

An Application of Decision Theory for the Treatment of Bipolar Disorder

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Abstract Bipolar disorder is a mental problem and causes difficulties in an individual's life. Both mania and depressive states dissipate the energy required for normal functioning. Often untreated patients lose their families, jobs, and meaning of life, which is a dangerous situation. In severest cases, people may end up taking their own life. The authors constructed the transition probability matrix from empirical data of observations for a concrete patient. Furthermore, we calculated the limiting probabilities for states. After, we offered an efficient policy to treat bipolar disorder. The global factors which affect the individual's happiness are health, career, and social contacts. Thus, the efficient policy needs to consider all these factors. The initial vector of potential energy was introduced. Here, the reward was the energy gained. Consequently, the final rewards were calculated. The main goal is to maximize potential energy for a normal state by decreasing the limiting probabilities of being in manic and depressive states. Boltzmann established that probability and energy are mutually related. These quantities are directly proportional. Boltzmann's idea was followed in this article, so the initial vector is given as the initial energy vector. The final result is potential energy. The recommendations for further research are given.

Keywords Bipolar Disorder, Transition probabilities, Policy, Reward

1. Introduction

Around 45 million of the population suffered from Bipolar disorder in 2017 [1]. This mental disease is characterized by instant mood changes. Mostly, there are two stages manic and depressive. Mania occurs shorter time and has the following symptoms: the deprivation of sleep, optimistic mood (euphoria), verbosity, and the abundance of incredible ideas. Depression takes a longer time and may last for years; bad mood, oversleeping, decreased mental and physical activity, hopeless thoughts, and loss of interest in life. The switches are happening at a random time thus cannot be controlled. Most of the patients diagnosed with depression lost the meaning of life. The life seemed worthless; the connections between them and their close ones vanished within a time of disease. The majority felt rejected, isolated from society, thus felt lonely, concentrated on failures, and could not find happy moments. At those times, they demonstrated the weak will to change a life. The patients diagnosed with bipolar disorder are at risk of committing suicide [2]. Hence, the idea of this paper is to construct the transition probabilities matrix from a dataset,

interpret the results, and give further recommendations for treatment.

2. Literature Review

Alafchi et al. [3] used the maximum likelihood method to obtain a probability transitional matrix for two states: mania and depression. Staying in state 1 was 0.76, and remaining in state 2 was 0.93. He concluded that the patient tends to stay in one of the persistent states (not transitional). Prisciandaro et al. [4] identified three mood states: euthymic (stable), depressed and mixed. The mixed state showed the similar symptoms as the manic state. For three states the transitional probabilities were found to be 0.94, 0.72 and 0.37 accordingly. However, they both did not calculate the final state probabilities, which are essential for treatment. Therefore, our research paper considers three states: mania, depression, and normal state. Moreover, we have calculated the limiting probabilities of these states (they were 1/3 each). This means that the patient has an equal chance, if untreated, to stay at any of these states. Zimmerman et al. [5] stated that the patients get the correct diagnosis only after 10 years. This delays the receipt of adequate treatment, increasing the costs of treatment. He recommends inquiring more about the history of mania to detect Bipolar disorder carefully. In this study, the mania and depression history were assessed carefully for the patient.

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3. A Physical Interpretation of Bipolar Disorder

No uniform allocation of energy is seen in bipolar patients. The lowest energy level is in the depression episode and the highest in mania (or hypomania). The target is to distribute the energy uniformly in the two episodes. Minimize it in the mania and maximize in the depression

$$\min E_m + \max E_d + E_n = E \quad (1)$$

Let t_1 -time for normal state, t_2 -time for depression, t_3 -time for mania.

$$\min(t_2 + t_3) + \max(t_1)$$

$$T = t_1 + t_2 + t_3 - \text{lifetime} \quad (2)$$

The time of the switch from one state to another is random. t_1, t_2, t_3 are individual for each patient, thus the statistical average should not be used.

The function of happiness $H(t)$ is characterized by satisfaction from life. The main goal is to maximize it.

