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A SYNTHESIZED MODEL OF MARKOV CHAIN AND ERG THEORY FOR BEHAVIOR FORECAST IN COLLABORATIVE PROTOTYPING

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ABSTRACT

This paper uses a Markov chain process to forecast a customer's behavior and combines the notions of collaborative prototyping and existence, relatedness, and growth (ERG) theory. Collaborative prototyping process allows two parties (e.g., customers and service providers) to anticipate the outcome of a design process. We also justify that the Markov chain within ERG theory would generate good performance in behavior prediction regardless of accuracy, precision, recall, and F1-measure.

INTRODUCTION

The processes of science and decision making share an important characteristic: success in each depends upon researchers or decision makers having some ability to anticipate the consequences of their actions. Conversely, "be-ing" predictive of unknown facts is essential to the process of related fields of research. Surely, the unknown facts could lie in the past or the future.

Decision-making, generally, is forward looking, formulating alternative tracks of action extending into the future, and selecting among alternatives by expectations of how things will turn out (Lasswell and Kaplan, 1950). The predictive capacity of science holds great appeal for decision makers who are grappling with complex and controversial environmental issues. Furthermore, it promises to enhance the ability to determine a need for and outcomes of alternative decisions.

Uncertainty is the condition of all human life for decision making which means more than one outcome is consistent with our expectations (Skidelsky, 2000). Expectations are a result of judgment, are occasionally based on technical mistakes and interpretive errors, and are shaped by values and interests (Pielke, 1999). Since uncertainty is a characteristic of each essential decision, it is no surprise that society looks to science and technology to assist in clarifying the expectations in ways that lead to desired outcomes.

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Hence, the qualified predictions which consider the uncertainty for superior decisions are significant. This paper utilizes the Markov chain process to forecast the needs and combines the notions of collaborative prototyping and ERG theory. Collaborative prototyping process allows two parties (e.g., customers and service providers) to anticipate the outcome of a design process. Furthermore, prototypes have two advantages: (1) they help customers evaluate unknown customized products and (2) guide both parties in searching for the optimal product specification.

Furthermore, ERG theory, proposed by Alderfer in 1969, prioritizes user's needs in a hierarchy. The acronym ERG stands for three need levels—existence, relatedness, and growth. The ERG theory is based on the work of Maslow, who reduced the number of levels of needs to three. Nevertheless, ERG theory differs from Maslow's theory in three ways: (1) it allows different levels to be pursued simultaneously; (2) it allows the order of needs be different for different people; and, (3) when the highest level of needs remain unfulfilled, a person may regress to a lower level of needs that are relatively easier to satisfy.

The remainder of the paper is organized as follows. In section 2 we explain the synthesis of three theories: collaborative prototyping, ERG theory, and Markov chain model. In section 3 and 4 developed an economic model and a method with proposed algorithm. In section 5 we demonstrate the evaluation of the proposed model. Ultimately, a conclusion is furnished in Section 6 to summarize the contributions of the research.

CONTRIBUTION

This paper makes a significant contribution to IS research in terms of a synthesized but novel model (Markov Chain and ERG Theory). This combined model is the "first attempt" to predict real-time needs in the context of collaborative prototyping. This is also the first study to examine the impact of probabilistic needs forecasting by analyzing the real-time behavior data, collaborating with the user and immediately responding to the user.

This research is expected to contribute the interest to the community of researchers interested in the sociological, social-psychological, and organizational impacts of information technology. Particularly, the research involves the application of social science theory to the information systems/technology phenomenon.

The study provides primitive evidence when combined with Markov chains and ERG theory outperforms Maslow's theory on several important dimensions, e.g. accuracy, precision/recall, and F1-measures. Furthermore, this work also gives an avenue for collaborative prototyping with behavior forecast. The novel model contributes to the problems decision-making in terms of a feasible resolution for online real-time behavior forecast.

RESEARCH BACKGROUND

Collaborative Prototyping

Costly information acquisition has remained an important topic in economic research since Stigler (1961) first addressed the issue. Economists have developed numerous equilibrium search models by citing several notions, such as information asymmetries and consumer search costs, to search for the lowest price. Models for optimal searching provide insight into the economics of concept testing. Nelson (1961) 0and Abernathy and Rosenbloom (1968) modeled product development as a series of stochastic events with discrete outcomes; they demonstrated that cost per test and scale of uncertainty drive the optimal number of parallel concepts that are required.

Thomke (1998) contributed the view that experimentation during new product development (NPD) solves problems, uncovers bugs and reduces errors, broadens searching and improves learning via parallel testing. Additionally, Srinivasan *et al*. (1997) obtained empirical evidence that parallel prototyping resolves certain residual uncertainties and is more profitable than a one-shot scheme. Thus, a prototype is essential to the NPD process, as it generates an optimal search model based on testing cost and scale of uncertainty.

Prototyping, the process of developing prototypes, is an integral part of iterative user-centered design; it enables designers to test ideas with consumers and to obtain feedback. The primary purpose in prototyping is to involve users in testing design ideas and acquire their feedback during the early stages of NPD, thereby reducing time and cost associated with NPD. Moreover, the prototype provides an efficient and effective method for refining and optimizing interfaces through discussion, exploration, testing and iterative revision.

In terms of an information system, prototypes are experimental and incomplete designs that are quickly and cost-effectively developed. Prototypes are utilized to assist system designers in building an information system that is intuitive and easily manipulated by end users.

The following advantages are associated with prototypes: (1) they reduce development time and costs; (2) they benefit from user involvement; (3) they provide developers with quantifiable user feedback; (4) they facilitate system implementation based on user anticipation; (5) they result in increased user satisfaction; and, (6) they expose developers to potential future system enhancements.

The prototyping process can be categorized as the following four stages: establish prototype objectives; define combinational services; develop prototype; and, evaluate prototype. During the first stage, goals of the prototype are identified based on current user needs. The developer should then identify the services to be included in the prototype. Ultimately, prototypes are delivered and evaluated iteratively.

Collaborative prototyping is a novel approach based on the notion of prototyping. Collaborative environments for product development have become the favored design paradigm for engineering organizations. During evolutionary design and development processes, prototyping has become an important tool for identifying user requirements and providing feedback on the working design relative to requirements.

Collaboration facilitates improved information sharing, concurrent engineering, virtual prototyping and testing, and total quality management. Furthermore, collaboration enhances product quality and decreases product lifecycle cost. Moreover, the anticipated benefits of prototyping in reducing risk must be weighed against the time and money required to build and evaluate a prototype. That is, taking time to build and test a prototype can allow a development team to detect problems that would not have been detected until after the NPD process was complete.

