YinYang Bipolar Diagnostic Analysis of Neurological Intrinsics of Brain Disorder

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Abstract: YinYang bipolar sets and lattices are introduced for bipolar cognition and neurological diagnostic analysis of brain disorder. Examples are presented to illustrate the basic concepts. It is shown that bipolar dynamic inference with non-linear bipolar modus ponens can unravel mental or neurological intrinsics of bipolar disorder from certain counter-intuitive symptoms in an open-world setting. Mathematical characterizations of such intrinsics are presented. A unified diagnosis and a unified effectiveness measure of a treatment are provided for different types of bipolar disorders. The significance of this work is 3-fold: (1) It fosters a standard representation and visualization of bipolar disorder for further clinical, therapeutical, and/or pharmaceutical researches and applications; (2) It introduces YinYang bioinformatics and biomedical researches; and (3) It introduces YinYang nanotechnology and bioscience.

Keywords: *YinYang Dynamic Modus Ponens; Open-world Inference; Bipolar Diagnostic Analysis; Neurological Intrinsics, Brain Disorder*

1. Introduction

In the history of classical logic and set theories, modus ponens has been the only generic rule for inference from which other inference rules can be derived. Classical logical systems, however, can be considered as linear static unipolar systems assuming a closed world. Despite of the great success of unipolar cognition, it can be observed that YinYang bipolar cognition as originated from the ancient Chinese Daoist philosophy (600BC) is necessary in the understanding of the mental or neurological intrinsics of bipolar disorder and depression with a holistic approach in an open-world setting.

Due to the fact that millions suffer from depression or bipolar syndrome to certain extend, the modeling, picturing, self or clinical diagnostic analysis of bipolar disorder bear great significance in both biomedicine and brain modeling. The works reported in [7,9] generalized strict bipolar spaces [6] to bipolar lattices and classical modus ponens to non-linear bipolar dynamic modus ponens for bipolar cognition. This work presents preliminary results in applying bipolar cognition to diagnostic analysis of mental depression and neurological disorder. Basic ideas are illustrated with application examples.

2. Bipolar L-Sets and Dynamic Modus Ponens

In [7,9] a **positive partially ordered set (positive poset) P^+** is defined as a usual partially ordered set of positive and neutral elements. **A negative partially ordered set (negative poset) P^-** is a partially ordered set of negative and neutral elements. Both positive posets and negative posets are called **unipolar posets**. **A bipolar partially ordered set (bipolar poset) S** is any subset of the Cartesian product $P = P_1^- \times P_2^+$ or $P = P_2^+ \times P_1^-$, where P_1^- is a negative poset and P_2^+ is a positive poset, and $\forall$ $(x,y),(u,v)\in P$, we have the **bipolar Comparison** defined on the absolute values of the poles as

$(x,y)\geq\geq(u,v)$, iff $|x|\geq|u|$ and $|y|\geq|v|$. (2.1)

We follow the convention: (1) if Θ is used as **a unipolar comparison operator,** $\Theta\in\{=, \leq, \geq, <,>\}$; and (2) if Θ is used as **a bipolar comparison operator,** $\Theta\in\{==, \leq\leq, \geq\geq, \leq\geq, \geq\leq, <<, >>, <>, ><, <\leq, >\geq, <\geq, >\leq, \leq<, \geq>, \leq>, \geq>\}$.

