A computational model of procrastination

Technical Artificial Intelligence
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Master's thesis

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Chapter 1

Introduction

Procrastination is a very common phenomenon that is widely spread among students (in some experiments students reported that one third of their daily activities consisted of procrastinating! (Pychyl et al., 2000)), but also chronically affects 15 - 20 % of the general population (Harriott & Ferrari, 1996). Research shows that procrastination has a negative influence on an individual's performance (Steel, 2007) and well-being (Tice & Baumeister, 1997). 95% of the procrastinators see this behavior as problematic and want to reduce it (Steel, 2007).

There are many definitions of procrastination and most of them include irrational and unnecessary delay and expected negative consequences. The definition of Klingsieck (2013, p. 26) combines all these features: *"the voluntary delay of an intended and necessary and/or [personally] important activity, despite expecting potential negative consequences that outweigh the positive consequences of the delay."* Note that voluntary in this context means that the activity that is performed when procrastinating is chosen, and the delay is not imposed on a person. Another thing to keep in mind is that not performing an intended action is not necessarily procrastination. It can be the case that something more important comes along and someone justifiably shifts his or her priorities towards this other task.

Procrastination is a phenomenon that is influenced by many factors. Psychologists have identified many of these factors, but how these factors interact and influence procrastination is poorly understood. There is no uniform theory that integrates all these factors. Since procrastination is a problem to many people, it is useful to first understand the problem, because that way, interventions can be more effective. For a better understanding, the main research question is: *'What are the different personality and task-related factors influencing procrastination and in what way do they influence procrastination and each other?'*

Answering this question starts by identifying all the factors with the use of psychological literature, as a lot of experiments have been conducted on the matter. All prominent factors are included in a conceptual model. The next part of the question is harder: *'How do these factors influence procrastination and each other?'* It is clear for some factors to what extent they influence procrastination, but it is not clear in what way they influence procrastination. This question will be answered by making a conceptual model in Chapter 2.

Using the conceptual model, a formalization can be made that captures the different factors and defines an agent that can choose to perform activities that are either task-related or not. The goal of the formal model is to gain a better understanding of the factors influencing procrastination and the connections between them. This can be done by observing the agent's behavior in a variety of settings. The model will be used to make a computational model to run simulations, train the model on empirical data and test it.

The model should be as generic as possible because in this way it can be used in many situations and domains. A possible application would be a program that can coach people to reduce their procrastination. A question related to the generic model is: *'Is it possible to make a generic computational model of procrastination?'*. And if it is possible to make a generic model, is this in accordance with empirical data on procrastination in different domains?

Students are well-known for their procrastination, but they are not the only ones: also non-students procrastinate. They procrastinate for example before going to bed or applying for pension pay. It is likely that all found factors will influence procrastination in a specific domain, but that there will be differences in the strength. For example, consider a person more averse to reading a very boring book than going to bed. When it is possible to make a generic model, this can be very useful because the same model can be used in different domains. However, even when it is not possible to make a generic model for procrastination in different domains, trying to make such a model will give a lot of insight on procrastination and may help to get better, more specific interventions. In this thesis, only data of on study-related tasks is used to validate the model. Knowing whether the model works in different domains requires more domain-specific data. However, this is not part in this thesis, but part of future work.

Procrastination can be problematic because people are not doing what they should be doing. This can have negative consequences for them, for example failing classes. Interventions can reduce procrastination. However, since there are different reasons to procrastinate, there are also different interventions that will work best for different people. One of the research questions associated with this is: *'What are the effects of interventions on procrastination in the model?'*. Will they work in the same way as in the real world? A related question is whether new interventions can be found in the model, for example for reducing procrastination in specific situations. Or when a strong relation between factors is found, some new intervention can be developed that combines both factors. Although these are interesting questions, they are not part of this thesis and can be answered in future work.

A part of this thesis was presented at the Benelux Artifical Intelligence Conference 2013 (Procee et al., 2013). This paper mainly discusses the background and formal model, as described in more detail in Chapters 2 and 4.

To summarize all the questions that are answered in this thesis:

- What are the different personality and task-related factors influencing procrastination?
- In what way do these factors influence procrastination and each other?
- Is it possible to make a generic computational model of procrastination?

This thesis is organized as follows. Chapter 2 presents a conceptual model of procrastination that is built from factors prominently featured in psychological literature. In Chapter 3, other models of procrastination will be discussed. A formalization of the model and its implementation is presented in Chapter 4. Chapter 5 discusses two different steps of validation of the model and the results. Chapter 6 will discuss the results, some improvements to the model and ideas for future work. Finally in Chapter 7, the research questions will be answered.

Chapter 2

Background

In the following sections, prominent factors influencing procrastination that are found in the literature will be discussed. The factors can be divided into different groups: task-related, personality-related and other factors like fear of failure, ego depletion, mood, temptations and coping strategies. All these factors and their influence on procrastination can be found in Figure 2.7 (page 14). The + and − signs of the arrows represent the influence from that factor on procrastination or another factor. This conceptual model has been reviewed by a self-regulation expert.

2.1 Task-related factors

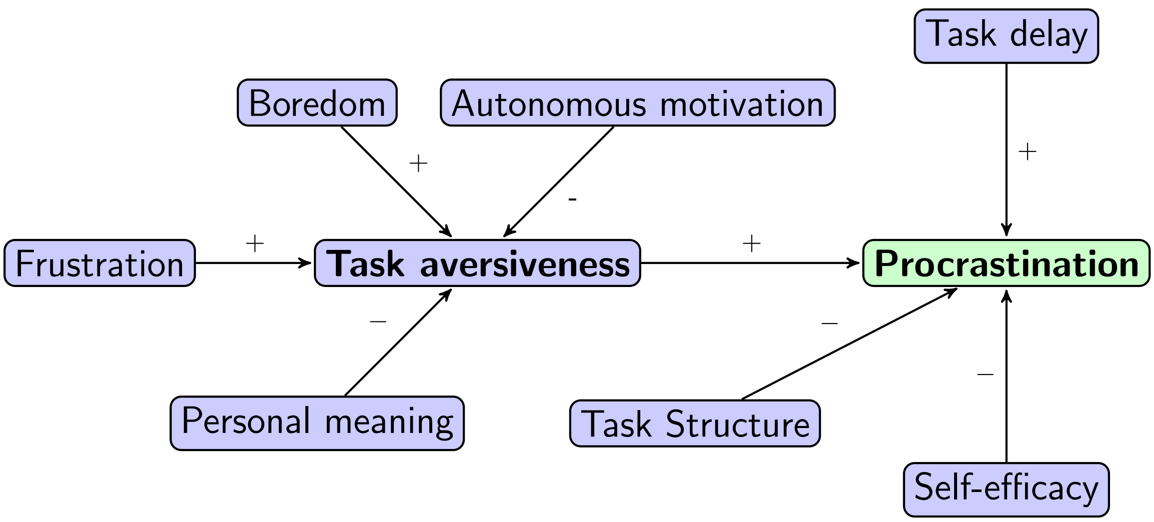

Figure 2.1: Relation between task characteristics and procrastination

The nature of the task influences how likely someone is to procrastinate. This task-related cluster can be divided into two different categories: causes that are related to a person, such as task aversiveness and self-efficacy, and more objective causes like task delay (the time to the deadline) and task structure.

Task aversiveness (Blunt & Pychyl, 2000) is defined as how unpleasant or unenjoyable a task is to perform. When aversion is higher, there is more procrastination. Gröpel & Steel (2008) found in a mega-trial that lowering task aversiveness, for example by interest enhancement, gives someone more energy to perform a task and this reduces procrastination.

Task aversiveness is a compound factor that can be divided into different elements:

- Boredom: When a task is really boring it is hard to sustain it as an intentional activity when there are less boring alternatives present (Blunt & Pychyl, 1998). The more boring a task, the more procrastination.
- Frustration: Being frustrated makes it harder to focus on a task because it causes uncontrollable cognitions and task-irrelevant emotions (Blunt & Pychyl, 2000). To manage these frustrations, someone is more likely to procrastinate by engaging in other activities.
- Personal meaning: The extent to which individuals feel their projects are worthwhile pursuits (Little, 1983). This includes factors as fun, pleasure, passion and other's benefit. The lower the personal meaning, the less desirable it is to do a certain task, which leads to more procrastination (Blunt & Pychyl, 2000).
- Autonomous motivation: A combination of intrinsic motivation, where there is an inner drive to reach a certain goal, and extrinsic motivation in which people see personal meaning (Deci & Ryan, 2008). Opposed to autonomous motivation is controlled motivation, which consists of external regulation in the form of a function of reward and punishment and self-regulation factors like self-esteem or avoidance of shame. Having autonomous motivation for a task leads to better performance (for example in Guay et al. (2008)) and less procrastination (Vansteenkiste et al., 2009).

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. It is equal to temporal discounting theory: people discount rewards that are further away (Frederick et al., 2002). When a deadline for a task is far away, there is high delay, and a person is more likely to procrastinate (Schouwenburg & Groenewoud, 2001).

Self-efficacy is a person's belief in his own competence. When someone has high self-efficacy on a certain task, one is more likely to put effort in a task and set appropriate goals for oneself (Bandura et al., 1989). High self-efficacy can be acquired by experience (therefore it is important to set realistic goals) or by seeing other people perform well (Bandura et al., 1989). Self-efficacy varies across different domains and tasks and is therefore grouped with the task-related causes. When self-efficacy is high and someone thinks he can reach a certain goal, he is less likely to procrastinate (Steel, 2007).

Structure of the task When a task is less structured and difficult to coordinate, there is more procrastination. The reason for this is that there are many points in time at which a decision has to be made about what to do next, and this gives more opportunities for procrastination (Blunt & Pychyl, 2000). Uncertainty about the task is also related to structure. A person who has an organized personality has good coping skills for these kinds of tasks.

Another aspect is unrealistic planning: thinking that one needs less time to finish a task than one actually needs. One of the reasons for this is that most people do not take possible delays into account or think they will work fully focussed without interruptions.

2.2 Mood

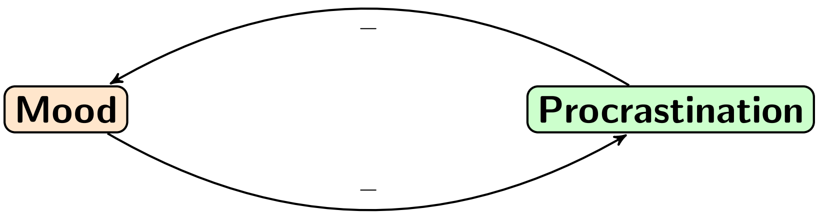

Figure 2.2: Relation between mood and procrastination

The influence of mood on procrastination is not clear. Research suggests that depression increases procrastination (Solomon & Rothblum, 1984). Depression is linked with less pleasure in life and a lack of energy (American Psychiatric Association, 1994). This makes it harder to initiate tasks and gives problems concentrating: it's no surprise that a depressed person is procrastinating. It is unclear what the influence of mood is on someone who is not depressed. According to Steel (2007) there is no relation between mood and procrastination.

One of the outcomes of procrastination is more anxiety and stress. Tice & Baumeister (1997) say that students procrastinating on a project that is due at the end of the semester feel less stressed in the beginning of the semester than non-procrastinating students, but a lot more by the end of the semester. This has a negative influence on the mood of a person and can cause a deviation-amplifying loop, or depression spiral. Wohl et al. (2010) indicate that self-forgiveness can reduce the negative affect and this reduces procrastination as well. This shows that a low mood/negative affect does influence procrastination in a way.

When a person is in a positive mood, he will have more self-control, thus reducing procrastination (Fedorikhin & Patrick, 2010). However, in order to have self-control, there has to be some focus, and a person that is in a very positive mood may be too aroused to focus on the current task, thereby causing procrastination as well.

Despite the mixed evidence, mood is included in the conceptual model to investigate the influence. In the validation however, mood was excluded because of this mixed evidence.

2.3 Ego resources

The ego strength needed for self-regulation is a limited resource and when this is depleted, it is much harder to control oneself (Baumeister, 2003). This resource depletes when one has regulated himself to do (or not do) a certain task (e.g. working on a boring task or not eating cookies), control emotions or other kinds of self-control. After this, a person is more vulnerable for impulsive behaviors (e.g. eat the chocolate pie). Sleep, exercise in self-regulation and

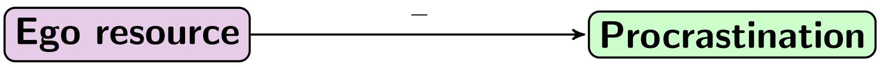

Figure 2.3: Relation between ego depletion and procrastination

positive emotional experiences can increase this strength again (Baumeister, 2003). Lower ego resources lead to more procrastination.

Lack of energy is in the top of most given reasons for procrastination (Steel, 2007). The less energy someone has, the more likely one is to procrastinate. This is one of the reasons why depression is linked with procrastination: depression is linked with less energy (American Psychiatric Association, 1994). The amount of energy can be increased by interest enhancement: identifying and focusing on the nice parts of a task, thus making it more interesting (Gröpel & Steel, 2008). The less energy someone has or the more ego depleted one is, the more likely one is to procrastinate.

There is also a link between mood and ego depletion. The reason for this is that a low mood makes a person more depleted, and a more depleted person has more difficulties maintaining a positive mood.

2.4 Coping strategies

Someone can have all the personality traits that should cause procrastination, tons of distractions, a very aversive task, so it seems like this person should be procrastinating, because he has all the qualities of a typical procrastinator and an aversive task. However, he is not procrastinating in this case. It might be that this person has very good coping strategies to reduce procrastination. For example, someone who sets concrete subgoals for oneself makes a task more structured, thus reducing the factor 'Task structure' and making it less likely to procrastinate.

There is a great number of strategies, but most of them can be divided into one of the following categories: problem-focused or emotion-focused coping strategies. A problem-focused person tries to focus on solutions for the problem while someone who tries to reduce the negative emotions is more emotion-focused (Folkman & Lazarus, 1980). Procrastinators are more likely to use emotion-focused coping strategies, while only the use of problem-focused strategies helps to reduce procrastination. Next, some of these strategies will be discussed.

Self-forgiveness (Wohl et al., 2010) makes someone focus on the things one has to do instead of trying to deal with the (negative) emotions of failing or not performing a task. When procrastinating, someone can feel very guilty about this, and to 'cure' this, one will procrastinate more. When one forgives oneself for procrastinating, one can start doing the tasks one has to do instead of feeling guilty about something that he can't change anymore.

Coping with distractions Knowing how to manage distractions reduces procrastination[1]. Another approach is trying to reduce the distractions that temp someone into procrastination. The first method is stimulus control, which works by altering the environment to reduce distractions (for example, by hiding the 'you've got new mail!' button) or have certain behavior in certain situations (for example, always study in the same location). Another method is creating more automatic routines. The more decisions that need to be made, the higher the probability for procrastination. When someone has a routine, fewer decisions need to be made and this reduces procrastination. Coping with distractions is a problem-focused coping strategy.

Goal setting is a problem-focused coping strategy about setting smaller goals to eventually achieve something bigger. An example of this is when someone has to write a paper that is due by the end of the semester. By setting deadlines for subsets of the task, one can divide the work pressure across the whole semester instead of the final week. Gröpel & Steel (2008) indicated that this does not work when the task is already pleasurable, because someone can feel obliged to do a certain task and therefore become more averted towards this task.