For instance, the probability of success in completing a final product is 70% and 30% when an injection mold must be modified iteratively in the conventional process (Abernathy and Rosenbloom, 1968). Nevertheless, the probability of success increases to 95% when prototypes appear in the NPD process as shown. The prototypes iteratively filter and rectify themselves based

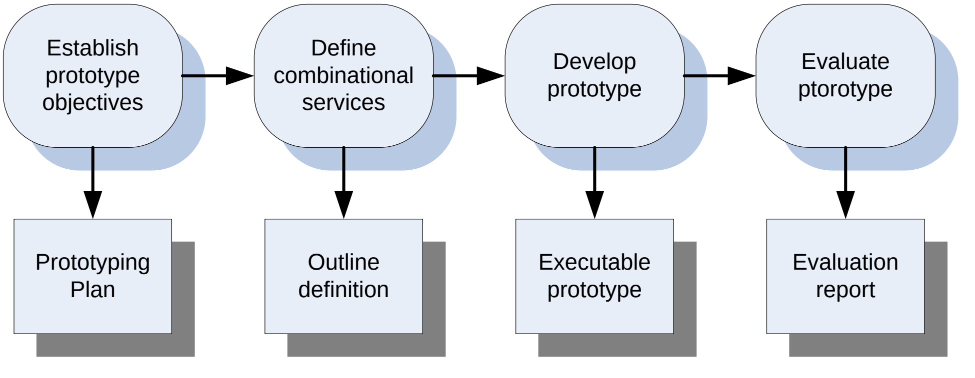

Figure 1 Prototyping Process

on user requirements, and the prototypes fulfill product needs until an appropriate prototype is developed that is an approximate version of the final product. Prototypes reduce costs and risks that can ultimately result in the development of an unacceptable product. Additionally, the probability for revising a product is extremely reduced to 5%.

Conversely, customer decision trees demonstrate the decision process when requesting prototypes. Customers have two options: they can request collaborative prototyping or purchase a standard product. If a customer requests prototypes, the outcomes could be purchasing a customized product or abandoning the transaction. Thus, collaborative prototyping is an effective and efficient technique for reaching NPD goals.

Furthermore, the cost and risk associated with prototypes can be considered two dimensions for segmenting into four quadrants. In the low-cost and low-risk quadrant, one prototype can be built for verification (e.g., printed goods). In the high-cost, low-risk quadrant, few or no prototypes are built (e.g., commercial buildings). That indicates that the product is specially designed and completely customized via user requirements.

Additionally, numerous comprehensive prototypes are constructed in the low-cost, high-risk quadrant (e.g., software). The cause of relatively high risk is the comprehensiveness of a prototype; that is, the products are not customized further. Airplanes or automobiles are examples of products residing in the high-cost, high-risk quadrant; such products have actually been sold. In other words, producers must ensure that they meet the high needs of the market; thus, they can deliver products via mass manufacturing.

In short, collaborative prototyping identifies user requirements and furnishes feedback on a working design measured against the requirements. Moreover, collaborative prototyping provides the following advantages: (1) reduces development time, costs and risks; (2) involves users are and provides user feedback; (3) facilitates system implementation based on user anticipation and satisfaction; and, (4) developers can enhance the product in a future iteration.

Moreover, customer needs communicated during product customization have been under-researched in various industries. Additional research is required to fully explore concepts such as conducting research to estimate effective and legitimate pricing methods during collaborative prototyping. Hence, although new technologies can replicate the process of turning a set of product specifications into a custom-built product, extensive interaction is needed for a master craftsman to identify customers’ actual needs.

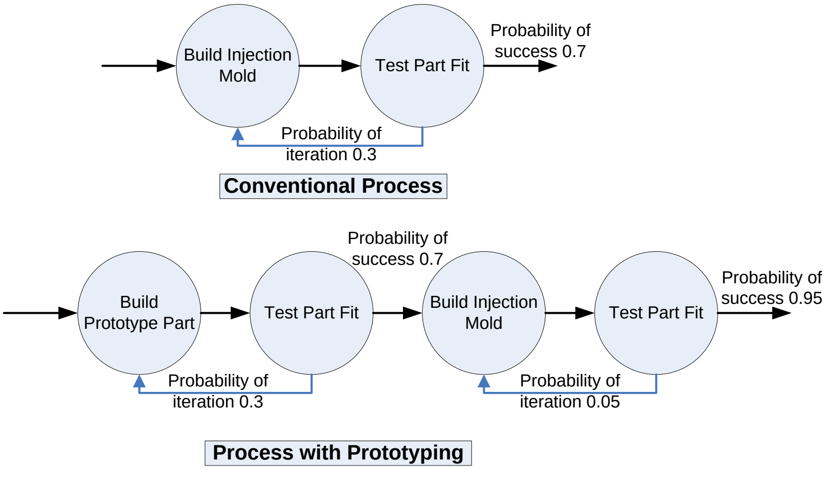

Figure 2 The difference between conventional process and with prototyping

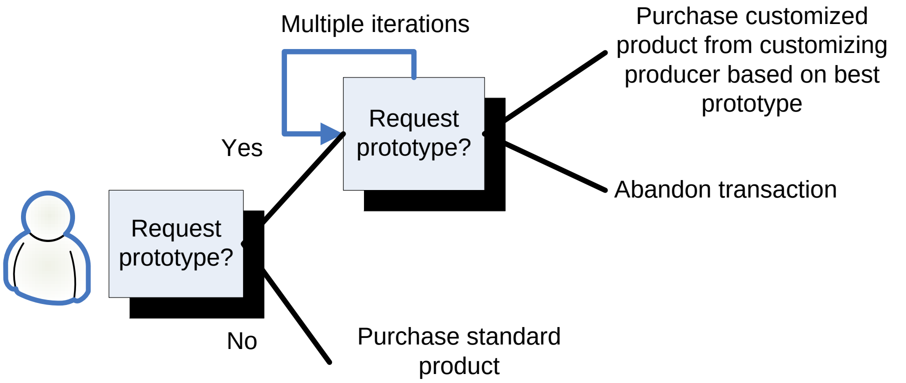

Figure 3 Customer decision tree

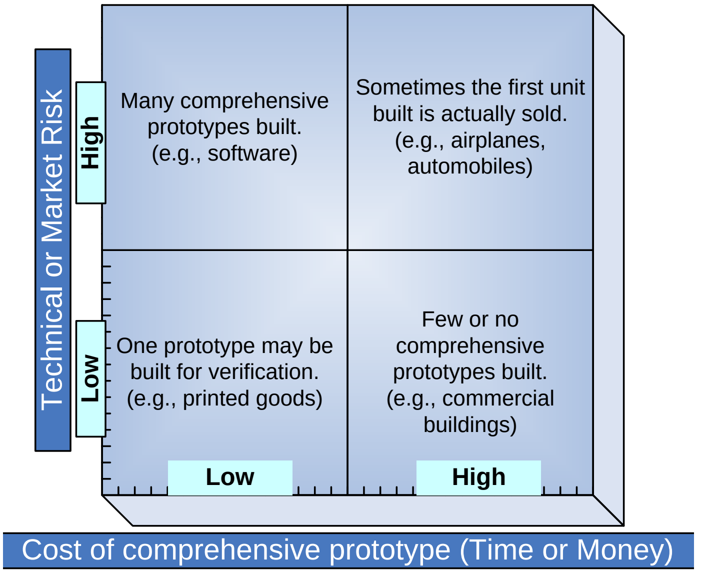

Figure 4 Prototypes located in Cost-Risk matrix

ERG Theory

The ERG theory, a model of human motivation developed 1969 by Clayton Alderfer, extended and simplified Maslow's Hierarchy using a relatively smaller set of needs. The ERG theory attempts to answer the question, "what motivates a person to act?" and assumes that all human activities are motivated by need. The ERG theory consolidated Maslow's five need categories into three levels of need; Existence, Relatedness, and Growth. Each category is described as follows.

1. *Existence Needs*: include all material and physiological desires (e.g., food, water, air, clothing, safety, physical love and affection).