NP bipolar lattice (blattice) B is defined as a quadruplet (B, $\oplus$, &, $\otimes$), where B is an NP bipolar poset and, $\forall(x,y),(u,v)\in B$, there is a **bipolar least upper bound (blub)**, a **bipolar greatest lower bound (bglb), and** a **cross-pole greatest lower bound (cglb)** as defined in the following:

blub((x,y),(u,v)) $\equiv (x,y) \oplus (u,v) \equiv (-(|x|\vee|u|),|y|\vee|v|)$
$\equiv (-\max(|x|,|u|),\max(|y|,|v|))$; (2.2)

bglb((x,y),(u,v)) $\equiv (x,y)\ \&\ (u,v) \equiv (-(|x|\wedge|u|),|y|\wedge|v|))$; (2.3)

cglb((x,y),(u,v)) $\equiv (x,y) \otimes (u,v) \equiv$
$(-(|x|\wedge|v|)\vee(|y|\wedge|u|), (|x|\wedge|u|\vee|y|\wedge|v|))$. (2.4)

A bipolar lattice B (crisp or fuzzy) is **bounded** if it has both a unique minimal element denoted (0,0) and a unique maximal element denoted (-1,1). A bounded bipolar lattice B is **complemented** if, $\forall(x,y)\in B$, we have the **bipolar complement** $\neg(x,y) \in$ B. A bounded and complemented bipolar lattice B (crisp or fuzzy) can be denoted as $(B,\equiv,\oplus, \otimes, \&, \neg, \Rightarrow)$ with $\neg$ and $\Rightarrow$ defined in the following:

Complement: $\neg(x,y) \equiv (\neg x,\neg y) \equiv (-1-x,1-y)$;
(2.5)

Implication: $(x,y)\Rightarrow(u,v)\equiv(x\Rightarrow u,y\Rightarrow v)\equiv(\neg x\vee u,\neg y\vee v)$. (2.6)

Based on the notion of bipolar lattice, we extend lattice-based sets [2,4,5] to bipolar sets (B-sets):

A **bipolar L-set $B=(B^-,B^+)$ in X to a bipolar lattice B_L** is defined as a bipolar equilibrium function or variable $B:X\Rightarrow B_L$. If B_L is a bipolar crisp lattice we call B a bipolar **L-crisp set**; if B_L is a bipolar fuzzy lattice we call B a bipolar **L-fuzzy set** [7,9].

$(\phi^-(A), \phi^+(A))$	$Dplr^{\vee}(\phi^-(A),\phi^+(A)) =\phi^-(A)\vee\phi^+(A)$	Existence/life	Negative Energy	Positive Energy	Energy Total (T)	Energy Imbalance (I)	Stability S=(T-I)/T
(0,0)	0	No existence/No Life	0	0	0	0	Undefined
(0,y)	y y>0	Existence/Life with yin-deficiency (non-equilibrium)	0	y	y	y	0
(x,0)	|x| |x|>0	Existence/Life with yang-deficiency (non-equilibrium)	x	0	|x|	|x|	0
(x,y)	$\|x\|\vee y$ $\|x\|\neq y$	Existence/Life with Unbalanced yin-yang (quasi-equilibrium)	x	y	|x|+y	|x+y|	1-|x+y|/(|x|+y)
(-1,1)	1	Existence/Full life with balanced yin-yang in harmony – full equilibrium	-1	1	2	0	1

Fig. 1. $Dplr^{\vee}(\phi^-(A),\phi^+(A))=\phi^-(A)\vee\phi^+(A)$ defines an existence or life function (Dplr: depolar function)

Non-Linear Bipolar Augmentation Rule (BAR) or Bipolar Dynamic Modus Ponens
BR1: $\forall(\phi^-,\phi^+),(\psi^-,\psi^+),(\varphi^-,\varphi^+),(\chi^-,\chi^+)$, Serializable$((\phi^-,\phi^+),(\psi^-,\psi^+))$, and Serializable$((\varphi^-,\varphi^+),(\chi^-,\chi^+))$,
$((\phi^-,\phi^+)\otimes(\psi^-,\psi^+))\&[((\phi^-,\phi^+)\Rightarrow(\varphi^-,\varphi^+))\&((\psi^-,\psi^+)\Rightarrow(\chi^-,\chi^+))] \Rightarrow ((\varphi^-,\varphi^+)\otimes(\chi^-,\chi^+))$;

