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From affect, behavior, and cognition to personality: an integrated personal character model for individual-like intelligent artifacts

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Abstract
An individual-like intelligent artifact is a special kind of humanoid which resembles a human being in assimilating aspects of its real human counterpart's cognition and neurological functions. Such an individual-like intelligent artifact could have a number of far-reaching applications, such as in creating a digital clone of an individual and bringing about forms of digital immortality. Although such intelligent artifacts have been created in various forms, such as physical robots or digital avatars, these creations are still far from modeling the inner cognitive and neurological mechanisms of an individual human. To imbue individual-like intelligent artifacts with the characteristics of individuals, we propose a Personal Character Model that consists of personality, the characteristics of affect, behavior, and cognition, and the relations between these characteristics. According to differential psychology and personality psychology, personality is the set of essential characteristics that make a person unique whereas characteristics in affect, behavior, and cognition explain a person's stable and abstract personality in their diverse daily behavior. In addition, relations among these characteristics serve as a bridge from one characteristic to another. To illustrate the computing process of the personal character model, we first designed three experiments to collect physiological data and behavior data from twenty participants. Then we selected data features from the collected data using correlational analysis. Finally, we computed several representative characteristics from selected data features and represented the computed results.

Keywords individual-like · personal character model · characteristics · personality · affect · behavior · cognition · relation · emotional stability · attention ability

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1 Introduction

A humanoid is a man-made object that has appearance or characteristics resembling a typical human. For example, the popular robot "Pepper" developed by Softbank has the ability to interact with people in lifelike ways [14]. Alongside the research into these kinds of humanoid, a special kind of humanoid named an individual-like intelligent artifact has emerged and been developed. An individual-like intelligent artifact is an artificial physical or digital thing that resembles a specific individual, such as the "Geminoid" created by H. Ishiguro, which has almost the same appearance and expressive features as its corresponding real human individual [20]. These individual-like intelligent artifacts may lead to some fantastic personal applications. For example, a digital clone of an individual could provide even more closely-tailored personalized service than is currently available, e.g., helping an invidiual reply to email in their own characteristic style, and communicating with others digitally on their behalf. The attractive concept of digital immortality is another example. The project "Cyber All Project" launched by Microsoft is aimed at creating a digital "you" to communicate with others through endless experience and learning [4].

Such individual-like intelligent artifacts could be created in different forms, e.g., a physical robot, a digital avatar, or even an invisible software application. The "Cyber-I" proposed by J. Ma is intended to be a comprehensive description of an individual, and could be embedded within either a robot, or an avatar or an invisible chatbot [44]. Although there has been a certain amount of progress on the external appearance and behaviors of individual-like intelligent artifacts, they are still far from assimilating the inner cognition and neurological functions of an individual, i.e., the mind. Therefore, it is absolutely essential to develop a computable model to systematically represent and synchronize the individual mind with such artifacts.

Many studies of the mental characteristics of individuals have been carried out in differential psychology, as well as into individual difference and personality psychology. Personality is a generally accepted concept in differential psychology referring to a person's general characteristics in various aspects, e.g., affect, behavior and cognition. However, current personality computing is still facing a big gap between concrete personal data and abstract personality. This gap not only hinders precise personality computation but also makes the use of computed personality difficult in practical applications, especially for individual-like intelligent artifacts. Based on differential psychology, a personality model encompassing the general characteristics of affect, behavior, and cognition [45], and an integrated personal character model (character refers to the collection of personal characteristics) is therefore proposed in this research. The proposed model consists of three basic components. The first component is the personality, as the macro characteristics of an individual. To reach comprehensive personality and practical applications for individual-like intelligent artifacts, the micro characteristics in affect, behavior, and cognition are designated as the second component. As an integrated model of personal character, the third component is the relational characteristics consisting of various relations among micro and macro characteristics. Such relational characteristics may also derive computation from one characteristic to another, e.g., talkativeness can be computed from the trait of openness to others since there is a clear relationship between both traits. Because the personal character model contains characteristics at different levels (i.e., macro characteristics, micro characteristics and relational characteristics), it can be more easily applied into applications than in psychological personality. For example, utterance characteristics could be used to make a chatbot similar to its corresponding human counterpart's speech. A user model is a

collection and categorization of personal data associated with a specific user [19]. The personal character model is similar to the user model, in that both collect personal data from various data sources. However, the personal character model targets the construction of comprehensive personal characteristics from these data sources, rather than from personal information, such as a demographic personal profile. Therefore, the computing methods of the personal character model and the user model are different, with the personal character modeling focuses more on the computing of characteristic, while the user modeling focuses on the collection of personal information.

The remainder of this paper is organized as follows. The research background and objectives are illustrated in Section 2. Section 3 describes the integrated personal character model in detail. To verify the feasibility of the proposed model, Section 4 describes three experiments to generate and collect twenty participants' data. Some representative characteristics are selected and computed in Section 5. Conclusions and future work are addressed in the last section.

2 Research background and objective

To clarify the motivation and necessity of studying the personal character model, we present the research background from three perspectives, namely, those of individual-like intelligent artifacts, differential psychology, and personal big data, as shown in Figure 1.

There has been an increasing amount of research focused on creating individual-like intelligent artifacts in recent years. An individual-like intelligent artifact is a man-made physical or digital thing that resembles a specific real individual. For example, H. Ishiguro created the robot "Geminoid HI-2" resembling his appearance, facial expression, and voice in 2007 [33]. In 2016, the famous robot "Sophia", modeled from its prototype – the famous actress Audrey Hepburn, was granted Saudi Arabian citizenship [15]. Although the robot is currently it's most common form, individual-like intelligent artifacts could be created in other forms, such as in an avatar, or even an invisible software application. For example, the project "Lifelike" was targeted at creating a digital graphic avatar of Alexander Schwarzkopf, a former

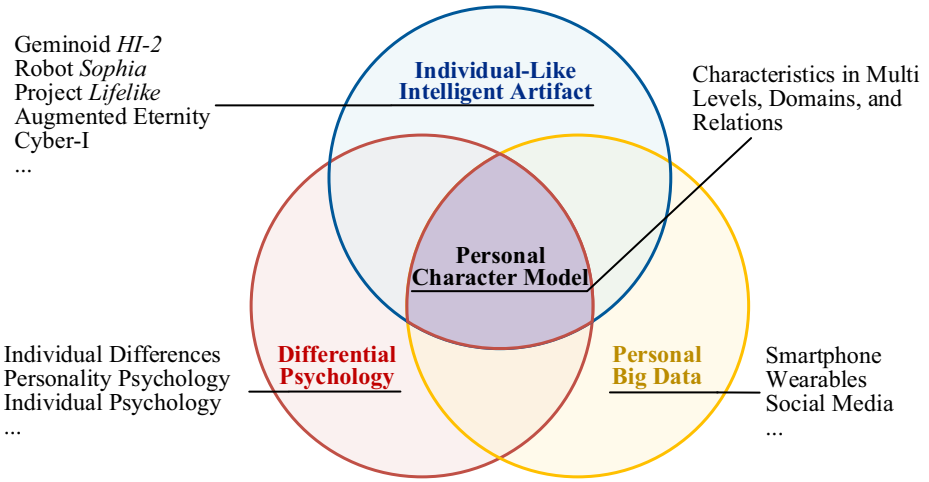

Figure 1 Sketch map of research background and objective

director of the National Science Foundation, based on different people's impressions of him [40]. The project "Augmented Eternity" conducted by the MIT Media Lab, was aimed at creating a user's digital identity without any external carrier, to communicate with others remotely [3]. "Cyber-I", proposed by J. Ma, aimed at a comprehensive description of a real individual in cyberspace [27]. In particular, the Cyber-I could be either an avatar or a robot or a virtual chatbot. It makes no difference whether communication is mediated by audio, video or text, or even directly, one identifies the individual communicating with us through voice, image or even physical movement as aspects of that individual's mind. In consideration of the importance of verification, we have referred to the famous Turing test and the self-Turing test [37] as its extension and propose an individual Turing test to evaluate individual-like intelligent artifacts. The Turing test was developed by Alan Turing in 1950 to evaluate a machine's ability to exhibit intelligent behavior indistinguishable from that of a human being [41]. The self-Turing test was proposed by R. Martine to evaluate a machine's consciousness is as good as the human's consciousness. In addition, the individual Turing test evaluates how easily as machine's likeness can be distinguished the individual it resembles. The Personal Character Model aimed at the characterization of an individual, especially of their mind, meeting the goal of a practical individual-like intelligent artifact, e.g., by passing the individual Turing test. Hence, the personal character model is the key to this individual-like research area.

