Examining the Influencing Factors of Intention to Use Domestic Robot by Grey Clustering Analysis

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***Abstract*—Domestic robots, even though introduced in the early 1980s, are still innovative products to the general public. This research combined Technology Acceptance Model and Innovation Diffusion Theory to explore the student's perception, acceptance, and adoption of domestic robot. The variables used in this study include relative advantage, trust, word of mouth, compatibility, communicability, attitude, consumer innovativeness, and simplicity. This study utilized a survey method to collect the perception data of using domestic robots and then grey clustering analysis to explore the influence of these factors. The questionnaires were administered to those students who took the course of general education. As the results showed that even if there are tremendously greater portion of the respondents have a high perception with Communicability and Simplicity than Word of Mouth and Relative Advantage, none of the eight factors reaches to high level with a proportion greater than 50%. That means that even though the performance and ease of use of domestic robots are well perceived, the image of relative advantage is still vague to consumers. Besides, the power of spread by word of mouth is amazingly weak with less than 9% of respondents falling in high level. This implies the domestic robot industries have to develop strategies to strengthen the relative advantage of domestic robots to convince the customers and to encourage users to share their user experience with the public.**

***Index Terms*—technology acceptance model, innovation diffusion theory, domestic robot, grey clustering analysis**

I. Introduction

Robotics comprises of two categories, namely, industrial robots and service robots. Service robots are produced for professional and personal/domestic use and the latter are manufactured to serve for mass market. Among personal/domestic use, household robots occupy the majority of the market share and grow at the fastest rate. This category includes vacuuming and floor cleaning robots, lawn-mowing robots, and entertainment robots. The former three robots are designed for domestic tasks and hence are called domestic (household or home) robots.

According to Ref [1], [2], the market size of professional service robots were 173,000 units with 32% growth rate in 2019 and the potential growth are expected to be 240,000 units (+38%) in 2020 and 537,000 units (+31% CAGR) in 2023. As for the market of service robots for personal and domestic use, the sold volume increased by 34% to 23.2 million units and the sales value grew up 20% to 5.7 billion U.S. dollars in 2019. Among these sales data, service robots for domestic/household tasks were 18.6 million units with 40% growth in 2019 and the potential growth rate are expected to be 21.6 million units (+16%) in 2020 and 48.6 million units (+31% CAGR) in 2023. The detailed sales are shown in Table I.

TABLE I. Robots for Domestic Tasks

	2018	2019	2020	2021	2022	2023
Millions of units	13.2	18.6	21.6	31.2	39.0	48.6
Billions of USD	3.5	4.3	5.0	6.7	8.2	10.0

Due to the rapid technological advancement of precise sensors, the Internet of Things, artificial intelligence, as well as cloud computing and storage, there are a variety of companies try to develop robots with different intelligent functions to meet the need of the market. It is expected that the household robots to integrate various functions to fulfill the features of the smart house. These functions include communication, entertainment, lifestyle, remote control, emotional expression, voice, pet care, baby care, silver care, home management, shopping, security, etc. [3].

Nevertheless, because of little advancement in technological killer application, the domestic robot market is still in its early stages. In this case, consumer views of domestic robots would have a substantial impact on the development of domestic robots. Precisely speaking, the disparity between expected and perceived quality of service is the key determinant of the acceptance

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of domestic robots [4]. That is why even though household robots introduced to the market can be traced back to the early years of the 1980s, domestic robots are still innovative products to the general public when compared to other consumer electronics, especially smartphones with 1.52 billion sold units in 2019 [5].

To investigate consumers' technology adoption behavior towards their acceptance of new technology and product, Ref. [6] proposed five innovation attributes as substantial decisive factors of technology adoption including relative advantage, compatibility, complexity, trialability, and observability. Ref. [7] identified two critical peculiarities of innovation to determine consumer's acceptable behavior towards innovation that is perceived usefulness and perceived ease of use. These two approaches were later called innovation diffusion theory (IDT) and the technology acceptance model (TAM) respectively and became the most important and popular theories to explain the prevalence of technology use. Afterwards, many researches modified and combined IDT and TAM to strengthen the power of explanation. Ref. [8], [9] clarified technical complexity as ease of use and relative advantage as perceived usefulness. Ref. [10] split observability into two independent dimensions as demonstrability and visibility. Ref. [11] argue that complexity is the opposite of simplicity. Furthermore, various research suggested other innovation attributes including communicability [12], word of mouth [13], [14], attitude [13], [14], trust [14], [15], and consumer innovativeness [16], [17]. Besides, Ref. [18] concluded that some of these factors will impede the diffusion of technology while some attributes will encourage the technology adoption decision.