Curiosity (Interest) -Goal- Action- Reward-Happiness

Action generates different combinations of thought. Neural networks increase, and neural paths change, which broaden the mind. The problem is to structure the main goals. When the person chooses the right strategy, he gets a reward for the effort. Rewards accumulate happiness. In economics, the utility function is maximized. The happiness function is broader than the utility. The global arguments are health, career accomplishments, and social contacts.

The individual feels happy if he is healthy, both mentally and physically; if the career is developing (achieves a satisfactory salary, awards, accolades, and authority among colleagues); if the social connections are strong (feel the support from family, parents, relatives, and friends).

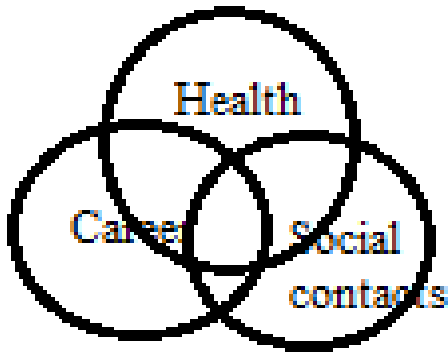


Figure 1. The global factors defining happiness

These circles are interconnected: if the person is not healthy, he faces difficulties in career and networking. If social bonds are weak, then problems with health will occur. The stressful situations between spouses or colleagues lead to neural system problems (the energy is dissipated and not returned). If the person is either unemployed for a long time

or a job seems unsatisfactory, then he loses social contacts. Thus, bipolar treatment will require setting up essential goals and planning life wisely. To choose the right people and job (hobby) which will help to develop the inner potential. Everyone is born with potential, and with its development, the individual gets the meaning of life. Depressed people find their life miserable. Why? Probably they did not set up the right goals. Depression episode lacks the energy that is dissipated in a mania state.

The patient was diagnosed with Bipolar disorder in 2017. The physical state was satisfactory: exercised, had a normal diet, slept 7-9 hours per day, and was not addicted to drugs, alcohol. Observations were made from 2017-2020. The results were obtained in the following table:

Table 1. States, Years, Months

Year 2017			
State	Months	Months	Months
Normal	April	May	
Depression	June	July	August
Mania	September	October	November

Year 2018			
State	Months	Months	Months
Depression	January	February	March
Normal	April	May	June
Mania	July	August	

Year 2019			
State	Months	Months	Months
Mania	September	October	November
Normal	December		
Depression	January	February	March

By using the data, the transitional probabilities are obtained:

$$P = \begin{pmatrix} 2 & 3 & 3 \\ 8 & 8 & 8 \\ 3 & 3 & 2 \\ 8 & 8 & 8 \\ 1 & 4 & 3 \\ 8 & 8 & 8 \end{pmatrix}. \quad (3)$$

The objective function is to maximize the number of months in a normal state, thus decreasing the months of mania and depression. The sum of the row's elements is 1.

$$\sum_{j=1}^3 p_{ij} = 1, \quad (4)$$

Where $p_{11} = \frac{2}{3}$, $p_{12} = \frac{3}{8}$, $p_{13} = \frac{3}{8}$. Therefore our

objective is to increase the values $p_{11} = \frac{2}{8}$, $p_{21} = \frac{3}{8}$, $p_{31} = \frac{1}{8}$ [6], [7], [8] for this purpose let's introduce the

initial vector. It is the energy, which should be allocated efficiently by the individual (potential energy). Decreasing entropy shows that the person is curing. The different policies are offered for a patient $r = 1$, $r = 2$, $r = 3$ [9], [10], [11]. For first policy $r = 1$, clinical psychologist offers the therapy that improves health by sticking to a diet and exercising.