2. *Relatedness Needs*: encompass relationships with significant others (e.g., to be recognized and feel secure as part of a group or family).

3. *Growth Needs*: impel a person to make creative or productive effects on himself and the environment (e.g., to progress toward one's ideal self).

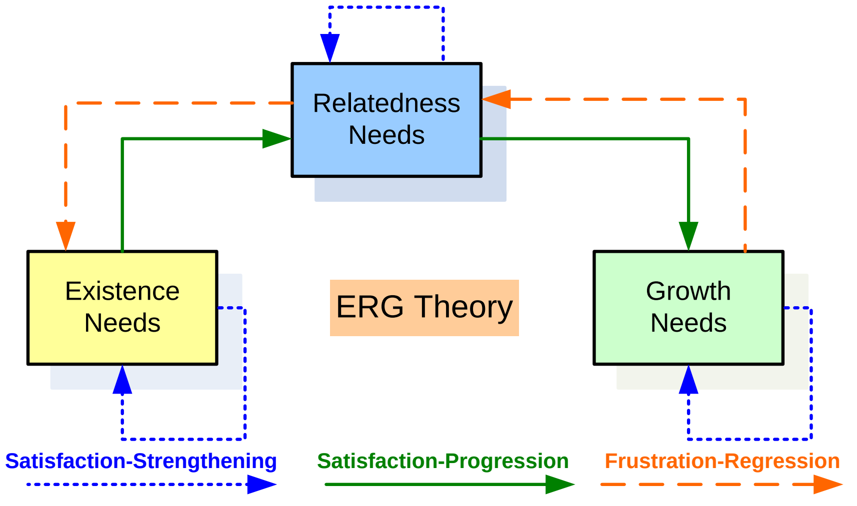

Figure 5 The concept of ERG theory
(Data Source: Alderfer, 1969)

The concepts of existence, relatedness, and growth needs are separate and distinct categories. The concept of prioritizing needs is based on a continuum in terms of their concreteness. Existence needs are the most concrete, and easiest to verify. Relatedness needs are less concrete than existence needs, which depend on a relationship between two or more people. Finally, growth needs are the least concrete in that their specific objectives depend on the uniqueness of each person.

Three relationships among different categories, satisfaction-progression, frustration-regression, and satisfaction-strengthening, are identified in ERG theory. Satisfaction-progression stands for moving up to higher-level needs based on satisfied needs. Frustration-regression is when a person moves backward from current unsatisfied needs to lower-level needs. The idea of satisfaction-strengthening represents strengthening a current level of satisfied needs iteratively.

Satisfaction-progression plays an important part in Maslow's original concept of a need hierarchy (but not in the ERG theory). In ERG theory, the movement upward from relatedness satisfaction to growth desires does not presume satisfaction of existence needs. However, the movement from existence satisfaction to relatedness desires is necessary according to Maslow's theory (i.e., individuals move up the hierarchy as a result of satisfying lower order needs.

Frustration-regression identifies one's motivation in explaining fundamental desires. Frustration-regression suggests that an already satisfied need can become active when a higher need cannot be satisfied. Thus, if a person is continually frustrated in his/her attempts to satisfy growth, relatedness needs can resurface as key motivators.

Satisfaction-strengthening indicates that an already satisfied need can maintain satisfaction or strengthen lower level needs iteratively when it fails to gratify high-level needs.

For instance, imagine that there will be three different parties on Saturday night; however, you can only go based on the several criteria (e.g., the food is good, the people are warm, and the conversation is stimulating).

- Party 1 (Existence Needs): The hosts are excellent cooks and take pride in serving guests well; however, they are not friendly and are boring conversationalists.
- Party 2 (Relatedness Needs): There may be some chips and soda, but the hosts and other partygoers are easygoing.

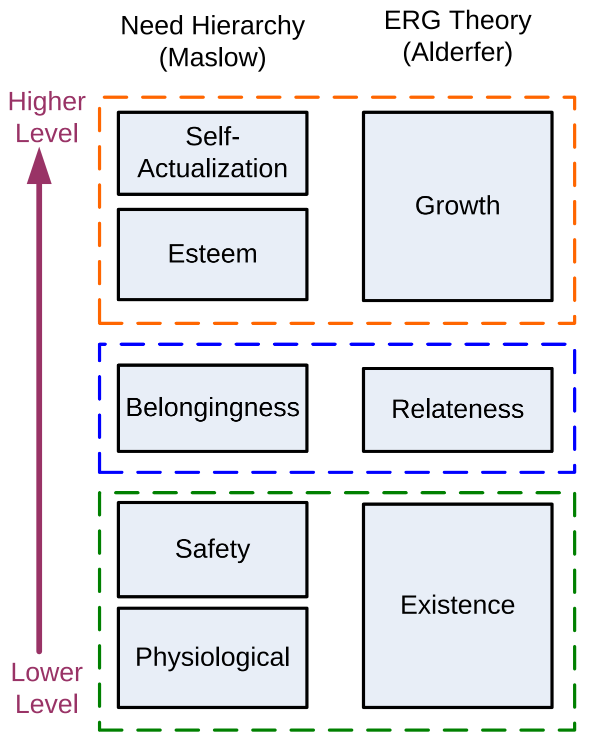

Figure 6 The Mapping of Need hierarchy and ERG theory

- Party 3 (Growth Needs): There will be no food unless it is brought. The hosts and others partygoers tend to be aloof and distant; however, some will be renowned experts in a topic of great interest to you.

A person's decision will be different according to the level of need that is predominant at that moment. Thus, the following three diverse results are predicted.

- A person who has been living on beans and rice for two weeks would probably favor party 1.
- A person who is recently divorced, sad and lonely is more likely to attend party 2.
- A person who is well fed and whose relationships are stable and satisfying has more to gain from party 3.

Conversely, the following differences exist between ERG theory and the hierarchy-of-needs theory: (1) a lower level need does not have to be gratified (i.e., a person may satisfy a need at hand, whether or not a previous need has been satisfied); (2) if a relatively more significant need is not gratified, the desire to gratify a lesser need will be increased (i.e., the frustration in meeting high-order needs might lead a person to regress to a more concrete need category); (3) ERG theory allows the order of the needs to differ for different people (e.g., it accounts for the "starving artist" who may place growth needs above existence ones).

The management implications of ERG theory assists managers in recognizing that an employee has multiple needs that must be satisfied simultaneously. Furthermore, if growth opportunities are not provided to employees, they may regress to relatedness needs. If managers recognize the needs in a given situation, then steps can be taken to concentrate on relatedness needs until the subordinate can pursue growth again.

Markov Chain Model

Chung (1969) proposed a Markov chain model for analyzing the prevailing states and to predict the future state of a need hierarchy based on Maslow's hierarchy of needs. The

Markov chain model investigated the dynamic structure of human needs and their relationships to motivation as multidimensional phenomena. Maslow rejected any atomistic classification of needs, preferring to identify clusters of needs in a holistic system. Classification is developed and based on the concept of "being contained within" rather than "being separated from." This concept refers to a pattern of human behavior that is influenced simultaneously by a number of causes.