Regarding the traits of innovation adopters, Rogers identified five customer segments of technology adoption as early as 1962. The top two categories including innovators (2.5%) and early adopters (13.5%) are both related to young people [6]. From then on, numerous research proposed that highly educated, young and high income consumers will adopt innovation more quickly and easily [19]. Young generation incline to be early adopters of innovation in Europe, US, and Japan [20].

Ref. [21] indicated that Millennials, youngsters in 2010s, are trustworthy, tolerant, individualistic, well-educated and more willing to use technology than their previous generations. Ref. [22] also suggested this generation is comprised of open, social, innovative, energetic, ambitious, reliable, motivated and intelligent young people. Ref. [23] proposed the reason why senior consumers avoid innovative products and services lies in the fact that awareness of age-related change and negative stereotype threat of aging restrict their innovativeness and shrink their intention to adopt novel products and services.

As for the cause of young generation apt to accept advanced products and services, ref. [24] suggested that the youngster's consumer behavior is considerably determined by technologies they grew up with.

Because IDT and TAM are both useful approaches to investigate the prevalence of innovate products and share some similar factors, it is reasonable to combine the factors induced from these two theories to explore the acceptance of household robots. Moreover, the fact that domestic robots do not prevail albeit youths have an inclination for accepting innovation is a serious topic deserves in-depth investigation. Accordingly, this study aims to incorporate the factors derived from IDT and TAM to conduct a survey to discover the perception of young generation on household robots and hence to develop suitable strategies to improve the popularity of home robots.

II. Research Methodology

A. Research Method

This research combined Technology Acceptance Model and Innovation Diffusion Theory to explore the student's perception of domestic robots. The variables used in this study include relative advantage, trust, word of mouth, compatibility, communicability, attitude, consumer innovativeness, and simplicity. This study investigates student's perception of domestic robots through survey method and grey clustering analysis (GSC).

This study utilized a survey method to collect the perception data of using domestic robots. A questionnaire containing twenty-one questions based upon the eight variables summarized from previous research in a literature review. Students were asked to rate their perception of each question according to the five-point Likert scales with the following classifications: strongly disagree", "disagree", "neutral", "agree" and "strongly agree" with "1" corresponding "strongly disagree" to 5 as "strongly agree". The questionnaire is designed as Table II, the factors and naming is showed as Table III.

TABLE II. Items of Questionnaire

No	Question
1	Domestic robot can help daily life
2	Domestic robot is safe enough
3	Domestic robot is effective
4	Family and friends advocate domestic robot
5	Domestic robot complies with my habits
6	Domestic robot has necessary function
7	The function of domestic robot is observable
8	I am always the first one to use new products
9	Household experts recommend domestic robot
10	I think domestic robot is a necessary appliance
11	Domestic robot is easy to use
12	Media promote the benefits of domestic robot
13	Domestic robot is reliable
14	The performance of domestic robot is obvious
15	I like to try new stuffs
16	Domestic robot can integrate appliances
17	I don't like domestic robot
18	Domestic robot is not so complicated
19	I have no confidence in domestic robot
20	Domestic robot complies with home appliances
21	I am always open to new ideas

TABLE III. FACTORS AND NAMING

Factors	Items	Naming
1	1, 3, 6	Relative Advantage
2	2, 13, 19 ^{R}	Trust
3	4, 9, 12	Word of Mouth
4	5, 16, 20	Compatibility
5	7, 14	Communicability
6	10, 17^{R}	Attitude
7	8, 15, 21	Consumer Innovativeness
8	11, 18	Simplicity

R: reverse question

B. Research Materials

A total of 181 copies of the questionnaire were administered to those students who took the course of general education in the fall semester of the year 2020 who participated voluntarily in this research. These students including freshmen, sophomores, juniors, and seniors came from the college of Management, humanities and social sciences, informatics, design, and engineering of the Chaoyang University of Technology This research didn't collect any identifying information nor offer any incentives to motivate students' participation. Consequently, 165 copies of the questionnaire were collected with a 90.05% response rate. After ruling out invalid responses, a total of 158 respondents were effective with 87.29% valid responses. The factor scores of 158 respondents are showed as Table IV.

