Consolidated findings from 6 years research on the age-differentiated design of human-computer interaction

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Abstract. The fast aging of many western and eastern societies and their increasing reliance on information technology create a compelling need to reconsider older users' interactions with computers. This paper summarizes the results of 6 years of research on the age-differentiated design of human-computer interaction. The well-known model of human information processing served as the theoretical framework. The model components "sensory processing", "perception", "working memory", "decision and response selection" and "response execution" were analyzed exemplarily in task settings on project management. In seven empirical studies with a total number of 405 participants between 20 and 77 years the human-computer interaction was analyzed regarding effectiveness, efficiency and user satisfaction. For most but not all studies the results reveal that age-induced differences in human-computer interaction can best be compensated by an ergonomic "design for all". In some cases however an age-specific approach is favorable.

Keywords: Human-Computer interaction, interface design, age-differentiated adaptation, aging

1. Introduction

The fast aging of many western and eastern societies and their increasing reliance on information technology create a compelling need for research and development on older users' interactions with computers. In Europe, for instance, the population of the EU-27 countries on January 1st, 2010 was estimated to be 501.3 million. The EU population ages at varying speed. Populations that are currently the oldest, such as Germany's and Italy's, will age rapidly for the next twenty years. In 2010, the median age of the EU population was 40.9 years, and it is projected to reach 47.9 years by 2060. The percentage of population aged 65+ is supposed to increase from 16% in 2010 to 29.3 % in 2060 [13]. The importance of computer work is increasing likewise. In 2010, 52% of the european working population uses a computer at least one time per week [8].

The literature tells us that as people age, changes occur in their perceptual, cognitive and motor systems that can have significant effects on their performance and well-being [3]. The so called deficit models dominated the theoretical underpinning of aging in the past. Deficit models postulate a graceful degradation in human information processing and physical functions from the late twenties on [20]. However, in recent years, models of aging had to be revised. Nowadays the changes that occur with aging are subsumed under the so called "compensation model" which acknowledges that age-dependent changes can be compensated by behavioral strategies, by experiences and attitudes, or that the elderly dispose over an alternative performance spectrum as compared to the younger [1]. In fact, the scope of decrease is highly individual and depends on the abilities under consideration and the particular characteristic of the task. Against the background of an aging workforce and the importance of computer technology to human work it is necessary to get a deeper understanding of the interrelationships between age-related changes in functional and physical abilities

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and the er gonomic d esign of future work system s. The Germ an Research Foundation (*Deutsche F or-schungsgemeinschaft*) responded to this gap of scientific kn owledge b y establishing P riority Pr ogramme 1184 on Ag e-differentiated W ork Syste ms in 2005. This i nterdisciplinary basic research pro gramme brings t ogether a t otal of 1 2 r esearch groups f rom engineering, psychology and economics with the goal of st udying t he i mplications an d e ffects of dem o-graphic change on human work and developing live-span models to create adequate working and learning conditions for employees of different ages. This paper summarizes the results of 6 years of research focusing on t he a ge-differentiated design a nd e valuation of human-computer interaction. Age related changes were analyzed exem plarily on the ba sis of a project management soft ware a pplication. C omputer s up-ported project m anagement i s pa rticular i nteresting, as it requ ires co mplex cogn itive skills as well as co - ordinative-communicative abilities.

The seminal Wickens model of human information processing [30] served as a t heoretical framework for the ag e-differentiated an alysis and i ntervention (Fig-ure 1). R egarding computer work with el ectronic in-formation displays the m odel elem ents " *Sensory Processing", "Perception", "Working Memory", "Decision and Resp onse S election" and "Response Execution"* were thought to have significant contribu-tion to the effectiveness, efficiency and user satisfac-tion of human computer interaction.
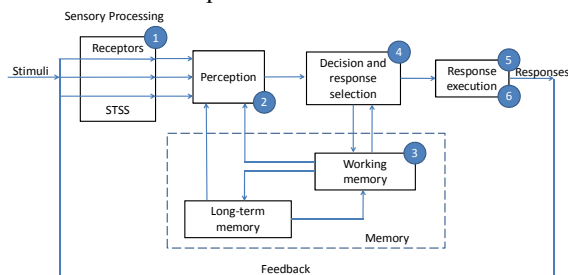

Fig.1: Model of human information processing
(Adapted from Wickens [30]).