Self-handicapping may seem a bit odd in this category, because it has a negative outcome instead of a positive. It is an emotion-focused strategy. There are two types of self-handicapping: *behavioral* self-handicapping, where an individual places obstacles for oneself that hinder good performance and *claimed* self-handicapping, where an individual states that there is some obstacle (Tice & Baumeister, 1990).
Procrastination is an obstacle that someone can put up for himself. When someone does this and —for example— writes a bad paper, this is because he didn't have much time to write it (because he spent too much time procrastinating) instead of being incapable to write a good paper. And when this approach unexpectedly leads to a good results, he did well *despite* the procrastination, so he must be really good at writing papers!

These coping strategies (except for self-handicapping) reduce procrastination. They reduce the effect that certain factors have on procrastination. For example, a coping strategy like 'Gamifying a task' can decrease procrastination by decreasing task aversiveness, while another strategy may affect the influence of a particular temptation. Coping strategies are not directly included in the figure. Instead, they are considered co-determinants for the weights of the connections that determine the influence of a factor on procrastination.

2.5 Personality-related factors

Some people are more likely to procrastinate than others and this is dependent on their personality. A lot of research has been done to connect the five-factor model of personality to procrastination. There is no correlation between procrastination, openness to experience and agreeableness (Steel, 2007). The other personality traits will be discussed next.

Impulsiveness Impulsive people are more likely act on the desires of the moment. When some distractions come along that are more interesting than what they should be doing,

[1] This coping strategy is only about external distractions. When someone is actively looking for a distraction, it is procrastination.

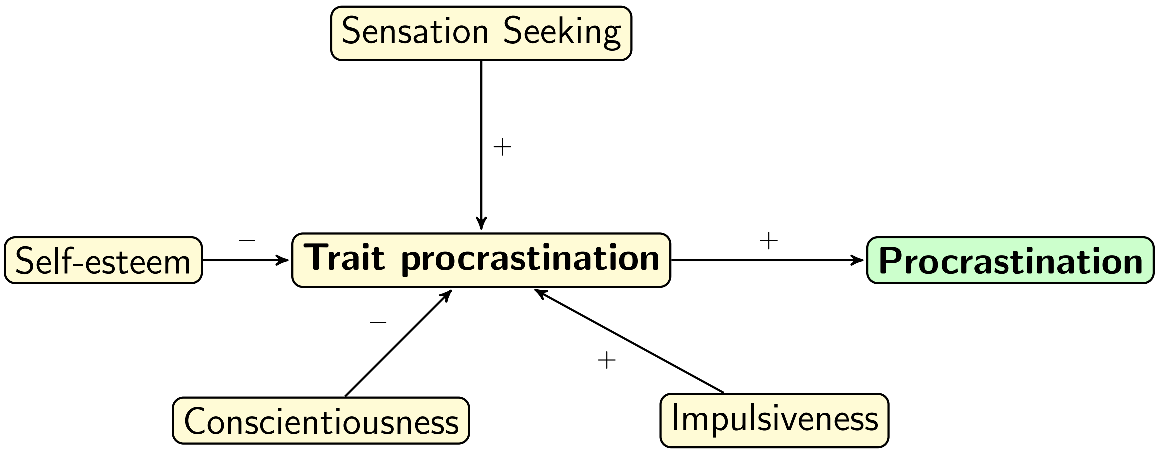

Figure 2.4: Relation between personality and procrastination

they are likely to switch to the other activity. Because of this, people that score high on impulsiveness are more likely to procrastinate.

Sensation seeking is the tendency to find exciting activities, take risks and avoid boredom. It might seem that sensation seekers like the tension of the deadline to work at their best, but this is not the case. One of the components of sensation seeking, boredom proneness, has more influence on procrastination. The higher someone scores on this trait, the more likely he is to procrastinate.

Conscientiousness Someone who scores high on this factor can be described in terms like orderly, neat and organized. This trait is associated with working hard and doing well in school. One of the elements of conscientiousness is organization and this results in good coping strategies like goal setting and automatic habits. Achievement motivation, enjoying performance for the sake of performance, is also an important aspect of conscientiousness. These persons have high standards and want to live up with them. People who score high on this trait are less likely to procrastinate (Lay, 1997; Schouwenburg & Lay, 1995).

Self-esteem is how someone evaluates onself. There can be variance in different domains, but self-esteem is generally measured as the average evaluation of oneself. When someone has low self-esteem, one is more likely to procrastinate. A low self-evaluation also correlates with automatic thoughts about oneself and procrastinatory cognitions, which leads to more procrastination (Flett et al., 2012).

2.6 Fear of failure

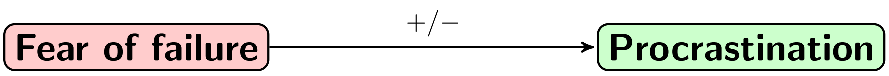

Figure 2.5: Relation between fear of failure and procrastination

Fear of failure (Haghbin et al., 2012) is the fear of the aversive consequences of not reaching one's goals. According to Conroy et al. (2002) it can be explained in five dimensions, including fear of: experiencing shame and embarrassment, devaluing one's self-estimate, having an uncertain future, important others losing interest and fear of upsetting important others.

Fear of failure consists of cognitive, emotional and motivational components. The cognitive component consists of beliefs about the threat of not succeeding or appraisals about aversive consequences, the emotional component about the negative emotions that follow from this and the motivational component is using this fear of failure to avoid negative consequences.

(Perceived) Competence, or self-efficacy, plays a role in which strategy is used to avoid these negative consequences. 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 procrastination (Haghbin et al., 2012). This is however not a conscious deliberation on the part of the procrastinator.

2.7 Temptations and distractions

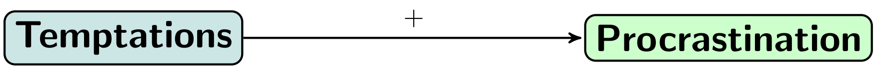

Figure 2.6: Relation between temptations and procrastination

Temptations and distractions are, for example, the friend that calls to go out tonight, some series on television that must be watched or any other activity that you would rather be doing than studying, going to bed early or the other thing that you should be doing. The stronger these temptations are, the harder they are to withstand. Good coping strategies make it easier to deal with distractions. However, the more distractions and temptations are present, the more likely someone is going to procrastinate (Steel, 2007).

2.8 Limitations of the conceptual model

In the previous sections, all prominent factors influencing procrastination were discussed. All these factors are combined in the conceptual model that can be found in Figure 2.7. The conceptual model shows what the different personality and task-related factors influencing procrastination are.

There are, however, some limitations to this approach. Not all factors found in literature were used to make this model. For some factors, the correlation between that factor and procrastination was not strong enough, indicating there was no influence of that factor on procrastination.

An example of this is that according to earlier research there was no relation between fear of failure and procrastination (see Section 2.6). A study by Haghbin et al. (2012) showed that there was influence of fear of failure on procrastination, but it was moderated by perceived competence. Because low perceived competence would cause fear of failure to have a positive influence on procrastination and high perceived competence a negative influence, the correlation would turn out to be around 0, making it look like there was no influence of fear of failure on procrastination. There might be more factors that seem to have no influence on procrastination but this could be moderated by a different factor. Because of this, there could be other factors that are missed in this model.

It could also be that some factors are missed completely in the research on procrastination. Although there has been ample research on this topic on many factors, it could be the case that there are factors (e.g. neuropsychological factors) that are not researched yet (Klingsieck, 2013).

For other factors, there is still debate on whether the factor has influence on procrastination. Mood is an example of this. It is included in the conceptual model, with unknown influence, but knowing more about the influence of this factor on procrastination would improve the model.

Another thing that is not included (except for mood, ego depletion and temptations) in the model are the influences between the different factors. For example, it is possible that personal meaning has influence on autonomous motivation. However, including this in the model would make it even more complex. Knowing that we had to use the conceptual model to make a computational model, we decided not to increase the complexity of the model, but this may have decreased the informational value and performance.

Besides the limitations of the conceptual model, it gives a well-organized summary of the factors influencing procrastination. Further research on other factors might give information on improvements and extensions to this model, and these new factors can easily be added to the model.

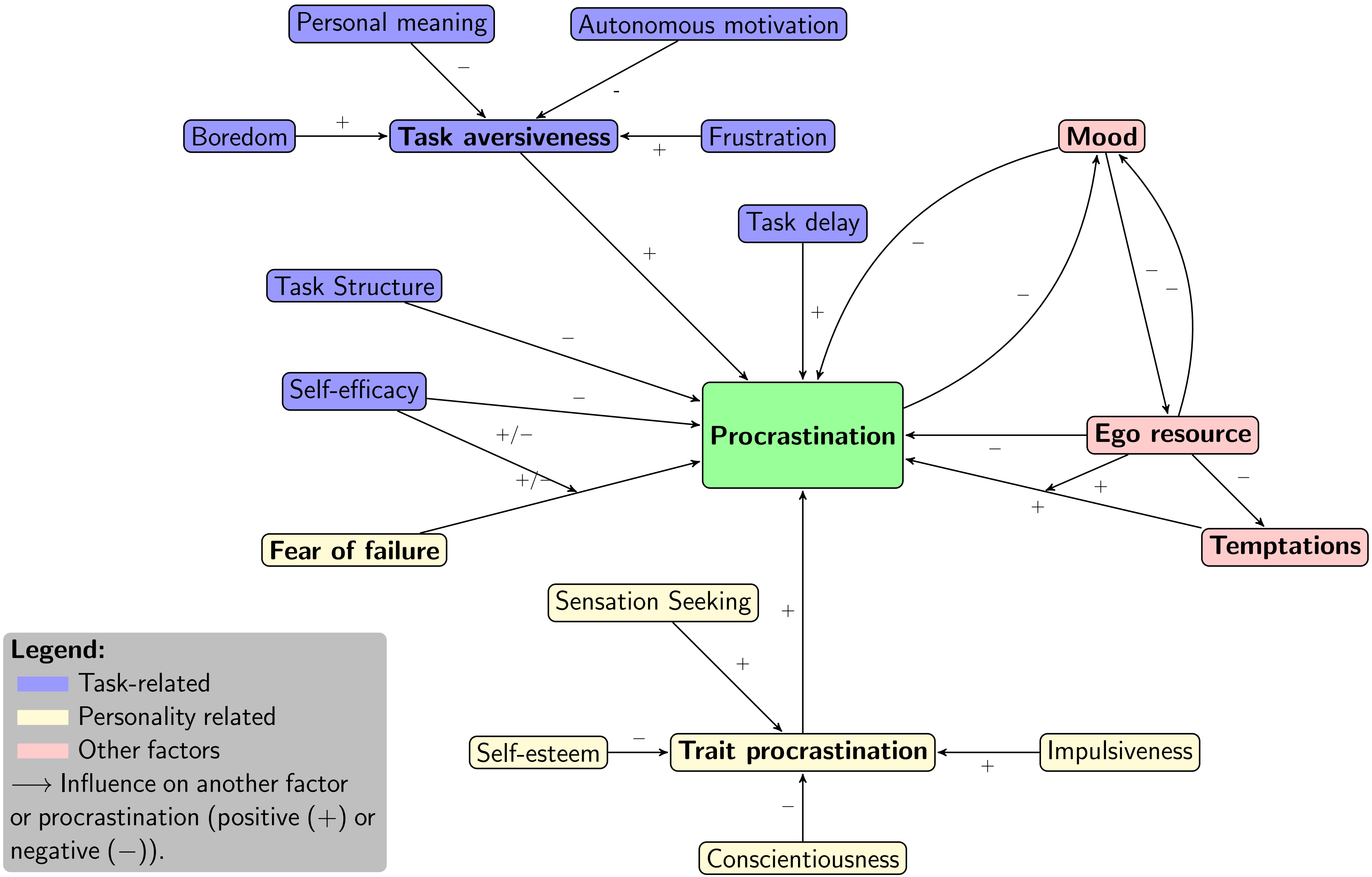

Figure 2.7: Overview of causes and relations of procrastination

Chapter 3

Related work

There are different models of procrastination. In this section, an overview of these models will be discussed. They represent different classes of models: the self-regulation models, economic models and temporal motivation theory (TMT).

First, a feedback model on self-regulation will be discussed. It gives some insight in the dynamics of self-control. The model is not specifically on procrastination, but since procrastination is a form of (failing in) self-regulation, it is useful to discuss this model.

Next, several economic models on procrastination will be discussed. The idea of the economic models on procrastination is that an agent can choose between some tasks. Each task is associated with costs that are incurred when the task is executed, and benefits that are received every next period. Traditional economic models assume time-consistency: an agents preference for a task remains the same over time. Most people are however time-inconsistent: they prefer well-being at an earlier date over a later date (Frederick et al., 2002). In economic models on procrastination this is taken into account. There are many more models like this that all have different interesting features and they can't all be discussed, so in this section the general idea of this type of models will be given.

Finally, the temporal motivation theory (TMT) by Steel & König (2006) will be discussed. It is based on economic models, but it also incorporates expectancy and need theory, and aims to integrate different theories on motivation and psychological concepts.

3.1 Feedback model for self-regulation

In the feedback model by Baumeister et al. (1994), self-regulation is defined as *'controlling oneself to not do what pops in the mind, but think about the longer-term effects as well'.* It can be seen as higher processes overriding lower ones. For example, someone has made a resolution to quit smoking (higher process), but craves a cigarette (lower process). Thinking about the resolution may prevent him to smoke this cigarette. For self-regulation, there are three prerequisites:

- **Standards:** The standards must be clear in order to make self-regulation effective. These can be in the form of social norms, personal goals or expectations.

- **Monitoring:** There can only be self-regulation when someone knows what he's doing and how this compares to the standards. This becomes more difficult when one is preoccupied with other activities. Sometimes a person wants to escape from this self-awareness, reduces the monitoring and this may cause unusual or disinhibited behavior.

- **Operate:** Once someone knows what the standards are and how he is doing according to these standards, he can, when there is a deviation, change himself to meet the standards again. This can fail because of inadequate ego strength. The lack of ego strength can be chronic, temporary or external:

  - Chronic: not having enough willpower or having specific character traits like impulsiveness.
  - Temporary: at some point willpower can be limited and a person becomes incapable of self-regulation. This can, for example, be caused by stress. Someone who knows his weaknesses, wouldn't start a diet in a very busy and stressful time.
  - External: a certain stimulus is presented, and it requires some strength to control the impulse or response. The motivation to control this impulse or response can change over time.

Other notions that are important with regard to self-regulation are psychological inertia and acquiescence. Psychological inertia describes the phenomenon that the longer someone is working on something or when the activity is a habit, the harder it is to change this behavior. Therefore it is better to try to change it as soon as possible. The other notion, acquiescence, means that people accept that they are wrong and are not going to change this. They might even look for a way to lose control instead of trying to get it back. This can be seen with procrastination as well. A person that is very negative about his procrastinatory behavior might feel guilty about this, and therefore procrastinate more to suppress these negative feelings[1].

To show what happens when a person fails to control himself and applies some coping strategies, an example is given. For example, someone is on a diet, sees a tasty chocolate cake and can't resist to take a small piece. Using self-forgiveness, a person could acknowledge his mistake and plan to do better next time. However, a person can also eat the whole cake after this small slip, because he failed anyway. Of course, this makes things worse. This is a typical example of acquiescence described in the previous paragraph.