The proposed model from Chung (1969) is based on Markov chain analysis, a method of analyzing a system with behavioral characteristics that involve multivariate, probabilistic, and dynamic elements. Markov chain analysis makes it possible to predict behavioral patterns in a system when the patterns for a previous period are known. A basic assumption in Markov chain analysis is that each period has a finite number of possible outcomes that are subject to chance elements. These probable outcomes are system states, and the probabilities that characterize behavior in these states are transition probabilities.

A Markov chain process is a sequence of system states in which the outcomes of a given period are dependent upon the outcomes of the immediately preceding period. When the process begins in a particular state with known probabilities of moving one state to another, Markov chain analysis can predict the system states for successive time periods. Thus, this study assumes that the system has known a finite number of possible outcomes that indicate the initial state (N^0) and the transition matrix (P).

The possible states in the need hierarchy at any given time can be determined according to the initial state and transition probabilities. The state in a given period depends on the iteration of the state for a preceding period (N^{t-1}) and the transition probabilities: $N^t = N(^{t-1})P$. The initial probabilities of P are derived from customer profile; these initial probabilities will be adjusted in accordance with user behavior. The composition of the need hierarchy can be expressed in a row vector (e.g., N^t=(N1, N2, N3, N4, N5) where N represents a need hierarchy and t is time).

Hence, the rationale for combining a Markov chain with a need hierarchy are as follows: (1) the outcomes of a given period may not only depend on the outcomes of the immediately preceding period, but also on other preceding events (i.e., a person's decision is typically based on experiences from the immediate past rather than the remote past); and, (2) transition probabilities remain stable during transitional periods (i.e., a personality is assumed stable for a reasonably long period).

SYSTEM ARCHITECTURE

In this research, we build a system synthesizing the models of Markov Chain and ERG Theory (as shown in Figure 8). The user's behavioral patterns will be mapped to

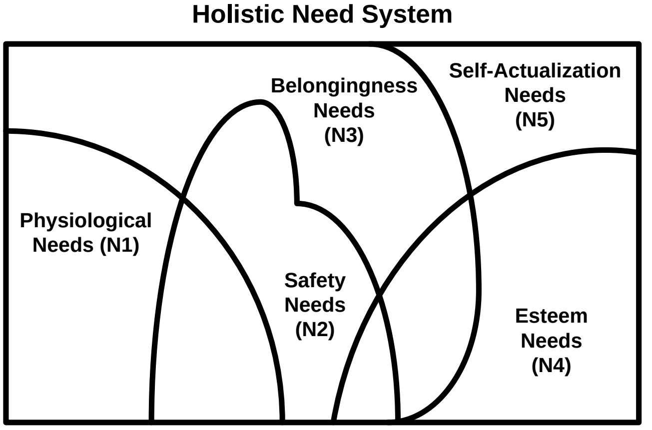

Figure 7 Holistic Need Hierarchy

instances of E, R or G based on the ERG theory. The system can then predict the user's needs for the next time point in the context of collaborative prototyping. A set of provider's services (reflecting the fulfillment of the predicted needs) will subsequently be presented to the user for his/her decision making in the next time point.

Conversely, instead of exerting a need hierarchy of Maslow to a Markov chain this system combines Markov chain with the ERG theory to estimate the possible state of needs in the subsequent time period during collaborative prototyping (for the purpose of the needs of a customer being predicted and evaluated accurately and efficiently).

This system also presents a novel algorithm of behavior forecast in collaborative prototyping (behavioral prediction algorithm, BP algorithm). When the BP algorithm is initiated, certain variables for declaration exist (from line 2–11 in Fig. 9). We define N, B_Needs, and V_Needs are row vectors and enfold three decimal points, which represent the existence, relatedness, and growth needs as shown in Table 1. In detail, N represents a current user's needs, B represents customized services based on the user's needs (B_Needs embodies the degree of ERG needs that B can satisfy), and V is the initially provided services that user chose (V_ Needs embodies the degree of ERG needs that V can satisfy).

Conversely, P and P_{mass} are transition matrixes that come from individual and mass customers. Notably, BP_Flag is a variable that records the user's decision, which indicates that if the user decides to enter the collaborative process, the value is set to 1; otherwise, the value is set to 0. Variable R obtains the user's response (i.e., accept is 1) when the customized bundle is delivered successfully.

The collaborative prototyping process is demonstrated from line 15–33 in Fig. 9; nevertheless, BP_Flag and R are set to 0 before the major procedure is initiated. The procedure is triggered when the BP_Flag equals 1, indicating that a user decided to seek a better bundle from the interaction. Thus, the system obtains the information for the selected version (V), reads the mass transition matrix (P_{mass}), and transforms initial needs (N^0) and the transition matrix (P) into V_Needs and P_{mass}, respectively.
Next, a repeated loop for confirm the convergence is initiated with the conditions that time (t) is greater than 0 and needs (N^t) are

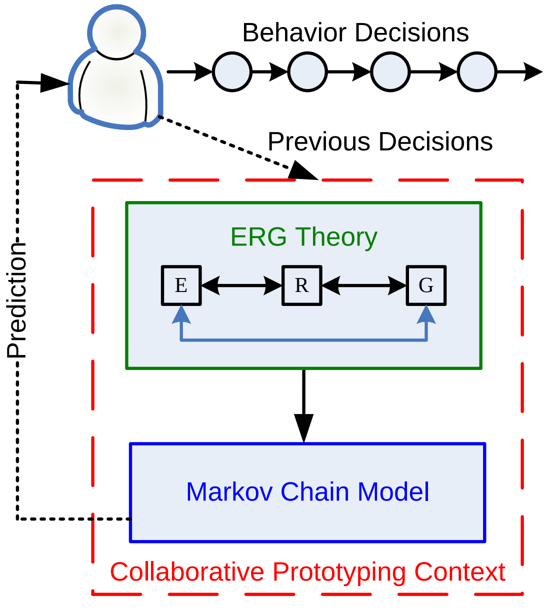

Figure 8 System Architecture

convergent (i.e., needs tend to be stable for over a prolonged time). The needs in a given time period (t) can be predicted using the Makorv chain that embeds ERG theory in the transition matrix. When a user's need is estimated at time t (i.e., $N^t = N(^{t-1})P$), the system assembles a bundle dynamically that is based on the current needs of the user and delivers it to the user immediately.

Conversely, the user may not accept that the customized bundle meets actual needs. Hence, variable R acquires a response from the user in which 1 represents accept and 0 represents reject. If the user rejects the customized bundle at this time, the system predicts the needs for the next time period based on current status of needs and the bundle. The while loop is terminated only when the user accepts the bundle or needs (N^t) are convergent.

In short, the Markov chain can predict user need in a given time period. The benefits of combining the Markov chain and an ERG need hierarchy as follows: (1) the outcomes of a given time period depend on a preceding period and other previous events; and, (2) transition probabilities move toward stability and are customized during transitional periods.

The BP algorithm combines collaborative prototyping and ERG theory to predicts and evaluate user needs accurately and immediately. Moreover, the BP algorithm generates prototypes during the collaborative process that are based on user needs.