Based on a literature an alysis on ag e-related changes in human inform ation pr ocessing six ad ap-tion di mensions wi th hi gh relevance f or computer-supported pr oject management could be d ifferenti-ated: (1) *angular font size of text and graphical sym-bols*, (2) *visualization of net work diagrams*, (3) *memorization of network diagrams*, (4) *interpretation of net work diagrams*, (5) *devices fo r information in-put* and (6) *manual information input on large touch screens* (for classification to the model of human in-

formation processing see numbered el ements i n Fig-ure 1).

The fi rst ada ption di mension *angular f ont size of text and graphical symbols* r efers to the encoding of information o n el ectronic i nformation di splays. D ue to ch anges of the v isual syste m th e ab ility to d etect and di fferentiate nearby o bjects (v isual acuity) n atu-rally deteriorates with increasing age. Although most software syste ms support the user s pecific ada ption of font size, t his feature is rarely use d by elderly computer users.

The sec ond a daption dimension *visualization of network di agrams* deals with the perc eption of and the navi gation in large gra phical st ructures. It is known t hat t he na vigation i n c omplex i nformation structures is po tentially strain ing, especially for t he elderly.

The th ird ad aption d imension *memorization of network di agrams* refers t o p ossible age- related changes in memorization of large graphical structures. Since co mputer wo rk primarily addresses co gnitive demands, an age-related decrease in working memory capacity also might have an effect on human perfor-mance measures. The state of findings concerning the effect of age on memorization performance of visual objects however is contradictory.

The fo urth adaption d imension *interpretation o f network di agrams* concentrates on possible a ge-related changes in the decision and response selection stages of i nformation p rocessing. I n t his c ontext i n-terpretation is a g eneral term referring to the mental processing, co mprehension a nd deci sion m aking i n computer s upported p roject pl anning wi th network diagrams.

The fifth adaption di mension *devices for inf orma-tion inp ut* refers to ag e-related ch anges in th e re-sponding stage of i nformation processing. Th e ag e-related decrease of m otor ski lls influe nces the s peed and accu racy of inform ation inp ut and po tentially impedes the e ase of use of c onventional i nformation input devices.

The sixth adaption dimension focuses on the *man-ual information i nput on la rge t ouch screens* as th is interaction-technique wa s f ound t o be beneficial fo r the performance of many user-groups, particularly for the elderly. However, the regular button size that is used i n m any softwa re syste ms is optim ized for mouse input and movements of t he hand-arm system are error prone when buttons are located in the upper area of the touch scree n. Thus, there is a ne cessity to develop basic concepts for an ergonomic information presentation and input on large touch screens.

2. Literature review

2.1. Exp. 1: Angular font size of text and graphical symbols

Eyesight is an ability of great importance for almost all work systems. Symptoms of an age-related eyesight degeneration process include a reduction of visual acuity, loss of power of accommodation or reduced color perception [18,25]. A loss of visual acuity in particular is often critical with regard to performance and safety. Normal visual acuity is represented by a visus value of 1.0, but it decreases with age. A 20-year-old normally has a visus between 1.0 and 1.6 whereas an 80-year-old's visus value lies between 0.6 and 1.0. The generalized decrease in visual acuity of older people is of particular importance when working with electronic information displays.

2.2. Exp. 2: Navigation in network diagrams

Ergonomic information visualization [5,7,29] has become an important paradigm for human-computer interaction. There are different approaches to support the navigation in complex network diagrams. In interfaces with an *overview map* show the details of a network activity together with a structural overview of the entire chart and can improve subjective satisfaction [21] and efficiency [2]. By the use of interfaces which provide *zoom function* the information space is directly visible and can be manipulated through panning and zooming. The most common zooming technique is the geometric zoom, where the scale linearly determines the apparent size of the object. A *fisheye view* functions analogous to a wide-angle camera lens, the idea is to show "local" detail in full (the objects of interest to the user), while displaying successively less detail for information out of the focus of attention.

