ECAI 2014
T. Schaub et al. (Eds.)

doi:10.3233/978-1-61499-419-0-747

An Agent-Based Model of Procrastination

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Abstract. Procrastination is a widespread type of self-regulation failure that can have serious negative effects on people's health (e.g., because people delay or omit important health behaviors) and well-being. New "e-coaching" technologies make it possible in principle to offer tailored support to individuals in their efforts to change their self-undermining behavior. In practice, however, such automated support is currently unfeasible because the causal mechanisms behind procrastination are complex and poorly understood. This paper presents a new agent-based model of procrastination that integrates insights from economic models about the dynamics of procrastination with psychological concepts that can help explain the behavior on an individual level. The model is validated by using 5-fold cross validation with simulated annealing to fit and test the parameters on an existing dataset on academic procrastination (n=293). Results show that the agent displays realistic behavior and that the model with the fitted parameters performs significantly better ($p<0.01$) than the model with randomly selected parameters.

1 Introduction

Procrastination — "to voluntarily delay an intended course of action despite expecting to be worse off for the delay" [27, p. 7] — is a widespread and well-known type of self-regulation failure [6]. This self-undermining behavior has been linked to a range of negative effects, from diminished performance in school [28] to increased stress [7], anxiety [21], and even depression [20]. In addition, more recent work in psychology shows that procrastination can also have detrimental effects on people's health and well-being because procrastinators delay or omit important health behaviors, such as making appointments with practitioners, or seeking therapy [24, 23, 26].

In light of this evidence, it is not surprising that the majority of the procrastinators (95%) see their behavior as problematic and want to reduce it [27]. Unfortunately, for many, overcoming procrastination is not just a matter of 'buckling down' and exerting one's willpower [10]. Instead, people need support. New "e-coaching" technologies (e.g., [13, 11]) could in principle be employed to offer people individualized support by monitoring their behavior, teaching them coping strategies such as plan-making [30] or self-compassion [31], and providing them with tailored feedback. The difficulty is that the effectiveness of a particular coping strategy will highly depend on an individual's personality and circumstances. And predicting which coping strategies will be effective on an individual basis is currently unfeasible because the causal mechanisms behind procrastination are complex and poorly understood.

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In this paper we present (Section 3) and validate (Sections 4 – 6) an agent-based model of procrastination that integrates aspects related to time (e.g., temporal discounting [1]) with a multitude of factors that prominently feature in the psychological literature. The aims of the model are 1) to shed light on the mechanisms that underlie procrastination, and 2) to serve as the basis for the development of an e-coaching system that can offer tailored support to people who want to overcome their struggle with (various aspects of) procrastination. In Section 7 we conclude with a plan for future work.

2 Related work

Procrastination is an object of study for many different disciplines, such as psychology, philosophy and behavioral economics. While the psychological and philosophical literatures teach us a great deal about the nature of the phenomenon, existing psychological and philosophical models are merely descriptive in nature, and generally leave out many details that are needed for operationalization. Economic models do better in that respect (i.e. many economic models specify conditions for agent behavior), and therefore we will center our discussion around the two most prominent economic models.

Early economic models of procrastination focus predominantly on people's time-inconsistency, i.e. that people prefer well-being at an earlier time over a later time [22]. In such models, agents typically only have one task and they have to choose when to perform it. O'Donoghue and Rabin note that this assumption is highly unrealistic, and offer an alternative model in which the agent is faced with "a menu of tasks" [17, p. 123] to choose from, where each task is associated with immediate costs that are incurred when the task is executed, and infinite delayed benefits that are received after the task has been completed. To our knowledge, O'Donoghue and Rabin's model is the most substantive economic model of procrastination currently available. Yet, even advanced economic models tend to ignore the large body of evidence that psychological research has uncovered about the many personality-related factors that play a role in procrastination (see Section 3). It is conceivable that in certain cases, economic models will approximate people's behavior well and that the predictions will be accurate. Still, as Heath and Anderson note, an economic model is a model "that can be used to represent the dynamics of procrastination, not as an *explanation* for why individuals procrastinate" [10, p. 240]. In other words, even if these types of models do make accurate predictions, they offer no insight into the psychological mechanisms behind procrastination. This means that economic models in practice are not well suited for determining causes of procrastination and identifying targets for intervention.