TABLE IV. FACTOR SCORES OF 158 RESPONDENTS

SBJ	Rel. Adv.	Trust	WOM	Comm.	Comp.	ATT.	Cons. Innov.	SPL.
1	2.33	3.33	2.67	3.00	3.33	3.00	2.67	4.00
2	3.33	4.67	3.67	4.00	5.00	4.50	3.33	5.00
3	2.33	3.67	3.00	4.00	5.00	4.00	3.67	5.00
4	3.67	3.67	3.00	2.00	4.00	2.50	3.67	4.00
5	2.33	3.33	3.00	4.00	4.33	3.00	3.67	3.50
6	3.33	3.00	2.00	4.00	3.33	3.00	2.33	3.50
7	3.67	4.33	2.67	4.00	4.00	5.00	2.33	3.00
8	2.33	2.67	3.00	3.00	3.00	2.50	2.33	2.50
9	2.67	3.00	3.00	4.00	4.00	3.00	3.00	3.00
10	3.67	4.00	3.67	5.00	5.00	5.00	5.00	5.00
11	2.67	3.33	2.33	3.00	4.00	2.50	3.33	4.00
12	2.67	3.00	3.00	3.00	3.67	2.50	2.67	4.00
13	3.33	2.67	3.33	4.50	2.00	3.50	2.00	3.00
14	2.00	2.00	3.00	3.50	2.67	2.00	2.67	2.00
15	1.00	2.00	3.00	3.00	3.67	2.50	2.67	3.00
16	2.67	3.33	2.33	3.00	4.00	2.50	3.33	4.00
17	2.67	3.67	3.00	3.50	4.00	3.00	3.67	3.00
18	2.67	3.00	3.00	3.00	3.67	2.50	2.67	4.00
19	3.00	3.00	3.00	3.00	3.33	3.00	3.33	3.00
20	4.00	3.33	2.33	3.00	3.33	3.50	4.00	3.50
…	…	…	…	…	…	…	…	…
156	2.00	3.33	2.33	3.50	3.33	2.50	3.33	2.50
157	3.00	4.00	3.00	3.50	4.33	5.00	4.33	5.00
158	3.00	3.67	4.00	4.00	4.00	4.00	4.00	4.00

C. Analytical Instrument

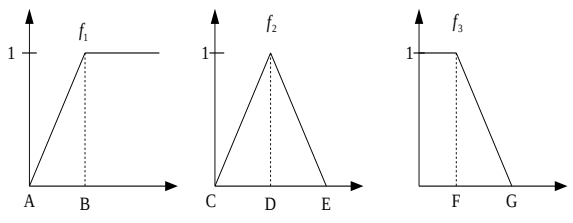
Likert scale is commonly used to design questionnaire and scale responses in survey research. When replying to Likert items, respondents have to sincerely identify their level of agreement on a symmetric agree-disagree scale for a series of descriptions. In this case, the range will confine their feelings for these items. Because this powerful explanation, Likert scale has been applied in various fields of social sciences [25]. However, several weaknesses of Likert scale have been documented in spite of its popularity. For example, some argued that the ordinal Likert scale may not precisely represent differences in the magnitude of perception [26]. Some indicated that participants may avert extreme responses and hence produce central tendency bias [27].

Besides, respondents are compelled to choose from the designed options that may not agree with their precise responses because the closed response format of Likert scale [28]. That means respondents may have to pick an ‘‘acceptable’’ answer in the insufficient range of responses [29].

Furthermore, the distance between any two consecutive values in interval scale are equal whereas the feeling assessed by Likert scale means a diverse interval between any two consecutive options [30]. That means the data obtained from Likert scale may be unreliable [31].

