn - 1xn - \ 2\ bxn(On) \tag{3}$$

For two states and three observations, we have A as 2 *2 and B as 2*3 matrix respectively. The initial state is a vector 1*2. The matrix A. B and vector are:

$$\mathrm{A} = \begin{array}{ccc} & I & A \\ I & 0.6 & 0.4 \\ A & 0.3 & 0.7 \end{array} \qquad B = \begin{array}{ccc} NW & WT & W \\ 0.6 & 0.3 & 0.1 \\ 0.1 & 0.2 & 0.7 \end{array} \tag{4}$$

$$\pi 0 = \ 0.4\ \ 0.6 \tag{5}$$

We take two states IA (inactive) and AC (Active) and five observations [0 1 2 0 2] for three emission probabilities as 0=No working, 1= Working and 2= Waiting conditions that produce logically 32 combinations as shown in Table I. We calculate the probabilities of optimal states as shown in line of the different logical combination.

B. Computation of Neural States

Here, in Table I, I and A stand for Inactive and Active neural states respectively. The numerical values in the even columns i.e. product of states corresponding to their respective logical combinations in odd column is calculated by (3). For example: In Table I, the various values in numerical form in the first row of columns 2, 4, 6, 8 as 0.0000557872, 0.0000130636, 0.0000699840 and 0.0000571536 respectively correspond to the logical combinations, given in the same row in the columns 1, 3, 5, 7 as I I I I I, I A I I I, A I I I I and A A I I I.

TABLE I
COMPUTATION OF NEURAL STATES

Logical Combination	Product of States	Logical Combination	Product of States	Logical Combination	Product of States	Logical Combination	Product of States
I I I I I	0.00005578 72	I A I I I	0.0000130636	A I I I I	0.0000699840	A A I I I	0.0000571536
I I I I A	0.0000261273	I A I I A	0.0000609638	A I I I A	0.0000326592	A A I I A	0.0000266728
I I I A I	0.0000311041	I A I A I	0.0000725760	A I I A I	0.0000388880	A A I A I	0.0000317520
I I I A A	0.0000508032	I A I A A	0.0000132096	A I I A A	0.0000635080	A A I A A	0.0000518714
I I A I I	0.0000829440	I I A I I	0.0000101606	A I A I I	0.0000103680	A A A I I	0.00002222 64
I I A I A	0.0000580608	I A A I A	0.0000474163	A I A I A	0.0000725260	A AA I A	0.0000922320
I I A A I	0.000024192	I A A A I	0.0000790272	A I A A I	0.0000302400	A A A A I	0.0000432180
I I A A A	0.0000395136	I A A A A	0.0000101606	A I A A A	0.0000493920	A A A A A	0.0000705894

TABLE II
SUM OF NEURAL STATES

	1	2	3	4	5
IA	0.00004878	0.00003038	0.00004231	0.0000443	0.000027
AC	0.00003045	0.00004885	0.00003692	0.0000349222	0.00005128

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TABLE III
BDI LOGICAL CONDITIONS AND SUM OF STATES

Logical Combination	Product of States	Logical Combination	Product of States	Logical Combination	Product of States
D D D	0 .00003	I I I	0.00054	B B I	0.001344
D D B	0.000018	I I D	0.000864	B I B	0.000269
D B D	0.001166	I D I	0.000648	B I I	0.000407
D B B	0.003267	I D D	0.00006	I B B	0.002673
B D D	0.000918	D I I	0.000004	I B I	0.000972
B D B	0. 001863	D I D	0.000024	I I B	0.000891
B B D	0.001009	D D I	0.000024	B B B	0.001863
B D I	0.000720	B I D	0.0001632	I B D	0.001458
I D B	0.000712	D B I	0.001188	D I B	0.000019

Table II shows the sum of IA (Inactive) states, where I is in the first, second, third, fourth and fifth places in Table I. Similarly, the second row shows the sum of AC in the increasing order of places in Table I. From of each of the row, we select the highest value in the row which is 0.00004878 in the first place, in the first row and correspond to 0: no working, condition. Description of Table II is given below in detail.

IV. COMPUTATION AND RESULTS

The order of probability of occurrence of a particular state depends on the observation of a particular set of emissions in a time sequence. In our case, the observation [0 1 2 0 2] is for the time sequence, starting from t0 as present and t1, t2, t3, t4, t5 for the consecutive past times, corresponding to observation 0 1 2 0 2 respectively. Table II is obtained by the calculation of the sum of probabilities, when the states IA and AC are in the first, second, third, fourth and fifth positions in the 32 logical combinations of states as shown in Table I. The interpretation of Table II is as follows.

For the 0 as NW (No Work) observation at time t-1 the value of state P(IA) is 0.00004878 and for the state AC, it is 0.00003045 in the first column of Table II. It means state IA is more active than the state AC. Similarly, it is observed that for the observations at other consecutive past time sequences 1: Working at time t-2, P(AC): 0.00004885>P(IA): 0.00003038; for 1 as waiting P(IA): 0.00004430 >P(AC): 0.00003692; for the 0 (no work) P(IC):0.00004430>P(AC):0.00003492; and also for the state (Working). P(AC): 0.00005182>P(IC): 00002741.

We obtain the optimal sequence of states IA AC IA IA AC i.e. I A I I A for the observance sequence (0 2 1 0 2 i.e. NW W WT NW W, taking into account the greater value from each column of Table II.