In contrast, the agent's behavior in our model is co-determined by its personality traits and its attitude towards the tasks, as well as by a judgement of its importance (that is, an agent can simultaneously find a task very important and very boring). Our model is also more complex, but the benefit of the added complexity is in the fact that it can be used not only to predict but also to understand people's behaviors. This, in turn, can help in supporting those who wish to change their behavior.

O'Donoghue and Rabin report two findings that, according to them, make their agent exhibit realistic behavior. The first is that "additional options can induce procrastination" [17, p. 124] and the second is that "any presumption that people do not procrastinate on important tasks should be dismissed" [17, p. 125]. Our model exhibits these same features.

Finally, there is one other model of procrastination that features so prominently in the literature that it deserves attention, namely *temporal motivation theory* (TMT) [29, 27]. It is based on economic models, but also incorporates expectancy and need theory, and aims to integrate different theories on motivation. As such, it bridges psychology and economics because it relates to the rational choice framework as well as to picoeconomics [14]. Steel and König apply TMT to procrastination using the following formula:

$$\text{Utility} = \frac{E \cdot V}{\Gamma D}$$

with expectancy E, value V (the costs and benefits received from performing a task), sensitivity to delay Γ (representing to what extent delay influences utility) and the time to the deadline D. This theory integrates a number of psychological notions connected to procrastination. In this respect, their work marks an important step forwards. Unfortunately, Steel and König do not specify exactly how TMT should be operationalized; only some small, non-formal examples are given. Moreover, like O'Donoghue and Rabin, Steel and König also leave many psychological factors out and focus mainly on the importance of time: as deadlines come closer, people are more likely to perform the tasks. Factors such as fear of failure, self-efficacy, and conscientiousness, which have been shown to be strongly related to procrastination [9], are not taken into account. In our model, we have taken Steel and König's formula as the basis for formulas for determining task priority and activity utility, but we have improved upon Steel and König's work by incorporating a multitude of psychological concepts.

3 The model

Figure 1 presents the conceptual model and shows the factors that influence procrastination. The factors are divided into different groups: task-related, personality-related and other factors like ego depletion, mood, temptations and coping strategies. This model was reviewed at an early stage by a self-regulation expert. In this paper a distinction is made between the complete model (as first proposed in [19]) and a slightly simplified model that was derived from the complete one on the basis of availability of data in the evaluation dataset. The difference between the two models is discussed in Section 4. Figure 3 depicts the model used for validation. The factors that are taken into account for validation are discussed in detail below.

Task aversiveness When a task is very unpleasant or unenjoyable to perform, a person is more likely to procrastinate [4].

Task Delay Events that are further away in time have less impact on people's decisions. So when the deadline or the consequences are far away, there is more procrastination [29].

Self-efficacy A person's belief in his/her own competence. When someone's self-efficacy for a task is high, one is more likely to put effort in the task and set appropriate goals for oneself [2]. Self-efficacy varies across different domains and tasks and is thus grouped with the task-related causes. When self-efficacy is high and someone believes that a certain goal is attainable, he/she is less likely to procrastinate [27].