The exploration of the human mind has long attracted many researchers' interest. Differential psychology, a specific psychological field, is the study of stable individual differences that help to identify differences between people. Accordingly, the framework of the Personal Character Model should be based on theories in and results of research into differential psychology. The personality, referring to stable individual differences in characteristic patterns of thinking, feeling, and behaving, is one of the most important research branches in differential psychology. Up to the nineteenth century, the Greek/Roman causal theory provided an explanation for personality traits. The causal theory stated that four humors (known as Yellow Bile, Phlegm, Blood, and Black Bile) related to four different temperaments. Individual difference lay in the differing proportions of the four humors [35]. In the early twentieth century, G. Allport summarized 4,504 adjectives from the dictionary that could be used to describe a person, and put forward personality trait theory [1]. Each adjective describes one personality trait. To grasp the most essential traits, Big Five personality trait theory was proposed and developed in the middle of the twentieth century [34]. Due to the simplicity of describing a person in only five dimensions, the use of Big Five personality trait theory has become more and more widespread. In recent years, psychologists have started to come to a better understanding of personality, as Big Five personality trait theory is limited in usability in some areas, especially in behavior prediction [34]. J. Wilt and W. Revelle proposed an ABCD model of personality, which consists of four aspects, namely affect, behavior, cognition, and desire [45] [36]. Furthermore, they showed that there were many correlations between personality traits in these four aspects. Some psychologists argue that desire should be regarded as another personality character aspect [46]. To find a better description of personality traits (especially for behavior prediction), C. Deyoung proposed the cybernetic Big Five theory [9], which posits a personality trait hierarchy of four levels: top level (meta-traits), second level (Big Five), third level (aspects) and fourth level (facets). Following the development of differential psychology, the Personal Character Model in this research is aimed at a model able to describe individual difference comprehensively. The Personal Character Model consists of characteristics in multi-levels, domains, and relations. Personality is comprised of high-level characteristics, whereas a series of characteristics in terms of three domains (affect, behavior,

and cognition) are low-level characteristics. Furthermore, relations between these characteristics are also regarded as characteristics in the Personal Character Model.

To calculate individual characteristics, e.g., personality traits, psychologists usually adopt psychological questionnaires that are able to measure a person's characteristics directly from a 20-to-30 min test. With the increasing popularity and development of the Internet, increasingly large amounts of personal data are available for computation. Some researchers have tried to calculate individual characteristics from these personal data. According to a survey of personality computing by V. Alessandro and M. Gelareh, personality traits are computed from different data sources, e.g., social media, mobile and wearable devices [42]. However, the authors stated that a wide gap exists between low-level information accessible to computer (e.g., text data and smartphone usage data) and high-level personality information [43]. Three aspects of the Personal Character Model – the characteristics of affect, behavior, and cognition, could serve as the bridge to traverse such a gap.

Personal big data has the potential to serve as the data source to enable the calculation of personal characteristics from different aspects. Personal big data is a large and continuous collection of rich data that is related to or generated by a specific individual. Accordingly, personal big data is data appropriate for the buildup of the Personal Character Model due to its three typical features. The first two features are its large quantity and its multi-dimensionality. Because personal big data is collected from various data sources, e.g., smartphones, wearables, social media, or even other models, these data sources could provide plenty of personal information reflecting a wide variety of aspects of a single individual. For instance, a smartphone log file indicates a person's daily usage of each app, while a sequence of data from a wearable shows a wearer's health and motion states. These large quantities of data with multi-dimensionality could benefit the computing of person's characteristics in multiple aspects. The third feature of personal big data is continuous data provision. Because of the easy accessibility of the Internet nowadays, many individuals create sizeable amounts of data daily. Such continuously generated personal data could be collected by lifelogging technology [18]. Thus, continuous data provision could benefit the increasingly accurate and comprehensive computing of the Personal Character Model.

To sum up, the Personal Character Model is essential to individual-like intelligent artifacts. Various theories on differential psychology can serve as the theoretical foundation of the proposed model. To build the model for each individual, the computing process can be based on the individual's personal big data. Therefore, two basic principles must be followed in modeling personal character. One is to exploit the wide scope of various theories in differential psychology or personality science. The other is to integrate personal characteristics in a hierarchy able to be computed incrementally with personal big data and to use this flexibly for sophisticated individual-like intelligent artifacts.

3 Integrated personal character model

According to the two basic principles summarized in the last section, the integrated Personal Character Model consists of three basic parts corresponding to an individual's personality, characteristics and their relations. To clarify the Personal Character Model, a hierarchical abstraction of the whole model is first presented, and then the detailed descriptions of the three parts are given respectively in the following subsections.

3.1 Hierarchical abstraction of personal character model

The Personal Character Model aims at a comprehensive description to characterize an individual more integrally to make individual-like intelligent artifacts. The term "character" refers to all the characteristics that make a person different from others [7]. Hence, an important feature of such a model is the extent of this integration. The basic aspects and structure of the proposed personal character model are shown in Figure 2. The integrated personal character model consists of three essential parts: the macro characteristics in personality (P), the micro characteristics in affect (A), behavior (B), and cognition (C), and the relational characteristics in A, B, C, and P.

Macro characteristics refer to the personality. Although there is no generally agreed upon definition of personality, it has been widely accepted in different psychological fields that personality consists of the individual differences in characteristic patterns in terms of wide-ranging aspects, e.g., thinking, feeling and behaving [28]. As defined by G. Allport in 1961: "personality is the dynamic organization within the individual of those psychophysical systems that determine his characteristics behavior and thought". R. S. Weinberg and D. Gould also defined personality in 1999 as "the characteristics or blend of characteristics that make a person unique". Others have defined personality as a set of characteristics that determine the large-scale characteristics of an individual. Thus, the personality is named as macro characteristics in the Personal Character Model. To describe personality, psychologists have proposed a variety of personality forms. The description of personality has been mainly classified into three basic forms: trait (e.g., the Big Five personality traits and the sixteen personality factor) [21] [6], type (e.g., Jung's twelve archetype and Myers-Briggs Type Indicator (MBTI)) [22] [13], and structure (e.g., the human psyche structure of S. Freud and the HEXACO model of personality structure) [12] [2]. Currently, a large amount of research literature exists on the correlation between personality and personal data (e.g., daily behavior) using a wide range of statistical analysis. One example would be a person with high openness (one personality trait) commonly has more interests and is more talkative than others with low openness. It's relatively simple to build a rough picture of a person based on their characteristics (e.g., talkative, wide range of interests, even the number of friends) just from their personality results. Personality is very useful for predicting a person's possible characteristics, not precisely but rapidly, which are thus regarded as macro characteristics of the Personal Character Model.