EVALUATION

The conventional Maslow theory is a well-known approach for interpreting a human needs hierarchy. This study employs Maslow theory as the benchmark for ERG theory. Needs predictions will vary when the applied theory changes. In particular, the states in the Markov chain matrix differ, the Maslow theory has five states, and the ERG has three states. We utilize certain indicators from information retrieval as the metrics to evaluate the performance of prediction in terms of accuracy, precision, recall, and F1-measure. Accuracy provides a macro perspective of our approach in order to examine if the use of ERG with Markov Chain is superior to that with Maslow. Precision and recall then furnishes a micro perspective about an in-depth analysis of prediction performance. Finally, the F1-measure investigates the overall performance considering both perspectives. This study compares the differences in prediction and accuracy for both approaches to demonstrate that ERG theory results are superior for predicting customer needs.

Assumption

The aim for evaluating BP module is to validate that the application of Markov chains to ERG theory is superior to that with Maslow theory. We assume three consumer stereotypes exist, which are regular, extroverted, and innovative. For regulative type, people live in a regular pattern and concentrate on meeting basic needs, for example, physiological (N1)

Table 1 The description of all variables

Variable	Description
N[E,R,G]	A vector; it represents the user's existence, relatedness, and growth needs.
V	The initially provided services that the user chose.
V_Needs[E,R,G]	A vector; it represents the needs that a version can satisfy.
B	Customized services based on the user's needs according to N[E,R,G].
B_Needs[E,R,G]	A vector; it represents the needs that a bundle can satisfy.
P	The transition matrix of a user.
P_{mass}	The transition matrix came from mass customers.
BP_Flag	The flag to record user's decision that accepts the initial version or interacts with the system.
R	The response of user that accepts or rejects the furnished bundle.
t	A time period.

```
BEGIN
INIT N[E,R,G] is a vector of user needs
INIT V is the initial provided services that user chose
INIT B is customized services
INIT B_Needs[E,R,G] is a vector of B
INIT V_Needs[E,R,G] is a vector of V
INIT P is the transition matrix of user
INIT P_mass is the transition matrix of mass customers
INIT CP_Flag is the flag to record the decision
INIT R is the response of user
INIT t represents the time
SET CP_Flag to 0
SET R to 0
SET t to 1
IF CP_Flag is the same with 1 THEN
  GET V from user
  READ P_mass
  SET N^0 to V_Needs
  SET P to P_mass
    WHILE t > 0 and N^t and N^(t-1) are not the same
      SET N^t to multiple N^(t-1) by P
      DETERMINE B
      DISPLAY B
        GET R from user
        IF R is the same with 0  THEN
          SET N^t to B_Needs
          INCREMENT t
        ELSE
          SET t = 0
    ENDWHILE
  PRINT B
ELSE
  PRINT V
END
```

Figure 9 Behavioral Prediction Algorithm

and safety (N2) needs in the Maslow theory or existence needs (E) in ERG.

For extroverts, people break through fundamental needs to higher level of needs, such as social (N3) and external esteem (N4) needs in the Maslow theory or relatedness needs (R) in ERG theory. Similarly, the innovative type focuses on top level needs such as self-actualization and internal esteem needs (N5) in the Maslow theory or growth needs (G) in ERG theory.

Additionally, we assume ideal needs have multiple choices based on Maslow and ERG constraints. That is, needs can move to relatively higher level only when the lower level is satisfied. For example, in the Maslow theory, consumers want to satisfy safety needs only after physiological needs are fulfilled. Similarly, consumers want to satisfy relatedness needs when existence needs are fulfilled in ERG theory.

Hence, an alternative with a low level for ideal needs is the basic assumption. For instance, if the ideal need is N2, then the possible needs for prediction are N1 or N2 (i.e., when the ideal need is R, the possible needs are E or R). The reason for a lower level and not a higher level needs (e.g., ideal need N1 for possible prediction N0 or N1 but not N0, N1 or N2) is to ensure a minimal recall rate with strict constraints. Once the recall rate is desirable with a strict constraint, it may be superior to a loose constraint.

Simulation

This study simulates 40 continuous behavioral points of needs (a series of needs) for each stereotype, and each pattern is encoded to three states (ERG) and five states (Maslow). Two-thirds of the data (26) are utilized for building the model and one-third of the data (14) are employed for verifying reliability and validity.

The initial probability distribution of needs for the three stereotypes is based on our assumption mentioned in the previous section. For example, regular type consumers have series of 26 type needs—18 existence needs (0.629307692), 7 relatedness needs (0.269230769), and 1 growth need (0.038461538) (Table 2).

In ERG theory, the principal need is existence for the regular type, existence and relatedness for the extroverted type, and related and growth for the innovative type. For the Maslow theory, the major need is N1 for the regular type, N1 and N3 for the extroverted type, and N4 and N4 for the innovative type (Table 3).

This study utilizes two-thirds of the data to construct the transition matrix for prediction and one-third of the data to verify the reliability and validity of the proposed system. That is, 26 behavioral patterns are utilized to build the predictive model (transition matrix) and 14 to verify model stability and precision. The first one of the rest 14 patterns is the initial point; thus, 13 time spots are allocated for prediction (Table 4 and 5).

Table 2 Initial probability distribution for ERG

	E	**R**	**G**
Regular	**0.692307692**	0.269230769	0.038461538
Extroverted	**0.461538462**	**0.423076923**	0.115384615
Innovative	0.269230769	**0.384615385**	**0.346153846**

Table 3 Initial probability distribution for Maslow

	N1	**N2**	**N3**	**N4**	**N5**
Regular	**0.65**	0	0.3	0.05	0
Extroverted	**0.45**	0	**0.4**	0.075	0.075
Innovative	0.175	0	**0.325**	**0.325**	0.1

Table 4 Assumptive behavioral patterns for three stereotypes (ERG)

ERG	**Behavioral Points of Needs**
Regular	E,E,E,E,R,E,R,E,R,E,E,R,E,E,R,E,G,R,E,E,E,E,E,E,R,E,**R,E,R,E,E,R,E,E,R,E,G,R,E,E**
Prediction	**R,E,E,E,E,E,E,E,E,E,E,E,E,E**
Extroverted	E,R,R,E,E,R,G,G,R,E,E,R,R,E,E,R,R,G,E,E,E,R,R,E,E,R,**G,G,R,E,E,R,R,E,E,R,R,G,E,E**
Prediction	**G,E,E,E,E,E,E,E,E,E,E,E,E,E**
Innovative	E,R,R,E,R,G,G,G,G,E,R,R,G,E,R,G,R,G,G,E,E,R,R,E,R,G,**G,G,G,E,R,R,G,E,R,G,G,G,G,E**
Prediction	**G,G,R,G,G,G,G,G,G,G,G,G,G,G**

Table 5 Assumptive behavioral patterns for three stereotypes (Maslow)

Maslow	**Behavioral Patterns**
Regular	N1,N1,N1,N1,N3,N1,N3,N1,N3,N1,N1,N3,N1,N1,N3,N1,N4,N3,N1,N1,N1,N1,N1,N1,N3,N1, **N3,N1,N3,N1,N1,N3,N1,N1,N3,N1,N4,N3,N1,N1**
Prediction	**N3,N1,N1,N1,N1,N1,N1,N1,N1,N1,N1,N1,N1,N1**
Extroverted	N1,N3,N3,N1,N1,N3,N4,N5,N3,N1,N1,N3,N3,N1,N1,N3,N3,N4,N1,N1,N1,N3,N3,N1,N1,N3, **N4,N5,N4,N3,N1,N3,N1,N1,N1,N3,N3,N4,N3,N1**
Prediction	**N4,N1,N1,N3,N1,N1,N1,N3,N3,N3,N3,N3,N3,N3**
Innovative	N1,N3,N3,N1,N3,N4,N5,N4,N4,N1,N3,N3,N4,N1,N3,N4,N3,N4,N4,N1,N1,N3,N3,N1,N3,N4, **N4,N4,N5,N1,N3,N3,N4,N2,N4,N5,N3,N4,N5,N1**
Prediction	**N4,N4,N4,N3,N4,N4,N4,N4,N3,N3,N3,N3,N3,N3**

Performance Measures

This section evaluates the BP module in terms of reliability and validity and compares it with the Maslow approach. Theoretically, needs converge according to the Markov property. Consequently, reliability verifies the stability of the system in terms of the convergence of needs for the Markov chain within the ERG or Maslow approaches. Validity confirms the predictive ability in terms of accuracy, precision/recall, and the F1-measure.