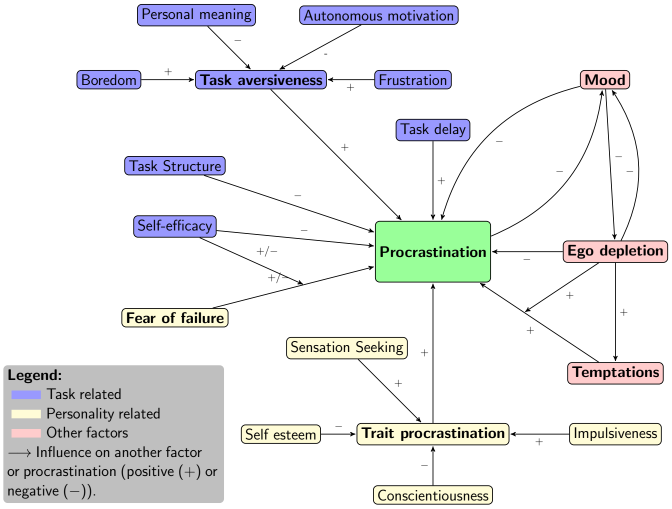

Figure 1. Overview of the determinants of procrastination. The + and − of the arrows represent whether an influence is positive or negative.

Task Structure When a task is less structured, there are more points in time at which a decision has to be made about what to do next, and this gives more opportunities for procrastination [4].

Fear of Failure The fear of the negative consequences of not reaching one's goals. How it affects procrastination is dependent on self-efficacy: individuals with fear of failure and high perceived competence believe they can avoid failure by working very hard, thus reducing procrastination. When the perceived competence is low, individuals feel that the probability of failing is very high and they will avoid this by procrastinating [9].

Trait procrastination One's tendency to procrastinate depends in part on their personality. Research shows that people are more likely to procrastinate when they are sensation seeking [27], when they have low self-esteem [8], when they score low on conscientiousness [16], and when they are impulsive [27]. Trait procrastination is a bundling of these factors [15].

Ego Depletion The strength needed for self-regulation is a limited resource and when this resource is depleted, it is much harder to control oneself [3]. The lower the ego resources, the more procrastination.

Temptations Activities that can be done instead of the current activity, but that do not contribute towards reaching any of the agent's goals. The more temptations there are, the more likely someone is to procrastinate [27].

In the model an individual agent p has various goals g_p that are part of his total set of goals G_p. A goal specifies what the agent wants to achieve, where

$$g = \ < \text{Description}, T_g, \text{Importance}, t_{\text{estimate}}, t_{\text{deadline}} >$$

and T_g is the set of tasks an agent can have. A task τ is defined as:

$$\tau = \ < \text{Description}, \text{Components}, \text{Priority}, \text{Structure}, \text{TaskAversiveness}, \text{SelfEfficacy}, t_{\text{estimated}}, t_{\text{deadline}} >$$

A goal can be implemented by task $\tau_i \in T_g$, which can be represented as a tree that can contain activities or other (sub)tasks (these are the Components). It is also possible that a (sub)task does not contain any activities and is a leaf of the tree, for example when the agent does not know (yet) which activities should be performed in order to complete that task. The task structure can be calculated by determining to what extent the agent knows the activities that need to be done in order to finish the task:

$$\text{Structure}_\tau = \frac{|\text{Activities}_\tau \text{ leaves}|}{|\text{Activities}_\tau \text{ leaves}| + |\text{Task leaves}|}$$

An activity a is defined as

$$a = \ < \text{Description}, \text{Kind}, \text{Utility}, \text{Task Aversiveness}, \text{SelfEfficacy}, t_{\text{estimated}}, t_{\text{spent}} >$$

The tasks are on a list of intended tasks and the place on this list is determined by the priority of the task. The agent can perform activities belonging to tasks ($a \in A_T$) to reach given goals or perform

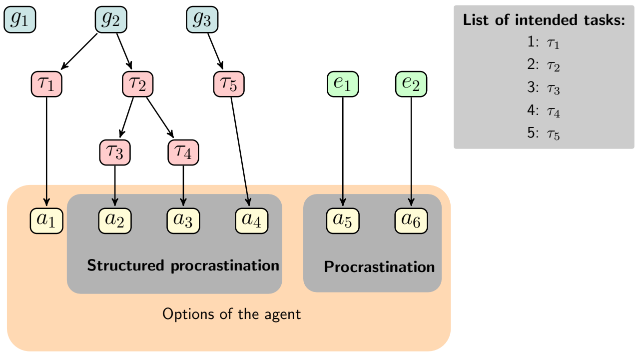

Figure 2. An illustration of the model

other activities that do not belong to a task ($a \in A_E$). The activities that do not belong to a task are generated by events.