3.2 Economic models of procrastination

In O'Donoghue & Rabin (2001), a model of procrastination is described. This model uses intelligent agents. An agent is something (e.g. a software program) that can perceive it's environment and act upon that environment autonomously (Russell & Norvig, 2003, p. 31). In this model, the agent will reason about the utility of different tasks. A definition for an utility function is a way to map a state onto a real number, which describes the associated degree of happiness (Russell & Norvig, 2003, p. 51).

In the model of O'Donoghue & Rabin (2001), an agent can choose a task from a 'menu

[1] A coping strategy to reduce this behavior is self-forgiveness (Wohl et al., 2010).

of tasks' and will either do the chosen task now or later. He is more or less aware of his future self-control problems.

In this model there is a menu of tasks X. The task $x \in X$ is represented by a pair (c, v), the costs c and benefits v. If the agent completes the task in period τ, this will cost c in this period τ and benefits v in every next period $\tau + 1$. In each period, an agent can either do a task x or do nothing. Action $x \in X$ means 'complete task x' and the strategy s specifies which action to complete in each period.

The agents have some properties. The parameter δ is the time-consistent impatience. Time consistency means that an agent's relative preference for well-being remains the same over time. When it is inconsistent, there is a preference towards well-being earlier than later. β represents the time preference for immediate gratification. When this is 1, it means that the preferences are time consistent and when $\beta < 1$, a person prefers now over the future. $\hat{\beta}$ is the agent's belief about the future self-control problems. The current preference V^t of an agent given his beliefs $\hat{s}^t$ provided there is an action $a = (c, v)$ available is:

$$V^t(a_t, \hat{s}^t, \beta, \delta) \equiv -c + \frac{\beta\delta}{1-\delta}v$$

where a_t is the current action and $\hat{s}^t$ the person's beliefs.

There are three kinds of agents in this model:

- Sophisticated agents that are fully aware of future self-control problems: $\hat{\beta} = 0$
- Naive agents that are fully unaware of future self-control problems, they believe they will not have such problems: $\hat{\beta} = 1$
- Partially naive agents, they are aware that they will have future self-control problems, but underestimate their magnitude: $\hat{\beta} \in (\beta, 1)$

A task can be β-worthwhile, which means that a person prefers doing it now to never given his taste for immediate gratification: $\frac{\beta\delta}{1-\delta}v - c \geq 0$. The β-best task is the best of the worthwhile tasks. A person procrastinates when he does nothing instead of the worthwhile task.

When there are multiple tasks available, the agent will choose the one with the highest preference. According to the authors, this means an agent is more likely to procrastinate on more important goals because these are more ambitious and have greater costs, thus increasing the chances of procrastinating.

Another model is the model proposed by Van Broekhuizen (2010) which has some similarities with the model of O'Donoghue & Rabin (2001). There are agents with different levels of *sophistication*, but in this model it is linked with conscientiousness. The more conscientiousness, the more sophisticated an agent is. An agent with low conscientiousness is called a *naive agent*.

In this model, the agent is given a task to do. This is a multiple-stage, divisible task with a deadline. When performing the task, the costs C are experienced directly, because it has some costs to work on a task. The reward F will be given after the deadline and is a function of the total time spent on the task. Agents set their own 'goal reward', F_G, so they need to work R hours, such that $F(R) = F_G$. The possible number of hours that can be used to finish a task on one day h_t is limited by 24, since there are only 24 hours a day. The utility on a certain moment is:

$$U^t(u_t, u_{t+1}, \ldots, u_T) = \gamma\delta^{S-t}F\left(\sum_{t=1}^{T} w_t\right) - C(w_t) - \beta^X \sum_{T=\tau+1}^{T} \delta^{T-t}C(w_\tau)$$

In this equation, γ is the salience of future relative to present rewards, β the salience of future relative to present costs, δ the time-consistent impatience and X is determined by α: the agent's level of conscientiousness or sophistication. α closer to 0 means that an agent is *more* sophisticated.

On a certain day, the agent can either do the task or not. He will only work on the task when the utility to perform the task is at least as great as the expected utility on the next days. So when the expected utility is higher on the next days, he will procrastinate on the current day. When an agent is perfectly sophisticated, he will estimate the utility to do a task today, tomorrow or any day before the deadline the same, so he will perform the task today. A naive agent believes that he's better off to perform the task later instead of now and is thus more likely to procrastinate. Only on the day before the deadline he will believe to be better off to perform the task now instead of tomorrow.

In Van Broekhuizen (2010), an example is given where three agents have to finish an essay. The assumption here is that the essay will be graded according to the amount of time spent on it. The agents have a certain goal, or grade, that they want to receive and estimate how much time is needed for this. They also know they can spend a specific amount of time writing the essay each day. The most sophisticated agent will start on time to spend enough time to write his essay. The least sophisticated agent will procrastinate too long and not be able to spend enough time on his essay and gets a lower grade. In this example, each agent can perfectly estimate the required time, and know how much time they can spend on writing. However, this is not realistic. When there is more uncertainty about these things, the grade can even be lower. This example shows that procrastination leads to a lower welfare.

These economic models give some insight in the dynamics of procrastination. However, it is often not clear how these models relate to relevant psychological concepts. To get a better understanding of procrastination, it is important to create models that specify how the model components are mapped to concepts in psychological literature. With this mapping, the outcome of the model can be compared to real world situations, and these situations can be expressed in the model, and conclusions can be drawn on the behavior of the agent in these situations.

3.3 Temporal motivation theory

The theory proposed by Steel & König (2006) tries to integrate different theories on motivation. They discuss each theory and the relevant parts are taken out of each theory. The

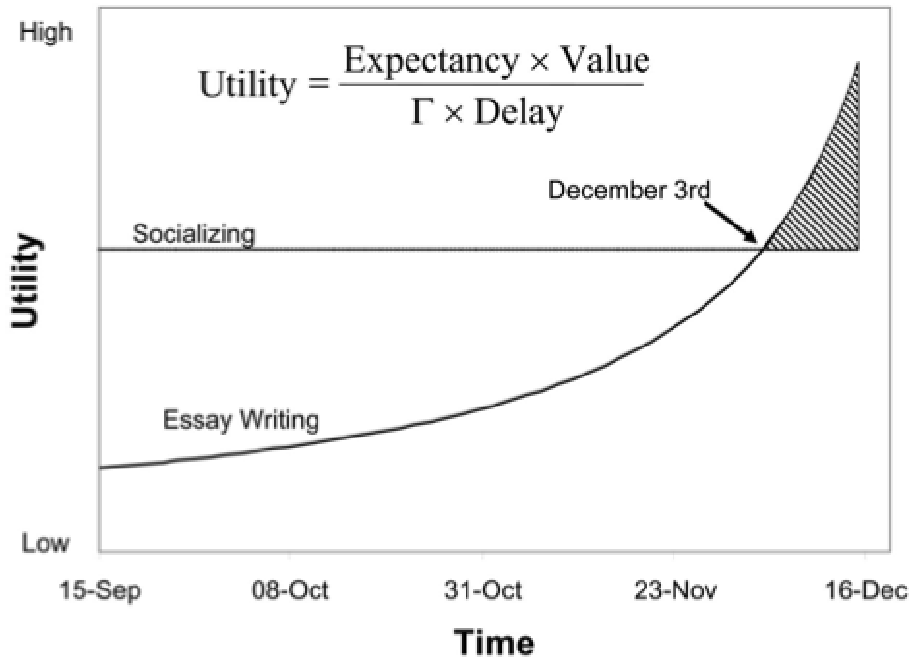

Figure 3.1: Graph of a students utility estimation for socializing versus writing an essay over the course of a semester. (Steel, 2007)

'final' formula is:

$$Utility = \sum_{i=1}^{k} \frac{E^{+}_{CPT} \times V^{+}_{CPT}}{Z + \Gamma^{+}(T - t)} + \sum_{i=k+1}^{n} \frac{E^{-}_{CPT} \times V^{-}_{CPT}}{Z + \Gamma^{-}(T - t)}$$

Where k is the number of gains, n the number of possible outcomes, E^{+}_{CPT} the transformed values for expectancy associated with k gains and V^{+}_{CPT} the (transformed) perceived value of these gains. $T - t$ is the delay of the reward and Γ to the sensitivity to delay. Z is a constant to prevent the equation going to infinity. The gains and losses are separated because gains and losses are perceived differently according to cumulative prospect theory (CPT). The summation sign is added to have multiple outcomes.

The authors provide some areas where TMT can be applied to because there is evidence that the theory describes fundamental effects, for example in group behavior, goal setting but also procrastination. However, how the theory should be implemented is not stated explicitly. Vancouver et al. (2010) have *'integrated TMT with a control-theory-based subsystems approach'* in their model of the pursuit of multiple goals with dynamic variables. However, they only used some notions of this theory.

In Steel (2007) there is some more information on TMT applied to procrastination. The following formula is given:

$$Utility = \frac{E \times V}{\Gamma D}$$

The expectancy E is associated with self-efficacy, the value V with the task aversiveness, need for achievement and boredom proneness. The sensitivity to delay Γ by impulsiveness, distractibility and lack of self-control. Age also plays a small role, as sensitivity to delay decreases with age. The actual delay $D = T - t$ is influenced by the timing of rewards, organization of a person (whether he creates subgoals) and the intention-action gap. Again it is not stated explicitly how the theory should be used. This utility function will be used as a basis for the utility function used in the formal model, because it contains most elements that influence procrastination. The adjustments that are made to Steel's utility function to use it in the formal model will be described in the next chapter.

An informal example to clarify TMT is given in Figure 3.1. The student has a to hand in an essay at the end of the semester. During this semester he can choose between two activities to do: writing the essay and socialize. Because the deadline is far away, the utility of writing the essay is very low at the beginning of the semester, but this increases during the semester. The student will choose to do the task with the highest utility, so he starts writing his essay near the end of the semester.

Temporal motivation theory integrates a number of psychological notions connected to procrastination. However, it is not specified how the theory should be implemented; only some small, non-formal examples are given. Implementation can provide new insights into the underlying mechanisms of procrastination instead of only giving the factors that influence it. Another reason to implement this theory is to get more ways of validating the model. Having a validated model will increase the number of conclusions that can be drawn from the theory.

Chapter 4

Formal model

In Chapter 2, the different factors that influence procrastination are discussed. In this chapter, a formal model will be presented that includes all these factors. The validation of the formal model can be found in Chapter 5.

4.1 Overview

In the model there is an individual agent that has various goals. This agent can perform activities to reach these goals or procrastinate: performing less useful activities or even doing nothing. First, an overview of the model will be discussed with an example, then all different aspects of the model will be discussed in more depth. Table 4.1 gives an overview of the symbols used in the model.

An individual agent has a specific, non-alterable personality, but also dynamic variables as ego strength and mood. The agent has goals, and these goals have tasks associated with them. These tasks, and the activities that are associated with the task, also have some agent-specific elements that represent the agent's attitude towards a task such as boredom or self-efficacy.

The goals of the agent are the personal projects (Little, 1983) an agent wants to complete. This can be anything. How these goals are determined is not specified explicitly in this model because it is beyond the scope of the model. A goal has a certain importance. To reach a goal, tasks have to be completed. These tasks are the implementation of the goal and have properties like personal meaning, boredom, frustration, autonomous motivation, fear of failure and self-efficacy.

A goal doesn't necessarily have to have tasks, for example when the agent hasn't thought about its execution yet. A task consists of one activity or at least one subtask. There are many similarities between goals, tasks and activities. For example, something like 'Enjoy a nice night out with friends' can be a goal for a socially anxious agent but just a small activity for others. It is not strictly defined whether 'Enjoy a nice night out with friends' should be a goal, task or activity because of these personal differences.

Next, an overview of the model with the use of a small example will be given. A schematic illustration of this example can be found in Figure 4.1. In this example, an agent has some

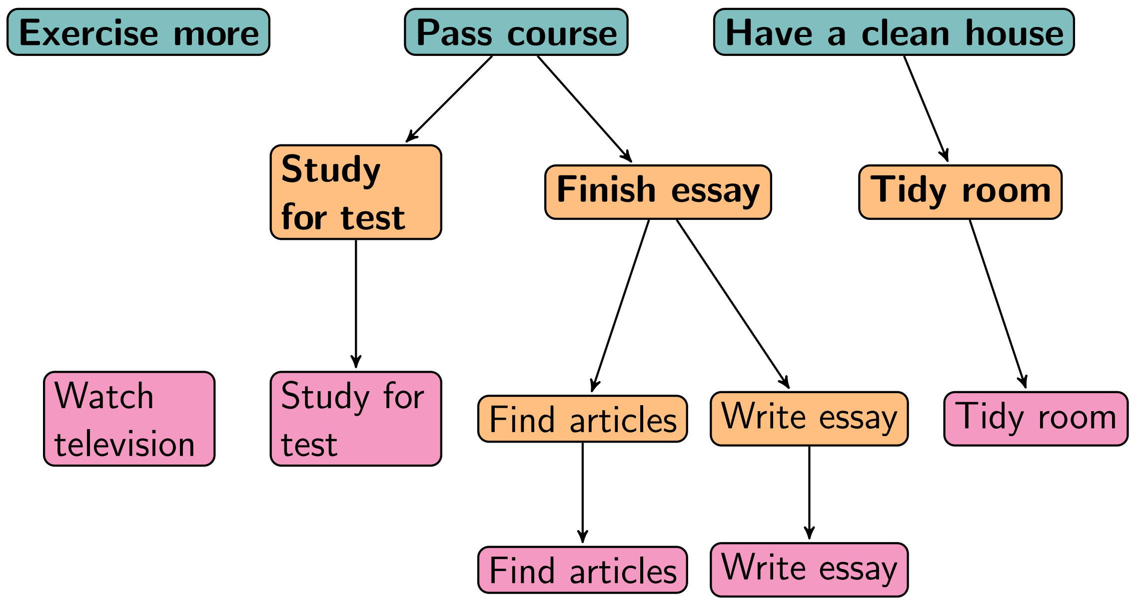

Figure 4.1: Goals (blue), tasks (orange) and activities (pink)

goals. The goal 'exercise more' is something the agent wants, but hasn't made a plan for yet. To pass the course, the agent has to complete two tasks: 'study for test' and 'finish essay'. Another task to complete is 'tidy room', which belongs to the goal 'having a clean house'. In order to complete all these goals, the agent has to prioritize and make a plan. This is done by making a list of intended tasks. All tasks are on this list and the order is mostly based on the importance of the goal and the deadline of the task, but also on the other characteristics of the task like boredom and frustration. It can be seen as some kind of to-do list. The ordered list in this example is:

1. Study for test
2. Finish essay
3. Tidy room

Now the agent has to decide which activity to perform. The agent has to select an activity from the set of activities. In this set are not only the activities that belong to a task, but also activities that can be performed and don't belong to a task. These other activities are generated by either internal or external events. In this example, the set of activities consists of 'Watch television', 'Study for test', 'Find articles', 'Write essay' and 'Tidy room', of which 'Watch television' is not task-related. Next, the utility of each activity is calculated. All task characteristics are included in this calculation. The activity with the highest utility will be performed until the activity is finished, the deadline has passed or an event has occurred.

In this example, the agent has full knowledge about everything that has to be done to reach the goals 'Pass course' and 'Have a clean house'. This is not always the case, as can be seen with the goal 'Exercise more'. The agent needs to make plans to complete this goal. It can also be the case that the agent has no knowledge on how to complete a certain task. The agent can search for new tasks or they can be presented in the form of an event.