Fortunately, many researchers have improved the ambiguous character of Likert scale responses to be more dependable by using fuzzy logic to evaluate responses [32]. For that matter, the grey numbers, used in grey system are numbers having clear upper and lower limits but with unknown location [33], have the same characteristics as fuzzy numbers. Additionally, grey clustering, a branch of grey system theory, is employed to deal with the classification of responses [34] and then perform evaluation through the calculation results of the clustered indicators [35].

In agreement with the theory of grey clustering analysis [36]-[41], assuming $f(x)$ is a linear monotonic function of x, where x is a grey numeral and $f(x) \in [0,1]$, then $f(x)$ is termed a whiteness function of the grey numeral x, where $f_{max.}=1$. Moreover, $f(x)$ is habitually categorized into three levels of high, middle, and low, which are always given subjectively according to the nature of x shown as Fig. 1.



(a)High (b) Middle (c) Low

Figure 1. The whiteness function of grey number x.

1) Definition of grey clustering

1. $a_1, a_2, a_3, \ldots, a_m$ are statistical objects.

2. $b_1, b_2, b_3, \ldots, b_n$ are statistical indexes.
3. $f_1, f_2, f_3, \ldots, f_l$ are grey whiteness functions, where: $m, n, l \in N$.
4. d_{ij} are the sample values of the objects, where

$$d_{ij}, 1 \le i \le m,\ 1 \le j \le n \quad (1)$$

5. D is the matrix form containing d_{ij}.

$$D = \begin{bmatrix} d_{11} & d_{12} & \ldots & d_{1n} \\ d_{21} & d_{22} & \ldots & d_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ d_{m1} & d_{m2} & \ldots & d_{mn} \end{bmatrix} \quad (2)$$

6. F is a mapping, and $op[f_k(d_{ij})]$ is the operation of $f_k(d_{ij})$, where

$$F: op[f_k(d_{ij})] \to \sigma_{jk} \in [0,1],\ k \in N$$
$$1 \le i \le m,\ 1 \le j \le n \quad (3)$$
$$\sigma_j = (\sigma_{j1}, \sigma_{j2}, \sigma_{j3}, \ldots, \sigma_{jl}),\ 1 \le j \le n \quad (4)$$

Hence, σ_j is named as "weighting vector sequence of b_j".

2) Operation procedure of grey clustering

1. Denoting the whiteness function f_1, f_2, f_3, ..., f_l subjectively (typically 3 levels).
2. Computing the values of index *j* corresponding to the whiteness function $f_k(d_{ij})$.

$$\sum_{i=1}^{m} f_1 = f_1(d_{1j}) + f_1(d_{2j}) + f_1(d_{3j}) + \ldots + f_1(d_{mj})$$
$$\sum_{i=1}^{m} f_2 = f_2(d_{1j}) + f_2(d_{2j}) + f_2(d_{3j}) + \ldots + f_2(d_{mj})$$
$$\sum_{i=1}^{m} f_3 = f_3(d_{1j}) + f_3(d_{2j}) + f_3(d_{3j}) + \ldots + f_3(d_{mj})$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\sum_{i=1}^{m} f_l = f_l(d_{1j}) + f_l(d_{2j}) + f_l(d_{3j}) + \ldots + f_l(d_{mj}) \quad (5)$$

3. Summating the values of index *j*.

$$\sum f = \sum_{i=1}^{m} f_1 + \sum_{i=1}^{m} f_2 + \sum_{i=1}^{m} f_3 + \ldots + \sum_{i=1}^{m} f_l \quad (6)$$

4. Normalizing the weighting vector sequence.

$$\sigma_{j1} = \frac{\sum_{i=1}^{m} f_1}{\sum f}, \sigma_{j2} = \frac{\sum_{i=1}^{m} f_2}{\sum f}, \ldots, \sigma_{jl} = \frac{\sum_{i=1}^{m} f_l}{\sum f} \quad (7)$$

5. Selecting the maximum value of σ_j.

$$\max.(\sigma_j) = \max.(\sigma_{j1}, \sigma_{j2}, \sigma_{j3}, \ldots, \sigma_{jl}) \quad (8)$$

