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Determination of Romantic Relationship Categories and Investigation of Their Dynamical Properties

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ABSTRACT In studies on dynamical modeling of romantic relationships, it is seen that individuals are divided into four different romantic styles. Most of these studies focused on the mathematical analysis of the dynamic expression of individuals' attitudes or tried to determine what kind of relationship evolution randomly assigned romantic style parameters will create. The categorization of relationship types and finding the general characteristics of the relationships in each category by identifying all combinations of four different romantic styles, to our knowledge, have not been attempted before. To fill this gap in the literature, this study divided individuals into four different romantic styles and identified ten different types of relationships formed by the combination of these four styles. The evolution of the love/hate situation of individuals in each type of relationship was modeled with a linear differential equation system and the short-term development of the relationship to evolve from an initial state was determined. According to the results, it was observed that in some types of relationships, couples achieved harmony in the love/hate mood over time, while in some types of relationships, a couple was reluctant. It has even been determined that the willingness in the relationship enters a periodic cycle. With the findings obtained, it can be determined what kind of relationship the couples are in, guidance can be provided and feedback correction can be provided to their attitudes in the relationship. Overall, this study aimed to be a starting point for the applicability of dynamic modeling with psychometric research.

KEYWORDS
Linear systems
Mathematical sociology
Human behaviour
Dynamics of love
Fixed points

INTRODUCTION

The expression of romantic relationships using a time-dependent system of differential equations has been studied by different researchers since Rapoport (Rapoport and Anatol 1960). Differential modeling studies on love dynamics have increased, especially after Strogatz's short paper, which made the topic popular in the literature. The most general form of the method discussed in the literature may be expressed as

$$\frac{dx}{dt} = f(x,y,t)\ ,\ \frac{dy}{dt} = g(x,y,t) \quad (1)$$

Here x is the love/hate of individual 1 against individual 2 and y is the love/hate of individual 2 against individual 1 as functions of time. Functions f and g give an expression for the time derivatives (speeds of the feelings) in terms of instantaneous love quantities (x and y) and time (t) explicitly. Different researchers have used different forms of functions f and g including linear, nonlinear, homogeneous, and non-homogeneous.

In 1988, Strogatz published a one-page paper that describes the evolution of the romantic relationship between Romeo and Juliet by systems of coupled ordinary differential equations (Strogatz 1988). His study is based on a simple linear model and it may be the simplest attempt to model love affairs. It is mathematically stated as

$$\frac{dR}{dt} = -aJ\ ,\ \frac{dJ}{dt} = bR \quad (2)$$

R and J represent the feelings of Romeo and Juliet, respectively. The coefficient 'a' describes the extent to which Romeo is encouraged by Juliet's feelings, while 'b' is the extent to which Juliet is encouraged by Romeo's feelings (Wauer *et al.* 2007).

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After Strogatz, many papers have been published to describe romantic relations in terms of systems of differential equations including linear, nonlinear, and non-homogeneous models. Among the linear studies, Rinaldi expressed the evolution of love with linear minimal models. Rinaldi proposed an improved linear model that is more realistic than that described by Strogatz although it is still a minimal model. The aspects of love dynamics, namely forgetting process (oblivion), the pleasure of being loved (return), and reaction to the partner appeal (instinct), are expressed by Eqs.3, 4 (Rinaldi 1998). He proposed the equation system below:

$$\dot{x}_1 = -\alpha_1 x_1 + \beta_1 x_2 + \gamma_1 A_2 \tag{3}$$

$$\dot{x}_2 = -\alpha_2 x_2 + \beta_2 x_1 + \gamma_2 A_1 \tag{4}$$

Variables x_1 and x_2 are measures of the love of individuals for their respective partners. Positive values of x represent positive feelings, ranging from friendship to passion, while negative values are associated with antagonism and disdain. Complete indifference is identified by $x = 0$. Another linear study was conducted by Patro with determined and dependent indeterminacy models. Patro modeled romantic relationships by applying neutrosophic logic to the dynamics of love. He used a linear model and stated that an indeterminacy must be calculated in love dynamics (Patro 2016).