The evaluation indices, such as accuracy, precision/recall, and the F1-measure, are widely used in the information retrieval domain. Accuracy is defined as the proportion of correctly predicted needs to all correctly and incorrectly predicted needs. Accuracy is important because "on balance, accurate forecasts are more likely than inaccurate forecasts to improve the rationality of decision making" (Ascher, 1979). Precision is defined as the proportion of predicted and ideal needs to all needs predicted. Precision considers all predicted needs and can be evaluated at a given cut-off rank by considering only the topmost results returned by a system.

Recall is defined as the proportion of ideal needs predicted out of all ideal needs available. It is trivial to achieve 100% recall by returning all needs in response to any given time point. That is, recall alone is insufficient; that is, one needs to measure the number of irrelevant predicted needs. The F1-measure is the weighted harmonic mean of precision and recall. The traditional F1-measure or balanced F-score is also known as the F_1 measure, in which recall and precision are evenly weighted.

1. $$Accuracy = \frac{\text{correctly predicted needs}}{\text{all correctly and incorrectly predicted needs}}$$

2. $$\Pr ecision = \frac{\text{predicted and ideal needs}}{\text{all needs predicted}}$$

3. $$\text{Re}\, call = \frac{\text{predicted and ideal needs}}{\text{out of all ideal needs available}}$$

4. $$F\text{-}measure = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Convergence of Needs

Supposedly, needs will converge according to the Markov property. This study simulates 30 rounds to verify the convergence for each stereotype at a given initial state of probability. Simulation results indicate that needs must be converged over a long-term period (e.g., roughly 13 rounds of prediction). The variation of needs tends to stabilize around 5 rounds but not completely converge (the probabilities still differ) for the ERG or Maslow approaches; that is, the Markov chain generates a general transition matrix with 5 time spots. This also verifies the basic assumption of the Markov property which provides evidence of stability.

For detailed comparison of the ERG and Maslow approaches, needs converge more smoothly for the ERG than Maslow regardless of stereotype. Conversely, needs fluctuate dramatically at roughly four rounds for extroverted and innovative types in the Maslow theory. Consequently, the performance of ERG is superior to Maslow, especially for extroverted and innovative types, and is not significantly different from the regular type. That is, needs variations affect the convergent process. For example, regular type does not influence much, however the innovative type does (as shown in Fig. 9 and 10).

Accuracy, Precision, Recall, and F1-measure

ERG Theory

The evaluation indices are utilized to measure the performance of the ERG in terms of accuracy, precision/recall and the F-measure. The accuracies for three stereotypes are 0.9230769, 0.9230769, and 0.5384615 (Table 6). The Markov within ERG achieves highly prediction accuracy for the regular and extroverted types. However, the accuracy for the innovative type is only approximately 50%; this may be caused by frequently changing ideal needs. Another reason may be that the transition matrix is typically stable; that is, possible needs will be predicted steadily.

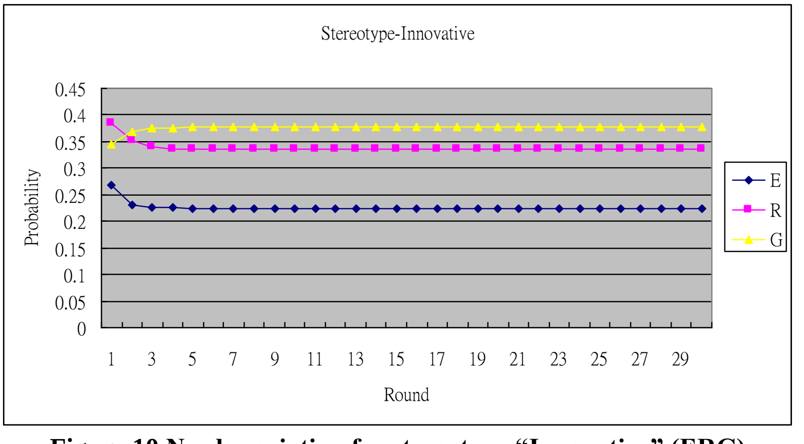

Figure 10 Needs variation for stereotype "Innovative" (ERG)

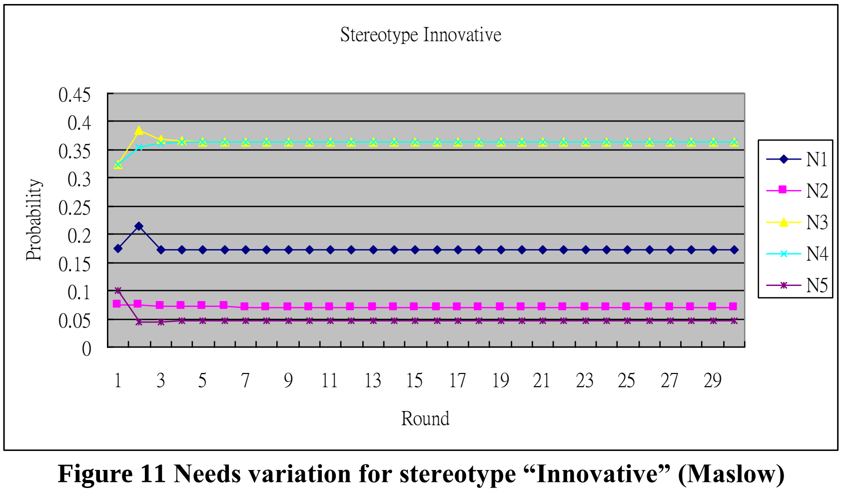

Figure 11 Needs variation for stereotype "Innovative" (Maslow)

Table 6 Accuracy for ERG

ERG	**Accuracy**
Regular	0.9230769
Extroverted	0.9230769
Innovative	0.5384615

Precision is the preciseness of predicted needs at given time points. Experimental results (Fig. 11) indicate that regular type has the highest precision rates (> 85%) at 13 time points. The precision rate for the extroverted type increases over time and attains a high precision rate gradually. However, the precision rates for the innovative type are unsteady at 13 time spots and always <60%. The reason is that the Markov chain tends to be stable and obtains incorrect predictions when needs frequently change.

Recall is the capability of a system to predict related/possible needs. The results (Fig. 12) demonstrate that all three stereotypes achieve >50% in recall rate for two-thirds of the time points (e.g., 86%, 80%, 50%). Regular and extroverted types increase linearly and gradually; however, the innovative type increases like steps on stairs.