6. Repeating steps (1) to (5) to find the other objects.

III. Analysis Results

A. Demographic Characteristics of Respondents

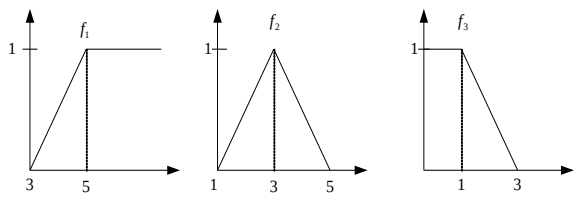
In this research, 158 valid respondents are analyzed. The demographic characteristics of these respondents are as Table V. Of the respondents, 64.6 percent of the survey respondents are females and 35.4 percent are males. This figure, combining with the greater proportion of respondents from management college (77.8%), largely reflects the fact that more females choose management school than males do. The majority of the answerers are junior and sophomore students accounting for 69%. As for the living status, over 40% of students live in parent's house followed closely by rented accommodations (39.2%) while only 20.3% of them live in dormitory. Regards the frequency of doing housework, doing sometimes (53.2%) and always doing (43.0%) jointly share the majority whereas never doing only account for 3.8%. Similarly, the majority of respondents have part-time (53.2%) and full-time (34.8%) work experience and only 12% have no experience of work.

TABLE V. Demographic Characteristics of Respondents

Variable	Response	Frequency	Percent
Gender	Female	102	64.6
	Male	56	35.4
College	Management	123	77.8
	Engineering	4	2.5
	Design	6	3.8
	HMAN & SS	12	7.6
	Informatics	13	8.2
Grade	Freshman	22	13.9
	Sophomore	49	31.0
	Junior	60	38.0
	Senior	27	17.1
Housing status	Parent's house	64	40.5
	Renting accom.	62	39.2
	Dormitory	32	20.3
Housework	Never	6	3.8
	Sometimes	84	53.2
	Always	68	43.0
Work experience	No	19	12.0
	Part-time	84	53.2
	Full-time	55	34.8

B. Grey Clustering Analysis

In line with the analytical process of grey clustering analysis, the first step set high level as between 3 and 5, middle level with 1, 3, and 5, and low level as between 1 and 3 according to the 5-point Likert scale of response options, shown as Fig. 2.



(a) High (b) Middle (c) Low

Figure 2. The whiteness function of factor scores.

In the second step, the factor scores of 158 respondents in Table IV were substituted into Eq. (5), Eq. (6), Eq. (7), and Eq. (8). The first factor, relative advantage, was taken as an example to illustrate the detailed calculation process as follows.

1. Calculating the values of high, middle, and low level of whiteness function of relative advantage.

$$\sum_{i=1}^{158} f_1 = f_1(2.33) + f_1(2.33) + f_1(2.33) + \ldots + f_1(3.00)$$

$$=0.000+0.165+0.000+\ldots+0.000=17.94$$

$$\sum_{i=1}^{158} f_2 = f_2(2.33) + f_2(2.33) + f_2(2.33) + \ldots + f_2(3.00)$$

$$=0.665+0.835+0.665+\ldots+1.000=108.79$$

$$\sum_{i=1}^{158} f_3 = f_3(2.33) + f_3(2.33) + f_3(2.33) + \ldots + f_3(3.00)$$

$$=0.335+0.000+0.335+\ldots+0.000=31.27$$

2. Summating the three-level values of whiteness function of relative advantage.

$$\sum f = \sum_{i=1}^{158} f_1 + \sum_{i=1}^{158} f_2 + \sum_{i=1}^{158} f_3$$

$$=17.94+108.79+31.27=158$$

3. Normalizing the three weighting vector sequences.

$$\sigma_{11} = \frac{17.94}{158} = 0.1135$$

$$\sigma_{12} = \frac{108.79}{158} = 0.6885$$

$$\sigma_{13} = \frac{31.27}{158} = 0.1979$$

4. Deciding the maximum value of σ_1.

$$\text{Max}(\sigma_1)=\max(\sigma_{11},\sigma_{12}, \sigma_{13})= \sigma_{12}=0.6885$$

The computation procedure of the other seven factors could be done correspondingly. Therefore, the results of grey clustering analysis for the eight factors were obtained and shown in Table VI. Finally, the calculation outcomes were proved by MATLAB toolbox [42], [43] as shown in Fig. 3.