Fig. 2. Bipolar Modus Ponus

Equilibrium, Balance, Energy, and Stability. While completeness is central in unipolar lattice theory, completeness is not a natural property to impose on bipolar lattices because a subset of a bipolar lattice may not have a cglb. Instead, balance, energy, and stability are important properties for bipolar lattices. Recall that a B-set $\phi=(\phi^-,\phi^+)$ is a bipolar crisp or fuzzy equilibrium function that maps a set of objects X onto a crisp or fuzzy bipolar lattice. Since a bipolar lattice has balanced and unbalanced elements, the concept of equilibrium has quasi- or non-equilibrium aspects self-contained. **Negative and positive energy** and stability functions are specified in Fig. 1 for an NP-bipolar lattice.

With the notions of bipolar sets and bipolar lattices, classical modus ponens can be generalized to a non-linear bipolar modus ponens (Fig. 2) for bipolar knowledge representation and open world inference.

3. YinYang Bipolar Diagnostic Analysis of Neurological Disorders

3.1 Bipolar Knowledge Fusion and Inference

In bipolar syndrome modeling, we may assume the following for a person P:

$\forall$P, negative-trigger(P) $\Rightarrow$ sorrow(P); and positive-trigger(P) $\Rightarrow$ joy(P).

Then, a knowledge fusion can be realized by the bipolar predicate

$\forall$P (negative-trigger, positive-trigger)(P) $\Rightarrow$ (sorrow, joy)(P).

The semantics of a bipolar crisp or fuzzy implication can be well-justified as in the following:

- $(-1,1) \Rightarrow (-1,1) \equiv (-1,1)$ stands for that "A person with both negative and positive triggers has both sorrow and joy" is a natural and rational consequence (bipolar true).
- $(-0.9,0.8)\Rightarrow(-0.8,0.7)=\neg(-0.9,0.8)\oplus(-0.8,0.7)=(-0.8, 0.7)$ indicates that the bipolar fuzzy implication has the bipolar truth-value (-0.8,0.7), which can be leveled to (-1,1) with a bipolar threshold.
- $(-1,1) \Rightarrow (0,0) \equiv (0,0)$ stands for that "A person with both negative and positive triggers has neither sorrow no joy" is unnatural and irrational (bipolar false).
- $(-0.9,0.8)\Rightarrow(-0.2,0.1)=\neg(-0.9,0.8)\oplus(-0.2,0.1)=(-0.2, 0.1)$ indicates that the bipolar fuzzy implication has the bipolar truth-value (-0.2,0.1), which can be leveled to (0,0) with a bipolar threshold.
- $(-1,1) \Rightarrow (-1,0) \equiv (-1,0)$ stands for that "A person with both negative and positive triggers has only sorrow no joy" is partially natural and rational (negative-pole true and positive-pole false).
- $(0,0) \Rightarrow (-1,1) \equiv (-1,1)$ is similar to the 2-valued implication $0 \Rightarrow 1$.
- $(-0.2,0.3)\Rightarrow(-0.4,0.5)=\neg(-0.2,0.3)\oplus(-0.4,0.5)=(-0.8, 0.7)$ indicates that the bipolar fuzzy implication has the bipolar truth-value (-0.8,0.7), which can be leveled to (-1,1) with a bipolar threshold.

Given the rule $\forall$P (negative-trigger, positive-trigger)(P) $\Rightarrow$ (sorrow, joy)(P) and the fact (negative-trigger, positive-trigger)(P)=(-0.9,0.4), the result by applying bipolar modus ponens is (sorrow, joy)(P) = (-0.9, 0.4).

On the other hand, given (sorrow, joy)(P) = (0,0), the result by applying bipolar modus tollens is (negative-trigger, positive-trigger)(P) = (0,0).