Bae modeled other factors such as the opinions of friends, parents, or other family members by adding a time-dependent external force term to the equation (Bae 2015). Chaotic phenomena appeared in the study with some choice of external forces. Barley and Cherif studied stochastic and deterministic models with nonlinear return functions. Their results showed that deterministic models tend to approach locally stable emotional behavior, but these complex and exotic patterns of emotional behaviors were observed in the presence of stochasticity in the models (Barley and Cherif 2011).

Satsangi and Sinha suggested that the effect of learning and adaptation and synergism after living together should be considered. This suggests that the emotional interaction of two individuals must be considered in the modeling process. By considering that the emotion of an individual with respect to another cannot increase infinitely, they assumed that it is proportional to $x_1.x_2$. Therefore, the term $x_1.x_2$ was added to the linear differential system of equations (Satsangi and Sinha 2012).

In studies of some researchers, hopf bifurcations were detected by nonlinear models with time delays (Deng *et al.* 2017; Liao and Ran 2007; Gragnani *et al.* 1996). Deng et al. have reported that Hopf bifurcation occurs when time delay passes through the critical value among three individuals, which is called a love triangle model (Deng *et al.* 2017). Liao and Ran investigated a love dynamical model with nonlinear couples and two delays and found that Hopf bifurcation occurs when the sum of the two delays varies and passes a sequence of critical values (Liao and Ran 2007). Rinaldi has detected three types of bifurcation curves, namely, supercritical Hopf, fold, and homoclinic, around a Bogdanov–Takens codimension-2 bifurcation point (Gragnani *et al.* 1996).

Other studies on the effects of time delays were conducted by different researchers. Bielczyk et al. showed that an unstable system without time delay can become stable when a certain range of time delay is included in a linear or nonlinear system (Bielczyk *et al.* 2013). It is possible for linear systems with only delays for different choices of the terms. In a different study, it was proved that changes in the stability of the stationary points occur for various intervals of the parameters that determine the intensity of interactions (Bielczyk *et al.* 2013). Son and Park investigated the effect of time delay on a dynamic model of love and found that time delay on the return function can cause a Hopf bifurcation and cyclic love dynamics (Son and Park 2011).

Ozalp and Koca have described and analyzed a fractional order nonlinear dynamic model of interpersonal relationships and obtained a stability condition for equilibrium points with a numerical example (Ozalp and Koca 2012). Owolabi has developed the Adams–Bashforth method to approximate the Caputo, Caputo–Fabrizio, and Atangana–Baleanu fractional derivatives. In his work, simulations of fractional-order have shown that interpersonal and romantic love affairs between two individuals can exhibit some chaotic scenarios (Owolabi 2019). Ahmad and Khazali proposed a fractional-order model of love to describe the dynamics of a love triangle under different structures and demonstrated that such a system can produce chaos in the presence of nonlinearity (Ahmad and El-Khazali 2007). Goyal et al. have tried different fraction values to compare the results of a fractional variational iteration method (FVIM) and fractional homotopy perturbation transform method (FHPTM). They have shown that the FVIM is successfully applied to obtain a rapidly convergent approximate numerical solution of a coupled nonlinear dynamical fractional model of romantic and interpersonal relationships for marriages (Goyal *et al.* 2019).

There are several attempts to use interesting approaches to a love model. Jafari et al. used complex numbers to represent the feelings of partners. They assumed that the feelings could be a combination of love and hate, so could be modeled by a complex variable that has a magnitude and a phase between 0° and 180° (Jafari *et al.* 2016). Bagarello et al. studied love dynamics from quantum mechanical and operator points of view (Bagarello and Oliveri 2010; Bagarello 2011).