Due to the biased explanation of precision and recall, the F1-measure is most commonly utilized to verify performance since precision and recall are equally weighted. The results (Fig. 13) demonstrate that the Markov within the ERG has high-quality performance in predicting needs for regular (0.96) and extroverted (0.92) types. Moreover, the F1 values also increase gradually. However, the Markov within ERG has low-quality performance in predicting needs for innovative type (0.7), and the F1 values for regular and extroverted are not significantly different.

Maslow Theory

The accuracies for the three stereotypes are 0.6153846, 0.5384615, and 0.4615385, respectively (Table 7). The Markov within Maslow theory generates similar prediction rates for regular (62%) and extroverted (54%) types. However, the accuracy for innovative type is only about 46%, and may be caused by frequent and significant changes to ideal needs (e.g., more than one state changes, such as N1 changed to N3 or N4 with 2 or 3 states changed). Another reason is that the transition matrix tends to be steady and possible needs will be predicted with stability.

Table 7 Accuracy for Maslow

ERG	**Accuracy**
Regular	0.6153846
Extroverted	0.5384615
Innovative	0.4615385

Precision is the preciseness of predicted needs at given time points. The results (Fig. 14) reveal that all three stereotypes have low

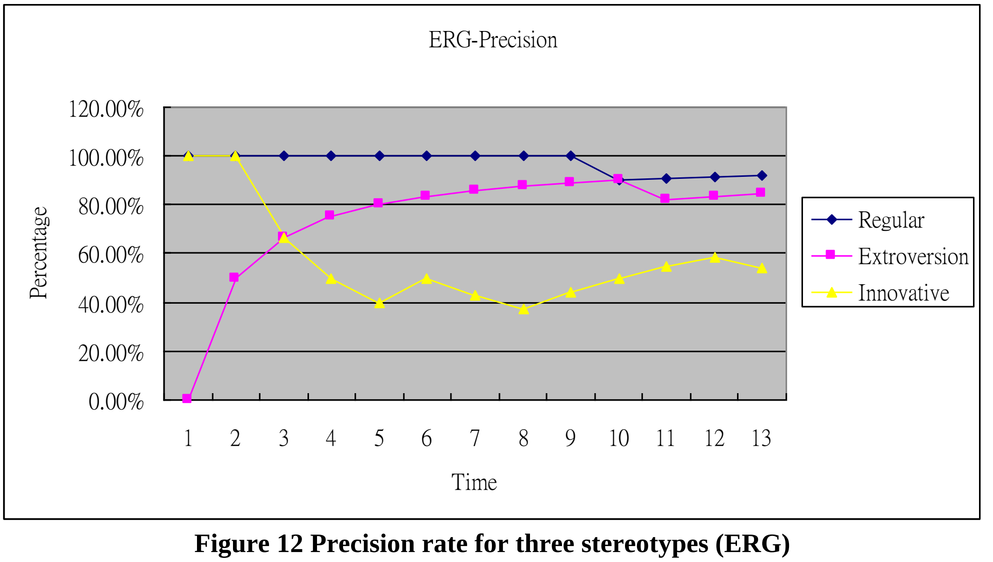

Figure 12 Precision rate for three stereotypes (ERG)

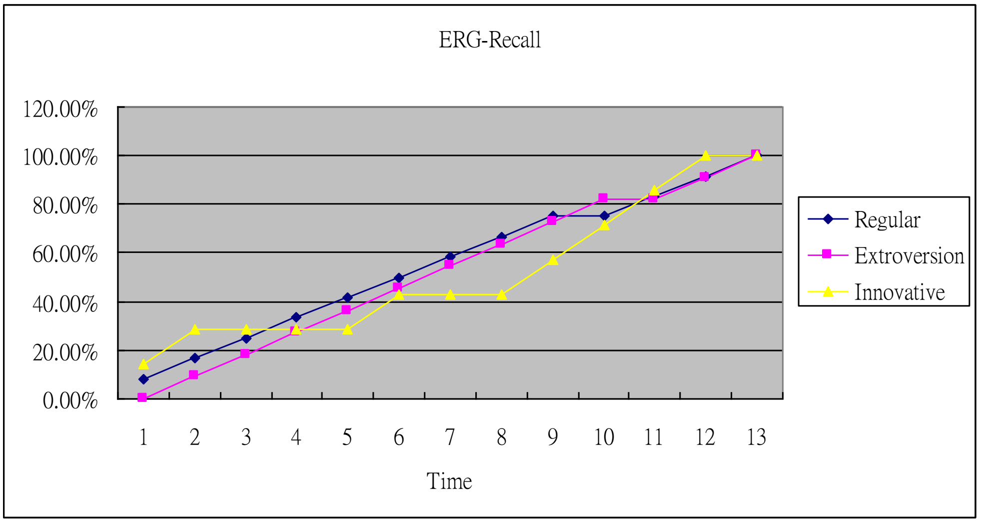

Figure 13 Recall rate for three stereotypes (ERG)

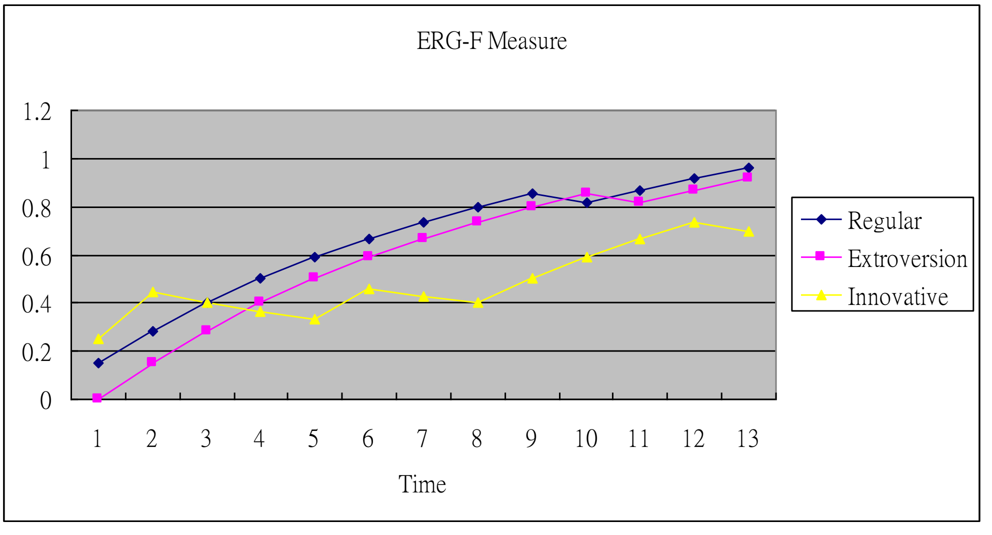

Figure 14 F1-value for three stereotypes (ERG)

precision rates (roughly 60%) after two-thirds time points. The needs fluctuated changed abnormally for the three stereotypes at 13 time points. This demonstrates that Markov with Maslow can predict needs incorrectly either over the short or long term.

Recall is the capability of a system to predict related/possible needs. The results (Fig. 15) suggest that all three stereotypes attained over 60% after two-thirds of the time points had passed. This means that the system predicts most related needs after 8 time points (e.g., 70%, 50% and 53% for the regular, extroverted and innovative stereotypes, respectively) and no specific stereotype has high-quality performance in recall rate all the time.