About two-thirds of the respondents perceived moderate level of agreement for the eight factors. Compared with other factors, communicability has the greatest proportion (0.3372) of respondents falling in high level of agreement whereas word of mouth has the smallest (0.0897). On the contrary, communicability has the smallest proportion (0.0376) of respondents falling in low level of agreement whereas word of mouth has the greatest (0.2247). Besides, simplicity, trust, and attitude are ranked second to fourth from the top and the last in the high and low level respectively, with proportion less than 10% in the latter. The ranking results reflect the effect that respondents not only understand the easy-to-use and benefit of domestic robotic but also have confidence in and good image on it. However, the power of word-of-mouth recommendations did not work effectively.

TABLE VI. THE RESULTS OF GREY CLUSTERING ANALYSIS

Factor	High level	Middle level	Low level
Communicability	0.3372	0.6252	0.0376
Simplicity	0.3244	0.6348	0.0407
Trust	0.2369	0.7055	0.0577
Attitude	0.2281	0.6813	0.0906
Compatibility	0.2247	0.6592	0.1161
Consumer Innovativeness	0.2229	0.6757	0.1014
Relative Advantage	0.1135	0.6885	0.1979
Word of Mouth	0.0897	0.6857	0.2247

*Ranking by high level

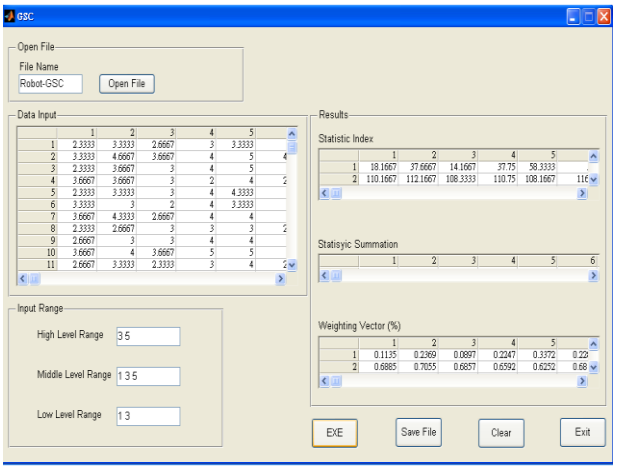


Figure 3. The verification for GSC by MATLAB toolbox.

IV. CONCLUSION

This study investigates student's perceptions of domestic robots through survey method and grey clustering analysis by combining the Technology Acceptance Model and Innovation Diffusion Theory. The variables used in this study include relative advantage, trust, word of mouth, compatibility, communicability, attitude, consumer innovativeness, and simplicity.

The fact that most respondents of this research living in parent's house (40.5%) and rented accommodations (39.2%) as well as doing housework sometimes (53.2%) and frequently (43.0%) suggested that there should be possibility for them to use home robots to reduce household burden. Similarly, it is practically expected that the majority of respondents have part-time (53.2%) and full-time (34.8%) work experience will have the ability to afford home robot. Owing to these two features combining with the natural inclination of young people to adopt new products and service, the eight variables integrated from IDT and TAM were supposed to have high level of appraisal by young generation. As the result shown in Table VI, even if there are tremendously greater portion of the respondents have high perception with Communicability (33.72%) and Simplicity (32.44%) than

Word of Mouth (8.97%) and Relative Advantage (11.35%), none of the eight factors reaches to high level with proportion greater than 50%. On the other hand, the percentage of low-level perception of each factor are all less than 25% led by Word of Mouth (22.47%) and Relative Advantage (19.79%). That means that even though the performance (communicability) and ease of use(simplicity) of domestic robots are well perceived, the image of relative advantage is still vague to consumers. Besides, the power of spread by word of mouth is amazingly weak. This conclusion accords with the inference by ref. [24] that development of innovative products ought to take into account consumer's perception of product value and ways of communication. That is to say, the domestic robot industries have to allocate more resources not only to strengthen the relative advantage of the domestic robot to convince the customers the products are worthy than other appliances but also to encourage users to share their user experience with the public.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Kuei-Chien Chiu and Chih-Sung Lai organized research design, wrote the manuscript, conducted literature review, formulated questionnaire, as well as handled questionnaire distribution, collection, and coding. Hsing-Hui Chu analyzed data and explained results. Rung-Ching Chen contributed to the reasoning of introduction and final version of the manuscript.

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