It is seen that the studies in the literature summarized above try to determine the differential equation of relationships (Eq.1) and examine the related equation from the perspective of bifurcation, chaos and stability. Therefore, the subjects such as the equations that can be used in modeling romantic relationships, the situations in which these equations will create chaos, their stability will change, or bifurcation diagrams have been studied extensively. However, no research has categorized romantic relationships, how many types of relationships can be between individuals and to determine the general characteristics of these relationship types. Such a classification study is necessary to make dynamic modeling more applicable in relationships and to predict the course of romantic relationships between two individuals. In this way, individuals' romantic styles can be determined by questionnaires or observations, and feedback can be provided on how the romantic futures of various styles will work.

MATERIALS AND METHODS

Construction of the Mathematical Model

As Rinaldi highlights, measuring the parameters that explain romantic styles in a typical differential equation is hard (Rinaldi *et al.* 2015). Especially in nonlinear models, it is difficult to propose an equation and to predict the parameters from the characteristics of the individual. For this reason, it is a major problem that theoretical studies do not have an area of use and cannot be presented for the benefit of humanity.

The primary aim of this study was to make dynamic modeling of romantic relationships applicable and measurable. Therefore, it was made the analysis as qualitative as possible and the following assumptions were made.

- As a function of time, instead of the love/hate state of the individual, the affection/indifference in a relationship that has begun or rapprochement/distancing has been chosen.

- In all relationships, it has been accepted that the interest of individuals toward each other can be linearized around the equilibrium point in a narrow time interval. Thus, homogeneous models linearized around the equilibrium point are adopted and the results are generalized to predict the relationship evolution in the short term.
- Determining the romantic style for each individual is reduced to determining the two parameters (ai and bi) in the linear model. According to the signs of these parameters, romantic styles were considered in four categories (eager beaver, cautious lover, narcissistic nerd, and hermit).

In summary, each individual was reduced to one of four specified romantic styles, and ten types of relationship formed by the combination of all different styles were named. It was assumed that all couples will fit into one of the ten types of relationship identified here. In this way,

- Counseling can be offered to couples.
- Algorithms can be developed to find the ideal match.
- Couples can be guided in their relationships.
- Couples and individuals can self-criticize and correct their romantic styles.

Our model is based on a system of linear differential equations describing the evolution of love into a romantic relationship between couples. There are two individuals whose emotions are represented by the functions $x_1(t)$ and $x_2(t)$ depending on time. The time derivatives x_1 and x_2, denoted by $\dot{x}_1$ and $\dot{x}_2$, represent the rate at which emotions change over time. If the derivative is positive, the interest/love will tend to increase; if it is negative, it will tend to decrease. Therefore, the rate of change in emotions may depend on both functions of emotions of the individuals. Mathematically, a linear relationship can be suggested with Eqs.5-8.

$$\dot{x}_1(t) = a_1 x_1(t) + b_1 x_2(t) \tag{5}$$

$$\dot{x}_2(t) = b_2 x_1(t) + a_2 x_2(t) \tag{6}$$

$$\frac{d}{dt}\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a_1 & b_1 \\ b_2 & a_2 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \tag{7}$$

$$\dot{\vec{x}} = \hat{R}\vec{x} \tag{8}$$

The coefficients a_1, b_1, a_2 and b_2 are related to the romantic styles of individuals. The main point is the determination of the parameters. It is difficult to measure them accurately but one can categorize individuals with respect to the value of the romantic style parameters. For a partner, the parameters *'a'* and *'b'* can be both positive and negative, so the combinations of signs can determine the style of the individual (Barley and Cherif 2011).

Different researchers used these parameters with different names. Gottman et al. (2002) use the term *'behavioral inertia'* for the parameter *'a'* and *'influence function'* for *'b'* (Gottman *et al.* 2002). Rinaldi named *'a'* and *'b'* forgetting coefficient and reactiveness, respectively (Rinaldi 1998). Wauer states that coefficient *'a'* describe the extent to which person 1 is encouraged by his/her own feelings and *'b'* are the extent to which he/she is encouraged by the feelings of person 2 (Wauer *et al.* 2007). How to measure these parameters and the questionnaires to be prepared for this purpose are so complicated that they are a separate study, so the measurement of the parameters is not mentioned here (Bagarello and Oliveri 2010; Bagarello 2011).