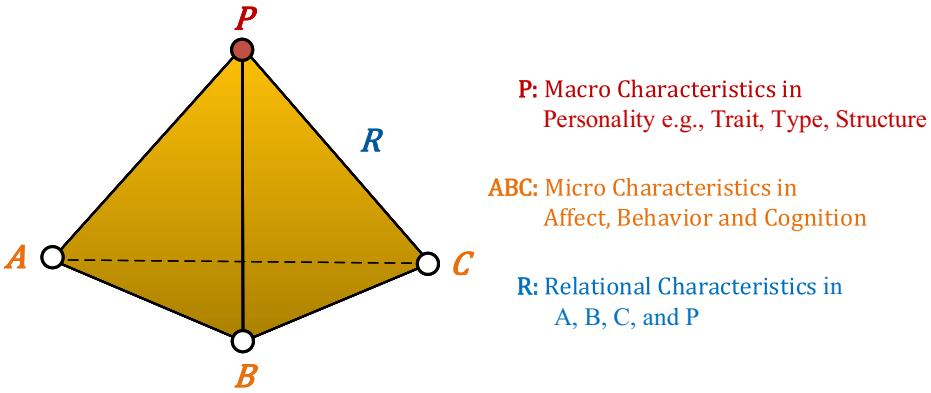

Figure 2 Basic aspects and structure of Personal Character Model

Micro characteristics are characteristics in different aspects. Although personality is statistically related to some personal characteristics, personality has two weaknesses. Firstly, it is hard to know a person exactly, e.g., how many interests a person has and what kind of interests they are fondest of. Because so many factors (e.g., facing different people, different physical conditions, different location, or having different occupations) may influence a person's daily behavior, there is no high correlation between the personality and daily behavior. Research by P. V. Sampo and A. C. Michael has also shown that personality is far from predicting a person's daily behavior [34]. Therefore, personality is insufficient for the comprehensive and precise construction of individual-like intelligent artifacts. Moreover, personality is hard to compute due to the low correlation between personality and measurable behavior. Hence, more characteristics than personality are needed to reach a concrete characterization of an individual. Extensive studies on broad individual difference and personality have been carried out by differential psychologists. According to the research of J. Wilt and W. Revelle, the Big Five personality traits, as a popular set of modern measurement parameters of personality, has wide correlations between affect, behavior, cognition, and desire [45]. W. Fleeson also regards personality traits as relatively stable patterns of affect, behavior, and cognition [10]. However, D. G. Winter et al., doubted that desire/motivation was one of the characteristics of personality from the results of correlations between personality traits and motivation [46]. For the convenience of modeling, the aspect layer consists of three personal characteristics, namely the characteristics of affect, behavior, and cognition. These characteristics from different aspects serve to create the concrete and comprehensive description of individual characteristics. Thus, characteristics from different aspects named micro characteristics are one of the essential components of the Personal Character Model.

Relational characteristics are the third essential component of the Personal Character Model. Relational characteristics exist not only among aspects of affect, behavior, cognition, and personality, but also within each aspect, e.g., within personality. For example the research of F. Adrian reveals the correlation between personality type (MBTI) and personality trait (NEO-PI) [13]. Specifically, people with different personality types have a different correlation between personality type and personality trait. Their results indicate the relational characteristics within the personality. In addition, the relational characteristics between personality, affect, behavior, and cognition have been widely researched. K. Erica and A. Trevor measured correlations among 17 characteristics (e.g., emotional stability, emotional coping, sociability) and four types of affective characteristics (e.g., high affective and low affective) [23]. Similarly, the research of S. Ramanathan et al. shows the correlation between four types of affective characteristics and the Big Five personality traits in a study involving 58 participants [38]. These research efforts support the idea that relational characteristics exist in affect, behavior, cognition, and personality. Therefore, relational characteristics could glue each macro characteristic and micro characteristics together. A helpful analogy is to consider that relational characteristics are to the Personal Character Model what concrete is to a house. Thus, relational characteristics could help build the personal character model with a solid and comprehensive understanding of the individual.

In summary, the categories of the personal character model are derived from state-of-the-art research in psychology. Specifically, macro characteristics are derived from cybernetic Big

Five theory [9], and micro characteristics and relational characteristics are based on the studies of J. Wilt and W. Revelle [45]. The personal character model is mathematically formulated as below,

$$PCM = (P, X, R) \tag{1}$$

where PCM represents the personal character model, P is the personality as macro characteristics, and X is the micro characteristics in different aspects. R is the relational characteristics in P and X. Each component of PCM is explained in detail in the following subsections.

3.2 Macro characteristics in personality

Macro characteristics in personality consist of a wide diversity of elements, such as the Big Five personality traits, and the 16 personality types. To achieve a better understanding, such macro characteristics in personality P, is formulated as below,

$$P = \{P_1, P_2, \ldots, P_p\} \tag{2}$$

where P_1 is the first element of P. The total element number of the personality P is p. Each element of P refers to one of the personality elements.

As mentioned in the first subsection, currently personality has at least three kinds of forms to our knowledge. Thus, these different forms belong to the personality P, and are formulated as below,

$$\{P_T, P_Y, P_S\} \subseteq P \tag{3}$$

where P_T, P_Y, and P_S refer to the personality trait, personality type and personality structure, respectively. Specifically, the Big Five personality traits (B5PT) could belong to the personality trait P_T, and are formulated as below,

$$\{Open, Con, Extra, Agree, Neuro\} \subseteq P_T \tag{4}$$

where *Open*, *Con*, *Extra*, *Agree*, and *Neuro* refer to five personality traits: openness, conscientiousness, extraversion, agreeableness, and neuroticism, respectively. A person with high openness typically has more curiosity, creativity, and a preference for novelty than others with low openness [29]. Another example is Raymond Cattell's 16 personality factor (16PF). The 16PF could belong to the personality trait P_T, and be formulated as below,

$$\{Warmth, Reasoning, Dominance, Liveliness\} \subseteq P_T \tag{5}$$

where *Warmth*, *Reasoning*, *Dominance*, and *Liveliness* are four elements of 16PF. A person with high reasoning ability is skilled in abstract-thinking, whereas a person with low reasoning ability is good at concrete thinking [16].

The personality type P_Y could cover various personality types proposed by different psychologists. For example, the Jung's 12 archetype could belong to the personality type P_Y, and be formulated as below,

$$\{Innocent, Hero, Explorer\} \subseteq P_Y \tag{6}$$

where *Innocent*, *Hero*, and *Explorer* are three of the Jung's 12 archetype [17]. A person with archetype *Innocent* tends to be happy, and fears being punished for doing something bad or

wrong whereas a person with the archetype *Hero* tends to prove his/her worth through courageous acts, and fears weakness and vulnerability [39]. In addition to these archetypes, personality type P_Y could contain many other types, such as the Myers-Briggs Type Indicator (MBTI), as expressed below,

$$\{ETSJ, IFIP, ETIP, IFSJ\} \subseteq P_Y \tag{7}$$

where *ETSJ*, *IFIP*, *ETIP*, and *IFSJ* are four types of MBTI. MBTI has 16 personality types, consisting of a pairwise combination of four pairs of variables: extraversion (E)/introversion (I), thinking (T)/feeling (F), sensation (S)/intuition (I) and judging (J)/perceiving (P) [32]. Regarding the first pair variable, a person would either exhibit extraversion or introversion.