The results of F1 values (Fig. 16) indicate that the Markov within Maslow achieves highly accurate performance in predicting needs for regular (0.76) and extroverted (0.7) types and has low performance in predicting needs of for the innovative type (0.63)—the F1 values for the three types were not significantly different.

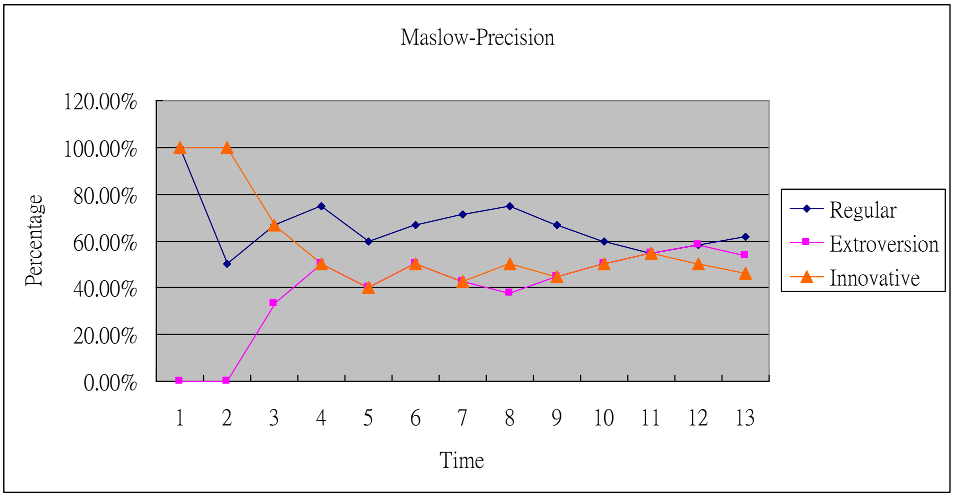

Figure 15 Precision rate for three stereotypes (Maslow)

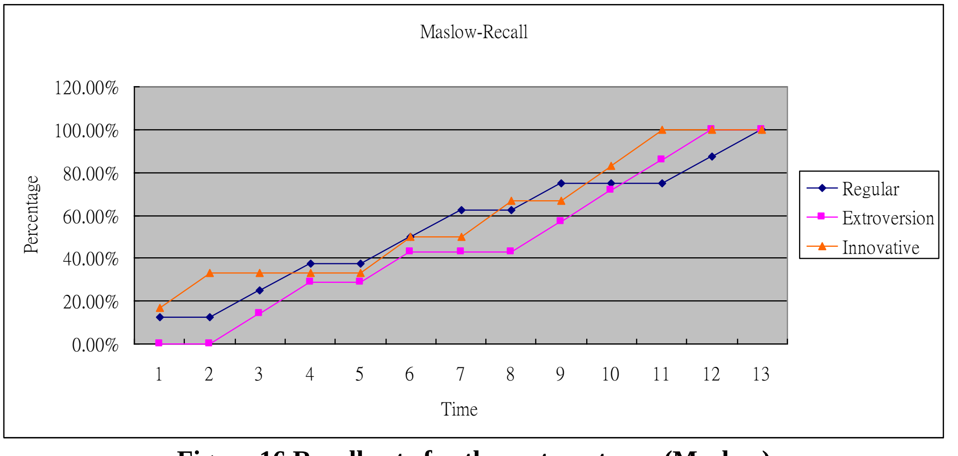

Figure 16 Recall rate for three stereotypes (Maslow)

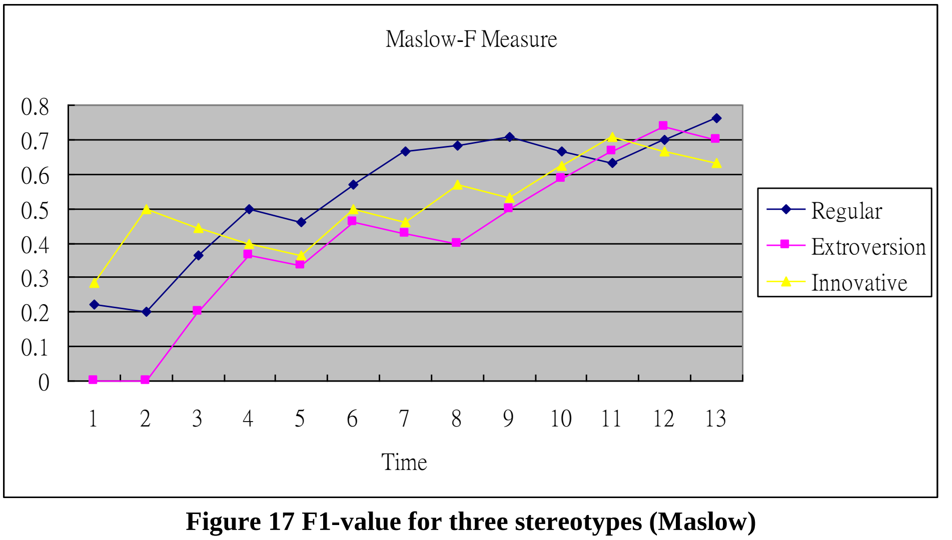

Figure 17 F1-value for three stereotypes (Maslow)

CONCLUSION

Collaborative prototyping allows firms to become deeply embedded in their customers' design and development processes by developing prototypes which has two advantages: (1) they help customers evaluate unknown customized products and (2) guide both parties in searching for the optimal product specification.

This paper contains several contributions which not only address the importance of needs prediction but furnish a behavior forecast algorithm for collaborative prototyping, using the synthesized model of Markov Chain and ERG Theory. This combined notion of Markov Chain, ERG Theory and collaborative prototyping is novel and advance the state of the art of software engineering and Maslow theory.

Furthermore, evaluation results demonstrate the Markov chain combined with ERG theory is superior to the Maslow theory regardless of reliability and validity. This study evaluates performances in terms of the convergence of needs and confirms the basic assumption of Markov property; that is, reliability has been proven. This study also utilizes certain metrics, such as accuracy, precision/recall, and F1-measure, to validate simulation results.

Precision and recall rates demonstrate that ERG theory is superior to the Maslow theory for regular and extroverted types. However, analytical results also indicate that innovative type for ERG theory has at least the same prediction results as those obtained by Maslow. The F1- measure shows that ERG is superior to Maslow over a long period for the three stereotypes; in particular, the regular and extroverted types are significantly different. Thus, the Markov chain with ERG theory predicts better than Maslow.

The combined approach is also different from previous related works. Markov chain model was utilized in numerous fields, such as human needs forecasting in psychology, portfolio forecasting in finance, baseball decision support in sports, website prediction in business, etc. However, unlike our work aiming for online real-time prediction, all these works were only meant for analyzing the historical data. In other words, our research has the advantages of analyzing the real-time behavior data, collaborating with the user and immediately responding to the user in comparison with the other existing works. Additionally, the performance evaluation also proves our synthesized model is superior to the work of Chung (1969) in terms of the consolidated but significant 3 types of needs modeled in the ERG theory (in comparison with the 5 types of needs in Maslow).

In summary, Markov chain within ERG theory generates good performance regardless of accuracy, precision, recall, and F1-measure. This paper verifies an avenue for collaborative prototyping with behavior forecast. Furthermore, the novel approach contributes to decision-making problems and proves it is feasible in real-world from our experimental simulations.

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