Two parameters define an individual's romantic styles: behavioral inertia *'a'* and reactivity *'b'*. According to the signs of the parameters, four different styles can be defined (Table 1). There is no need to consider that the parameters are zero, as a zero value in styles can be treated as a sub-case.

Ten combinations are obtained by coupling different romantic styles (Table 2). In Table 2, different relationships are named R_{ij}, which means that the relationship is between style i and j in Table 1. The relation matrices in Eq.7 are also given in Table 1. Analyzing the matrices according to Eq.8 will give the possible results of the processes improving in the relation.

Analysis of the Relationships

Generally, a relation matrix has the form

$$R = \begin{pmatrix} a_1 & b_1 \\ b_2 & a_2 \end{pmatrix} \tag{9}$$

For a 2×2 matrix, the types of phase portraits with respect to the parameters of the matrix are shown in Fig.1. The relation matrix has four real numbers. The determinant of R is $\Delta = a_1 a_2 - b_1 b_2$ and its sign indicates whether the fixed point is a saddle or not. If $\Delta < 0$, the origin is a saddle node. If $\Delta > 0$, the origin is a node or spiral. If the trace of the matrix $\tau = a_1 + a_2$ is positive, nodes, lines, or spirals are always unstable. The sign of the discriminant $D = \tau^2 - 4\Delta = (a_1 - a_2)^2 + 4b_1 b_2$ determines whether the fixed point is a focus or node (see Fig.1). Five types of fixed point can be assigned to analyze the relation matrix: saddle point, stable node, unstable node, stable spiral, and unstable spiral.

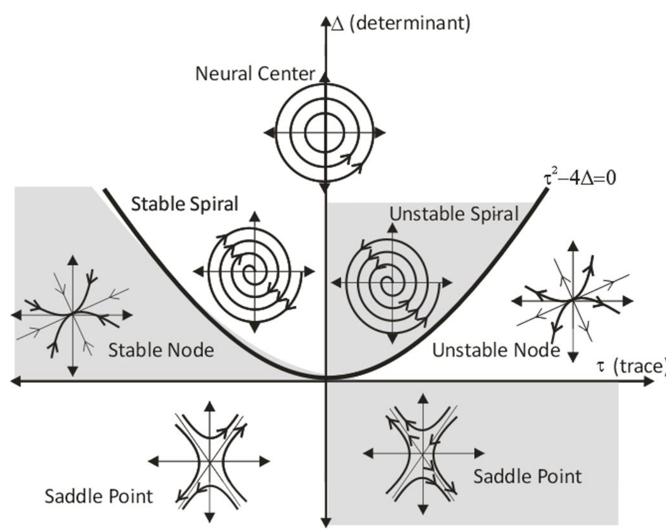

Figure 1 Phase portraits for a system of linear first-order differential equations.

On a phase portrait showing the relationship process (e.g., Fig.2), the first quadrant means that both individuals agree with the relationship or love. Similarly, the third quadrant means that the pairs agree with separation or apathy. However, the second and fourth quadrants point to a disagreement or inconsistency between the pairs. One individual is unwilling while the other desires him/her. According to Fig.1 and the explanation in Table 2, types of possible phase portraits are examined in Table 3.

