Measuring acceptance of an assistive social robot: a suggested toolkit

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Abstract—**The human robot interaction community is multidisciplinary by nature and has members from social science to engineering backgrounds. In this paper we aim to provide human robot developers with a straightforward toolkit to evaluate users' acceptance of assistive social robots they are designing or developing for elderly care environments. We will explain how we developed the measures for this analysis, provide do's and don'ts in designing the experiments, demonstrate the application of the measures we have developed for this purpose and the analysis and interpretation of the data. As such we hope to engage human robot interaction developers in evaluating the acceptability of their own robot to inform the development process and improve the final robot's design.**

I. Introduction

In facing a growing elderly population and increasing labor shortage in the industrialized world, robots and screen agents are considered a potential contribution to a solution [1-3]. However, if indeed robots are to be used in the (near) future by elderly users, they have to be accepted and although a large category of elders may be open to facilitating technologies, technology acceptance remains a delicate matter [4]. There is a range of systems and applications developed to fit the demands of elderly such as being monitored, medication reminding, physical assistance and mediation between users and advances (assistive) technologies. However, often these technologies are still not actually used, often because of factors like stigmatization, (non-)adaptability or social influences.

Defining user acceptance as "the demonstrable willingness within a user group to employ technology for the tasks it is designed to support" [5] brings the need to develop evaluation methodologies. Specifically for robots and screen agents several methods have been used, varying from applying heuristics [6] or other usability type tests [7] and classifying tests [8] to measuring physical responses [9]. Also an adaptation of the Technology Acceptance Model [10] has been used [11] - a methodology that does not only provide insight in the probability of acceptance of a specific technology, but also in the influences underlying acceptance tendencies. However, technology acceptance models have not been developed for systems that can be perceived as a social entity, such as a robot or screen agent and also not particularly for elderly users. Influences that are known to be of importance in acceptance of a social entity have never been adapted by any technology acceptance model and neither have influences that are known to be of influence by elderly users.

Therefore, in our study we research the possibilities of using an acceptance model for quantitative research on acceptance of assistive social robots. We include in this category all those robots that are in any way assistive to older adults and that are socially interactive [12] (this is a more extensive category than socially assistive robots [13]). We aim to include specific influences representing social acceptance and the specific demands of elderly users.

In the next sections we will discuss the essentials of technology acceptance and show how we developed a model and instrument that can be applied to evaluate acceptance of assistive social robots. Next, we explain how it can be applied by running through an actual user study with a social assistive robot in an eldercare institution.

II. Technology Acceptance Models

An overview of technology acceptance modeling usually starts with the introduction of the technology acceptance model (TAM) by Davis in 1989 [10], based on the work of Ajzen and Fishbein [14]. In its most basic form it states that usefulness and ease of use as perceived by the user determine the behavioral intention to use a system and it assumes that this behavioral intention is predicting the actual use. The model has been used for many different types of technology and has been extended with other factors that supposedly influenced Intention to Use or usage.

The instruments developed to measure technology acceptance have each construct (such as Intention to Use) represented in a questionnaire by a group of questions or statements that can be replied to on a five or seven point Likert type scale. The validation of a model typically includes gathered data on the actual use that has to relate to scores on the indicated intention to use the technology.

In 2003, Venkatesh et al. [15] published an inventory of current models and factors and presented a model called UTAUT (Unified Theory of Acceptance and Use of

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Technology) in which all relevant factors were incorporated.

III. DESIGNING A NEW MODEL FOR ASSISTIVE SOCIAL ROBOTS

The UTAUT model has been used for a study into acceptance of a conversational robot as described by De Ruyter et al [16]. It concerned a robotic interface which was tested in a Wizard of Oz experiment where the robot was controlled remotely by an experimenter while the participants perceived it to be autonomous. This experiment was done in a laboratory setting, with adult, but not elderly participants.

Results showed that a more extravert robot was perceived as more socially intelligent and was more likely to be accepted by the user than a more introvert version. The same robot was used in an experiment by Looije et al. [17] as a personal assistant for a small group of people with diabetes. Results showed that participants appreciated a more social intelligent agent more and had a higher intention of using it.