Figure 2 gives an illustration of the model. The events e_1 and e_2 are triggers that add activities a_5 and a_6 to the agent's options. When one of the activities in the block 'Procrastination' is performed, the agent is procrastinating. The agent will only consider switching to another activity when (i) the current activity is finished, (ii) the deadline of the current activity has passed, or (iii) an event occurs. In this model, temptations are modeled as events. An event e is defined as

$$e = \ < \text{Kind}, \text{Activity}, \text{Salience}, t_{\text{deadline}} >$$

where Kind defines the nature of an event: internal (agent-driven, such as hunger or being tired) or external (environment-driven, such as a cat that jumps on one's lap, or a friend calling to hang out). When an event occurs, the related activity will be added to the options of the agent. Saliency is a value that represents how difficult it is to resist the activity associated with the event.

In the model, an agent p is defined as

$$p = \ < \text{CurrentActivity}, \text{TraitProcrastination}, \text{FearOfFailure}, \text{EgoResource}, I, G_p, O >$$

where O is the set of all possible activities an agent can choose from (i.e. the agent's *options*): $O = A_E \cup A_T$. I is the set of tasks ordered by their priority. This order is used to determine whether the agent is procrastinating or not. *Structured procrastination* occurs when an agent is doing something useful that is on the list of intended tasks, but not the most important thing to be done [18]. In Figure 2, there is structured procrastination when the agents performs a_2, a_3 or a_4.

Priority is calculated as

$$\text{Priority}(\tau, p) = \frac{E_{\tau,p} \cdot V_{\tau,p}}{\Gamma_p \cdot D \cdot w_{delay}} \cdot \text{Importance}(g_\tau)$$

Both this function and the one for utility described later in this section are inspired by the utility function of the TMT as proposed by Steel and König (described in Section 2). In it, $E_{\tau,p}$ is the expectancy of succeeding in the task, $V_{\tau,p}$ is the value of a task, Γ_p is the sensitivity to delay (this is determined by the agent's personality traits), D is the delay (the time left to perform the task before the deadline), and w_{Delay} is the weight of the delay. The expected success and sensitivity to delay are calculated by the following formulae:

$$E_{a_\tau,p} = \text{SelfEfficacy}_{a_\tau} \cdot w_{\text{selfefficacy}} + \text{newFearOfFailure}_{p,a_\tau} \cdot w_{\text{fearOfFailure}}$$

$$\Gamma_p = \text{TraitProcrastination}_p \cdot w_{\text{TraitProcrastination}}$$

The influence of fear of failure on procrastination depends on the agent's self-efficacy [9]. The following formula implements this dependence:

$$\text{newFearOfFailure}_{p,a_\tau} = \begin{cases} \text{FearOfFailure}_p & \text{when SelfEfficacy}_{a_\tau} > 0.5 \\ -\text{FearOfFailure}_p & \text{else} \end{cases}$$

The value of a task depends on the expected costs and benefits of performing that task. In the model it is calculated as:

$$V_{\tau,p} = \ - \text{TraitProcrastination}_p \cdot w_{\text{TraitProcrastination}} + \text{EgoResource}_p \cdot w_{\text{EgoResource}} - \text{TaskAversiveness}_\tau \cdot w_{\text{TaskAversiveness}} + \text{Structure}_\tau \cdot w_{\text{Structure}}$$