2.3. Exp. 3: Memorization of network diagrams

As stated in the introductory section, the effect of age on memorization performance of graphical objects is indistinct. Many authors found evidence for an age-related decline in memorization performance of the spatial locations of objects [24,11,6,14,17,22]. Other authors however could not detect age-differences in recall performance of spatial object position [27,12]. In most studies on memorization performance, the experimental stimuli are presented in a sequential order. There are, however, no age-differentiated studies on the memorization performance regarding complex graphical structures as network diagrams. Based on investigations conducted by Winkelholz and Schlick [32], it was assumed that an improvement of memorization performance will occur for horizontally rather than vertically arranged network diagrams, as well as for a purposeful modification in spatial spread of activities.

2.4. Exp. 4: Interpretation of network diagrams

Regarding the interpretation of complex network diagrams it is assumed that according to the Proximity Compatibility Principle [31] a small spatial spread between activities leads to better performance. A positive effect due to horizontal orientation is also expected in this case [32].

2.5. Exp. 5: Devices for information input

Effective, efficient and satisfying human-computer interaction is strongly influenced by the use of input devices. As a result, different input device characteristics pose different requirements on human abilities. Therefore the compatibility between device characteristics and the abilities of the user determines the objective and subjective input performance to a large extent. Changes in motor abilities as reduced muscle strength, reduced range of motion and greater difficulty executing fine movements are highly correlated with age [28] and of major importance for information input. Thus elderly computer users may need other input devices than younger users with less requirements on motor abilities and less complex visuo-motor transformations.

2.6. Exp. 6: Manual information input on large touch screens

Large touch screens provide a promising alternative to classical electronic information displays in application areas where one has to display and manipulate complex information at once (plant design, project management, architecture, etc.). Research has shown that this interaction-technique can be beneficial for many user-groups, particularly for the elderly [15,19,23]. The effectiveness and efficiency of information input however depends highly on the ergonomic design of the user-interface. When redesigning application software originally designed for classical

desktop computers for large touch screens one has to consider where to display menus, buttons or icons, and which size these elements should have in order to improve pointing performance. To determine 'optimal' target sizes and target positions Fitts' Law [10] provides a highly satisfactory model. Fitts' Law states that the movement time (*MT*) is linearly dependent on the index of difficulty (*ID*) of a pointing task. The *ID* is defined as the dyadic logarithm of the quotient of amplitude of the movement (*A*) and horizontal target width (*W_h*):

$$MT = a + b \log_2\left(\frac{2A}{W_h}\right) \qquad (1)$$

Fitts' original study only considered one-dimensional movements, however on large touch screens one has to deal with two-dimensional movements and bivariate targets. As a first step in building a concept for the ergonomic information input on large scaled touch screens Fitts' Law had to be refined regarding two-dimensional pointing of bivariate targets.

3. Method

Over the 6 years of research 405 participants between 20 and 77 years participated in seven empirical studies regarding potential age-related differences in human-computer interaction.

3.1. Exp. 1: Angular font size of text and graphical symbols

The age-induced change in visual acuity and its impact on performance in a target detection task was investigated in an empirical study with 75 subjects aged between 20 and 72 years. Subjects were divided into three age groups (AG I: 20-35, AG II: 40-59, AG III: 60-72 years) with 25 persons in each group. Acuity of vision was measured using the standardized eyesight Rodatest 302. In the target detection experiment Landolt rings of three different angular font sizes (12, 16 and 22 arc minutes) served as targets displayed on a TFT-LCD screen. The participants' task was to react to a Landolt ring with a particular position of opening by pressing the space key. The participant thus had to detect and recognize the previously specified target Landolt ring out of a sequence of 120 Landolt rings composed of 15 correct

and 105 incorrect Landolt rings. Each ring was shown for 1.5 seconds. After a five minute break, the procedure was repeated with the next permutation of font size, et cetera. The number of correctly detected Landolt rings (hits), the number of wrongly detected Landolt rings (false alarms) and the response time of correct responses were analyzed using an ANOVA with repeated measures. The relationship between visus data from Rodatest 302, the participant's age in years and the response time in the target detection task was analyzed by correlation analysis.