It seems that perceived social abilities of a robotic system are indeed appreciated as they would be in a human conversational partner. In our earlier research we tried to find evidence that this can be applied to elderly users of a social assistive robot. We applied the UTAUT model but found it had a low explanatory power (43 percent) and it insufficiently indicated that social abilities contribute to the acceptance of a social robot by this particular user group. We found that it needed to be further adapted to the specific technology of assistive social robots [18, 19]. UTAUT constructs that were applicable were Anxiety, Attitude, Facilitating Conditions, Social Influences and the 'classic TAM constructs' Perceived Ease of Use and Perceived Usefulness.

We carried out several studies, focusing on possible constructs that could be added to these and found Perceived Enjoyment, Perceived Sociability and Social Presence to be applicable to social robots and Perceived Adaptability to be applicable to the specific user group of older adults [20-22]. Perceived Enjoyment is a construct that has been applied in several TAM studies concerning hedonic systems and we found that robots are indeed partly experienced as such. Perceived Adaptability is a construct that turned out to be specifically applicable to users of assistive technologies: they want a system only to help them when it is really necessary and to be adaptive if their needs are changing. Social Presence and Perceived Sociability relate most specifically to social acceptance of robots. Although they have been studied as relevant aspects in human-robot interaction, they have not been used in any acceptance model yet. In earlier studies, we could not establish a direct influence of these constructs on the intention to use the system, but we found that an increase of a robots social abilities leads to an increased sense of Social Presence and this again would lead to an increase of Perceived Enjoyment.

We constructed a questionnaire in which each construct is represented by multiple statements. In the used forms, these statements are not to be presented in this sequence, but randomly ordered and renumbered. Users can reply to these statements on a Likert type scale. Of course, statements on relevant external variables like age, gender, education or computer experience can be added. When processing the results of this questionnaire, one to five points are noted for replies. If a statement can be characterized as positive, (like item 18) a higher rate of agreement results in a higher score, so 'strongly agree' would be five points. When a statement can be characterized as negative (like item 3) a stronger agreement leads to a lower score.

TABLE 1 – MODEL OVERVIEW

Code	Construct	Definition
ANX	Anxiety	Evoking anxious or emotional reactions when using the system.
ATT	Attitude	Positive or negative feelings about the appliance of the technology.
FC	Facilitating conditions	Objective factors in the environment that facilitate using the system.
ITU	Intention to use	The outspoken intention to use the system over a longer period in time.
PAD	Perceived adaptability	The perceived ability of the system to be adaptive to the changing needs of the user.
PENJ	Perceived enjoyment	Feelings of joy or pleasure associated by the user with the use of the system.
PEOU	Perceived ease of use	The degree to which the user believes that using the system would be free of effort
PS	Perceived sociability	The perceived ability of the system to perform sociable behavior.
PU	Perceived usefulness	The degree to which a person believes that using the system would enhance his or her daily activities
SI	Social influence	The user's perception of how people who are important to him think about him using the system
SP	Social presence	The experience of sensing a social entity when interacting with the system.
Trust	Trust	The belief that the system performs with personal integrity and reliability.
Use	Use/Usage	The actual use of the system over a longer period in time

As Table 1 and Figure 1 show, we found interrelations between constructs, which can be used as hypotheses when the model is used for a specific system. If the entire model is used, there are seven hypotheses:

- H1 Intention to Use is determined by (a) Perceived Usefulness, (b) Perceived Ease of Use, (c) Attitude, (d) Perceived Enjoyment, (e)Social Influence and (f)Trust.
- H2 Use is determined by (a) Intention to Use and influenced by (b)Social Influence and (c)Facilitating Conditions.
- H3 Perceived Usefulness is influenced by (a) Perceived Ease of Use (b) Perceived Adaptability and (c) Anxiety
- H4 Perceived Ease of Use is influenced by (a) Anxiety, (b) Perceived Enjoyment and (c) Perceived Usefulness
- H5 Perceived Enjoyment is influenced by Social Presence and Perceived Sociability
- H6 Perceived Sociability is influenced by Trust
- H7 Social Presence is influence by Perceived Sociability

H2 can not always be applied, since gathering data on actual use of the system is not always possible. In that case the items on Facilitating Conditions can be removed from the questionnaire.