All influences on the agent's behaviors can be weakened or strengthened by weights.[5] These weights influence the strength of a factor on procrastination and they are used to calculate the utility. The utility of an activity expresses how desirable it is for an agent to perform this activity. The utility for task-related activities and event-related activities is calculated slightly differently. First, the utility of task-related activities will be discussed. When an agent selects an activity, a small bonus B is added to the utility which reflects the position of the task associated with the activity in the list of intended tasks (ordered by priority). This bonus is added to let the priority of the task contribute to the utility of an activity. The following formula is used to calculate the bonus and the utility of task-related activities:

$$B_{a_\tau} = 1 - \frac{\text{position of } \tau \text{ in } I}{|\text{ items in } I|}$$

$$\text{Utility}(a_\tau, p) = \frac{E_{a_\tau,p} \cdot V_{a_\tau,p}}{\Gamma_p \cdot D_\tau \cdot w_{delay}} \cdot B_{a_\tau}$$

For event-related activities the same utility function is used, except that the bonus B_{a_τ} is replaced by the Salience_e of the associated event and the denominator is replaced by the estimated time for the activity.

4 Approach

The model was evaluated in two ways: by running simulations to test whether the model is able to reproduce known patterns of procrastination, and by using an existing dataset to find optimal parameter settings for the model in order to accurately predict procrastination. The performance of the model with these found weights is compared to the performance of the model using random weights instead (run 10 times with different random weights). First, the model was implemented in Matlab and several simulations were run with different settings. In Section 5 one simulation will be discussed in more detail. In this simulation, the agent had an average personality, i.e., each trait variable was assigned a value of 0.5 on a scale between 0 and 1.[6]

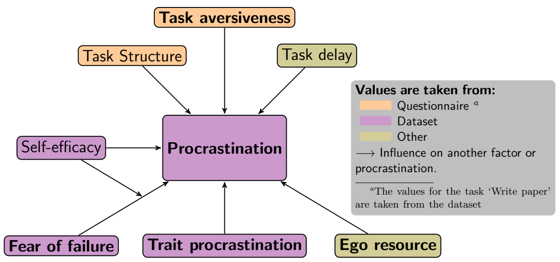

Figure 3. Simplified conceptual model

Secondly, an existing dataset from a psychological experiment on the relation between fear of failure and competence and their influence on procrastination [9] was used to determine optimal weights

[5] Each factor can also be influenced by coping strategies, which are represented in the model as weights as well. However, due to lack of available data, the coping strategy weights were all kept equal in the validation and are omitted here for simplicity.

[6] A full specification of the parameter settings can be found at http://bit.ly/ecai_params.

Algorithm 1 Process overview

```
for time t < maximum number of timesteps do
    if A_T ∪ A_E = ∅ then
        Search for new tasks and activities
    else
        Egoresource = EgoResource · updatespeed
        for Each task τ in I do
            Calculate priority
        end for
        Sort I
        for each activity a in O do
            Calculate Utility(a, p)
        end for
        for Each time step t do
            for Each activity a do
                if SpentTime_{a_τ} > EstimatedTime_{a_τ} then    ▷ Remove finished activities and their tasks
                    O = O \ a_τ
                    T_G = T_G \ τ
                    Break to line 1
                end if
            end for
            for each task τ do
                if t ≥ Deadline_τ then    ▷ Remove tasks with passed deadlines and their activities
                    O = O \ a_τ
                    T_G = T_G \ τ
                    Break to line 1
                end if
            end for
            if an event e occurs then
                if activity a is associated with a task τ_g then
                                      ▷ Add activity to set of task-related activities
                    T_g = T_g ∪ τ
                    A_T = A_T ∪ a
                    I = I ∪ τ
                else                  ▷ Add to set of event-related activities
                    A_E = A_E ∪ a
                    O = O ∪ a
                end if
                Break to line 1
            end if
            HighestUtility= MaxUtility(a|a ∈ O)
            if HighestUtility > 0 then    ▷ Choose the activity with the highest utility
                CurrentActivity_p = MaxUtility(a|a ∈ O)
            else                  ▷ When the utility is too low, search further
                Search for new tasks and activities
            end if
            if Activity is event-related then
                EgoResource = EgoResource - Saliency_e
            end if
        end for
    end if
end for
```