3.2. Exp. 2: Navigation in network diagrams

The navigation in complex network diagrams was investigated with 90 participants between 20 and 75 years of age. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. Three different visualisation variants of network diagrams (overview map, detail window and zoom function) were tested against a network diagram which can be found in many commercial off-the-shelf software packages. In this variant detailed information of the activities (name, starting time and duration) was given and the scrolling bar had to be used to explore the network diagrams. In the overview map, the default network diagram was enriched by structural information displayed in an overview window. For the two other visualization variants the information displayed on the activities was reduced. Thus, the whole network diagram was displayed on the screen and scrolling was not needed. By touching an activity detailed information was provided either at a fixed position in the upper left corner of the screen (detail window) or at the position of the respective activity (zoom function). The experimental task was carried out on a 17" touch screen. The participants had to execute typical project management tasks like changing the starting time or duration of an activity and connecting or deleting activities with each of the visualization variants. Execution time, errors, scrolling and search time as well as subjective mental workload (NASA-TLX) were measured as dependent variables.

3.3. Exp. 3: Memorization of network diagrams

The memorization of complex network diagrams was investigated with 90 participants between 20 and 75 years. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. Six network diagrams layouts

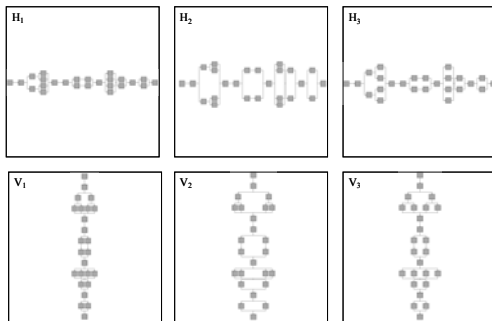depicted in figure 2 were displayed on a TFT-LCD computer screen.

Fig. 2: Six layouts of the network plans.

Each network diagram consisted of 25 activities. The diagrams differed regarding their orientation, horizontal (H) versus vertical (V), and their spatial spread: (1) no spread, (2) clustered, (3) uniformly spread. After an acoustical signal, a randomly created sequence of five activities was highlighted by color changing. Each activity was highlighted for two seconds. The end of a sequence was indicated by a second acoustical signal. The participant had to repeat the sequence by clicking the activities in correct order with a mouse. After five activities a short break was obligatory and the next sequence was presented. There were six randomly created sequences for each layout. The same six sequences corresponding to one layout were presented to each subject. The order in which the various layouts were presented was balanced. Execution time and the number of correctly repeated sequences were measured as dependent variables.

3.4. Exp. 4: Interpretation of network diagrams

The memorization of complex network diagrams was investigated with the sample of experiment 3. The six network diagram layouts depicted in figure 2 were used in a simplified form. Additionally, the start and end times for each activity were displayed within the diagram (see figure 3).
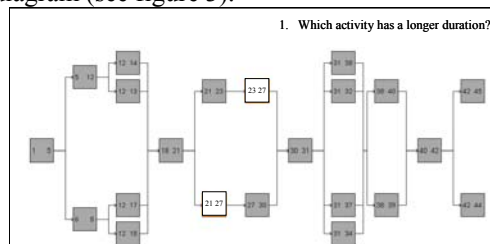

Fig. 3: Screenshot of layout H2.

After an acoustical signal, one or two randomly chosen activities were highlighted. After two seconds, one of the following four questions concerning the highlighted activities appeared: *(1) "Which activity has a longer duration?", (2) "Which activity ends first?", (3) "How many direct predecessors does this activity have?" (4) "How many direct successors does this activity have?"*. The subject had to answer the question by marking the correct activity, respectively, the correct number, by mouse click. Then the next question was presented. Each test subject had to answer identical questions in the same sequence per layout. The order in which the various layouts were presented was balanced between test subjects. Execution time and the number of correctly answered questions were measured as dependent variables.

3.5. Exp. 5: Devices for information input

Three input devices, (1) mouse, (2) touch screen and (3) eye-gaze control, were contrasted with one another on the basis of a two-dimensional pointing task. A total of 90 subjects between 20 and 75 years participated in the study. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. The pointing task had to be executed with each of the three input devices as fast and accurately as possible. When using the mouse, the cursor had to be positioned in the starting circle first and then moved to the target square. The start and target positions had to be confirmed with a mouse click. When using the touch screen, the task consisted of touching the starting circle, followed by touching the target square with the index finger. For the eye-gaze control, the task required first to visually fixate on a point within the starting circle and then to fixate the target square. The fixation dwell time on the target object was set to 100 ms. The execution time and the error rate were dependent variables.