3.2 Bipolar Disorder Syndrome Classification and Characterization

Bipolar disorder syndromes can be classified [1,3] as in the following three major categories:

- **Bipolar I Disorder:** Characterized by the occurrence of one or more manic episodes or mixed episodes. Often individuals have also had one or more major depressive episodes. Using a bipolar crisp set, a bipolar I disorder can be characterized as a manic episode (ψ^-,ψ^+) = (self-negation, self-assertion) = (0,1) which stands for "with excessive self-assertion without adequate self-negation ability." Using a bipolar fuzzy set, this type can be more precisely characterized as (n,p) where p is significantly larger than |n|.
- **Bipolar II Disorder:** Characterized by the occurrence of one or more major depressive episodes accompanied by at least one hypomanic episode. Using a bipolar crisp set, a bipolar II disorder can be characterized as a depression episode (ψ^-,ψ^+) = (self-negation, self-assertion) = (-1,0) which stands for "with excessive self-negation without adequate self-assertion ability." Using bipolar fuzzy set, this type can be more precisely characterized as (n,p) where p is significantly smaller than |n|.
- **Cyclothymic Disorder:** A chronic fluctuating mood disturbance involving numerous periods of hypomanic symptoms and numerous periods of depressive symptoms. This can be characterized as the vacillating sequence (ψ^-,ψ^+) = (self-negation, self-assertion) = $(-1,0) \otimes (-1,0) \otimes .. \otimes (-1,0) = (-1,0)^N$ or $(n,p) \otimes (n,p) \otimes .. \otimes (n,p) = (n,p)^N$, where (n,p) is significantly unbalanced. When N is even $(-1,0)^N = (0,1)$, when N is odd, $(-1,0)^N = (-1,0)$. $(n,p)^N$ results in a similar vacillating sequence with fuzzy granularities.

3.3 Unraveling Mental or Neurological Intrinsics

At this point, some big questions remain unanswered such as (1) How could a person in deep depression become suicidal or even kill his/her children? (2) How could a bipolar disorder patient P shows no feelings or even laugh at tragic news? (3) What would happen if a bipolar II patient P is given a negative trigger (treatment)?

To answer the above questions we first recall that a bipolar lattice B can be considered as a combination of two lattices - a linear bipolar lattice $(B, \oplus, \&)$ and a non-linear bipolar lattice $(B, \oplus, \otimes)$. We try to unravel and characterize mental and neural physiological intrinsics of bipolar disorder from both rational and irrational symptoms using linear and nonlinear bipolar modus ponens with a focus on $(B, \oplus, \otimes)$.

Bipolar $\oplus$ Intrinsics: Bipolar $\oplus$ intrinsics can be uncovered from symptoms whether a bipolar I or II patient has any capability to combine the effects from triggers with opposing polarities and improve his/her YinYang bipolar balance.

Let P be a bipolar I or II patient characterized by $(\psi^-,\psi^+)(P)$. Let $(\varphi^-,\varphi^+)(P)$ = (negative-trigger, positive-trigger)(P) and (ϕ^-,ϕ^+) (P) = (bad-feelings, good-feelings)(P); and, $\forall P, (\phi^-,\phi^+)(P) \Rightarrow (\varphi^-,\varphi^+)(P)$.

Let $(\psi^-,\psi^+)(P) = (0,0.5)$; $(\varphi^-,\varphi^+)(P) = (-0.5,0)$; and $((\phi^-,\phi^+)\oplus(\psi^-,\psi^+))(P)=(-0.5,0.5)$. Based on linear bipolar modus ponens, we have,

$[((\phi^-,\phi^+)\oplus(\psi^-,\psi^+))(P)=(-0.5,0.5)] \Rightarrow [((\varphi^-,\varphi^+)\oplus(\psi^-,\psi^+))(P)=(-0.5,0)\oplus(0,-0.5)=(-0.5,0.5)]$.

In this case P can be diagnosed as showing the capability of combining the effect from opposite trigger with $\oplus$ that leads to improved YinYang bipolar balance.