in the model. This dataset (hereinafter dataset A) contains values for 293 participants (219 female, 74 male, age median of 19 years) on fear of failure, self-efficacy, trait procrastination and frequency of procrastination for five academic tasks: writing a paper, studying for exams, weekly readings, registering for classes, and contacting advisor. For one of the tasks, 'write paper', it also contains information on task aversiveness and task structure. In order to be able to compare all tasks in the proposed model, a questionnaire ($n = 36$) was distributed among Dutch university students to gather information on task structure and task aversiveness for the other tasks.[7] Analysis of overlapping questions showed that there was no significant difference (t-test) in the values for task structure and task aversiveness of 'writing paper' in both sets. On the basis of this, the assumption was made that the average scores from the added questionnaire for task aversiveness and task structure would approximate the actual answers of the 293 original participants.

Although dataset A contains data on several of the factors in the model proposed in this paper, some values were missing. These were either time-related values (task delay, mood, ego depletion and temptations) or values that are part of task aversiveness or trait procrastination. In order to deal with these missing data, the model as shown in Figure 1 was adjusted. The resulting model and the methods used to obtain factor values can be found in Figure 3. Considering the inconclusive influence of mood on procrastination [25, 5], this factor was left out. Task aversiveness and trait procrastination are aggregated factors that include the factors influencing them. The values for task delay and ego depletion were estimated for the simulations, and temptations were implemented by the occurrence of events.

In the dataset, procrastination is defined on a scale that denotes how frequent someone procrastinates on a specific task. This frequency value was converted to a number between 0 and 1. For the agent-based model, the outcome of one simulation is whether the agent procrastinated or not. In order to compare these two outcome measures, 20 simulations were run for each agent for each task. The frequency of procrastination is defined as the number of simulations in which the agent is procrastinating divided by 20 (so also a number between 0 and 1). The pseudocode for choosing activities and updating values can be found in Algorithm 1.

The weights in the model influence the strength of a factor on procrastination and are used to calculate the utility. As these weights are initially unknown, dataset A was used to fit the model using 5-fold cross validation with simulated annealing with the aim to find one set of weights that performs well for all agents with regard to their degree of procrastination on different tasks. Simulated annealing was chosen because it works well with problems with a large number of parameters and has a high probability of finding the globally optimal solution. The parameters that were used for the simulated annealing algorithm can be found in Table 1.

Table 1. Simulated annealing parameters

Paramter	Value
Max. number of steps	25
Initial temperature	0.1
Minimum temperature	1^{-4}
Max. successes	10
Jump factor	0.5

5 Results

In Figure 4, an example scenario is shown to provide insight into the workings of the model. It shows some goals, tasks, and activities an agent can have. In Figure 5, the utility of all activities during one simulation can be found. At t_1, the agent calculates the priority of all tasks (assuming goal importances are known) and orders this list. It will also calculate the utilities of all activities. The agent will choose to execute 'Find article', because it has the highest utility. The agent will continue with this activity until t_5, when a friend calls to have a drink (event). The agent will recalculate all utilities and will again choose the activity with the highest utility. The same happens at t_6, when a deadline passes. At this point the agent chooses 'Write essay'. The task associated with this activity is, however, not on the top of the list of intended tasks, because that task does not have the highest priority. As a result, the agent displays 'structured procrastination'. The utility of 'study test' increases over time because it is getting closer to the deadline (cf. TMT). At t_{26}, however, there is a drop in utility for the activity 'study test'. This drop is caused by the agent as it assigned a higher priority to the task 'finish essay' (without underlying activity, so not in Figure 5) than to the task 'study

[7] The questionnaire (in Dutch) can be found at http://bit.ly/ecai_survey.