The personality could be a structured model as well. Several structured personality models could belong to the personality structure P_S, and be formulated as the following,

$$\{Structual\ Model\ of\ the\ Psyche, CAPS, SEMP\} \subseteq P_S \tag{8}$$

where the structured model of the psyche is that proposed by S. Freud. Freud considered individual behavior to result from the interaction of three basic functions inside the mind, that is the Id, Ego and Superego. Despite the controversy surrounding Freud's model, such a model could still provide an explanation of a human's mind. The cognitive-affective personality system (CAPS) proposed by W. Mischel and Y. Shoda in 1995, provides another explanation of the functions of the mind [30]. A person's CAPS would consider the situation they are involved at a certain time and make a behavior decision through a cognitive-affect function. A socio-ecological model of personality (SEMP) proposed by B. R. Little provides an explanation of personality from social and biological aspects [26]. Thus, these personality structures/models could belong to the personality structure P_S. In summary, multiple personality models have been proposed in personality psychology, and different personality models have different dimensions, or structure. Each personality model is a sub-model or element of the macro characteristics. Moreover, these personality models could be vectorized to calculate other macro characteristics. For example, the 16PF and B5PT could be vectorized, and put together to measure two general personality traits, namely 'stability' and 'plasticity', according to the cybernetic Big Five theory [9].

3.3 Micro characteristics in affect, behavior and cognition

Micro characteristics are the kind of personal characteristics that are more closely related to an individual's daily behavior than macro characteristics. Take the focusing of attention as an example. The ability to pay attention refers to the brain's ability to concentrate on a target stimulus for any period of time [11]. When driving a car, a person with high attention ability pays more attention to the road, to other cars, to car speed and to traffic signs than those with low attention ability. Emotional intensity is another example. A person with high emotional intensity will exhibit stronger emotional responses regardless of the specific emotion evoked, such as frenzy and ecstasy [25]. These micro characteristics have typical relations with concrete affect, behavior, and cognition. Such micro characteristics are relatively stable and correlate with

personality. To achieve a better understanding, micro characteristics are formulated as below,

$$X = \{A, B, C\} \tag{9}$$

where micro characteristics are denoted by X, which is derived from the term "characteristics" ("$\chi\alpha\rho\alpha\kappa\tau\eta\rho\iota\sigma\tau\iota\kappa\acute{o}\varsigma$" in ancient Greek). According to differential psychology, individual difference exists not only in personality, but also in the four domains of effective functioning: affect, behavior, cognition and desire/motivation [35]. Since desire is still controversial and hard to compute from measurable data, micro characteristics therefore consist of characteristics from the aspects of affect, behavior, and cognition, denoted by A, B, and C, respectively.

Characteristics of affect consist of numerous characteristics, and are formulated as below, $A = \{A_1, A_2, \ldots, A_a\}$ (10).

where A_1 is the first element of affect characteristics A. The total element number of A is a. Each element of A, e.g., affect intensity and emotional stability, refers to one affect characteristic. Behavior characteristics are also one of the micro characteristics and formulated as in the following,

$$B = \{B_1, B_2, \ldots, B_b\} \tag{11}$$

where B_1 is the first element of behavior characteristics B. The total element number of B is b. Each element of B, e.g., visual acuity, auditory ability, and driving ability, refers to one behavior characteristic. Cognition characteristics are the third component of micro characteristics, and formulated as below,

$$C = \{C_1, C_2, \ldots, C_c\} \tag{12}$$

where C_1 is the first element of cognition characteristics C. The total element number of C is c. Each element of C, e.g., attention ability and memorization ability, refers to one cognition characteristic.

3.4 Relational characteristics

As the third essential component of the personal character model, relational characteristics widely exist in different individual characteristics. For a better understanding, relational characteristics are formulated as below,

$$R = \{R_{tr}, R_{te}\} \tag{13}$$

where relational characteristics are denoted by R. R consists of two types of relational characteristics: intra-relational characteristics within each aspect (e.g., within affect) denoted by R_{tr} and inter-relational characteristics between each of two aspects (e.g., between affect and behavior) denoted by R_{te}. According to its definition, R_{tr} consists of relational characteristics in terms of affect, behavior, cognition, and personality, and is formulated as below,

$$R_{tr} = \{R_A, R_B, R_C, R_P\} \tag{14}$$

where R_A, R_B, R_C, and R_P are intra-relational characteristics within affect, behavior, cognition and personality, respectively. Take personality as an example. The personality type TF of MBTI, referring to a person who favors either thinking or feeling, has significant correlation

with the agreeableness and openness of the Big Five personality traits [13]. As to the affect, the affect intensity has a significant correlation with arousability (emotional response) [25].

In addition to R_{tr}, inter-relational characteristics between each two aspects of A, B, C, and P is another type of relational characteristics, are denoted by R_{te} and formulated as below,

$$R_{te} = \{R_{AB}, R_{BC}, R_{AC}, R_{PA}, R_{PB}, R_{PC}\} \tag{15}$$

where R_{AB}, R_{BC}, R_{AC}, R_{PA}, R_{PB}, and R_{PC} refer to the inter-relational characteristics between affect and behavior, between behavior and cognition, between affect and cognition, between personality and affect, between personality and behavior, and between personality and cognition, respectively. Specifically, research by J. Wilt and W. Revelle revealed relational characteristics between the Big Five personality traits and ABC [45]. Agreeableness is positively correlated with sympathy, whereas it is negatively correlated with humor, and conscientiousness is positively correlated with the tendency to dislike impulsive people.

4 Experiments for personal data collection

The personal big data acquired from various sources is a fundamental dataset to build the Personal Character Model. To demonstrate the model's construction, a variety of personal data was therefore collected in experiments. To guarantee the validity of model construction, twenty participants, ten women and ten men between the ages of 23–29 years (M±SD = 25.89±2.26), were recruited. These twenty participants consisted of five undergraduates, ten postgraduates and five doctoral students. Three experiments were performed with data collection for micro characteristic recognition and further computation of some macro characteristics. To measure different micro characteristics in terms of affect, behavior, and cognition, three experimental scenarios were created: reading news and answering questions, watching a short film and playing a game. Because the integrated personal character model covers various characteristics in different aspects, one principal of experimental scenario design is therefore to arouse the subjects' different states and collect their personal data from different sources. These three experiments are described in the following subsections respectively, to explain the corresponding experiment process and data collection.

4.1 Read news and answer questions while listening to music

The first experiment is derived from the cognitive test in [8], where the subjects are asked to recognize significant information from a mass of messages to measure their cognitive ability. Similarly, the first experiment comprised of data collection while subjects read news and answered questions while listening to music to generate the participants' various levels of attention and emotions. The experimental process is shown in Figure 3, in which each participant was asked to read news and answer a series of questions based on the news content as fully as possible. Specifically, news was collected from the BBC World News website, covering different topics without political content, e.g., technology and health. The questionnaire for each news item consisted of five short questions upon the news content. For example, one question was "Sequencing the human genome took years and cost about $ billions". During the whole process of reading and answering, the participant simultaneously listened to

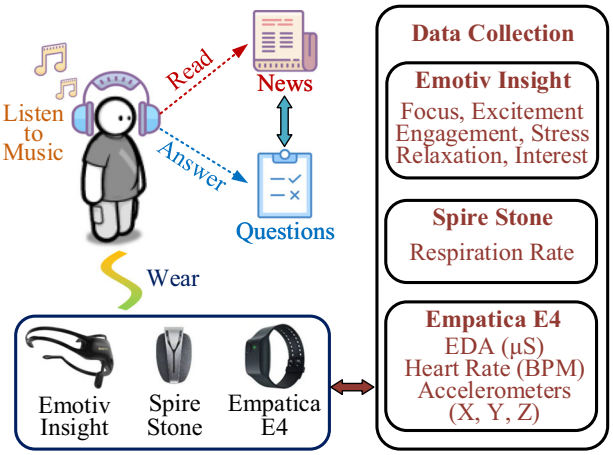

Figure 3 Data collection while reading news and answering questions and listening to music

music. Each participant underwent the experiment three times, with different news topics and questions, and different types of music. The participants listened to silence, their favorite music, and specific music, respectively during each iteration. While listen to different genres of music, the participants experience three different states in total during the experiment (tension, relaxation, and boredom) and provide their personal data.