Table 1 Romantic styles with their parameters

Style	a	b	Name	Description of a	Description of b
S_1	(+)	(+)	Eager beaver	Unstable in his own feeling	Positive reaction to the interest
S_2	(+)	(-)	Narcissistic nerd	Unstable in his own feeling	Negative reaction to the interest
S_3	(-)	(+)	Secure or cautious lover	Stable in his own feeling	Positive reaction to the interest
S_4	(-)	(-)	Hermit	Stable in his own feeling	Negative reaction to the interest

Table 2 Matrices of the types of relationship

.	S_1 = [+ +]	S_2 = [+ -]	S_3 = [- +]	S_4 = [- -]
S_1 = [+ +]	$R_{11} = \begin{bmatrix} + & + \\ + & + \end{bmatrix}$	$R_{12} = \begin{bmatrix} + & + \\ - & + \end{bmatrix}$	$R_{13} = \begin{bmatrix} + & + \\ + & - \end{bmatrix}$	$R_{14} = \begin{bmatrix} + & + \\ - & - \end{bmatrix}$
S_2 = [+ -]		$R_{22} = \begin{bmatrix} + & - \\ - & + \end{bmatrix}$	$R_{23} = \begin{bmatrix} + & - \\ + & - \end{bmatrix}$	$R_{24} = \begin{bmatrix} + & - \\ - & - \end{bmatrix}$
S_3 = [- +]			$R_{33} = \begin{bmatrix} - & + \\ + & - \end{bmatrix}$	$R_{34} = \begin{bmatrix} - & + \\ - & - \end{bmatrix}$
S_4 = [- -]				$R_{14} = \begin{bmatrix} - & - \\ - & - \end{bmatrix}$

Table 3 Examination of matrices according to their traces (τ), determinants (Δ), and discriminant (D) via Fig.1 and Fig.2.

	τ	Δ	D	Fixed points (0,0)	Fig.2
R_{11}	+	±	+	Saddle I or unstable node	a, e
R_{12}	+	+	±	Unstable node or spiral	e, h
R_{13}	±	-	+	Saddle I	a
R_{14}	±	±	±	All possibilities (saddle IV)	a, e-i
R_{22}	+	±	+	Saddle II or unstable node	b, e
R_{23}	±	±	±	All possibilities (saddle III)	c, e-i
R_{24}	±	-	+	Saddle II	b
R_{33}	-	±	+	Saddle I or unstable node	a, f
R_{34}	-	+	±	Stable node or spiral	f, g
R_{44}	-	±	+	Stable node or saddle II	b, f

RESULTS AND DISCUSSION

The following criteria should be considered when interpreting the results.

- Because the model is linear, it should be viewed as a first-order approximation of a much more complex equation. The time interval should be kept short for the linearization to converge realistically. Therefore, predicting short-term movements after a certain traumatic onset give more realistic results.
- The x and y parameters in the equations were taken as care/indifference instead of the love/hate determined by Strogatz. Unlike other studies, it refers to the state of interest/indifference of individuals who are in a relationship with each other, rather than the process of initiating a relationship. These parameters (x and y) have an interval scale. Therefore, a value of zero is a shift toward homogenizing the system of equations rather than expressing a lack of emotion. For example, if $x = 2$ units and $y = -1$ unit of interest are the equilibrium point for the relationship, the $(x, y) = (2, -1)$ point is taken as the origin.
- Any extraordinary event during the relationship creates a new starting point. For example, in a fight that may arise from a jealousy crisis, the woman may fall into a situation where her interest has decreased (cooled down) and the man has increased it (trying to forgive). That is, they may have started the routine of daily life when their emotional state was at the point (female, male) = $(x, y) = (-1.5, 2.3)$. After this point, how the relationship will evolve can be predicted by following the arrows in the phase diagram. After such a starting point, as the R_{11} relationship moves toward reconciliation with time, R_{12} can also enter a periodic cycle. In fact, the woman may get much colder in R_{14}, or both individuals may become colder toward each other over time in R_{23}.
- Quadrant 1 in the phase portrait is an ideal region where couples reciprocate their interests together. The third quadrant is the region where both partners cool off toward each other. The second and fourth quadrants can be interpreted as the region where one person in the couple escapes and the other chases after them. In short, quadrants 1 and 3 represent parallel and 2 and 4 represent opposite emotions. While interpreting the phase portrait, it is more appropriate to understand the relationship by determining in which regions to spend more time or target.