Similarly, let $(\psi^-,\psi^+)(P) = (-0.5,0)$; $(\varphi^-,\varphi^+)(P) = (0,0.5)$; and $((\phi^-,\phi^+)\oplus(\psi^-,\psi^+))(P)=(-0.5,0.5)$. The same diagnosis can be made.

Bipolar $\otimes$ Intrinsics: Bipolar $\otimes$ intrinsics can be uncovered from symptoms whether a bipolar I or II or III patient has oscillating episodes or not.

Let P be a bipolar I or II or III patient characterized by $(\psi^-,\psi^+)(P)$. Let $(\varphi^-,\varphi^+)(P)$ = (negative-trigger, positive-trigger)(P) and (ϕ^-,ϕ^+) (P) = (bad-feelings, good-feelings)(P); and, $\forall P, (\phi^-,\phi^+)(P) \Rightarrow (\varphi^-,\varphi^+)(P)$. There are two typical cases as in the following.

First let $(\psi^-,\psi^+)(P) = (0,1)$; $(\varphi^-,\varphi^+)(P) = (-1,0)$; and $(\phi^-,\phi^+)(P)\otimes(\psi^-,\psi^+)(P) = (-1,0)$. Based on nonlinear bipolar modus ponens, we have,

$[((\phi^-,\phi^+)\otimes(\psi^-,\psi^+))(P) = (-1,0)\otimes(0,1) = (-1,0)] \Rightarrow [((\varphi^-,\varphi^+)\otimes(\psi^-,\psi^+))(P)=(-1,0)\otimes(0,1)=(-1,0)]$.

In this case P can be diagnosed as with correctly functioning $\otimes$ intrinsics.

Secondly, let $(\psi^-,\psi^+)(P) = (-1,0)$; $(\varphi^-,\varphi^+)(P) = (-1,0)$; and $(\phi^-,\phi^+)(P)\otimes(\psi^-,\psi^+)(P) = (0,1)$. Based on nonlinear bipolar modus ponens, we have,

$[((\phi^-,\phi^+)\otimes(\psi^-,\psi^+))(P)=(0,1)] \Rightarrow [((\varphi^-,\varphi^+)\otimes(\psi^-,\psi^+))(P) =(-1,0)\otimes(-1,0)=(0,1)]$.

This case is counter-intuitive that deserves special attention. $(\psi^-,\psi^+)(P) = (-1,0)$ indicates that P is in deep depression. $(\varphi^-,\varphi^+)(P) = (-1,0)$ indicates a strong negative trigger. $(\phi^-,\phi^+)(P)\otimes(\psi^-,\psi^+)(P) = (0,1)$ indicates that P has a very positive feeling. It is irrational and counter-intuitive for any normal person to have positive feelings with a negative trigger, for instance, to have good feelings with bag news. Nevertheless, this observation does lead to the diagnosis that the mental or neurological $\otimes$ intrinsic of P is correctly functioning. This may well-explain the fact that (1) any closed dynamic system tends to become an equilibrium; and (2) a person in deep depression may become suicidal or even kill his/her children to pursue positive feelings. Similarly, a serious bipolar disorder patient P may show no feelings at sad event or even get wild with joy.

3.4 Fuzzified Bipolar Syndrome Diagnostic Analysis

Note that $B_1 = \{-1,0\}\times\{0,1\}$ suffers from a major limitation. That is, it does not support different gray levels on the negative and positive poles for representing quasi- or fuzzy-equilibria. This limitation is circumvented with $B_F = [-1,0]\times[0,1]$ to provide different granularities for the seriousness measures of bipolar symptoms. For instance, if (x,y)=(-0.9, 0.2), the vacillating sequence would be (-0.9,

$0.2)^N$. When N is even, $(-0.9,0.2)^N = (-0.2,0.9)$; when N is odd $(-0.9,0.2)^N = (-0.9,0.2)$.