TABLE 2 – QUESTIONNAIRE

ANX	1. If I should use the robot, I would be afraid to make mistakes with it
	2. If I should use the robot, I would be afraid to break something
	3. I find the robot scary
	4. I find the robot intimidating
ATT	5. I think it's a good idea to use the robot
	6. the robot would make my life more interesting
	7. It's good to make use of the robot
FC	8. I have everything I need to make good use of the robot.
	9. I know enough of the robot to make good use of it.
ITU	10. I think I'll use the robot during the next few days
	11. I am certain to use the robot during the next few days
	12. I'm planning to use the robot during the next few days
PAD	13. I think the robot can be adaptive to what I need
	14. I think the robot will only do what I need at that particular moment
	15. I think the robot will help me when I consider it to be necessary
PENJ	16. I enjoy the robot talking to me
	17. I enjoy doing things with the robot
	18. I find the robot enjoyable
	19. I find the robot fascinating
	20. I find the robot boring
PEOU	21. I think I will know quickly how to use the robot
	22. I find the robot easy to use
	23. I think I can use the robot without any help
	24. I think I can use the robot when there is someone around to help me
	25. I think I can use the robot when I have a good manual.
PS	26. I consider the robot a pleasant conversational partner
	27. I find the robot pleasant to interact with
	28. I feel the robot understands me.
	29. I think the robot is nice
PU	30. I think the robot is useful to me
	31. It would be convenient for me to have the robot
	32. I think the robot can help me with many things
SI	33. I think the staff would like me using the robot
	34. I think it would give a good impression if I should use the robot.
SP	35. When interacting with the robot I felt like I'm talking to a real person
	36. It sometimes felt as if the robot was really looking at me
	37. I can imagine the robot to be a living creature
	38. I often think the robot is not a real person.
	39. Sometimes the robot seems to have real feelings
Trust	40. I would trust the robot if it gave me advice.
	41. I would follow the advice the robot gives me.

ANX: Anxiety, ATT: Attitude, FC: Facilitating Conditions,
ITU: Intention to Use, PAD: Perceived Adaptability,
PENJ: Perceived Enjoyment, PEOU: Perceived Ease of Use,
PS: Perceived Sociability, PU: Perceived Usefulness,
SI: Social Influence, SP: Social Presence

IV. APPLYING THE MODEL

If a system is tested to map all influences on its acceptance, the complete questionnaire can be used. A study can also focus on specific influences, which means only a part of the constructs is used. If the focus is for example on social abilities or social presence, a study could focus on the lower part of the model, as visualized in Figure 2. This would be typical in a situation where developers work on features that increase the users' sense of social presence.

A study concerning highly adaptive robots for elderly users would perhaps only use the upper part of the model, while if a study does not concern elderly users, the construct of perceived adaptability is less relevant.

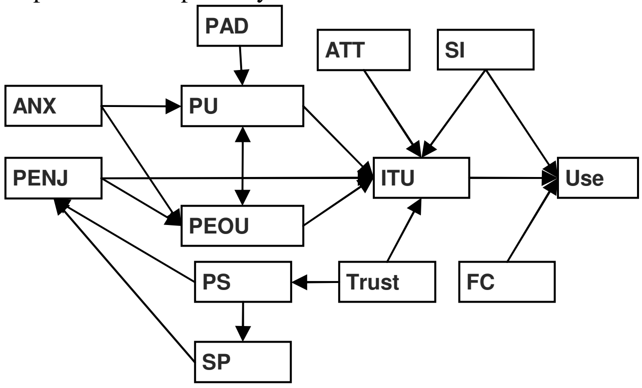

Figure 1. Overview of construct interrelations

The model or parts of it can also be adapted or even be used for other systems than assistive social robots. In that case it has to be re-validated: a significant relationship between Intention to Use and Usage has to be established.