Concept	Formal notation	Definition
Agent	p	An individual agent in the model.
Goals	$g_p \in G_p$	The personal projects of the agent. Not generated inside the model. G_p is the set of goals of an agent p.
Task	$\tau \in T_g$	Implementation of the goal g. A task consists of either at least one subtask or an activity.
Activity	$a \in A_E \cup A_T$	Description of what an agent can do. An activity belongs either to an event (a_e) or task (a_τ), and is thus either part of the set of all activities belonging to an event (A_E) or task (A_T).
Intended tasks	List I	This list contains all tasks known to the agent ordered by priority. The priority is a function of the importance of the goal and other task characteristics. $I \subseteq T$.
Options	$o \in O$	Options are all possible activities an agent can do. $O \subseteq A_E \cup A_T$.
Event	$e \in E$	Something that triggers the agent to reconsider his current activity. Also adds a new activity the options of the agent. This activity is not necessarily connected to a goal or task.
Utility	$U(a, p)$	Representation of the desirability of an activity a for a person p.

Table 4.1: List of definitions

An event is something that happens and requires some attention of the agent. An event can be seen as a trigger for an activity. For example, the event 'Receiving a text from a friend to go out' has the activity 'Going out' associated with it. Events can be external (as the example) or internal (e.g. being hungry and eating something). As a consequence of an event, the agent will reconsider the current task. An event has an activity, a value that represents salience and a deadline. The salience indicates how difficult it is to resist the event. The deadline of an event indicates until when it is possible to perform the activity, for example, a specific television show on Tuesday night can't be watched on Wednesday anymore.

The activity is added to the options of the agent and can be performed when the utility is high enough. When this activity belongs to a task, the activity is connected to the task and this task is included in the list of tasks. An example of an event is a call from a friend to go for a run together. Since it is associated with the goal 'Exercise more', the task 'Go running with friend' is added to the list of intended tasks.

An activity of an event is not always associated with a task or goal. When it doesn't belong to a task it is just added to the set of options. The agent will re-calculate the utilities (for both event- and task-related activities) again and choose the activity with the highest utility. This can belong to the current task or the just added task 'Go running', but there is also the option that the agent will choose another task. For simplicity of the model, an agent can only perform one activity at the time.

Procrastination is defined as *"the voluntary delay of an intended and necessary and/or [personally] important activity, despite expecting potential negative consequences that outweigh* *the positive consequences of the delay."* (Klingsieck, 2013, p. 26). In this model, the agent is procrastinating when performing an activity that doesn't belong to a task on the list of intended tasks. This is according to the definition because the agent knows what the important tasks are, namely the ones on the list of intended tasks, but decides to do something else and thereby delays the tasks that have to be done.

One particular form of procrastination is structured procrastination (Perry, 2012). This means doing something useful, but not the most important thing to be done. An example of this is the increase in cleanliness of student housing by the end of the semester because students don't feel like studying but still want to do something useful. In this model, when the agent is performing an activity that belongs to a task on the list of intended activities, but not the top one, it is structured procrastination. An exception to this is when the agent wants to perform the activity that belongs to the the task with the highest priority and this activity has preconditions so the agent has to execute a precondition first.

In Figure 4.2 it is shown when procrastination and structured procrastination occur.

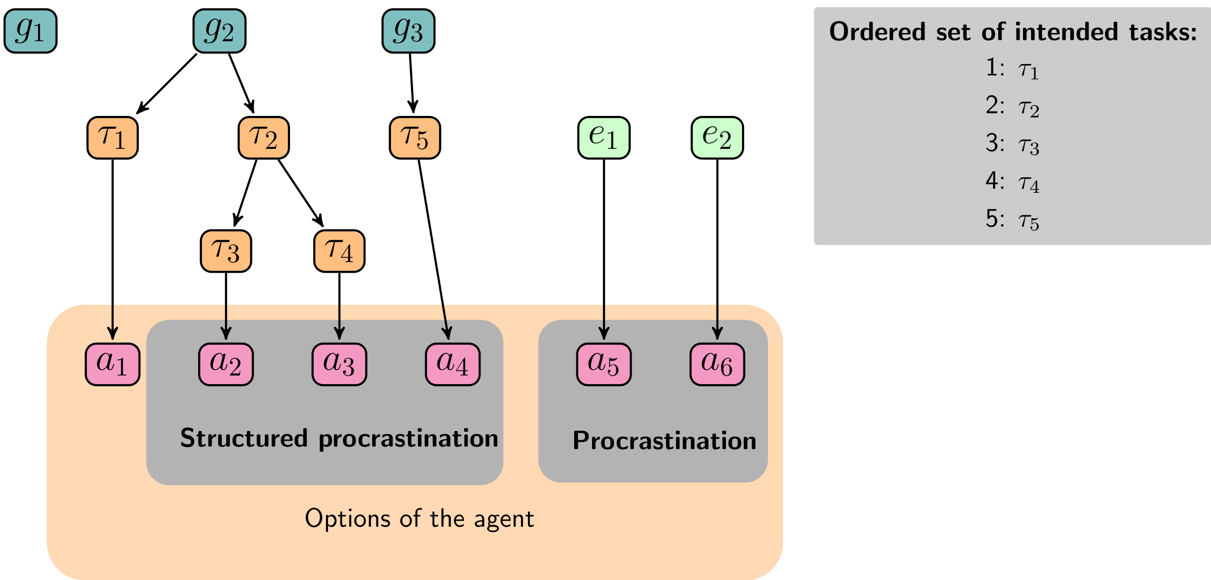

Figure 4.2: Illustration of the model. Note that the events e_1 and e_2 are triggers that add a_5 and a_6 to the agents options. When, for example, one of the activities in the block Procrastination is performed, the agent is procrastinating.

4.2 Agent

The agent p is defined as a 10-tuple:

$p =<$Mood, EgoResource, SensationSeeking, SelfEsteem, Conscientiousness, Impulsiveness, I, G_p, CurrentActivity, $O >$

where I is an ordered set containing all intended tasks ordered by their priority, G_p the set of personal goals of the agent, CurrentActivity the activity the agent is performing and O the set of all possible activities an agent can choose from (i.e. the agent's options): $O = A_E \cup A_T$ (where A_E is the set of all activities that belong to any event and A_T the set of all activities that belong to any task). In Section 4.8 is explained how the list of options is determined. The current activity is the behavior of the agent. The assumption is made that an agent can only execute one activity at the time.

Ego resource (or willpower) is an dynamic variable that changes over time that is represented as the interval $[0, 1]$. Ego resources will drop over time when the agent is performing activities. When an activity is aversive or when there are a lot of events that distract him from his current activity, the ego resources will drop more quickly. For now, ego resource will decrease every time step, independent of what activity the agent is doing. The ego resource can go up again when performing a relaxing activity, doing nothing for a while or eating something.

The personality traits sensation seeking, self-esteem, conscientiousness and impulsiveness are found in the literature. These are static variables that influence the utility. A personality trait is represented as a number between 0 and 1: the higher a person scores on a certain trait, the closer it is to 1.

4.3 Goals

A goal specifies what an agent wants to achieve. A goal g is a 5-tuple:

g =<Description, T_g, Importance, EstimatedTime, Deadline>

where $T_g = \{\tau_1, \ldots, \tau_n\}$ is the set of tasks belonging to a goal. This set can be empty when the agent has not implemented the goal yet with some tasks. It is assumed that each goal has a known importance value for the agent. Different goals can have the same importance.

How the goals and their priority are determined is not specified in this model. The description and other variables are given for each goal and also the tasks that have to be completed to achieve the goal (when applicable).

The estimated time to complete a goal is different per person. However, for simplicity of the model we assume this time is fixed. EstimatedTime and Deadline will be 0 when the agent doesn't know these values.

4.4 Tasks

A task τ is a 13-tuple:

τ =<Description, Components, Priority, EstimatedTime, Deadline, Preconditions, Structure, Boredom, PersonalMeaning, AutonomousMotivation, Frustration, FearOfFailure, SelfEfficacy>

where Components $= a_\tau |$ Subtasks. Subtasks is a set of tasks (these tasks can have subtasks as well). So a task either has an activity, other tasks or nothing as its component.

Preconditions of a task τ are the tasks that have to be performed before τ can be performed. The costs of the tasks that have to be done before τ are not included in the calculation of the utility. However, it would be interesting to see what the implications are of including this in future work. It would mean that when the preconditions of a task are for example very boring, it is less likely that the agent will choose that task. However, including this can have implications like the agent won't perform anything because everything could be a precondition of everything. In order to avoid these kind of problems, preconditions are not taken in to account for the calculation of the utility and priority of activities and tasks. It is however an interesting addition to explore in future work.

Priority is used to determine the order in the list of intended tasks. It can be calculated with the following formula:

$$Priority(\tau, p) = \frac{E_{\tau,p} \cdot V_{\tau,p}}{\Gamma \cdot D \cdot w_{Delay}} \cdot Importance(g_\tau)$$

where $E_{\tau,p}$ is the expectancy of succeeding in the task, $V_{\tau,p}$ the value, which are the costs and benefits of performing τ, Γ the sensitivity to delay, D the delay, w_{Delay} the weight of the delay and g_τ is the goal associated with task τ. How these values are calculated can be found in Section 4.7, except for $V_{\tau,p}$, which is given below.

$V_{\tau,p}$ is calculated slightly different (than $V_{a_\tau,p}$ for activities), because the structure of a task is taken into account. The agent has no full knowledge on all tasks and activities that can be performed (see Section 4.8). The structure of the task is dependent on the agent's knowledge of the tasks and activities he has to perform to complete the task. When an agent is less aware of the things that have to be done to complete a task, he is more likely to procrastinate. The structure of a task can be calculated as:

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

The activity leaves are activities and the task leaves are tasks. An activity is already the smallest unit that can be executed directly, so there is no need to expand anymore. A task can't be executed directly, so in order to complete the task, it has to have an activity (or subtasks with activities). The more knowledge an agent has on what needs to be done (activity leaves), the higher the structure of task.

If we take a look at Figure 4.2 and assume that a_1 and a_2 are unknown to the agent, the set 'Activity leaves' contains a_3 and a_4. 'Task leaves' contains τ_1 and τ_3. The structure would be $\frac{2}{2+2} = 0.5$.

The formula to calculate the value for a task:

$$V_{\tau,p} = -\text{Boredom}_\tau \cdot w_{\text{boredom}} - \text{Frustration}_\tau \cdot w_{\text{frustration}} + \text{AutonomousMotivation}_\tau \cdot w_{\text{AutonomousMotivation}} - \text{SensationSeeking}_p \cdot w_{\text{SensationSeeking}} + \text{Conscientiousness}_p \cdot w_{\text{conscientiousness}} + \text{EgoResource}_p \cdot w_{\text{EgoResource}}$$

$+\text{PersonalMeaning}_p \cdot w_{\text{Personalmeaning}} + \text{Mood}_p \cdot w_{\text{Mood}} + \text{Structure}_\tau \cdot w_{\text{Structure}}$

EstimatedTime is a summation over all subtasks or the underlying activity:

$$\text{EstimatedTime}_\tau = \text{EstimatedTime}_{a_\tau} + \sum_{\text{Subtasks} \in \tau} \text{EstimatedTime}_{\text{Subtasks}}.$$

A task has to have a deadline, otherwise there would be no reason to do the task now instead of later. This deadline can be self-imposed or set by other people. The deadline of the task has to be before or the same as the deadline of the goal because it wouldn't make sense to finish a task after the goal should be completed. Also, the estimated time for the task has to be equal or smaller than the estimated time for the goal, because otherwise it is highly unlikely that the agent is able to complete the goal before the goals' deadline. The agent should plan the tasks in a way that it is possible to complete them instead of making it (almost) impossible from the start. This is modeled by not executing an activity when the delay[1], the time to the deadline minus the estimated time, is lower than 0.

The other elements are task-related factors as described in Chapter 2.

4.5 Activities

An activity a is a 12-tuple:

a =<Description, Kind, Utility, EstimatedTime, Preconditions, Boredom, PersonalMeaning, AutonomousMotivation, Frustration, FearOfFailure, SelfEfficacy, SpentTime>

An activity can be executed. Kind is whether the activity is associated with a task or an event. When an agent performs an activity that is not related to a task, it is procrastination. The utility is calculated by the formula in Section 4.7.

The estimated time for the activity has to be equal or smaller than the estimated time for the task. Before an activity can be executed, all the activities that are in the set of preconditions have to be finished. SpentTime counts how much time steps the agents has already spent on the task.

The other elements are activity-related factors as described in Chapter 2.

The operations that can be performed on the set of tasks T_g belonging to goal g are:

- Remove task τ_i from T_g:
  - $I = I \setminus \tau_i$
  - $T_g = T_g \setminus \tau_i$
- Add task τ_i to T_g:
  - If ($\text{Deadline}_{\tau_i} \leq \text{Deadline}_g$) And ($\text{EstimatedTime}_{\tau_i} \leq \text{EstimatedTime}_g$)

[1] $D_{a_\tau} = \text{Deadline}_\tau - \mathit{CurrentTime} - \text{EstimatedTime}_{a_\tau}$

    - * Add τ_i in T_g

The operations that can be performed on the set of activities for task τ A_τ are:

- Remove activity a_i from A_τ:
    - $O = O \setminus a_i$
    - $A_\tau = A_\tau \setminus a_i$
- Add activity a_i to A_τ:
    - If ($\text{Deadline}_{a_i} \leq \text{Deadline}_\tau$) And ($\text{EstimatedTime}_{a_i} \leq \text{EstimatedTime}_\tau$)
        - * Add a_i to A_τ

4.6 Events

In this model, an event is a trigger for the agent to reconsider the current activity. Temptations are modeled as events. The reason for this is that when an agent is working on an activity, it is most likely that it continues with this activity. An agent will consider switching to another activity only when:

- the current activity is finished
- the deadline of the current activity passed
- an event occurs

An event grabs the attention away from the current activity, so after that, the attention can go somewhere else. An event e is defined as:

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

where Kind can be internal or external, Activity is an activity that will be added to the options of the agent (and, when applicable, connected with a task) and Saliency is how difficult it is to resist the activity associated with the event.

The activity associated with the event will be added to the options of the agent and, when applicable, connected with a task. For example, when a friends calls to go out, the activity associated with this event is 'Going out'. Every event has an activity associated with it. However, this can be something small and insignificant like staring out of the window because there was some noise. Sometimes the activity is associated with a task. In this case, the agent will re-evaluate his list of intended tasks to see where this new task should be on the list.

The salience of an event is how difficult it is to resist the activity associated with the event. This is used to calculate the utility: the higher the saliency, the higher the utility. It also influences ego depletion.

Internal events are governed by rules of the following form:

If Value(c) $<$ threshold,
Then Event $e =<\text{Internal}, a, 1 - V(c), d >$

where c is one of the (changing) values of the agent (e.g. Ego resource) or the activity currently working on and d the deadline.

External events can also be governed by rules, but will initially be added to the model on a certain time step to model a given situation. An example of an external event is a friend who calls to have a drink. This event has the activity 'Go out for a drink' associated with it.

Events can have a deadline. For example, when the event is a friend calling to go out for a drink, the deadline is by the end of the nights, since all the places to go for a drink are closed, so there is no possibility to perform this activity anymore.