During the experiment, the participant was required to wear three wearables and an earplug. To provide highly immersive music playback, the selected headphones were the "BOSE QC30" with an embedded active noise canceling module. Three wearables were selected as data sources in this experiment, namely the "Emotiv Insight" headset, the "Spire Stone" waist accessory, and the "Empatica E4" wristband. The "Emotiv Insight" provided the timely electroencephalographic (EEG) data. EEG is an electrophysiological monitoring method to record the electrical activity of the subjects' brain. Furthermore, six kinds of data were calculated and collected from inside the headset, provided 2 times per second. These data were real-time values for focus, excitement, engagement, stress, relaxation and interest. These data indicated participants' timely states in affect and cognition. The "Spire Stone", as a further data source, provided the participant's respiration rate at one-minute intervals. In addition, the "Spire Stone" APP helped the participants to calm down by issuing guidance to slow their breathing rate to under ten times per minute. The "Empatica E4" provided high-quality Electrodermal Activity (EDA) data (also known as galvanic skin response (GSR)) and heart rate data as well as triaxial accelerometer data. The EDA measures perspiration, which is controlled by the sympathetic nervous system. Also, the EDA data could reflect the people's specific personal states, such as excitement, pain, or fear. The data from these three wearables were collected as part of the experimental data, for the further calculation of the Personal Character Model.

4.2 Watching a short film

Movies are good stimuli to evoke human emotion, especially romances and horror movies. Therefore, the second experiment was designed for participants to watch a short film. The experimental environment is shown in Figure 4.

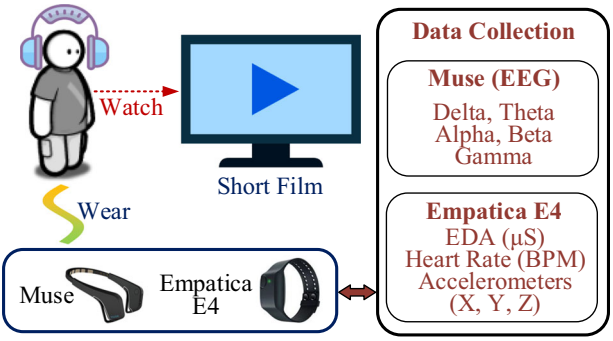

Fig. 4 Data collection while watching a short film

A short film, "The Phone Call", was selected for this experiment, because a short drama had validated the effect of emotion-evocation in our previous research of the correlational analysis of behavior and personality [5]. The participants are expected to be emotionally moved while watching the movie. While the movie was being watched, the participant wore the "Sony WH-1000xm3", a headphone with high fidelity (Hi-Fi) sound reproduction and strong noise reduction, to provide the high-level immersion of movie watching. During the experiment, the participant was required to wear two wearables, namely the "Muse" headband and "Empatica E4" wristband. Due to its easy-to-wear design, the "Muse" headband was adopted in this experiment to collect four-channel Electroencephalogram (EEG) data unobtrusively. Each channel of EEG data consists of five different waves, namely the delta, theta, alpha, beta and gamma waves. These five types of brain waves refer to five different wave frequencies. For example, the frequency of alpha waves ranges from 8 Hz to 12 Hz. The data collected by the "Empatica E4" wristband is the same as in the experiment mentioned in the first subsection.

4.3 Playing the game "Spot the Differences"

Gaming is not only a good stimulus to evoke people's emotion, especially excitement, but also a tool to show personal ability. Score ranking in competitive games indicates gaming skill in such games. Some research in psychology has also used games to measure a person's ability, e.g., memory tests, attention tests and reaction tests [8]. Therefore, the third experiment is a gaming test, namely "spot the differences". The interface of this game is shown in Figure 5.

The well-known game "spot the difference" is easy to play and requires the gamer to be patient and concentrate on the game. After the start button is clicked to play the game, two pictures are displayed in the game interface, as shown in the left-center of Figure 5. The participant is asked to find the differences between these two pictures within three minutes (with a progress bar to show the remaining time). The two pictures are almost identical, except with four slight differences. The participant used a mouse to click the parts of these two figures which differed. The participant's name, gender, time log of finding each difference, error hits of gaming and the time cost are displayed on the right in the interface, as shown on the right of Figure 5 and were recorded. The bottom of the interface shows the record of mouse movement and mouse click activity, as shown in Figure 5. The mouse click record shows the positions of correct hits (with a blue circle) and error hits (with a red cross) as to the four differences in the picture. Each participant played six rounds of this game. The game pictures represented

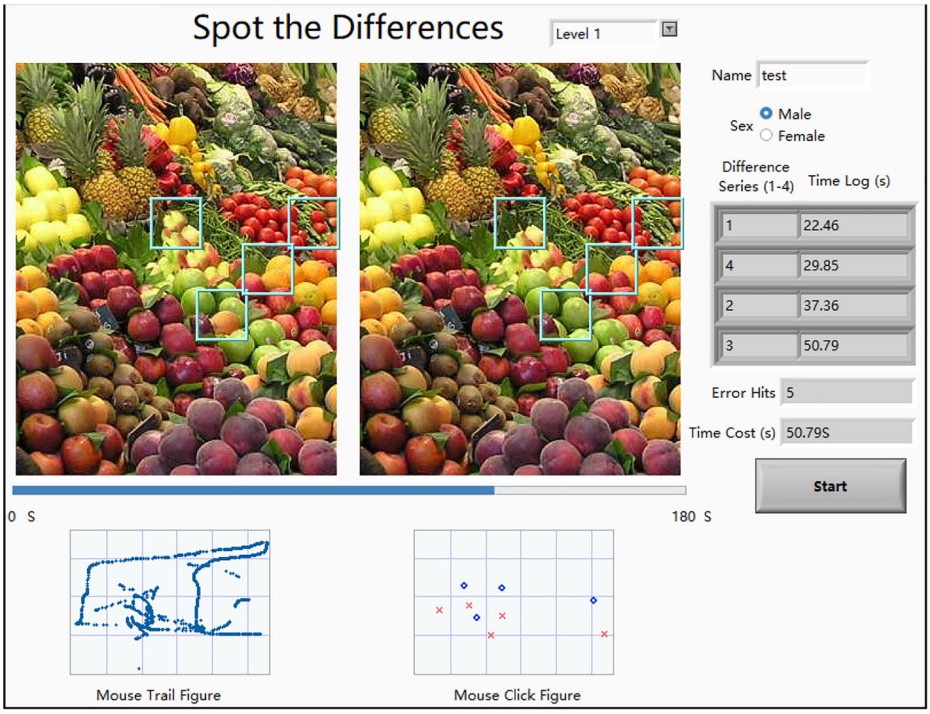

Figure 5 Interface of the game "Spot the Differences"

different representations, such as a house, a map, and a supermarket, to provide comprehensive gaming data from each participant for further analysis.