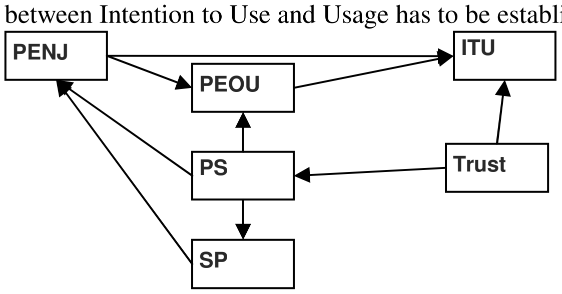

Figure 2. Limited model for studies on social abilities or social presence

Processing the results of the questionnaire usually includes the following procedure:

- Calculating the scores for each construct by averaging the scores on the items.
- Establishing Cronbach's Alpha for the items of each construct [23]. A solid construct would have an alpha of at least .7 [24]. If a construct consists of more than two statements, it is a good idea to see what the score would be if a question is omitted, especially if the alpha is not high enough. In that case, omitting a statement could be an option if solid arguments can be found.
- Analyzing basic descriptive statistics: minimum, maximum and mean scores, and standard deviation to get a first impression on the scores.
- Testing hypotheses with correlations (strictly explorative) or linear regression analysis [25, 26]. A linear regression analysis would demand preferably at least 20 participants for each construct, but never less than 5. It can be performed separately for each hypothesis, which means a test would preferably include at least 120 participants and no less than 30. It measures how much each determining construct (being independent variables) is influencing a particular

construct (being a dependant variable). Usually also an ANOVA table is generated with a regression analysis. This can be used to analyze the predictive value of the combined constructs within a hypothesis.

- The most profound way to analyze results would be to apply structural equation modeling. This could be used to establish alternate paths and the strength of construct interrelations. This would demand at least 15 to 20 cases (users) per construct though, and in this field it is often not possible to gather that many participants.
- Correlation scores can be established with any number of participants. They can't be taken as proof for determining relationships, but as an indication. Correlation analysis is especially useful if multiple tests need to be compared or if proving determining relationships are not subject of study.
- Of course there can be additional statistics. When comparing different conditions or user for example, a t-test or Mann-Whitney u-test can be carried out.
- To test (parts of) the model, especially if any changes are made, also factor analysis with rotation component matrix can be used to check if items that belong to a construct indeed 'load' on the same factor.

V. CASE EXAMPLE

Our example study concerns a user study in which the full set of constructs is used to map the influences on acceptance of a specific social assistive robot. This means we actually tested all seven hypotheses. Besides, actual use is measured, which makes it possible to demonstrate the validity of the model if a significant relationship between Intention to Use and actual use can be established.

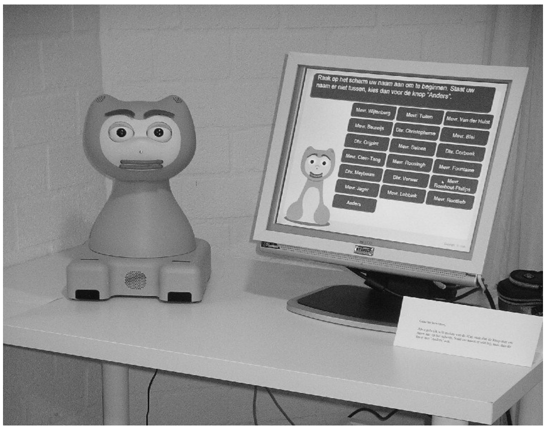

Figure 3. Setup iCat with touch screen

The robotic agent we used in this user study is the iCat, also used in the experiments by De Ruyter et al. and within our own project. The iCat is a 38 cm tall immobile robot with movable lips, eyes, eyelids and eyebrows to display different facial expressions to simulate emotional behavior. There is a camera installed in the iCat's nose which can be used for different computer vision capabilities. The iCat's base contains two microphones and a loudspeaker.

A. *Setup*

For our user study we used a setup in which the robot was connected to a touch screen as is shown in Figure 3.

It could be used for information and for fun: participants could ask for weather forecast, a television program overview or a joke by pressing the appropriate choices from a menu on the screen. The information was then given with pre-recorded speech by the iCat, for which we used a female voice. The recording was done with a text to speech engine.

B. *Subjects*

There were 30 participants, recruited both by eldercare personnel and by students. Their age ranged from 65 to 94, while 22 of them were female and 8 were male. Some of them lived inside the eldercare institutions; some lived independently in apartments next to the institutions.