4.7 Utility

The utility of an activity expressess how desirable this activity is to a person. In this model, the calculation of the utility is based on the temporal motivation theory (TMT) of Steel & König (2006), later applied to procrastination by Steel (2007). The simplest formulation of Steel's formula is:

$$U = \frac{E \times V}{\Gamma D + Z}$$

According to Steel, expectancy E is associated with self-efficacy and value V with task aversiveness, need for achievement and boredom proneness. The sensitivity to delay Γ by impulsiveness, distractibility and lack of self-control. The actual delay D (time to the deadline) is influenced by the timing of rewards (by finishing the task) and organization of a person (whether subgoals are created). Z is a constant to prevent the equation going to infinity.

Steel doesn't explain explicitly how to implement this formula. In Chapter 2, several factors influencing procrastination where identified and they were used in the previous sections to define agents, goals, tasks and activities. Each of these factors plays a role in the utility function, but not all of them are in the example of Steel (2007). Since it is unclear how strong the influence of each factor is, a weight is assigned to each factor. The utility (a, p) is the utility of an agent p for an activity a.

The expectancy E of an agent p for activity a is the likelihood of a good result:

$$E_{a_\tau,p} = \text{Selfefficacy}_{a_\tau} \cdot w_{\text{selfefficacy}} + \text{SelfEsteem}_p \cdot w_{\text{selfesteem}} + \text{AdjustedFearOfFailure}_p \cdot w_{\text{fearOfFailure}}$$

The influence of fear of failure on procrastination is dependent on the self efficacy. When this is high, a person will work harder and procrastinate less, when it is low, a person will procrastinate more (In Section 2.6 this is explained in more detail). The following formula implements this:

$$\text{AdjustedFearOfFailure}_p = \left\{ \begin{array}{ll} \text{FearOfFailure}_p & \text{when SelfEfficacy}_{a_\tau} > 0.5 \\ -\text{FearOfFailure}_p & \text{else} \end{array} \right\}$$

Value V is the expected value, or the costs of the task:

$V_{a_\tau,p} = -\text{Boredom}_{a_\tau} \cdot w_{\text{boredom}} - \text{Frustration}_{a_\tau} \cdot w_{\text{frustration}} + \text{AutonomousMotivation}_{a_\tau} \cdot w_{\text{AutonomousMotivation}} - \text{SensationSeeking}_p \cdot w_{\text{SensationSeeking}} + \text{Conscientiousness}_p \cdot w_{\text{conscientiousness}} + \text{EgoResource}_p \cdot w_{\text{EgoResource}} + \text{PersonalMeaning}_p \cdot w_{\text{Personalmeaning}} + \text{Mood}_p \cdot w_{\text{Mood}}$

The sensitivity of delay Γ is dependent of the impulsiveness:

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

The delay D of a task is dependent on the time left to the deadline:

$D_{a_\tau} = \text{Deadline}_\tau - t - \text{EstimatedTime}_{a_\tau}$

When a task is on the list of intended tasks, a small bonus B is added to the utility, depending on the position in the list. This bonus is added to include the priority of the task (the higher on the list of intended tasks, the higher the priority) in the calculation of the utility function of an activity. When a task is not on the list, $B = 0$, otherwise the following formula is used to determine B_τ:

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

The final formulas based on TMT will be:

$$Utility(a_\tau, p) = \frac{E_{a_\tau,p} \cdot V_{a_\tau,p}}{\Gamma_p \cdot D_\tau \cdot w_{Delay}} \cdot B_\tau \qquad Utility(a_e, p) = \frac{E_{a_e,p} \cdot V_{a_e,p}}{\text{EstimatedTime}_{a_e}} \cdot \text{Saliency}_e$$

where $E_{a_\tau,p}$ is the expectancy, $V_{a_\tau,p}$ the value, Γ_p the sensitivity to delay, D_τ the delay, w_{Delay} the weight of the delay, Saliency_e the strength of an event and B_τ a small bonus when the activity is associated with a task in the list of intended tasks. The bonus B_τ is added to make a link between priority (the list of intended tasks) and utility.

The weights w determine how strong a factor influences procrastination. The formulas include all factors discussed in the conceptual model (Chapter 2). Some factors have a positive effect, others a negative, and this is dependent on the influence of this factor on procrastination. The value of these weights are determined in Section 5.2.

When the utility is negative, the agent won't perform the activity. It won't make sense to perform an activity that will have a negative influence on the agent, for example by performing activities that are not useful or too frustrating. The agent will search for other tasks.

4.8 Options of the agent

Options of the agent is defined as all the possible activities an agent can do and this is a subset of $A_E \cup A_T$ (see Table 4.1). The agent has no complete knowledge on all the possible tasks that can be performed. People know that they must do something, but are not always aware of all the preconditions (e.g. filling out a form and only then become aware that there are some important documents to include) or what the subtasks or activities are of a certain task (e.g. for the task 'Finish essay', the agent must decide what to do to complete this task).

The agent will add new activities to his options and new tasks to his list of intended tasks when:

- An event occurs: the activity associated with this event will also be added to the options.
- When an activity has preconditions: the preconditions are added to the options.
- The agent performs the activity 'Search for new tasks and activities' and succeeds in this.

'Search for new tasks and activities' is an activity that is performed when at least one of the following conditions is the case:

- An agent doesn't have any activities to do anymore.
- The utility of all activities in the options is too low or negative.
- When the most important task has a very high priority but no activities.

When 'Search for new tasks and activities' is performed, the agent will choose the highest task on the list of intended activities that isn't explored completely yet. The agent will try to find new subtasks or activities for this task. The way it is is modeled, all activities and tasks are already generated and in the system, but they are hidden for the agent. When an activity is found, this is added to the options of the agent. When the agent finds a subtask, it is added to the list of intended tasks of the agent, this list is ordered by priority again and the agent will continue to search until an activity is found, because the reason for trying to search was the lack of (good) activities. When all the goals are completed, the search for new activities and tasks is not possible anymore until there are new goals.

4.9 Process overview

This section contains an overview of the process of the model. It explains how an agent chooses activities and what happens when events occur. Algorithm 1 (on page 33) gives a more formal specification.

In each time step, Ego resource is updated. Then, the priority of all the tasks in the model is calculated to determine the order in the list of intended tasks. Next, for each activity the utility is calculated with one of the formulas given in the section 'Utility'.

After that, it is checked whether activities are finished, and if so, they are removed. Tasks with deadlines that are passed are also removed. After this, the utility of all activities is calculated again. When an event occurs, it is checked whether they belong to a task. When this task doesn't have an activity yet, the activity is connected to this task and added to the task-related activities A_τ. When this task already has an activity, this activity is updated with the new values. An example of this is an announcement to find additional articles to finish the essay. When the new activity doesn't have a task associated with it, the activity is added to the set of event-related activities A_e.

After this, the utility of all activities is calculated again. If none of the activities or tasks are finished and no events occur, the activity with the highest utility is chosen. When the utility of this activity is not negative, this activity is performed. Otherwise, the activity 'Search for new tasks and activities' will be performed.

When this activity is in A_e, the agent is procrastinating because the agent is performing an activity that doesn't belong to a task so isn't part of the agent's goals. When an agent is performing an activity that doesn't belong to the task on top of the list of intended tasks, it is structured procrastination.

Searching for new tasks and activities is not (structured) procrastination since it will only be done when there are no other activities to do or at least no suitable activities, but there can still be tasks to complete. Finding ways to complete these tasks is necessary to do and has no negative consequences so it is no procrastination.

Algorithm 1 Process overview

1: **for** time $t <$ maximum number of timesteps **do**
2: **if** $A_T \cup A_E = \emptyset$ **then**
3: Search for new tasks and activities
4: **else**
5: Egoresource = EgoResource · updatespeed
6: **for** All tasks τ in I **do**
7: Calculate priority
8: **end for**
9: Sort I
10: **for** each activity a in O **do**
11: Calculate $U(a, p)$ ▷ agent p
12: **end for**
13: **for** Each time step t **do**
14: **for** Each activity a **do**
15: **if** $\text{SpentTime}_{a_\tau} > \text{EstimatedTime}_{a_\tau}$ **then** ▷ Remove finished activities and their tasks
16: $O = O \setminus a_\tau$
17: $T_G = T_G \setminus \tau$
18: Go back to line 1
19: **end if**
20: **end for**
21: **for** Each task τ **do**
22: **if** $t \geq \text{Deadline}_\tau$ **then** ▷ Remove tasks with passed deadlines and their activities
23: $O = O \setminus a_\tau$
24: $T_G = T_G \setminus \tau$
25: Go back to line 1
26: **end if**
27: **end for**
28: **if** an event e occurs **then**
29: **if** activity a is associated with a task τ_g **then**
30: ▷ Connect activity with associated task and add to set of task-related activities
31: $T_g = T_g \cup \tau$
32: $A_T = A_T \cup a$
33: $I = I \cup \tau$
34: **else** ▷ Add to set of event-related activities
35: $A_E = A_E \cup a$
36: $O = O \cup a$
37: **end if**
38: Go to line 1
39: **end if**
40: HighestUtility= MaxUtility(a) ▷ Choose the activity with the highest utility
41: **if** HighestUtility > MinimumUtility **then** ▷ Default MinimumUtility = 0
42: **if** Preconditions(a) = $\emptyset$ **then**
43: CurrentActivity_p = MaxUtility(a)
44: **else** ▷ When there are preconditions, add them to the list of options
45: $O = O \cup$ Preconditions(a)
46: CurrentActivity_p = Preconditions(a)
47: **end if**
48: **else** ▷ When the utility is too low, search further
49: Search for new tasks and activities
50: **end if**
51: **if** Activity is event-related **then**
52: EgoResource = EgoResource - Saliency_e
53: **end if**
54: **end for**
55: **end if**
56: **end for**

Chapter 5

Validation

The proposed model described in the previous chapter should provide insights into the mechanisms of procrastination. In this chapter, the evaluation steps will be described. First, the model will be implemented in Matlab and some initial simulations will be run. A few different scenarios with different kinds of agents (that, for example, are expected to procrastinate) will be tested to see if the expected behavior will follow from the model. If this is not the case, the model will have to be adapted.

Secondly, an existing data set from a previous psychological experiment on procrastination is used as training data to determine the appropriate weights for the model. Simulated annealing will be used to train the model. A part of the dataset is used to train the model, the other part is used to evaluate the weights. The specifications can be found in Section 5.2. The results of the model with the best found weights will be compared to a model with random weights to evaluate the quality of the model and the found weights.

5.1 Initial simulations

In this example, there is one agent who is average on every personality trait i.e., has been assigned a value of 0.5 for each trait. The agent has two goals: having a clean house and passing a course. Having a clean house is far less important than passing a course. Each goal has two tasks, and all but one don't have subtasks but activities directly under them. One of the tasks has subtasks and the task 'Write essay' has as precondition 'Find articles'. A graphical explanation can be found in Figure 5.1. The tables with the exact data used for this example can be found in Tables 5.1, 5.3, 5.4 and 5.5 on page 39.

First, the implementation will be discussed with a small example. In this example are two events: one internal and one external. The internal event occurs when ego resource drops below a certain value (since this is the only value of the agent that changes). As a result, the activity 'Eat something' is added to the list of options. In line with the findings as discussed in Section 2.3, an activity like this will also increase the ego resources. The external event occurs at a certain time step. The event is a friend calling to go out for a drink, the activity associated with it is going out for a beer.

The output of the program can be found in Figure 5.2. The top graph shows the utility

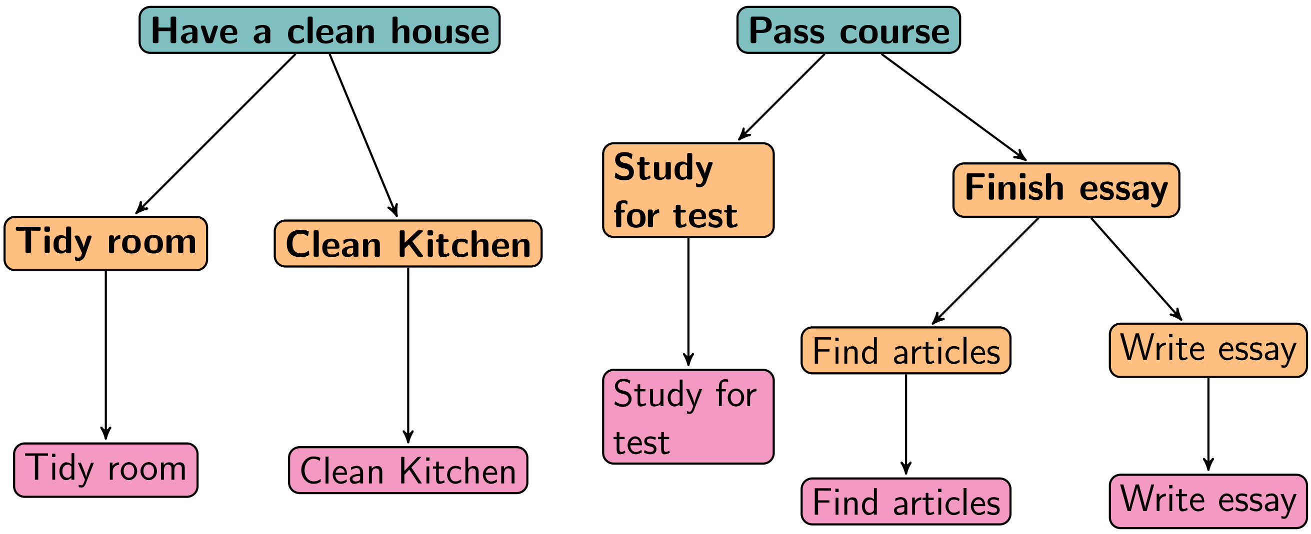

Figure 5.1: Goals (blue), tasks (orange) and activities (pink)

of the different activities. The horizontal lines are the utilities of all the activities that are in the list of options on each time step. The vertical lines are the time steps when the utility (and priority) needs to be recalculated: a missed deadline (red), event (blue) or a finished task (green).

In the bottom graph in Figure 5.2, the current activity of the agent is shown. The number on the y-axis corresponds to the activities. The 'X' represents the current activity of the agent. When there is a red circle around it, the agent is procrastinating: performing an activity associated with an event (and not working towards its goals!). When there is a blue circle, the agent is performing structured procrastination: performing a useful activity, but not the most important one.

In this example, the agent has full knowledge on all tasks and activities, so in the first time step the IntendedTasks are Find Articles (5) - Study for test (3) - Finish Essay (4) - Write Essay (6) - Tidy Room (1) - Clean kitchen (2) The order of this list is determined by the calculated priority. The set of options is [Tidy room, clean kitchen, study for test, find articles, write essay]. This is an unordered list containing all activities that are known to the agent.

The utility of all options is calculated. Activity 5 (Find articles) has the highest utility and will therefore be chosen by the agent and executed. Activity 5 (Find articles) has the highest utility mainly because the deadline is very close.

In time step 5, an event takes place: a call from a friend. The activity is added to the options, and the utility and priority of everything is re-calculated. Activity 5 (Find articles) still has the highest utility and is executed.