For the second $r = 2$ the patient is advised to switch the job or change the specialty. For third, the doctor offers to change the surrounding environment, update the social contacts. Initial vector of energy:

$$d_i^r = \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix}. \quad (5)$$

Let's introduce the following function for calculating the final reward for observing the patient.

$$w_i = d_i^r + \beta \cdot \sum_j p_{ij}^r \cdot w_j. \quad (6)$$

Here, β is the discount factor, $0 \leq \beta \leq 1$. Let the first policy to have the initial vector of energy

$$d_i^1 = \begin{pmatrix} 3 \\ 1 \\ 5 \end{pmatrix}. \quad (7)$$

Then obtain the system of equations:

$$\begin{cases} w_1 = 3 + 0.5 \cdot \left(-\frac{1}{4} \cdot w_1 + \frac{3}{8} \cdot w_2 + \frac{3}{8} \cdot w_3 \right), \\ w_2 = 1 + 0.5 \cdot \left(-\frac{3}{8} \cdot w_1 + \frac{3}{8} \cdot w_2 + \frac{1}{4} \cdot w_3 \right), \\ w_3 = 5 + 0.5 \cdot \left(-\frac{1}{8} \cdot w_1 + \frac{1}{2} \cdot w_2 + \frac{3}{8} \cdot w_3 \right). \end{cases} \quad (8)$$

Solving it,

$$\begin{cases} 16w_1 = 48 + 2w_1 + 3w_2 + 3w_3, \\ 16w_2 = 16 + 3w_1 + 3w_2 + 2w_3, \\ 16w_3 = 80 + w_1 + 4w_2 + 3w_3. \end{cases}$$

$$\begin{cases} 14w_1 - 3w_2 - 3w_3 = 48, \\ -3w_1 + 13w_2 - 2w_3 = 16, \\ -w_1 - 4w_2 + 13w_3 = 80. \end{cases}$$

Obtain the final results:

$$w_1 = 5.90, \quad w_2 = 3.78, \quad w_3 = 7.77.$$

Explaining the initial reward vector,

$$d_i^1 = \begin{pmatrix} 3 \\ 1 \\ 5 \end{pmatrix} \quad (9)$$

Here, the first component of a vector indicates the initial energy in the normal state. The second component is the initial energy in a state of depression. The third component of the vector is initial energy in a manic state. We compose the following equation to determine the limiting probabilities:

$$\begin{pmatrix} 2 & 3 & 3 \\ - & - & - \\ 8 & 8 & 8 \\ 3 & 3 & 2 \\ - & - & - \\ 8 & 8 & 8 \\ 1 & 4 & 3 \\ - & - & - \\ 8 & 8 & 8 \end{pmatrix} \cdot \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix} = \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix}. \quad (10)$$

Obtaining the final values:

$$\pi_1 = \frac{1}{3}, \quad \pi_2 = \frac{1}{3}, \quad \pi_3 = \frac{1}{3}.$$

This paper deals with a case with one patient. Based on the observations, a transitional matrix of probability was obtained. This matrix shows the patient's states change from normal to depressive, from depressive to manic, and vice versa. A clinical psychologist should select the individual treatment for a patient. We selected the patient who gave conscious consent for examination. The limitation of the study: genetic predisposition to bipolar disorder was not assessed.

At the physical level, a person's state can be interpreted as potential energy. The energy vector is introduced as the initial energy vector.

4. Conclusions

For the second and third policies analogically, the corresponding values can be obtained [12]. We calculate the limiting probabilities. A policy with a limiting probability for a normal state greater than the limiting probability for

depressive and manic states is selected as the best. At the same time, the number of policies may increase. Different combinations of strategies can be generated. Each strategy includes a chain of policies. Consequently, select the optimal strategy among the proposed. The result is the highest potential energy for the normal state by reducing the transitional probabilities for depressive and manic states. This article launches a series of papers on mathematical applications to bipolar disorder treatment. Bipolar disorder is a particular issue in developing countries because dictatorship suppresses the human rights of individuals. Therefore, the main focus of this article is not the theory of pure mathematics but the applications of applied mathematics. We propose the basic ideas of a patient's correct treatment direction. The problem turns out to be the wrong distribution of the patient's energy. In subsequent articles, this problem will find its further development. The optimal energy distribution for the treatment of bipolar disorder has been studied hardly. Even though we sought all relevant articles, we could not find a similar approach. Therefore, we achieved a novelty.

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