3.6. Exp. 6: Manual information input on large touch screens

In the first study [26] the two most common target width definitions W_{min} and W' were analyzed in an empirical study with 30 right-handed subjects (20-73 years) in a pointing task on a large scaled touch screen (projection area 865 mm x 649 mm, 4:3 ratio). Subjects were divided into two age groups (AG I: 20-32, AG II: 58-73) with 15 persons each. The experimental task showed rectangular target ob-

jects at a constant angle of 0° (movement to the right) which were rotated around their centre. Hereby, W' was varied systematically, whereas W_{min} was kept constant.
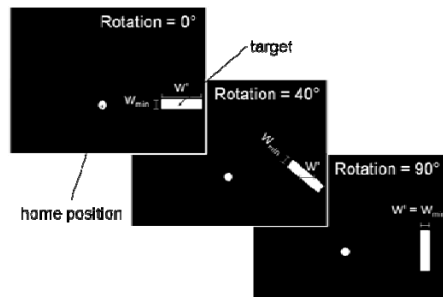

Fig. 4. Experimental setting for target rotations of 0°, 40°, 90°.

In the second study [4] the motion angle was investigated with 30 participants aged between 21 to 77 years. Subjects were divided into two age groups (AG I: 21-36, AG II: 58-77) with 15 persons each. The angle between start-and target object was varied systematically in 10° steps between 0° (movements to the right) and 180° (movements to the left). To eliminate influences of the target width, circular target objects were used.
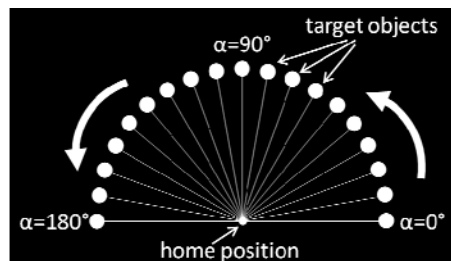

Fig. 5. Experimental setup for a start position at 0°.

The mean response time of correct responses was calculated as a dependent variable.

4. Results

According to the experimental designs the data was analysed by analyses of variance with repeated measures (ANOVA), correlation analyses and linear as well as nonlinear regression analyses. The significance level for each analysis was p=0.05. For significant main effects the effect size ω^2 for repeated measures [9] was calculated. Only main results are reported. For a detailed analysis the reader is referred to the original publications.

4.1. Exp. 1: Angular font size of text and graphical symbols

The results from an ANOVA show a strong effect of font size ($\omega^2=0.73$) and a medium age-related effect ($\omega^2=0.48$) concerning the response time of correct responses. The interaction effect of font size and age group ($\omega^2=0.10$) shows that age-related differences in response time can be compensated by enlarging the angular font size from 16 to 22 arc minutes. Results from partial correlation analysis show that an age-differentiated adaptation of font size is recommended rather than an adaptation based on measurement of visual acuity.

4.2. Exp. 2: Navigation in network diagrams

The ANOVA of the execution time across all visualization variants shows a significant main effect of age group with a medium effect size of $\omega^2=0.66$. The visualization variant also has a significant effect on the execution time with a large effect size of $\omega^2=0.91$. Furthermore, the data show that for the 20-39 year-olds and 40-59 year-olds the shortest average execution times are reached by working with the detail window whereas the elderly participants (60-75 year olds) performed best when using the zoom function. Regarding the number of errors, the ANOVA indicated significant effects of age group ($\omega^2=0.23$) and visualization variant ($\omega^2=0.13$). The lowest error rate was found for the detail window and zoom function. The control variant leads to longest searching times and the reduced network diagram with zoom function to the shortest. Scrolling time is shorter with the overview window compared to the control variant. Regarding the subjective evaluation of mental workload the zoom function leads to the least and the control layout to the highest workload.