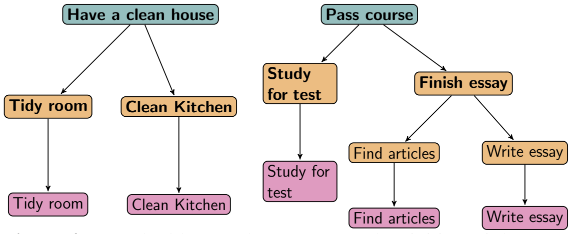

Figure 4. Goals (blue), tasks (orange) and activities (pink)

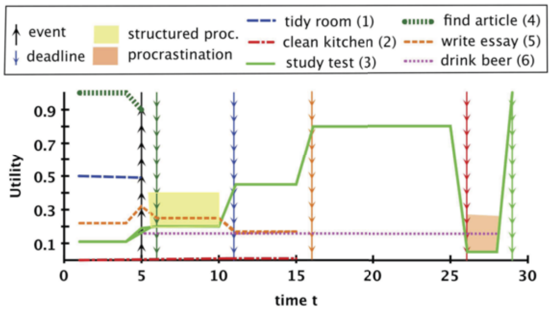

Figure 5. The utility of all activities

test'. Because at this point in the simulation there are only two activities left, 'study test' is assigned a very low bonus in the utility function.

Several scenarios were tested by running simulations and they show that, all other values equal, an agent with high conscientiousness (0.9) will procrastinate less than an agent with low conscientiousness (0.1), and an agent with a task that is not very structured will procrastinate more than one with a very structured task.

In order to compare the output of the model with the data in dataset A, a scenario was developed in which the agent has to complete one task (one of the five present in dataset A) and there are two external events that can distract it: one event occurs at t_1, the other occurs at a random time step. The events generate generic 'NotStudying'-activities. The tasks, events and activities have a random value for $t_{\text{estimated}}$ and t_{deadline}. The scenario runs for 20 time steps.

The set of weights that performs best can be found in Table 2, and the errors obtained by using these weights, as well as the task-specific errors, are shown in Table 3. The weights (with an average of 0.444) influence the strength of the corresponding factor on procrastination. Due to their different influences in the formulae, no direct conclusions can be drawn from the weights about the importance of a factor. These weights were tested on the entire dataset A. The mean error with the best set of weights is 0.329. This error is the difference between the frequency of procrastination from dataset A and the frequency of procrastination calculated by the model, within a range of [0-1].

Table 2. Best set of weights

Weight	Value
w_Task avers.	0.237
w_Structure	0.332
w_Task delay	0.397
w_Trait proc.	0.427
w_Fear of failure	0.438
w_Self-efficacy	0.605
w_Ego resource	0.674

Table 3. Errors for average and task-specific weights

Task	Error weights average	Error weights task
Overall Error	**0.329**	**0.300**
Write paper	0.224	0.240
Study exams	0.299	0.294
Weekly reading	0.235	0.240
Register for class	0.461	0.334
Email advisor	0.427	0.390

These results were evaluated by comparing them to the performance of the model with randomly selected weights.[8] The mean error of those runs was 0.48. A t-test shows that the fitted parameters perform significantly better: $p < 0.01, t = 8.53$ with a moderate effect size (Cohen's d=0.57). In addition, with exception to 'registering for classes', the found parameters also perform significantly better for each of the individual tasks ($p < 0.01$).

In the following section these results are discussed in more detail.