In time step 6, the deadline of task 5 (Find articles) has passed. Therefore, the priority is calculated again and the new list of intended tasks is: Study for test (3) - Finish Essay (4)

- Write Essay (6) - Tidy Room (1) - Clean kitchen (2). The utilities are calculated again and the activity with the highest utility will be executed. This is activity 6 (Write essay), which belongs to task 6. This task is not on top of the list of intended tasks, so it is structured

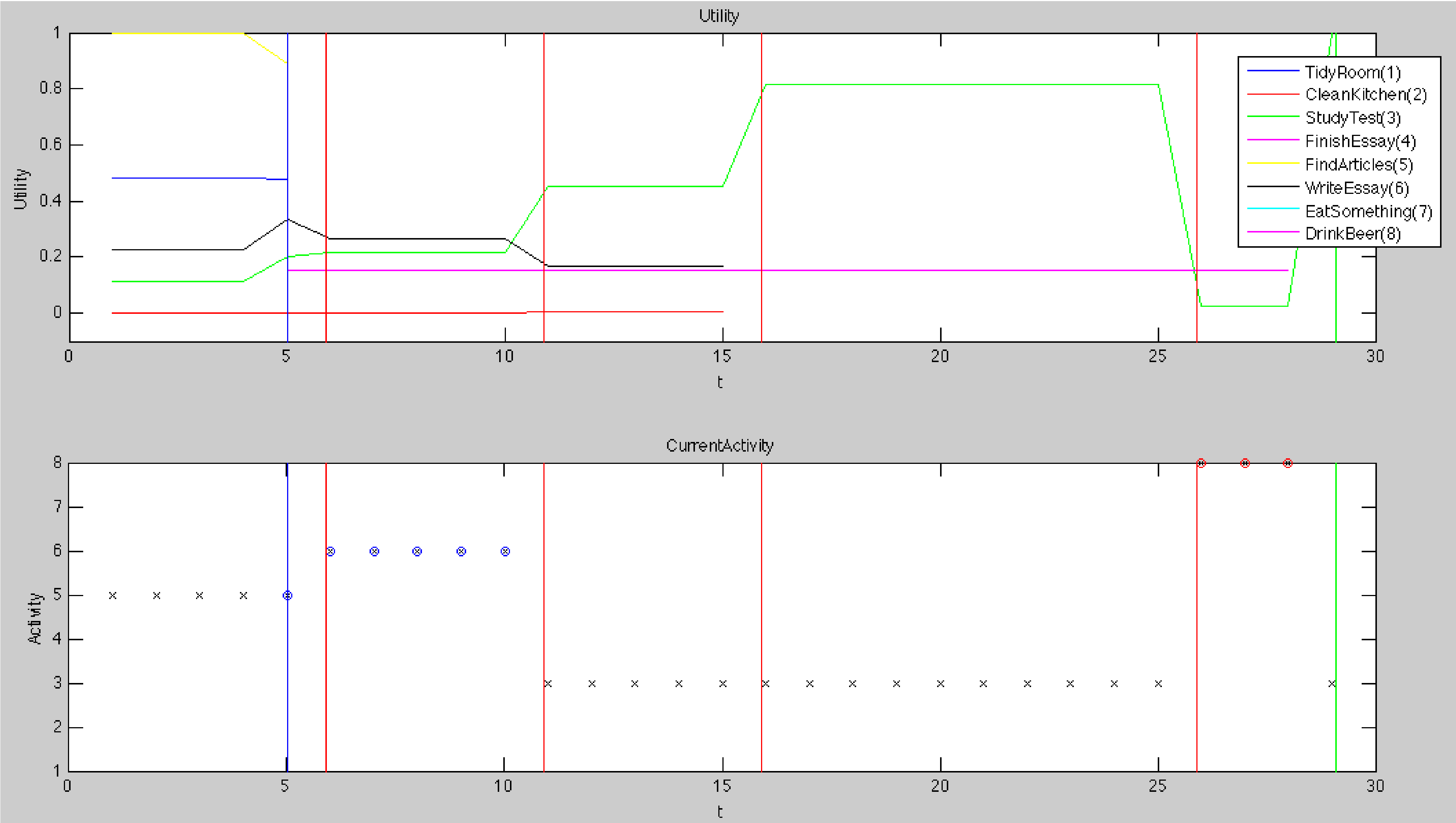

Figure 5.2: The utility of all tasks (top graph) and current activity (bottom graph)

procrastination.

In time step 11, the deadline of task 1 has passed, and this task will also be removed from the list of intended tasks. The new list is: Study for test (3) - Finish Essay (4) - Write Essay (6) - Clean kitchen (2). The activity with the highest utility is 'Study for test (3)' and this task is on top of the list of intended tasks, so the agent is doing exactly what he should be doing. Although in time step 16 the deadline for task 6 (Write essay) has passed, the agent continues with activity 3 (Study for test) because it has the highest utility.

In time step 26, the deadline for task 2 (Clean kitchen) has passed. Because of this, the agent will recalculate the utilities again, and activity 8 (Drink beer) will be executed. Since this activity does not belong to a task, the agent is procrastinating.

In time step 29, activity 8 (drink beer) is finished, so the agent has to choose another activity. This is activity 3 (Study test), which is still on top of the list of intended tasks, so the agent is not procrastinating.

5.1.1 Mini-scenarios

In the previous section, the model was explained with a scenario. In this section some small adjustments will be made to this scenario in order to show whether the model works as expected or not. A few small hypotheses will be given and some simulations will be run with adjusted values. The other values will remain the same as in the tables on page 39 unless specified otherwise.

In order to make the scenario a bit more informative over the longer run, the deadlines and estimated times were changed. In the default scenario that runs for 60 time steps with the values in the tables on page 39, the agent completes 4 tasks and procrastinates on 8 time steps. There is also structured procrastination at 21 time steps.

An agent with high conscientiousness will procrastinate less than an agent with low conscientiousness

As can be seen in Section 2.5, a person with high conscientiousness is likely to procrastinate, and a person with low conscientiousness is less likely to procrastinate. To test this hypothesis, there will be two simulations. The value 'Conscientiousness' of the agent is adjusted. For the agent with high conscientiousness, this will be set to 0.9. For the agent with low conscientiousness, this will be set to 0.1.

The conscientious agent will finish more tasks (4 instead of 1 for the agent with low conscientiousness) and will procrastinate on only 6 time steps (instead of 48). This agent will however have slightly more structured procrastination (18 instead of 9), but the total number of time steps the agent is not doing the activity with the highest priority is still lower. The outcome of the two simulations shows that the hypothesis is confirmed: an agent with high conscientiousness will procrastinate less than an agent with low conscientiousness.

In a scenario where the agent has no complete knowledge, there will be more

Table 5.1: Description of the agent

Agent	Mood	EgoResource	SensationSeeking	SelfEsteem	Conscientiousness	Impulsiveness	I	G_p	CurrentActivity	O
1	0.5	0.8	0.5	0.5	0.5	0.5	0	0	0	0

Table 5.2: Goals

Agent	Description	T_g	Importance	EstimatedTime	Deadline
1	1	[1;2]	3	10	0
1	2	[3;4]	9	30	0

Table 5.3: Tasks

Agent	Description	Goal	Kind Components	Components	Priority	Estimated Time	Deadline	Preconditions	Structure	Boredom	Personal Meaning	Autonomous Motivation	Frustration	Fear Of Failure	Self Efficacy
1	1	1	A	[1]	0	2	10	0	0	0.5	0.3	0.8	0.2	0.2	0.9
1	2	1	A	[2]	0	3	25	0	0	0.4	0.3	0.6	0.2	0.4	0.9
1	3	2	A	[3]	0	5	30	0	0	0.4	0.7	0.9	0.9	0.8	0.2
1	4	2	T	[5,6]	0	6	30	0	0	0.8	0.9	0.2	0.8	0.9	0.2
1	5	2	A	[5]	0	3	5	0	0	0.3	0.8	0.2	0.7	0.9	0.9
1	6	2	A	[6]	0	3	15	0	0	0.8	0.5	0.2	0.6	0.2	0.4

Table 5.4: Activities

Agent	Description	Task	Kind	Utility	Estimated Time	Preconditions	Boredom	Personal Meaning	Autonomous Motivation	Frustration	Fear Of Failure	Self Efficacy	Time Spent
1	1	1	T	0	12	0	0.5	0.3	0.8	0.2	0.2	0.9	0
1	2	2	T	0	6	0	0.4	0.3	0.6	0.2	0.4	0.9	0
1	3	3	T	0	15	0	0.4	0.7	0.9	0.9	0.8	0.2	0
1	5	5	T	0	10	0	0.3	0.8	0.2	0.7	0.6	0.9	0
1	6	6	T	0	15	5	0.8	0.5	0.2	0.6	0.2	0.4	0

Table 5.5: Events

Event Description	Kind (0 = internal, 1= external)	Saliency	Deadline	Time step	Agent	Description	Components	Utility	Estimated Time	Preconditions	Boredom	Personal Meaning	Autonomous Motivation	Frustration	Fear Of Failure	Self Efficacy	Time Spent
1	0	0.9	0	0	1	7	[7]	0	2	0	0.2	0.9	0.9	0.1	0.1	0.9	0
2	1	0.5	0	5	1	8	[8]	0	2	0	0.5	0.5	0.5	0.5	0.5	0.9	0

procrastination.

When an agent has no complete knowledge on what to do to complete a task, the structure of this task is lower. As can be seen in Section 2.1, a lower task structure will lead to more procrastination. In order to test this hypothesis, the initial options and list of intended tasks will be smaller. The activity 'Clean kitchen' and the subtasks of 'Finish Essay' (and their activities) will be removed from these sets.

The agent can search for activities, and in this scenario, the agent will eventually find all possible tasks and activities but will procrastinate slightly more: 18 time steps in a scenario with non-complete knowledge and 8 when the agent has complete knowledge. The agent will also complete fewer tasks (3 vs. 4). The agent will however have more structured procrastination, but the total number of time steps the agent is not doing the activity with the highest priority is slightly smaller. So when a agent has no complete knowledge, there will be more procrastination.

An agent with high fear of failure and low self-efficacy for the task 'write essay', will procrastinate more on this task.

In the 'standard scenario', the agent has average fear of failure and average self-efficacy. In the scenario with high self-efficacy (0.9) and low fear of failure (0.1) there is the same amount of procrastination compared to the 'default scenario'. The reason for this is that the activity with the highest utility will be executed. So even when the utility for this specific activity increases, it can be the case that another activity still has a higher utility.

5.2 Determining weights

In the model, there are weights for all factors. The weights influence the strength of a certain factor on procrastination. They are used in the formulas to calculate the utility function. For example, one part needed to calculate the utility is Γ, the sensitivity to delay. The formula used to calculate this is:

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

where the value for Selfesteem of an agent p is taken from the data, and the value for weight $w_{\text{Selfesteem}}$ has to be determined by some learning algorithm because it's impossible to try out all possible combinations. In this section it is described how these weights will be determined.

In the mini-scenarios all weights were set equal, so all factors had the same influence on procrastination. This is however not realistic: some factors have a stronger influence on procrastination than others. For example, the conscientiousness of a person has a lot of influence on procrastination ($\bar{r} = -0.62$ (Steel, 2007)) while other factors have less influence like sensation seeking, which only has a correlation of 0.17 to procrastination (Steel, 2007). More of these correlations can be found in Chapter 2.

In order to determine the weights, data from an experiment on the relation between fear of failure and competence and their influence on procrastination were used to fit the parameters of the model (Haghbin et al., 2012). The dataset of Haghbin et al. (2012) can be used to determine the weights because it contains many factors that are present in the model and many (293) participants.

The data contains the results of different surveys that were filled in by 293 participants (the sample consisted of 219 women and 74 men with a median age of 19 years). These surveys included the General Procrastination Scale (Lay, 1986) and the Procrastination Assesment Scale - Students (Solomon & Rothblum, 1984) where the participants reported on their own procrastination. The latter scale contains questions about the frequency of procrastination for different tasks, but also about the reasons people give about why they procrastinate on a specific task: writing a term paper. The other surveys that were included measured fear of failure, need for autonomy and competence (self-efficacy).

Not all variables that are present in the formal model are present in the data (see Table 5.6). One of the most important missing factors is time. It plays a role to determine the task delay and the dynamics of ego depletions. Because of this major role, excluding this from the validation will make the validation less meaningful. The only information we have on that topic is the frequency of procrastinating which is somewhere between 'never procrastinate' and 'always procrastinate' on a certain task. This is used to measure the outcome. The other time-related values will be randomized. A more detailed explanation on how to deal with missing data (both time and the other data) can be found in Section 5.2.1.

In the data, the question asked to determine procrastination was *'To what degree do you procrastinate on this task?'* combined with the following instructions: *'Rate each item on an "a" to "e" scale according to how often you wait until the last minute to do the activity'*. This means the outcome should not be the percentage of time an agent is procrastinating, but the number of times the agent was procrastinating on a certain task. So of the 20 papers that had to be written, how many times did the agent wait until the last minute to perform the task?

In order to answer that question, there must be multiple simulations and the number of times the agent is procrastinating is counted. However, when a static scenario is used as described in Section 5.1, the outcome of the simulations will always be the same. Running the model multiple times will be useless unless some changes are made. The introduction of some randomness will make the outcome of the model different every time. This is done by randomizing all values that belong to the events and randomizing the estimated time and deadlines of the tasks and activities. A more detailed explanation can be found in Section 5.2.1.

5.2.1 Missing data

To determine the weights, we need to run the model with the values from the data. In Table 5.6 a mapping can be found between the found factors in the conceptual model and the data. However, not every variable that we need is in the data. The missing values are either time-related values (task delay, mood, ego depletion and temptations) or values that are part of either task aversiveness or trait procrastination. The changes that are made to the computational model because of the missing values will be discussed with the help of the

Conceptual model	**Data**	**Scale**
Boredom	No, but influences Task Aversiveness.	
Personal meaning	No, but influences Task Aversiveness.	
Autonomous motivation	Yes.	1 to 7
Frustration	No, but influences Task Aversiveness.	
Task aversiveness	Yes (but only for 'writing paper'), a combination of different reasons for procrastinating.	1 to 5
Task delay	No	
Task structure	Yes (but only for 'writing paper'), answer to the question 'Hard time knowing what to include and what not to include in your paper' (However, the research classifies this as 'Difficulty making decisions')	1 to 5
Self-efficacy	Yes.	1 to 7
Fear of Failure	Yes.	1 to 7
Sensation-seeking	No, but influences Trait Procrastination.	
Self-esteem	No, but influences Trait Procrastination.	
Conscientiousness	No, but influences Trait Procrastination.	
Impulsiveness	No, but influences Trait Procrastination.	
Trait Procrastination	Yes, Lay's Procrastination Scale	1 to 5
Mood	No. As already noted in the background section, the relation between mood and procrastination is unclear. We don't know whether it is a constant or not, so this won't be taken into account.	
Ego depletion	No.	
Temptations	No. In the simulated model, they are represented as events and have no weights.	
Procrastination	Yes, answer to the question 'To what degree do you procrastinate on this task?'	1 to 5

Table 5.6: Overview of the variables in the conceptual model and presence in the data

formula's that are used to calculate the utility[1].

Mood will be excluded from the validation. As already noted in the background section, the relation between mood and procrastination is unclear. We don't know whether it is a constant or not, and what kind of influence it has on procrastination. According to some (Steel, 2007), there is no relation between mood and procrastination, according to others being in a negative mood, while others suggest that being in a very positive mood will make you more likely to procrastinate. Because of all these uncertainties, mood won't be taken into account for the validation. Mood is used in the formula for value V, so the altered formula will be:

$$V_{a_\tau,p} = -\text{Boredom}_{a_\tau} \cdot w_{\text{boredom}} - \text{Frustration}_{a_\tau} \cdot w_{\text{frustration}} + \text{AutonomousMotivation}_{a_\tau} \cdot w_{\text{AutonomousMotivation}} - \text{SensationSeeking}_p \cdot w_{\text{SensationSeeking}} + \text{Conscientiousness}_p \cdot w_{\text{conscientiousness}} + \text{EgoResource}_p \cdot w_{\text{EgoResource}} + \text{PersonalMeaning}_p \cdot w_{\text{Personalmeaning}}$$

Task delay is dependent on the time needed for the task, deadline and current time step. There is no data for these values. It is however an important factor. Therefore, these values will be chosen randomly. The estimated time will be between 2 and half of the maximum number of time steps and the deadline between 2 and the maximum number of time steps with the constraint that it should be possible to finish the task within the available time: the deadline must be later than the estimated time for a task.