4.3. Exp. 3: Memorization of network diagrams

For the number of correctly memorized sequences as well as the overall execution time ANOVAs confirmed significant age effects ($\omega^2=0.32$; $\omega^2=0.25$), with the highest memorization performance in the group of the 20-39 year olds. The results of the layout design of the network diagrams show significant effects of spread ($\omega^2=0.68$) on execution time ($\omega^2=0.15$) and number of correctly repeated sequences ($\omega^2=0.68$). The layouts "cluster spread" and

"uniformly di stributed s pread" are beneficial for memorization performance (high am ount of c orrect answers, l ow amount of required t ime). The l ayout without sp read scores si gnificantly lo wer. Regarding the orientation o f the network diagram, a h orizontal layout sc ores significantly h igher t han t he vert ical layout (ω^2=0.70).

4.4. Exp. 4: Interpretation of network diagrams

Since there was v ery little v ariance in the number of c orrectly a nswered questions as al most no er rors occurred, only th e resu lts of th e respon se t ime were analyzed with an ANOVA. The results reveal that the age group (ω^2=0.41) and the spatial spread (ω^2=0.27) of the n etwork activ ities h ave sign ificant effects on response time. Post-hoc paired comparisons of means showed sign ificant differences bet ween all a ge groups. Response time increases with increasing age. Regarding the spatial spread, it was found that equal-ly d istributed spread lead to sho rter response tim es than a cl uster spread or a layout without spread . However, spatial ori entation of the network di agram had no significant effect on response time.

4.5. Exp. 5: Devices for information input

The ANOVA of the execution times across all in-put devices shows a significant main effect in relation to age group (ω^2=0.55). Post-hoc paired comparisons of m eans showed significant differe nces betwee n AG I and AG II as well as between AG I and AG III. The input device also has a significant effect on exe-cution time (ω^2=0.51). The touch screen leads to sig-nificantly bette r performance than t he eye-gaze con-trol an d m ouse in put. Furthermore, a si gnificant in-teraction e ffect bet ween a ge gr oup and i nput device occurs. Th e data show t hat the a verage execution times of AG II and A G III diffe r sig nificantly only for mouse input.

4.6. Exp. 6: Manual information input on large touch screens

Linear regression a nalysis shows that the move-ment time varies as a function of the t arget width in the direction of motion (W'). Furthermore, significant effects of the target height perpendicular to the direc-tion of motion (H') were found. The best empirical fit was found for a model taking into account the target width in the direction of motion (W') and the target height perpendicular to the direction if motion (H'):

$$MT = a + b \log_2\left(\frac{A}{W} + 1\right) + c \log_2\left(\frac{A}{H} + 1\right). \quad (2)$$

The results of the seco nd stud y r eveal t hat move-ment t ime fol lows a si nusoidal c urve de pending on the angle. Based on the results of both studies a mod-el for two-dimensional pointing and bivariate, rectan-gular target objects was derived:

$$MT = a + b \log_2\left(\frac{A}{W} + 1\right) + c \log_2\left(\frac{A}{H} + 1\right) + d \sin(2\alpha) \quad (3)$$

The formulas (2) and (3) are based on the Shannon formulation [16] by MacKenzie and Buxton.

5. Discussion

For a detailed discussion of t he results in the lig ht of the literatu re th e reader is referred to the o riginal papers. Becaus e of limited space the results are bro-ken down in consolidated "take home messages" for the age-differentiated design of HCI as follows:

- Elderly c omputer u ser d o be nefit from a l arger font size. In most cases it is not nec essary to measure visual acuity, but simply to enlarge an-gular font size based on age up to 22´.
- If possible, reduce information displayed at once by t he use of zoom fu nctions. El iminate or re-duce scrolling activities.
- Arrange n etwork diagrams (or sim ilar g raphical models) ho rizontally. Reg arding th e spatial spread of activ ities it dep ends on th e task . If memorization is m ore im portant, use a l arge cluster spread , if in terpretation do minates, choose a narrow equally distributed spread.
- Use touch screens for the elderly. For physically impaired c omputer user ey e gazed input is a promising alternative.
- When designing software for large touch screens, the refined Fitts´ Law can b e used to determine an 'optimal' an gular po sition of buttons and in-teraction el ements. Furthermore, t he m odel ca n be used a priori to calculate the best proportions of t he si de l engths f or buttons a nd i nteraction elements depending on the angle.

Acknowledgement

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