C. *Procedure*

The user study consisted of two parts: a first initial test after which the questionnaire was used and a public use period to gather usage data. For the initial test, participants were brought into a room were they were instructed to simply play with the robot for three minutes. Subsequently they were brought to another room where they were given the questionnaire. They could ask for help if they were unable to read the statements. After the initial test series were completed, we left the robot for public use in a tea room for seven days. On the screen were buttons with the names of the test session participants and one extra button saying "I'm not listed". Passers by were informed by a note that anyone could use the robot and that they could start a session by pressing the button with their name on it or the "I'm not listed" button if their name was not on the screen. During the days the iCat was available for use, the system made video recordings as soon as it was used trough the camera in its nose. Furthermore, it kept a log of the start and end times of individual user sessions. The end time was either the time a user actively ended his session or if it was not used for 90 seconds. By comparing the video footage to the log, we could later check if users had pressed the right button.

D. *Results*

The test session and the questionnaire were completed by 30 participants. Scores were processed as described above, with values from one to five, while for usage both minutes and times of use were calculated for each user.

First we calculated Cronbach's alpha to test the construct reliability. As stated earlier, an alpha of 0.7 and higher is acceptable. Table 3 shows all constructs were reliable.

TABLE 3 – CRONBACH'S ALPHA

Construct	Alpha	Construct	Alpha
ANX	,812	PEOU	,726
ATT	,851	PS	,878
FC	,707	PU	,865
ITU	,948	SI	,794
PAD	,709	SP	,816
PENJ	,774	Trust	,732

Standard descriptive statistics show a high variance in the scores (see Table 4). Standard deviations were high and there was apparently a high Intention to Use and little Anxiety (as described, scores on 'negative' statements like the ones on Anxiety had reverse scores).

TABLE 4 - DESCRIPTIVE STATISTICS

	Minimum	Maximum	Mean	Std. Dev.
ANX	2,00	5,00	4,2333	,73089
ATT	2,00	5,00	3,7444	,81501
FC	1,00	5,00	3,9000	,87494
ITU	2,00	5,00	4,0500	,98129
PAD	2,67	4,67	3,7667	,54068
PENJ	2,80	4,60	3,7933	,51857
PEOU	2,60	4,80	3,8867	,59581
PS	1,75	4,75	3,6333	,72139
PU	2,00	4,67	3,7111	,71510
SI	2,00	4,00	3,3500	,60387
SP	2,00	4,20	2,7267	,68578
TRUST	2,50	4,50	3,7167	,63901
Times	0	10	3,20	2,441
Min	0	134	33,93	33,686

ANX: Anxiety, ATT: Attitude, FC: Facilitating Conditions, ITU: Intention to Use, PAD: Perceived Adaptability, PENJ: Perceived Enjoyment, PEOU: Perceived Ease of Use, PS: Perceived Sociability, PU: Perceived Usefulness, SI: Social Influence, SP: Social Presence

Table 5 shows all relationships between constructs within the hypotheses could be confirmed with correlation scores, except for Facilitating Conditions and Social Influence determining Usage. Also it shows a strong correlation between Intention to use and actual usage.

TABLE 5 – HYPOTHESES AND CORRELATIONAL SCORES

Hypothesis	Independent variables	Dependent variable	Pearson correlation	Sig. (2-tailed)
H1	PU	ITU	,504**	,005
	PEOU		,633**	,000
	ATT		,519**	,003
	PENJ		,420*	,021
	SI		,127	,505
	Trust		,483**	,007
H2	ITU	Usage (min)	,625**	,000
	FC		-,133	,484
	SI		,236	,209
H3	PEOU	PU	,468**	,009
	PAD		,936**	,000
	ANX		,393*	,032
H4	ANX	PEOU	,181	,337
	PENJ		,252	,179
	PU		,468**	,009
H5	SP	PENJ	,606**	,000
	PS		,583**	,001
H6	Trust	PS	,418*	,022
H7	PS	SP	,540**	,002

Of course, correlations only show that variables are related, not that there is a determining influence in a particular direction. They also do not state which influences are dominating determinants on particular constructs. Therefore, a regression analysis would be appropriate, although the number of participants is quite low.

As Table 6 shows, regression results confirm only part of the hypothesis. It confirms Intention to Use predicting Usage and it confirms the last three hypotheses. Intention to Use however, is only significantly determined by (very strongly) Perceived Ease of Use and Attitude. This does, by the way, not mean that other influences are not there, it can simply mean they are overwhelmed by the significant ones [15].

Also the third and fourth hypotheses are only partly confirmed: Perceived Adaptiveness is the only significant influence on Perceived Usefulness and the latter is the only determinant on Perceived Ease of Use.