Ego depletion cannot be found in the data, so the exact values are unknown. In the literature it was found that the ego resources will drop over time. There are a few things that make it go up again such as eating something or sleeping.

In the model, ego resource will drop every time step. In theory, some events will increase the ego resources again. However, introducing such events in the simulations would bring more uncertainty into the model. Therefore, there are no events in the scenario that increase the ego resources again.In the scenario, the ego resources will drop with 1 % in every time step.

Temptations are modeled as events. Instead of using multiple temptations with different values, there will be multiple 'Not studying'-events that will occur at random times, random values and random saliency.

Task aversiveness is a factor positively influenced by boredom and frustration and negatively influenced by personal meaning and autonomous motivation. In the computational model, these values (boredom, frustration, personal meaning and autonomous motivation) are all used to calculate the value V. Since it is unknown how strong the influence of these factors is on task aversiveness, we can't use the separate values. In the validation, instead of these separate factors, the value for task aversiveness is used.

Task aversiveness has a positive influence on procrastination: the more aversive a task, the more procrastination. Task aversiveness is used to calculate the value V, and the higher the

[1]As a reminder: Utility $= \frac{\text{Expectancy} \cdot \text{Value}}{\Gamma \cdot \text{Delay}}$ or see Section 4.7 again.

value, the higher the utility (and lower probability of procrastinating on the task). Because of this, Task aversiveness will be added to the formula of value V, while the separate factors are removed, because we don't have information on them. This gives the following formula:

$$V_{a_\tau,p} = -\text{SensationSeeking}_p \cdot w_{\text{SensationSeeking}} + \text{Conscientiousness}_p \cdot w_{\text{conscientiousness}} + \text{EgoResource}_p \cdot w_{\text{EgoResource}} - \text{TaskAversiveness}_p \cdot w_{\text{TaskAversiveness}}$$

Trait procrastination is a factor positively influenced by sensation seeking and impulsiveness and negatively influenced by self-esteem and conscientiousness. Self-esteem is used to calculate the Expectancy, impulsiveness for the sensitivity to delay Γ and conscientiousness and sensation seeking are used to calculate value V in the utility function. In the data these factors are missing. Unlike the separate values of task aversiveness, the values of trait procrastination are used in different formulas, so we cannot just replace these value with one compound value.

Recall the formulas used to calculate the utility:

$$Utility(a_\tau, p) = \frac{E_{a_\tau,p} \cdot V_{a_\tau,p}}{\Gamma_p \cdot D_\tau \cdot w_{Delay}} \cdot B_\tau \qquad Utility(a_e, p) = \frac{E_{a_e,p} \cdot V_{a_e,p}}{\text{EstimatedTime}_{a_e}} \cdot \text{Saliency}_e$$

The higher the value for trait procrastination, the lower the utility. Also, we cannot just replace all the factors that are part of trait procrastination with the value for trait procrastination because it will have too much influence.

When we take a closer look at the numerator of the utility function, $E \cdot V$, trait procrastination is used three times. Removing trait procrastination from E is no problem, since it has the smallest influence of all factors used to calculate E. The adjusted formula:

$$E_{a_\tau,p} = \text{Selfefficacy}_{a_\tau} \cdot w_{\text{selfefficacy}} + \text{AdjustedFearOfFailure}_p \cdot w_{\text{fearOfFailure}}$$

Value V contains conscientiousness with a positive influence and sensation seeking with a negative influence. This means that when replacing these values for the value for trait procrastination, their influence will be 0. Because trait procrastination has a positive influence on procrastination, and the lower the value V, the higher the procrastination, trait procrastination must have a negative influence on the value V:

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

The last formula that has to be adjusted is Γ, the sensitivity to delay, which only consists of Impulsiveness. The higher the sensitivity to delay, the lower the utility. When trait procrastination is higher, the utility lowers. Since the value of trait procrastination must have the same influence on procrastination as impulsiveness, the value of Impulsiveness will be replaced by the value of trait procrastination.

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

In the text was shown how the calculation of the utility was altered. The calculations for the priority will be altered in the same way. Recall the formula to calculate the priority:

$$Priority(\tau, p) = \frac{E_{\tau,p} \cdot V_{\tau,p}}{\Gamma \cdot D \cdot w_{Delay}} \cdot Importance(g_\tau)$$

It contains the same elements as the formula used to calculate the utility, but the values for a task are used instead of the values for an activity. The only difference is the calculation of value V because 'Task structure' is included and this is not the case when calculating the utility. The changed formula for value $V_{\tau,p}$:

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

The simplified conceptual model in Figure 5.4 gives a graphical overview of the weights that need to be found.

5.2.2 Questionnaire

As mentioned in Section 5.2.1, the dataset of Haghbin et al. (2012) contains many measures. Unfortunately, because of the way the survey was set up, there is only information about task aversiveness and task structure for the task 'Writing paper'. It is missing for the other tasks, but this information is needed for the simulations. In order to get these values for the other tasks, a questionnaire was distributed among Dutch students.

The questionnaire is based on the Procrastination Assesment Scale - Students (Solomon & Rothblum, 1984), where students assess their procrastinatory behavior by giving the frequency of their procrastination and the reasons why they procrastinate. Only the reasons that are relevant to get more information about task aversiveness and task structure are included. For each of the 5 tasks (see page 48) that can be found in the dataset of Haghbin et al. (2012), the same set of questions as in Figure 5.3 are asked, but geared towards the specific task (e.g. instead of 'You really disliked writing term papers' the question for another task was 'You really disliked weekly reading assignments').

There were 97 responses. Due to a technical error, not all responses were saved correctly so the results of 61 participants could not be used. 'Frequency of procrastination' was saved correctly for all participants. A t-test comparing the means of 'frequency of procrastination' of the set of participants with correctly saved data and incorrectly saved data showed that there was no significant difference ($p > 0.5, t = 0.18$ (average for all tasks)) between both samples. [2]

Of the 36 complete responses, 51% of the participants were male. The average age was 23 years. The average values of frequency of procrastination, task aversiveness and task structure can be found in Table 5.7.

There was a small overlap of questions that were asked in the extra questionnaire and the

[2] The assumption is that a t-test can be performed on ordinal data (Norman, 2010)

Writing term paper

To what degree do you procrastinate on this task?

- I procrastinate never on this task
- I procrastinate almost never on this task
- I procrastinate sometimes on this task
- I procrastinate nearly always on this task
- I procrastinate always on this task

Reasons to procrastinate

Think of the last time the following situation occurred. It's near the end of the semester. The term paper you were assigned at the beginning of the semester is due very soon. You have not begun work on this paper. There are reasons why you have been procrastinating on this task.

Rate each of the following reasons on a 5-point scale according to how much it reflects why you procrastinated at the time.

	Not at all reflects why I procrastinated		**Somewhat reflects**		**Definitely reflects why I procrastinated**
You really disliked writing term papers.					
You didn't have enough energy to begin the task.					
You felt it just takes too long to write a term paper.					
You had a hard time knowing what to include and what not to include in your paper.					

Figure 5.3: Part of the questionnaire (which was based on the Procrastination Assesment Scale - Students (Solomon & Rothblum, 1984)). A Dutch translation was filled in by the participants.

Task	Frequency of procrastination	Task aversiveness	Task structure
Write paper	3.86 (0.90)	2.92 (0.81)	3.92 (0.94)
Study for exams	3.56 (1.09)	2.72 (0.81)	2.28 (1.19)
Weekly reading	3.31 (1.21)	2.85 (1.04)	1.58 (0.97)
Administration	2.56 (1.34)	1.71 (0.87)	2.44 (1.5)
Attendance tasks	2.83 (1.21)	2.22 (1.05)	2.92 (1.4)

Table 5.7: Average results questionnaire (and standard deviation)

dataset. A t-test comparing the means of 'frequency of procrastination' of both samples showed no significant difference between the samples ($p > 0.5, t = 0.51$ (average for all tasks)).

There is also data on the task aversiveness and task structure for the task 'writing paper' and this is compared to the values from the questionnaire. There is no significant different difference in the values for task structure and task aversiveness of both sets ($p > 0.5, t = 0.37$).

The standard deviation of the data from the questionnaire is on average 1 on a five-point scale. The standard deviation expresses how much variation from the mean exists: how far are the data points on average away from the mean? On a five-point scale, a standard deviation of 1 might seem rather high. However, in the questionnaire the difference between the options 'always procrastinate' and 'nearly always procrastinate' is 1. The participants might not be able to assess the difference between these options exactly, so in light of that, the standard deviation of 1 is actually considered low.

Because the standard deviation is around 1 and is considered as a low value, it is assumed that the average values for task aversiveness and task structure for each task can be used in the simulations. In order to verify this, we will run simulations with the found values from the questionnaire and simulations with random values to check whether the found values give a lower error than random values. The results of this can be found in Section **??**.

The results of the questionnaire show that people have different reasons to procrastinate on certain tasks. For example, task aversiveness plays a major role in procrastinating on writing a paper, while it is less of an influence on administrative tasks. And task structure having a major role in procrastinating on writing a paper and not so much on the weekly readings makes sense because weekly reading assignments are generally very clear. 'Read chapter X' is a very clear assignment while writing a paper consists of multiple steps that are not clearly defined.

Finally, three extra questions were included in the questionnaire and these were saved correctly for all 97 respondents. They asked whether the participant was using the questionnaire to procrastinate, and if this was the case, what they were procrastinating on and why. 55 % of the participants was procrastinating, mostly on studying for exams, making assignments or writing a thesis. There was no correlation between the frequency of procrastination and procrastination at that moment ($p < 0.05, t = 2.85$). However, some of the given reasons were not procrastination by definition, for example taking a small break and filling in the questionnaire, but most reasons corresponded to the factors found in Chapter 2, for example procrastinating because the task is very boring.

5.2.3 Converting data

To use the dataset of Haghbin et al. (2012) and the questionnaire in the simulations, all values have to be converted to a number between 0 and 1. The following formula is used to convert the data:

$$\text{ConvertedValue} = \frac{\text{Value} - 1}{\text{MaximumScale} - 1}$$

where Value is the value to convert and MaximumScale the maximum on the scale that is used. For example, on a 5-point scale this is 5. The '-1' is added because otherwise '1' on the 5-point scale would not correspond to '0' on a scale $[0, 1]$ after conversion.

For example, when the value of a specific participant for task aversiveness is 3.5 on a 5-point scale, the ConvertedValue that is used in the model is $\frac{3.5 - 1}{5 - 1} = 0.625$.
The results of converting and combining the dataset of Haghbin et al. (2012) and the questionnaire can be found in Table 5.8. Note that the values for 'Task structure' and 'Task aversiveness' are the average values found in the questionnaire and they are used for every task but 'Write paper', because there was more information on this task in the dataset of Haghbin et al. (2012). The standard deviation for these values is 0 because the same number is used for every participant. The values found in this table are the values used to run the simulations and validate the model.

There is data available for the following tasks:

- Writing a term paper
- Studying for exams
- Keeping up with weekly reading assignments
- Academic administrative tasks (more specific: registering for classes)
- Attendance tasks (more specific: send e-mail to student advisor)

5.2.4 Simulated annealing

To determine the weights to use in the model, simulated annealing is used. Simulated annealing is an optimalisation algorithm used to find the optimal parameters for a function (Van Laarhoven & Aarts, 1987).

The algorithm starts with an initial set of random weights and an initial temperature of the system. The temperature represents how close the system is to a solution: the closer to the minimum temperature, the closer to a solution. The initial temperature will drop over time and when a certain minimum temperature is reached (or one of the other stopping criteria is met like a certain number of steps or successes), the algorithm is finished. The simulated annealing algorithm also has some other parameters that can be adjusted. Adjusting these parameters changes the accuracy of the results and the computation time. The parameters for the algorithm are determined manually, by trying different combinations of parameters.

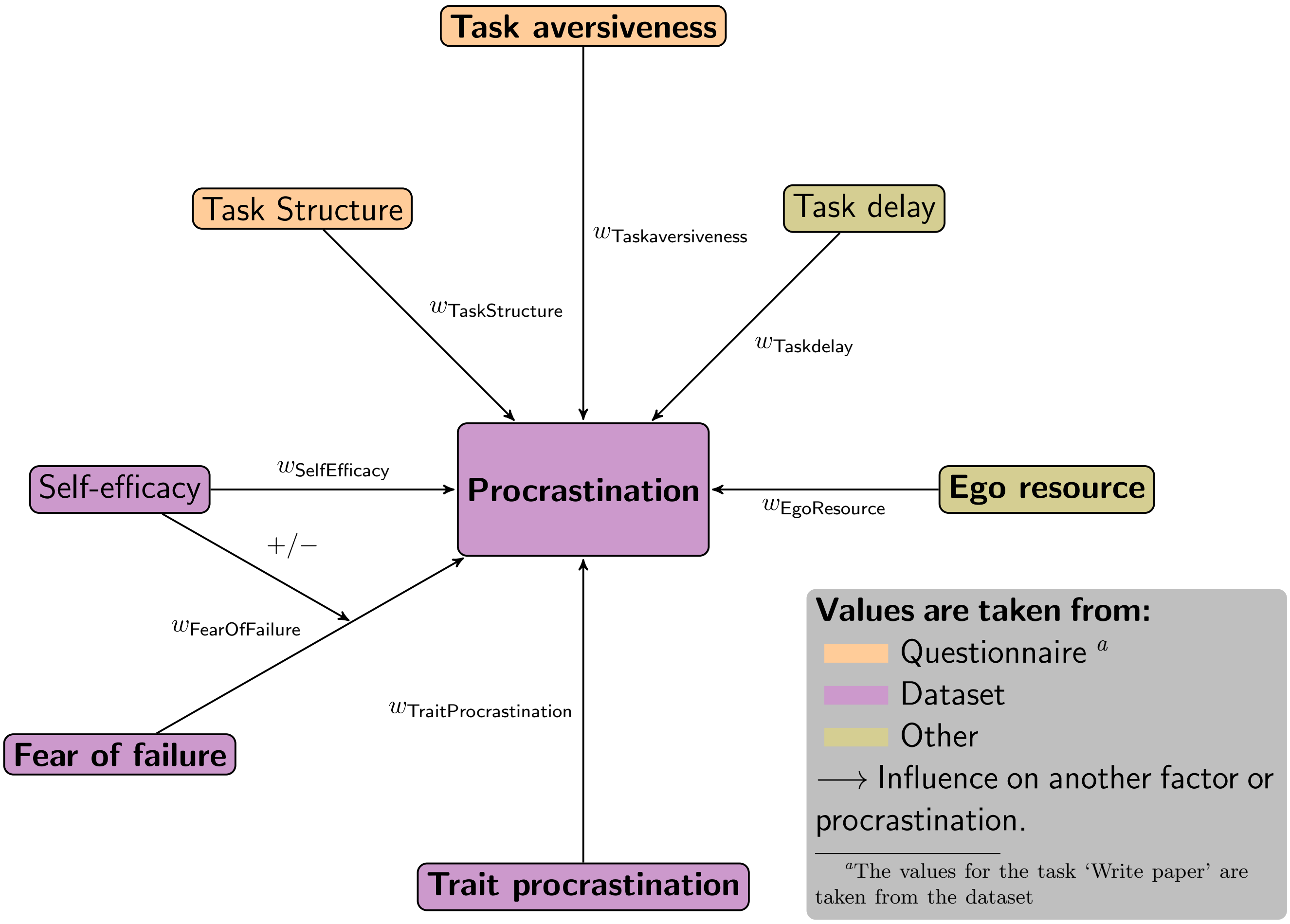

Figure 5.4: Simplified conceptual model

Task	Value	Mean	Standard deviation
Agent	Trait procrastination	0.4798	0.1623
	Fear of Failure	0.5452	0.1587
	Self Efficacy	0.6419	0.1572
Writing paper	Task aversiveness	0.5077	0.2619
	Task structure	0.6365	0.2892
	Total procrastination	0.6647	0.2633
Study exams	Task aversiveness	0.43	0
	Task structure	0.32	0
	Total procrastination	0.5725	0.2762
Weekly reading	Task aversiveness	0.4625	0
	Task structure	0.145	0
	Total procrastination	0.7014	0.2814
Administration	Task aversiveness	0.1775	0
	Task structure	0.36	0
	Total procrastination	0.3481	0.2721
Attendance	Task aversiveness	0.305	0
	Task structure	0.48	0
	Total procrastination	0.4061	0.3071

Table 5.8: Converted data combining the dataset of Haghbin et al. (2012) and the results from the questionnaire

The best set of parameters resulted in the lowest error after all simulations. These parameters can be found in Table 5.9.