The analysis of relationships according to the above criteria is given in Fig.2 which is prepared by (Hollis 2010) and Table 4. For detailed analysis, the phase portraits in Fig.2 can be examined. The general characteristics of romantic relationship types are summarized in Table 4.

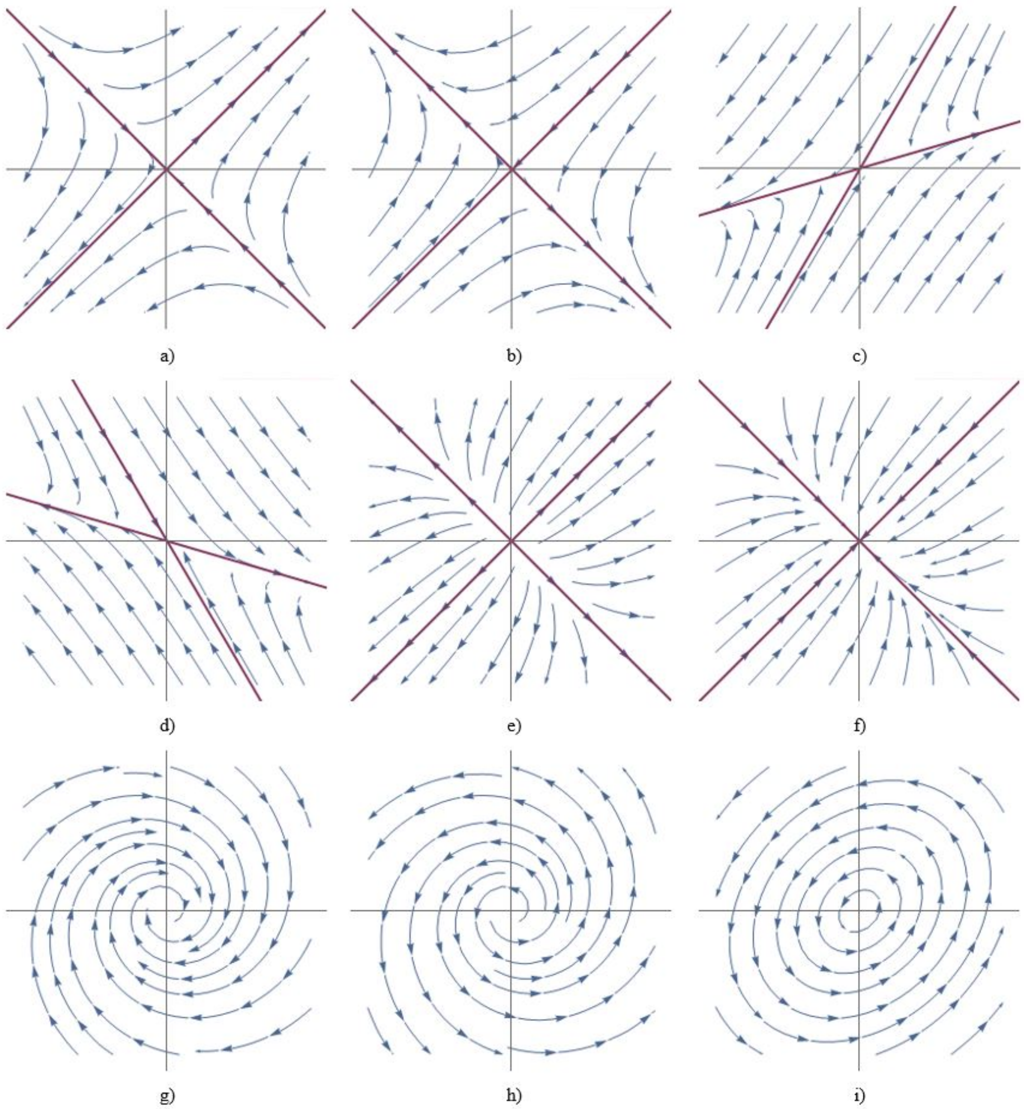

Figure 2 a) Saddle I: R=[1 2 ; 2 1]. Unstable in incompatible regions (2nd and 4th quadrants). According to the quantity of parameters and emotions, it evolves into the positive or negative compatible regions (1st and 3rd quadrants). **b)** Saddle II: R=[-1 -2 ; -2 -1]. Unstable in compatible regions (1st and 3rd quadrants). According to the quantity of parameters and emotions, it evolves into the positive or negative incompatible regions (2nd and 4th quadrants). **c)** Saddle III: R=[1 -2 ; 1 -3]. In this type of situation, x is luckier than y because when x has positive emotions, both partners go into positive compatible territory. The same is true when x is negative. But still compatible regions are targeted. **d)** Saddle IV: R=[1 2; -1 -3]. In this type of situation, incompatible regions are targeted. In the positive compatible region, y moves away from his/her partner over time, while in the negative fit region he/she gets closer. **e)** Unstable node: R=[2 1; 1 2]. Whatever the initial condition, the type of emotion grows over time without much change. **f)** Stable Node: R=[-2 -1; -1 -2]. Whatever the initial condition, the type of emotion decay over time without much change. **g)** Stable spiral: R=[-0.5 2; -2 -0.5]. As they make periodic transitions to different emotional states, their emotions decay over time with each periodic repetition. **h)** Unstable spiral: R=[0.5 -2; 2 0.5]. As they make periodic transitions to different emotional states, their emotions growth over time with each periodic repetition. **i)** Center: R=[0.5 -2; 2 -0.5]. As they make periodic transitions to different emotional states, their emotions remain the same with each periodic repetition.

Table 4 Summary of the properties of relationships

Type	Explanation
R_{11}	It is a compatible type of relationship. The attitudes of individuals toward each other turn into mutual love or mutual indifference.
R_{12}	It cannot be said that there is a stable relationship. Sometimes periodically, sometimes regularly, they move away from their initial equilibrium point. They cannot aim for a stable level of love.
R_{13}	It is rare for one to chase after the other. They quickly move into a state of harmonious interest.