TABLE 6 – HYPOTHESES AND REGRESSION SCORES

Hypothesis	Independent variables	Dependent variable	Beta	t	Sig. (2-tailed)	R2
H1	PU	ITU	,094	,510	,615	63
	PEOU		,545	3,373**	,003	
	ATT		,447	2,078*	,049	
	PENJ		-,078	-,347	,731	
	SI		-,225	-1,491	,149	
	Trust		,044	,223	,826	
H2	ITU	Usage (min)	,671	4,603**	,000	50
	FC		-,276	-1,909	,067	
	SI		,133	,937	,357	
H3	PEOU	PU	,066	,882	,386	
	PAD		,884	11,265**	,000	
	ANX		,065	,906	,373	
H4	ANX	PEOU	,080	,378	,708	
	PENJ		,215	1,017	,318	
	PU		,473	2,238*	,034	
H5	SP	PENJ	,411	2,446*	,021	
	PS		,361	2,144*	,041	
H6	Trust	PS	,418	2,435*	,022	
H7	PS	SP	,540	3,399**	,002	

E. Discussion and conclusions of user study results

The results demonstrate how correlations show the intensity of relations between constructs (which can be a valuable outcome for some studies) but regression analysis is needed for confirming the direction of these relations.

For this specific setup, it shows how Perceived ease of Use is the mere influence on its acceptance. This can be explained by the type of functionalities: the robot is only in a very limited way assistive and usefulness may indeed not be its most outstanding characteristic. The significant influence of Attitude may be explained by the way our participants were recruited. They all volunteered spontaneously to our call and there was no pressure from the staff to participate. So all participants had a positive attitude to (experimenting with) a robot to begin with. The strong influence of Perceived Adaptability on Perceived Usefulness demonstrates how important this feature is for this specific user group.

Both correlation analysis and regression analysis tell us some interesting things about the factors at play in user acceptance of this specific technology and user group.

Of course, more valuable user data could be collected if the robot would be available for a longer period. That would make it possible for the initial excitement to 'wear of' and possibly show stronger impact of factors that seem irrelevant at this point. Besides, a larger group of participants would increase the possibilities and the significance of the findings.

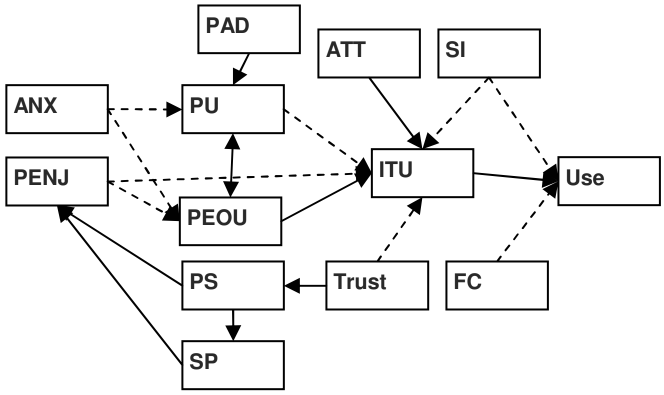

Figure 4. Construct interrelations confirmed by regression analysis

Figure 4 shows, visualizing the regression results, how the focus is on Intention to Use and the constructs directly influencing it. However, often the strength of these direct influences can only be explained by the remaining constructs as we found in a study on the influence of social abilities [21] where Social Presence turned out to be a key factor.

VI. DISCUSSION

Although it would take more than one example case to demonstrate the possibilities of our model, the given example gives a good indication – not only on possibilities, but also on limitations.

An advantage would be, that it is suitable for repetitive testing, which makes it possible to study factors that are often subject to change, like Attitude and Trust. Besides, of course, the Intention to Use a social assistive robot system can change as adults grow older and develop different needs.

Besides, it can effectively be used to compare different systems or to study the effect of different conditions as we did in earlier studies, comparing a more sociable condition of a robot to a less sociable one, or male to female users.

A disadvantage is the need for high numbers of participants if hypotheses have to be confirmed with regression analysis. This is inherent to a methodology that focuses on quantitative results. Still, an acceptance model like this one is often used for qualitative studies if only a small number of participants is available, especially in combination with other methods [27].

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