Fig. 3 shows the 2-D space of B_F after converting it to the 4th quadrant following the convention of graphical user interface (GUI) design (P-positive, N-negative, S-small, M-medium, L-large). In Fig. 3, the (0,1) corner characterizes symptoms of **bipolar I disorder**. The (-1,0) corner characterizes symptoms of **bipolar II disorder**. The vacillation amplitude and frequency with respect to the (0,0) — (-1,1) diagonal characterizes **cyclothymic disorder.** (-1,1) is the perfect equilibrium state. (0,0) is the zero energy or cease-to-exist state.

3.5 Two Unified Measures

The intrinsics unraveled provide leads for further clinical, therapeutical, and/or pharmaceutical research and applications. Based on such intrinsics a unified diagnosis and a unified measure of effectiveness are formulated in the follows for optimization, coherence, and coordination in the care of bipolar disorder and depression.

A unified diagnosis on all three types of disorders. For an healthy adaptive agent, self-correction can be defined as negative reflexivity characterized by (-1,0). Then we have $(-1,0)\oplus(-1,0)^2=(-1,0)\oplus((-1,0)\otimes(-1,0))=(-1,0)\oplus(0,1)=(-1,1)$, which indicates a self-adjusting to YinYang bipolar balance. The key here is that an adaptive agent should have the physical and mental ability for the fusion of two opposing feelings with Blub using operator $\oplus$. Otherwise, the agent would have the vacillating sequence
$(-1,0)^N \in B_1$ or $(n,y)^N \in B_F$. *Therefore, all three types of disorders can be diagnosed as the lack of physical or mental bipolar fusion and balancing abilities in maintaining bipolar equilibrium and harmony.*

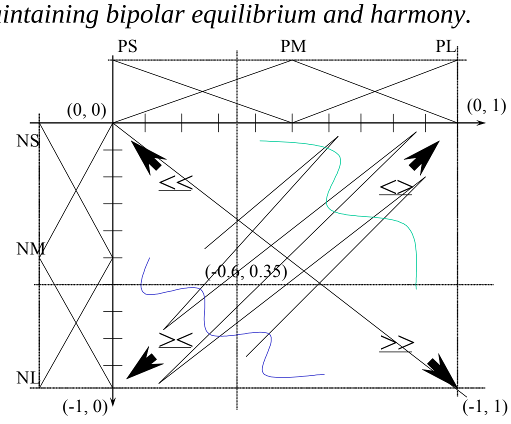

Fig. 3 Bipolar space and bipolar syndrome diagnostic analysis

A unified measure for the effectiveness of a treatment. Equilibrium energy and stability in bipolar lattices can be naturally applied as unified measures for the effectiveness of a treatment for any of the three types of bipolar syndromes. Let (ψ^-,ψ^+) = (self-negation, self-assertion), $(\psi^-,\psi^+)(P_{t0}) = (n_0,p_0)$, $(\psi^-,\psi^+)(P_{t1}) = (n_1,p_1)$, where P_{t0} indicates that the treatment started on P at t0. We say P is **getting better** if

(1) $stability(n_1,p_1) > stability(n_0,p_0)$ or $(1- |n_1+p_1|/(|n_1|+p_1)) > (1- |n_0+p_0|/(|n_0|+p_0))$; and
(2) $total\_energy(P_{t1}) > total\_energy(P_{t0})$ or $(|n_1|+p_1) > (|n_0|+p_0)$.

It should be noted that stability along can not determine the effectiveness of a treatment, an effective treatment should move $(\psi^-,\psi^+)(P)$ toward (-1,1) in time. Also note that the human brain is a dynamic system and bipolar disorder assumes an open world.

4. Conclusions

YinYang bipolar sets and non-linear bipolar modus ponens have been introduced that build a bridge from a linear, static, and closed world to a non-linear, dynamic, and open world of equilibria or fuzzy-equilibria for open world reasoning. Basic ideas are illustrated in the open world of bipolar syndrome characterization and diagnostic analysis.

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