5 Computing representative characteristics of the personal character model

To demonstrate the feasibility of computing the Personal Character Model, several representative characteristics in terms of micro characteristics and macro characteristics were selected for the case study. Emotional stability, attention ability, and affect intensity were selected as micro characteristics, and the Big Five personality traits were selected as macro characteristics. The general computing process is illustrated in the first subsection. Following the computing process, the results of each stage are presented in the rest of subsections.

5.1 General computing process

The general computing process for representative characteristics is shown in Figure 6. There are three main computing steps, namely feature selection, ABC characteristics computing, and personality characteristics computing.

As the twenty participants' data was collected during the three experiments described in the last section, features which existed in these data of diverse types (e.g., mean value and deviation value) were extracted and selected for further characteristic computing. Similar to the process of some of the affect computing and personality computing, feature selection is

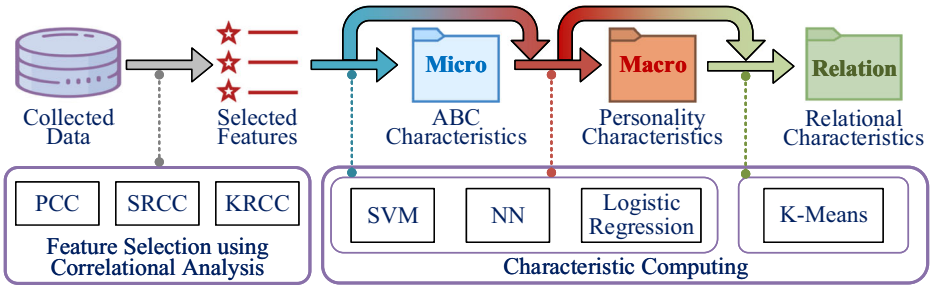

Figure 6 General computing process of representative characteristics

based on correlational analysis [24] [31]. Accordingly, twenty participants filled out four psychological questionnaires corresponding to each characteristic for correlational analysis and a baseline for characteristic computing. Three criteria were adopted for correlational analysis, namely the Pearson Correlation Coefficient (PCC), Spearman's Rank Correlation Coefficient (SRCC) and the Kendall Rank Correlation Coefficient (KRCC). If a data feature shows a high correlation and high degree of confidence with the results of the psychological questionnaire in any of three correlational criteria, such a data feature is selected are one element for further characteristic computing.

Three micro characteristics in terms of affect, behavior, and cognition, and the Big Five personality traits as macro characteristics, are the representative characteristics. Both ABC and personality characteristics follow the same computing process. The difference is that the ABC characteristics are based on selected data fetures, while the personality characteristics are based on both selected data features and calculated ABC characteristics. The ABC characteristics are more stable than human states, thus augmenting the computing of personality. Characteristics computation is carried out through three common machine learning methods: Support-Vector Machine (SVM), Neural Network (NN), and Logistic Regression (LR). The results of feature selection and characteristic computing with these three computing methods are presented in the following subsections.

As discussed in Section 3, relational characteristics are individual differences among macro characteristics of personality and micro characteristics of ABC. Therefore, the computation of relational characteristics is based on the results of macro characteristics and micro characteristics. The general computing process is the selection of each of two personal characteristics, and of the use of clustering algorithms, e.g., K-Means in this study, to verify if significant differences or clusters between selected personal characteristics exist. The clusters between two personal characteristics refer to their relational characteristics.

5.2 Features selection

Different types of the data collected possess different data features. The potential features of this data are shown in Table 1. During the first experiment (reading news and answering questions while listening to different kinds of music), the three devices provided ten types of data. These were the six kinds of emotional and cognition states collected by the "Emotiv Insight" headband, the three types of data provided by the "Empatica E4" wristband, and the respiration rate data provided by the "Spire Stone". Four features (maximum, minimum, deviation, and amplitude) are extracted from each kind of data. During the second experiment

Table 1 List of data features

Experiment	Data features	
Read & Answer	Arousal, Focus, Engagement, Relaxation, Interest, Stress, ACC_Q, HR, EDA, Respiration Rate	Max, Min, Deviation, Amplitude
Movie	Delta, Theta, Alpha, Beta, Gamma, ACC_M, ACC_E4, HR, EDA	
Game	ACC_G Game Duration, Total Correct Hits, Total Error Hits	

(watching a short movie), the two devices provided nine types of data. These were the five kinds of mind wave detected by the "Muse" headband, and the three types of data provided by the "E4" wristband. The same four features (maximum, minimum, deviation, and amplitude) are extracted from these data. During the third experiment (playing a game), four kinds of data were collected, these were the mouse acceleration data, game duration, and the totals of correct hits and error hits. Four features are extracted from the mouse acceleration data (maximum, minimum, deviation, and amplitude), and the sums of game duration, correct hits, and error hits are calculated from their corresponding data, respectively. To sum up, 91 features are extracted from the experimental data.

Correlational analysis is used to select the feature having the highest potential correlation with certain macro and micro characteristics. Therefore, the twenty participants' characteristics are quantified through the use of psychological questionnaires as the baseline for correlational analysis. The range of the twenty participants' characteristics are shown in Figure 7. Four psychological questionnaires, namely the short form Affect Intensity Measure (AIM), the Jasper/Goldberg Adult ADD Questionnaire, the Eysenck Personality Questionnaire, and the Big Five Inventory (BFI-44) were selected for the measurement of affect intensity, attention ability, emotional stability and the Big Five personality traits, respectively.

The correlational analysis (through three analytical methods) of each feature extracted from the collected data and each characteristic measured through psychological questionnaires are shown in Tables 2, 3 and 4.

O = Openness, C = Conscientiousness, E = Extraversion, A = Agreeableness, N = Neuroticism.

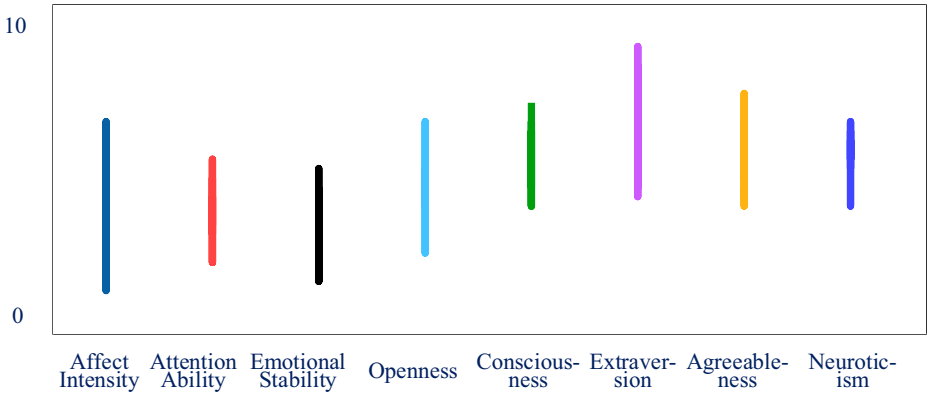

Figure 7 Ranges of macro and micro characteristics from psychological questionnaires

Table 2 Pearson correlational analysis (selected by high correlations)

	AI	AA	ES	O	C	E	A	N
ACC_M_Max	−.04	.01	.28	.1	−.23	.07	.06	**.56***
EDA_M_Min	**.60***	.38	**.63***	.13	**.56***	**.63***	.26	−.53
HR_M_Min	.27	−.02	.01	**.59***	.45	.05	−.23	.04
HR_Q_Min	.63*	.23	.15	−.18	.05	−.04	−.28	**−.42***
Gamma _Max	−.01	**.59***	−.06	.15	−.09	.20	−.01	−.05
Arousal_Dev	.36	.46	**.79****	−.06	.38	**.64***	.45	−.25
Arousal_Amp	.31	.47	**.59***	**−.58***	.06	.35	.26	−.21
Focus_Amp	−.22	.47	.28	.14	.08	**.57***	.26	−.23
Engage_Dev	−.16	**.37***	.60	.11	.02	**.60***	.4	−.03
Interest_Min	−.13	−.13	−.17	.17	**.57***	−.18	−.14	.17
Stress_Min	.12	−.24	.17	−.11	.07	−.10	.22	**.64***

*$p < .05$, **$p < .01$. AI = Affect Intensity, AA = Attention Ability, ES = Emotional Stability

O = Openness, C = Conscientiousness, E = Extraversion, A = Agreeableness, N = Neuroticism.