The computation of product of states for the observation sequence (0 2 1 0 2) and the states logical combination I A I A I is done in the following steps:

Step 1: The initial value for the state I is taken as πx0 is 0.4 and bx0 (o0) and its value from the emission table in the first row for I and first column is 0.4 and their product is 0.24

Step 2: Write the transition from state I to A from the state transition matrix A which is 0.4 and the value of observation variable from matrix B as 0.1 and their product is 0.04

Step 3: Repeat the step 2 to obtain the transitions A-I I-A A-I as 0.9, 0.04, 0.03 respectively to obtain the product of logical combination of states I A I A I as 0.000072576 as shown in Table I.

Another intentionality instance is taken for the mental states as BDI. For three states B D and I, and three working conditions, there are 27 logical conditions and sum of states is shown in Table III. The logical combinations of this one is not straight forward as the logical combinations obtained for five observational states as shown in Table I. These are in the following steps:

Step 1: Since there are three states we take two states at a time such as D and B and assume D as low and B as high. Then, we get the nine combinations as shown in the first column of the table.

Step 2: We then take further two states D and I and assume I as low and D as high to obtain the logical combinations as shown in second column.

Step 3: Similarly, in the next step, we take B and I as high and low states respectively and the concerned logical combinations are shown in the third column.

Step 4: The common combinations among states BD, ID and BI are written only once in the table

Step 5: All these combinations count to twenty one. Other six combinations are obtained by taking one state at left most and other two states changing logically right to it. These combinations are shown as last two rows in each column Table III.

The HMM parameters for [A], [B] and π_0 in the matrix form are given below. There are three states B, D, I as shown by 3*3 matrix as A and three observational states W, WT NW which are column and three states BDI as row in the matrix B. The initial values of the three states are shown.

$$A = \begin{matrix} 0.5 & 0.3 & 0.2 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.2 & 0.5 \end{matrix} \qquad B = \begin{matrix} 0.33 & 0.33 & 0.34 \\ 0.2 & 0.3 & 0.5 \\ 0.1 & 0.3 & 0.6 \end{matrix} \tag{6}$$

$$\pi 0 = \begin{bmatrix} 0.4 & 0.3 & 0.3 \end{bmatrix} \tag{7}$$

Table IV is generated in the same way as Table II. In the Table IV, optimal sequence of state in position 1 is believe which has the highest value as 0.01373. At position 2, believe

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has again the highest value and also the believe has highest value at position 3. The optimal states are BBB.

TABLE IV
SUM OF BDI STATES

Believe	0.01373	0.00763	0.01256
Desire	0.00579	0.00496	0.00828
Intention	0.0101	0.00534	0.00693
Total	0.02962	0.01795	0.0277

From Table IV, it is observed that for the working the sum of the three states BDI is 0.02962 which is highest among the three. It is natural that one should have all the three states active up to certain level, greater than wait and no work conditions (observations). The sum values of these states for wait condition is less than, but greater than NO work conditions WT: 0.02777 > NW: 0.01795 but less than W: 0.02962. Similarly, the sum of the values of BDI in NW: 0.01795 is lowest among the three conditions (W NW WT).

V. DISCUSSION AND CONCLUSION

We have obtained computational results to demonstrate the applicability of HMM for correlation of neural activation to working condition and another of mental states BDI to the working conditions of brain. Intentionality is an internal opaque mechanism of mind, based on certain states that govern the dynamics of various mental process that are displayed by action for some cognitive functions. Believe Desire and Intention (BDI) are the prime mental states that govern the abstract mental processes such as thinking, reasoning decision making as well certain mental processes that are based on cognitive functions: perception, learning and memorizing.

The BDI states of mind can be correlated with the three conditions of human activity. Generally, it is observed that when believe (knowledge), desire and intentions are high then a work is performed correctly in time. When believe is high but desire is low and intention is low then there is no work done. High and low levels of BDI affect the neuronal activities in brain which we have shown by our result in Table IV.

BDI are mental states that affect the physical entities i.e. neuronal ensemble of particular sub regions which further enable certain actions to be observed such as: Working, no working and waiting conditions, for which the computation is done and the corresponding result is shown in Table III.

Intentionality is a conduct controlling characteristic of an agent. It can be judged from the fact that how much of its past actions were compatible with its commitment. It is also an agent's individual intention towards a state of affair that entails the agent's commitment to acting towards the achievement of that state. Our focus in this work has been to correlate intentionality i.e. BDI as states, with working conditions of agent and also correlation of activeness and inactiveness as states of neural ensemble in some brain regions as states with the working conditions.

The components or ingredients of intentionality as manifested by philosophers are dependent to each other. For instance, if an agent knows (believes) the state affairs in the world i.e. the world in which one has to act, then one can desire to work and then shows the intention by generating and following the executing states to complete the work. The other mentally beamed instances like will, preference choices etc. are reflected in the ontology of intentionality. This work can be extended to some directions as follows: The practical measure of activeness and inactiveness of neural ensemble by fMRI or other imaging techniques and by EEG/MEG signal processing means should be performed. From computational perspective, the parameters of HMM i.e. states and observational no. of sequences can be increased. The levels of BDI can also be increased. If we do take into account certain cognitive tasks such as: attention, memorizing and learning to correlate the processes or procedure of any of these with mental stares (BDI), then modal logic based on Kripke Semantics would be more appropriate instead of FOL [7]. Experimentation is sought for verification of the simulation as a scope for further work.

The computation becomes cumbersome if states and observations are increased. For example, if we increase the states from two to three then the logical combinations would be 3^5= 243 which amounts to a large set of computation. Thus, instead of hand calculation, development of an efficient algorithm for computing the large combinations and the corresponding programming is required.

The levels BDI can be introduces as HIGH and LOW i.e. have more realistic grading of the mental states [9].

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