R_{14}	It is rare for them to have harmonious feelings and they cannot stay in this state for long. They quickly move toward an opposite emotional state.
R_{22}	It is a negative type of relationship. They easily go into an opposite mood.
R_{23}	They usually target the positive territory, even if they are likely to go through a cyclical process.
R_{24}	It is perhaps the most negative type of relationship. They tend to gravitate toward an area where one is interested and the other less.
R_{33}	It is generally a balanced relationship. It does not take long for individuals to tend to oppose each other.
R_{34}	It is generally a balanced relationship. Sometimes they come to equilibrium by making loops.
R_{44}	They cannot stay in the compatible area for long. They either go into balance or into negative territory.

CONCLUSION

In this study, possible phase portraits obtained by coupling individuals with different romantic styles were examined and it was deduced how the relationship would evolve. When these portraits were examined, the state of emotions was observed in the regions where the love/interest status of individuals was similar (1^{st} and 3^{rd} quadrants) and in the regions where they were opposite (2^{nd} and 4^{th} quadrants), and accordingly the compatibility or incompatibility of the relationship was determined.

It can be seen from the analysis that R_{13} and R_{33} are the most compatible and R_{22} and R_{24} are the most incompatible among the types of relationship. The most ambiguous and most sensitive to romantic parameters were determined as R_{14} and R_{23}. If the above results are analyzed, it is seen that the most fortunate or successful romantic styles in relationships are S_1 (eager beaver) and S_3 (cautious lover), while the most unlucky or unsuccessful ones are S_2 (narcissistic nerd) and S_4 (hermit). From the common features of these styles, it is seen that the most important romantic feature is to show a positive attitude toward attention/love. It can be concluded that the types who run away when they see interest/love or chase when they do not see it create a problematic relationship in every relationship combination. The second important romantic style characteristic is attachment to one's own feelings. It can be surmised that those who are stable ($a<0$) are slightly more fortunate than those who are not ($a>0$).

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Availability of data and material

Not applicable.

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