O = Openness, C = Conscientiousness, E = Extraversion, A = Agreeableness, N = Neuroticism.

The columns of these lists are eight representative characteristics, which are, from left to right, affect intensity (AI), attention ability (AA), emotional stability (ES), openness (O), conscientiousness (C), extraversion (E), agreeableness (A), and neuroticism (N), respectively. The rows show the selected features with at least one high correlation with one of the characteristics. The total number of high correlations for each representative characteristic from the three correlation analyses are: 4 features for AI, 3 features for AA, 7 features for ES, 5 features for O, 4 features for C, 6 features for E, 1 feature for A, and 6 features for N. Because agreeableness has just one data feature with a high correlation, it is insufficient for the computing process. Thus, the result of computation of the rest of the characteristics is represented below, excluding agreeableness.

Table 3 Spearman correlational analysis (selected by high correlations)

	AI	AA	ES	O	C	E	A	N
ACC_Q_Dev	.08	−.15	−.08	**.56***	−.18	.27	.28	−.04
ACC_Q_Min	**.63***	.47	**.63***	.33	**.56***	**.66***	.25	−.38
EDA_Q_Min	−.08	.01	−.23	.32	**.47***	−.17	−.29	**.58***
HR_M_Dev	.14	.03	**.16****	.70	.44	.09	−.20	.03
HR_Q_Min	.07	**.57***	−.01	−.26	.17	−.07	−.32	.13
Gamma_Max	−.05	**.69****	.02	.32	−.08	.37	.03	−.01
ACC_M_Dev	−.02	.06	.01	−.02	.02	.03	−.03	**.55***
Arousal_Max	.53	.23	**.78****	.12	.04	.55	**.36***	−.37
Arousal_Amp	.41	.43	**.87****	−.14	.06	.50	.21	−.25
Focus_Max	−.24	.36	−.09	**.49***	.20	.46	.09	−.01
Focus_Amp	−.14	.41	.35	.21	.08	**.71****	.35	−.08
Engage_Dev	−.13	.17	**.56***	.06	.02	**.57***	.40	−.12
Interest_Min	.04	−.10	−.20	−.10	**−.56***	−.24	−.05	.33
Interest_Dev	−.24	.16	.23	.12	−.10	**.57***	.38	.03

*p < .05, **p < .01. AI = Affect Intensity, AA = Attention Ability, ES = Emotional Stability

Table 4 Kendall correlational analysis (selected by high correlations)

	AI	AA	ES	O	C	E	A	N
ACC_Q_Min	**.48***	**.42***	**.53***	.23	**.56***	**.50***	.20	−.31
EDA_Q_Min	.01	.17	−.21	−.23	.47	−.11	−.26	**.50***
HR_M_Dev	.09	.02	.14	**.52***	.44	.09	−.11	.04
HR_Q_Min	.03	**.45***	.17	−.20	.16	−.06	−.22	.09
Gamma_Max	−.06	**.50***	.02	.22	−.08	.27	.03	−.01
ACC_M_Amp	.01	.02	.01	−.01	.02	.03	.03	**.49***
Arousal_Max	.40	.20	**.66****	.09	.03	.40	.26	−.22
Arousal_Dev	.41	.40	**.67****	.06	.38	**.50***	.32	−.32
Arousal_Amp	.27	.32	**.73****	−.14	.06	.35	.14	−.15
Focus_Amp	−.08	.25	.26	.16	.08	**.50***	.18	−.07
Interest_Min	.06	−.05	−.11	−.09	**.56***	−.19	−.03	.21

*p < .05, **p < .01. AI = Affect Intensity, AA = Attention Ability, ES = Emotional Stability

5.3 Computing of micro characteristics

The computed results of the three micro characteristics (i.e., affect intensity, attention ability, and emotional stability) from the selected features are shown in Table 5. The results of computing these characteristics consist of accuracy, precision, recall, and F1 value, according to three different methods (i.e., support-vector machine, neural network, and logistic regression), and are shown in the columns of Table 5, from left to right. For example, affect intensity is computed from 4 features, namely the minimum heart rate value and acceleration value, and the deviation of engagement value during the questioning and answering, and the maximum gamma mind wave value detected while watching the movie. Similarly, attention ability and emotional stability are computed from 3 features and 7 features respectively. The best result for computing attention ability was an accuracy of 0.731 reached by the neural network. While the best result for computing attention ability and emotional stability were accuracies of 0.761 and 0.923 reached by the neural network and the logistic regression, respectively.

Table 5 Results of affect intensity, attention ability, and emotional stability

AI	Accuracy	Precision	Recall	F1
SVM	0.115	0.066	0.115	0.08
NN	0.731	0.744	0.730	0.721
LR	0.615	0.545	0.615	0.570
Features: HR_Q_Min, Gammar_Max, Acc_Q_Min, Engagement_Dev				
AA	**Accuracy**	**Precision**	**Recall**	**F1**
SVM	0.307	0.268	0.307	0.255
NN	0.682	0.665	0.692	0.655
LR	0.761	0.803	0.761	0.761
Features: EDA_M_Min, HR_Q_Min,ACC_Q_Min				
ES	**Accuracy**	**Precision**	**Recall**	**F1**
SVM	0.308	0.186	0.308	0.222
NN	0.903	0.912	0.923	0.9238
LR	0.923	0.942	0.923	0.915
Features: EDA_M_Min, Arousal_Dev, Arousal_Amp, Arousal_Max, ACC_Q_Min, HR_M_Dev, Engagement_Dev				

AI = Affect Intensity, AA = Attention Ability, ES = Emotional Stability, SVM = Support-Vector Machine, NN = Neural Network, LR = Logistic Regression

Table 6 Correlations between Big Five personality traits and three micro characteristics

	O	C	E	A	N
Affect Intensity	−.13	.41	.30	.32	−.39
Attention Ability	−.28	−.04	.18	−.27	−.03
Emotional Stability	.04	.46	**.63***	.44	**−.49***

*p < .05, **p < .01

5.4 Computing of macro characteristics

Regarding the computing process, the macro characteristics could not only be calculated from highly correlated data features, but also from the highly correlated characteristics in affect, behavior, and cognition. The Big Five personality traits were selected as the target macro characteristics. Accordingly, correlations between each personality trait and three micro characteristics are shown in Table 6.

O = Openness, C = Conscientiousness, E = Extraversion, A = Agreeableness, N = Neuroticism.

Emotional stability has a high correlation with both extraversion and neuroticism, reaching 0.63 and 0.49, respectively. The coefficient of these two correlations are significant ($p < 0.05$). Hence, emotional stability is selected as an additional feature for the computing of these two traits. Four of five personality traits in total (i.e., openness, conscientiousness, extraversion, neuroticism) are computed from their corresponding high correlational features, as shown in Table 7.

Table 7 shows the result of computing four personality traits with a similar form to the result of computing micro characteristics in Table 5. Four indicators (i.e., accuracy, precision, recall, and F1 value) present comparative results computed separately from SVM, NN, and LR.