6 Discussion

The mean error for predicting outcomes with the found parameter set over all 5 tasks was 0.329 (scale 0-1). To determine the quality of this result, two ways of evaluating the error were used. In both the questionnaire to gather additional data and dataset A, the average standard deviation for the questions 'frequency of procrastination' was 0.22 (after conversion to a scale from 0 to 1). Because the calculations are based on answers from all questionnaires, it is unlikely that the model will be more accurate than this. Therefore, an error close to 0.22 will be considered a good result. According to this definition, the model performs well for some tasks, such as 'Writing paper' (0.2235) and 'Weekly reading' (0.2346), while worse for others. Assuming that randomly selected parameters would approximate 0.5 (justifiably, given the experimental result of 0.48), a mean error of 0.329 over 5 different tasks can be taken to be a *fair* score. Notably, the tasks 'Register for classes' and 'Email advisor' have a high error. A reason could be that both tasks are quite small and of a more incidental nature: normally, they would take around 5 to 10 minutes to complete while the other tasks require multiple hours of effort. Because of this difference between tasks, the overall weights may be skewed, and the model might perform better with task-specific weights. To test this, the errors were compared to the errors obtained when task-specific (instead of overall) weights were used. Although the results for the smaller tasks do improve with task-specific weights, they are still not as good as for the other tasks. We suspect that this is because people do not perform these tasks very often, so they might not recall accurately whether they usually procrastinate or not on such tasks.

There are a number of limitations to the present study. First, for some of the factors in the conceptual model, the influence on procrastination is unclear in the psychological literature (e.g., for mood there is no clear evidence whether it has a positive or negative influence). Moreover, while the literature review was thorough, some factors or influence relations may have been missed. Secondly, the dataset from Haghbin, McCaffrey and Pychyl does not contain all the information that is incorporated in our model. For that reason, the model had to be simplified to make the best use of the available data. In simplifying the model, a number of additional assumptions were made. For example, the dataset contains no actual information about behavior over time, except for the self-reports on 'frequency of procrastination'. Also, in the experiments, random values had to be used to model time-related aspects (e.g., deadlines, or the estimated time needed for tasks). Lastly, it was assumed that all tasks require a random number of time steps to complete, but that they are all within the same range. This is not very realistic because some tasks will take significantly more time than others. Having a more complete dataset that includes information per individual about these person-related and task-related factors over time would give us more insights into the validity of the model. Despite these limitations, the results presented here help to identify strengths and weaknesses of the model

[8] Ideally, we would also compare our results to results from rivaling models. However, at the time of writing, no implemented models were available.

and as such are an encouraging step towards a validated agent-based model of procrastination.

7 Conclusions & Future work

In this paper we presented a new agent-based model of procrastination that embraces the psychological underpinnings of procrastination, while retaining the insight from economic models that time is an important explanatory factor of people's procrastinatory behavior. Besides sharing the two main features of O'Donoghue and Rabin's model (Section 2), our agent displays behavior that is in line with a number of psychological findings. To validate the model, we used 5-fold cross validation with simulated annealing to fit and test parameters to an existing set of data. The results show that the fitted parameters perform significantly better than random parameters.

In future work, we aim to do four things. First, we will collect new data using the same measures as well as additional ones (e.g., about actual behavior over time) to confirm the validity of the parameters that were found. Secondly, we will test the found parameters for validity in other domains. The present work focused on a dataset concerned with 'academic procrastination'. It will be interesting to investigate if the fitted model extends to other types of procrastination, such as 'bedtime procrastination'. Thirdly, the fitted model will then be used to determine points of influence that appear to be sensitive to manipulation, but for which there are currently no interventions or coping strategies. In addition, the model can be used to simulate the effect that a newly developed intervention might have on a person. Finally, we will design mechanisms to automatically hypothesize about the causes of someone's procrastination on the basis of this model (e.g., with a rule-based reasoning approach as described in [12]). Such hypotheses can then lead to specific, tailored interventions (e.g., persuasive messages on one's smartphone) or coaching strategies (e.g., to improve self-compassion) to be performed by an e-coaching application.

ACKNOWLEDGEMENTS

We would like to thank Floor Kroese from the Self-Regulation Lab for reviewing the conceptual model. We are grateful to Haghbin, McCaffrey and Pychyl for kindly agreeing to share their research data with us. This research was supported by Philips and Technology Foundation STW, Nationaal Initiatief Hersenen en Cognitie NIHC under the Partnership programme Healthy Lifestyle Solutions.

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