Table 7 Results of openness, conscientiousness, extraversion, neuroticism

Openness	Accuracy	Precision	Recall	F1
SVM	0.461	0.292	0.461	0.355
NN	0.730	0.797	0.730	0.722
LR	0.767	0.753	0.760	0.771
Features: HR_M_Min, Arousal_Amp, Acc_Q_Dev, Focus_Dev, AHR_M_Dev				
Conscientiousness	**Accuracy**	**Precision**	**Recall**	**F1**
SVM	0.308	0.222	0.308	0.254
NN	0.692	0.734	0.692	0.688
LR	0.807	0.815	0.807	0.807
Features: EDA_M_Min, ACC_Q_Min, EDA_Q_Min, Interest_Min				
Extraversion	**Accuracy**	**Precision**	**Recall**	**F1**
SVM	0.446	0.332	0.443	0.369
NN	0.654	0.718	0.654	0.653
LR	0.769	0.85	0.85	0.833
Features: Emotional Stability, ACC_Q_Min, Arousal_Dev, Focus_Amp, Engage_Dev, Interest_Dev, EDA_M_Min				
Neuroticism	**Accuracy**	**Precision**	**Recall**	**F1**
SVM	0.539	0.487	0.538	0.499
NN	0.615	0.674	0.615	0.606
LR	0.846	0.869	0.846	0.841

Features: Emotional Stability, ACC_M_Max, HR_Q_Min, Stress_Min, EDA_Q_Min, ACC_M_Dev, ACC_M_Amp

SVM = Support-Vector Machine, NN = Neural Network, LR = Logistic Regression

Openness and conscientiousness are computed from 5 data features and 4 data features respectively, while extraversion and neuroticism are calculated from both 6 data features and emotional stability. The best results for four of the personality traits are 0.767, 0.807, 0.769 and 0.846 respectively, both computed from the logistic regression method. Accordingly, it is noticeable that the results of computing extraversion and neuroticism calculated with a micro characteristic (emotional stability) show higher accuracy than those without micro characteristics. Thus, it indicates the correlation between micro characteristics and macro characteristics. Moreover, the result of computing personality traits is not as good as the result of computing micro characteristics, as such personality traits are more abstract and harder to compute than micro characteristics.

5.5 Computing of relational characteristics

The computing of relational characteristics is based on the K-Means clustering algorithm. Each computation is drawn from any two of affect intensity, emotional stability, attention ability, openness, consciousness, extraversion, and neuroticism. Four-pairs of personal characteristics with significant individual difference are selected and presented in Figure 8. The horizontal and vertical axis of each graph refer to two personal characteristics selected from macro and/or micro characteristics. The number of the clustering center is 3. All the four graphs show the individual difference, or relational characteristics. Take the first graph of Figure 8 as an example. The distribution of openness and affect intensity could be divided into three parts. Each part represents

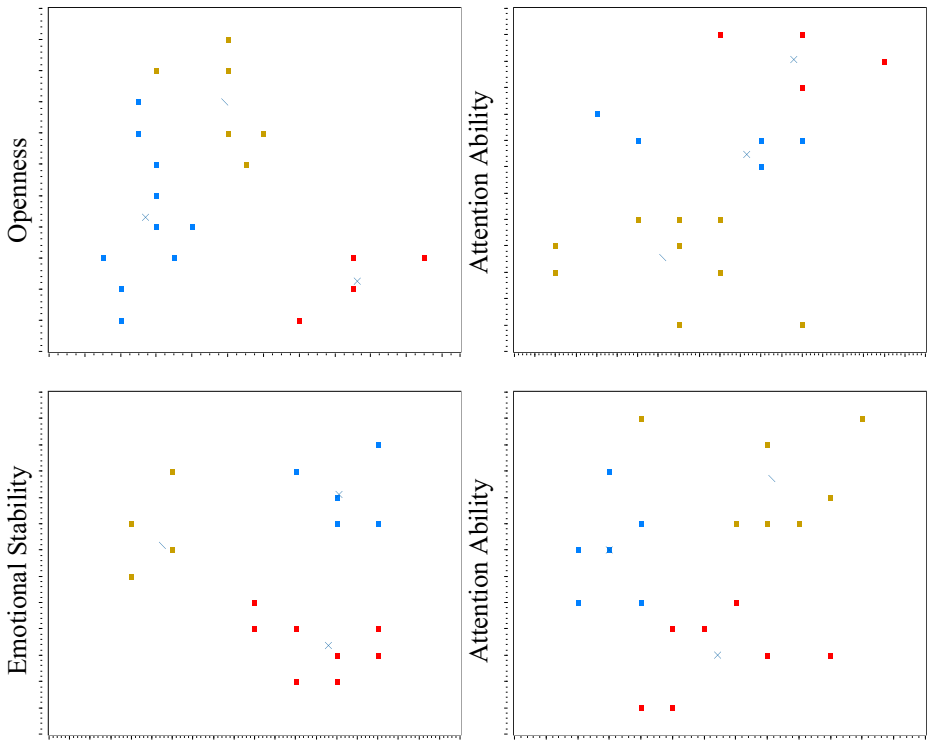

Figure 8 Four-pairs of personal characteristics Clustered by K-Means

a correlation between openness and affect intensity. Therefore, at least three correlations between these two characteristics exist according to 20 subjects' personal data.

6 Conclusion and future work

The individual-like intelligent artifact, as summarized in this paper, is a man-made physical or digital thing that resembles an existing human individual. Due to the lack of a sufficiently sophisticated internal mechanism to assimilate an individual, this research has focused on personal characteristics and proposed an integrated Personal Character Model based on three pillars. The individual-like intelligent artifact is therefore a potential application of the personal character model. Theories on differential psychology (ABCD of personality) and personality psychology provide the theoretical support, and personal big data role the data source for the Personal Character Model, due to such data's abundant quantity, continual provision and breadth of sources. To describe the proposed model vividly, a pyramid structure of Personal Character Model has been demonstrated with three types of personal characteristics, namely macro characteristics in personality (P), micro characteristics in affect (A), behavior (B) and cognition (C), and relational characteristics in A, B, C, and P. Each characteristic had a mathematical description with some psychological examples provided. To demonstrate the feasibility of computing the proposed model, three experiments were conducted and a variety of personal data was collected from twenty participants. Emotional stability, affect intensity, attention ability, and Big Five personality traits were selected as representative characteristics and were computed from the participants' personal data. One basic feature of the proposed personal character model is that it contains various personal characteristics at different levels (i.e., in macro, micro and relational). Such a quantity of personal characteristics could easily be integrated into applications for individual-like intelligent artifacts. This study carried out case studies to present the characteristic computing process as well as the computing results. The characteristic computing is based on three mainstream regression methods, and the computing results clearly showed individual differences in different aspects.

So much work remains for further study in the following aspects. Firstly, the personal character model could be enhanced to adapt to a greater number of psychological models. For example, desire is also highly correlated with personality according to W. Revelle's research. Since desire is hard to compute and describe, it is possible to regard desire as part of an individual's internal state, whereas the environment is one's external state. Secondly, a general and rational modeling process remains to be created because this paper is only putting forward a computing process using experimental data, whereas big personal data consists of data much richer variety of data, such as the lifelog data that is generated continually from an individual's daily behavior. Hence, the general modeling process should consider this diversity of data to reach more comprehensive and precise modeling. Lastly, more experiments should be conducted involving more participants, and a series of evaluation methods be adopted to estimate the rationality of the proposed model and the feasibility of its modeling process, as this paper simply describes the computing process in approximate terms, without detailed evaluation.

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