Simulated annealing is suitable to learn the weights of the computational model because it works well on problems with a large number of parameters. It will also not get stuck in a local optimum, so it has a high probability of finding the optimal solution. The algorithm will always find a solution because one of the stopping criteria is a certain number of steps in the model.

In each step, a new set of weights is calculated that is close to the previous set. This is done by adding a random number (a random number is used because it is computationally not feasible to visit all possible weights) multiplied with the jump factor (this parameter determines how close the new weights should approximately be to the previous weights (the higher the jump factor, the further away the new value) and is determined manually) to the shifted previous weights. This number can be negative. After that, it is checked whether it is within the bounds (between 0 and 1). If this is not the case, it will be calculated again. If the new weights are within the bounds, the performance of these new weights will be calculated.

When the new set is better, the algorithm will use these weights. When they are worse, there is a small probability that the new set is chosen anyway. This probability is dependent of the temperature: the higher the temperature, the higher the probability that a worse solution is accepted[3]. Accepting new, worse solutions with a certain probability avoids the algorithm getting stuck in a local optimum.

For every task (the list of all the tasks that are used can be found on page 48), there will be 20 simulations where the agent can choose between this specific task and one or more 'NotStudying'-tasks that are triggered by events. The task is part of the goal 'Finish studies'. An illustration of this scenario can be found in Figure 5.5. To make sure the agent always has a choice there will be one event on t=1. The other event will occur at a random time step. The event at the first time step is to make sure the agent can always choose between different activities. As already mentioned in Section 5.2.1, the estimated time and deadline for both tasks and events are random.

The outcome for each simulation is whether the agent was procrastinating or not. When all simulations are finished, the frequency of procrastination is calculated by dividing the number of simulations where the agent was procrastinating by the total number of simulations. The outcome is then compared to the frequency of procrastination from the data. The absolute difference between these numbers is the error. The goal of the simulated annealing algorithm is to minimize this error.

The number of simulations (20) and the number of time steps in each simulation (20) are determined manually by trying a few settings. The number of simulations is high enough to not let one strange, arbitrary simulation have too much influence and not too high because

[3]When $e^{\frac{\text{current energy} - \text{new energy}}{1 \cdot \text{temperature}}}$ is higher than some random number, the new set of weights will be accepted, otherwise the weights stay the same.

Algorithm 2 Process overview

```
for each set k do                              ▷ Step 1: Divide the data randomly into |k| different sets.
    Set validation set = members of k
    Set training set = members of all other sets
    for each task t do                         ▷ Step 2: Tune the parameters
        for each person p in the training set do    ▷ Find the optimal weights for task t for person p
            Tune the parameters with simulated annealing
        end for
        Calculate the average weights for all participants in the training set for task t
    end for
end for
Calculate the average weights of all sets k for all tasks    ▷ Outcome: 6 sets of weights: 5 task-specific, 1
overall
for each person p do                           ▷ Step 3: Test the found weights
    for each task t do
        for each simulation s do               ▷ s = 20
            Run the model for a 20 time steps with the average weights of all sets k
            Save whether person p was procrastinating in this simulation
        end for
    end for
    Calculate the error for person p on all tasks t
end for
Calculate the average error for every person on all tasks
```

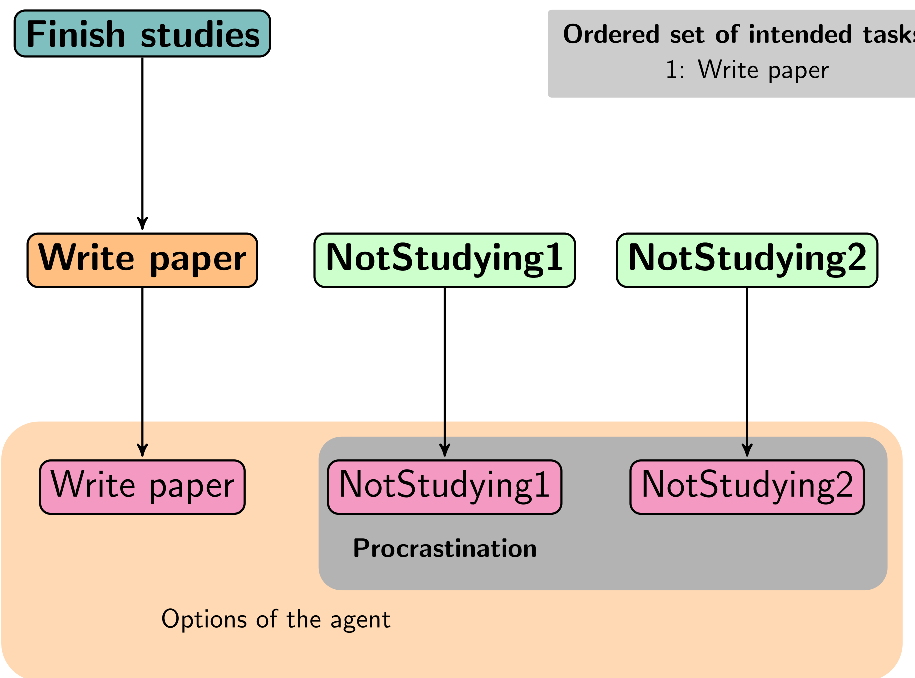

Figure 5.5: Illustration of the simulation for the task ‘Write paper’. Note that the events NotStudying1 and NotStudying2 are triggers that add the corresponding activities to the agents options. When, for example, one of the activities in the block Procrastination is performed, the agent is procrastinating.

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

Table 5.9: Parameters of the simulated annealing algorithm

this would take too long to compute.

k-fold cross validation is used to divide the data into k different sets (Russell & Norvig, 2003). In k-fold cross validation, every item is used as validation once and this reduces overfitting. One of these sets is used as validation, the other sets are used to train the model. After that, a different set is used as validation, and the other sets are used to train the data with new starting weights. This is done until every set is used as validation. After that, the average weight and error for all sets are calculated. In the simulations, 5-fold cross validation is used. A overview of how simulated annealing is used with 5-fold cross validation can be found in Algorithm 2.

5.2.5 Results

The goal of all these simulations is to determine the weights. Recall that the weights determine the influence of a specific factor on procrastination. It is important to know these weights, because they will improve the accuracy of the model. The aim was to find a single set of weights that would give a reasonable approximation for each agent's behavior with regard to performing different tasks. The simplified conceptual model in Figure 5.4 gives a graphical overview of the weights that need to be found.

After running the simulated annealing algorithm with different parameters, the weights that gave the lowest error were found. This error was 0.329. As mentioned above, this error is the difference between the frequency of procrastination from the data and the frequency of procrastination calculated by the model. This is a number between 0 and 1. Converting this error of 0.329 back to a 5-point scale in natural language means it is roughly equivalent with the difference between 'I procrastinate never on this task' and somewhere between 'I procrastinate almost never on this task' and 'I procrastinate sometimes on this task'.

A way to evaluate a computational model is to compare it with another model. Since there are no other working models on procrastination, some simulations were done on the current model with all weights set to random. When running 10 simulations with different random weights, the average error of those runs was 0.48.

In Section 5.2.2, the assumption is made that the average values that were found in the questionnaire per task can be used for all participants[4]. Whether this is a valid assumption will be determined by comparing a simulation that uses the answers from the questionnaire

[4]The values that are used in the simulations can be found in Table 5.8.

with a simulation with random values. Comparing the errors showed that it was good assumption: the average error when using the values from the questionnaire was 0.329. Using random values gave an error of 0.47, and this is a significant difference ($p < 0.01, t = 14.5$).The overall results with random starting weights with and without the random values from the questionnaire can be found in Table 5.11.

Weights

The overall weights can be found in Table 5.11. The weights influence the strength of a certain factor on procrastination. The higher the weight, the stronger the influence on procrastination. In this section, the weights of the simulation with the lowest error will be discussed.

The average weight is 0.444. The weights of task aversiveness and task structure are below the average weight and respectively 0.2372 and 0.3315. This means that task aversiveness and task structure have relatively little influence on the frequency of procrastination. The weights of self-efficacy and ego resource are higher than the average weight and respectively 0.6048 and 0.590. This means that self-efficacy and ego resource have a lot of influence on the frequency of procrastination. First, task aversiveness and task structure will be discussed and next self-efficacy and ego resource.

A likely explanation for the low influence of task aversiveness and task structure could be that the same value is used for all participants instead of the participant-specific value found in the dataset of Haghbin et al. (2012). This means that that these values are only an approximation of the correct value of that participant, but not entirely correct. This means that these values do not have a lot of predictive value over the outcome of the model and can only decrease the error.

Unfortunately, this does not explain the lower values for task aversiveness and task structure. The reason for this is when instead of the values found in the dataset of Haghbin et al. (2012), the values of the questionnaire are used for the task 'Write paper' (like all other tasks), the influence of task aversiveness is even lower! So there must be another reason why the influence of task aversiveness and task structure are much lower. A reason for the lower value for 'task structure' could be that it is only used in the calculation of the priority and not for the utility, meaning it doesn't have as much influence as the other factors.

A reason for the high influence of self-efficacy could be that it also influences fear of failure. Recall from Section 2.6 that the influence of fear of failure to procrastination is moderated by self-efficacy. Self-efficacy determined whether fear of failure has a positive or negative influence on procrastination. This means it has a lot of influence on the outcome of the utility function and can explain why the influence of this factor is quite high.

In Steel (2007) the correlations of many factors to procrastination are given. Correlations are not equal to the weights, so the correlation of a certain factor and the weight of a certain factor cannot be compared directly. However, they both say something about the relative influence of the factors on procrastination: the expectation is that a factor with a high correlation should have a high weight. There is however no relation between these correlations and the found weights. For example, the correlation between task aversiveness and procrastination

	Trait procrastination	High fear of failure	Low fear of failure	Self-efficacy	Task-aversivenesss	Structure
Write paper	0.6519	-0.1549	0.1452	-0.2535	0.4161	0.1479
Study Exam	0.5481	-0.1599	0.2421	-0.2664	-	-
Weekly reading	0.4980	-0.1543	0.1868	-0.0913	-	-
Administration	0.4473	-0.0753	0.1128	-0.1321	-	-
Attendance	0.3640	0.0091	0.3218	-0.2665	-	-
Average	0.502	-0.107	0.202	-0.202		

Table 5.10: Correlations between frequency of procrastination and the other variables in the dataset of Haghbin et al. (2012)

is 0.4 and the correlation between self-efficacy and procrastination is -0.38, so the weights should be approximately the same. However, task aversiveness is one of the lowest weights while self-efficacy on of the highest!

One of the reasons for this could be that in Steel's paper, he combined the data of many different studies on procrastination. The different studies studied procrastination in different domains and settings, so it could be the case that this makes it hard to compare the correlations from that paper with the found weights from this work. To check this, the correlations in the dataset of Haghbin et al. (2012) were calculated[5]. This shows that the correlations found in the dataset are not equal to the correlations found in Steel. However, a clear relation between the found weights and the correlations found in the dataset can not be drawn.

Results per task

The results for each task separately are also saved and are discussed in this section. These results can be found in Table 5.12. This shows that there are some differences between tasks. The error ranges between 0.223 and 0.461 (on a scale from 0 to 1) when we use the overall average weights and from 0.283 and 0.452 when using the task-specific weights. First will be discussed why 'Administration' and 'Attendance' have a higher error than the other tasks, and after that, the results of the other tasks will be discussed.

The tasks 'Administration' (more specific: registering for classes) and 'Attendance' (more specific: send e-mail to student advisor) have a high error. A reason could be that both tasks are quite small: they normally would take around 5 to 10 minutes to complete while the other tasks require multiple hours of effort. Because of the difference with the other tasks, the overall weights can be skewed more towards the other tasks. The improvement of the error when task-specific weights are used suggests this plays a role. However, although the results improve, they are still not as good as the other tasks. A reason for this could be that the used scenario is not very suitable for these small tasks. Another reason could be that people don't do these tasks very often, so it might be that they cannot recall whether they were procrastinating on this task and if this was the case, why.

Surprisingly, using random values (instead of the answers from the questionnaire) reduces

[5]Only the correlations found in the dataset are shown in this table.

the error for these tasks instead of increasing the error like for the other tasks. This can support the claim that people can't recall their procrastination and reasons to procrastinate on this task very well.

'Write paper', 'Study exams' and 'Weekly reading' have the lowest errors. The low error for 'Write paper' cannot be explained by the use of the values for task structure and task aversiveness from the dataset of Haghbin et al. (2012). This is because when the values from the questionnaire are used, the error is only slightly higher with no significant difference.

The reasons why these tasks have a low error could be because most students perform these activities very often, they have clear deadline and require most of the times at least multiple hours of work. Because of this, students have a good intuition about their procrastination and the reasons for procrastinating and their answers to the questionnaires will resemble their actual behavior better.

Writing paper

For the task 'Writing paper', the values of task aversiveness and task structure are available in the dataset of Haghbin et al. (2012). But in the questionnaire were also some questions on 'Writing paper', so the values for task aversiveness and task structure are also known. These values are used to check whether there were no significant differences between the dataset of Haghbin et al. (2012) and the questionnaire.

Knowing multiple values for task aversiveness and task structure for this specific task gives opportunities to test multiple settings by varying the values used for the outcome, task aversiveness and task structure. The results can be found in Table 5.13. An explanation of the different settings:

1. **Data:** the values for task aversiveness, task structure and the outcome (amount of procrastination) are taken from the data. (Error: 0.2471)
2. **Random:** the values for task aversiveness and task structure are randomized. The outcome is taken from the data. (Error: 0.5241)
3. **Questionnaire, outcome from data:** the average values for task structure and task aversiveness are taken from the results of the questionnaire. The outcome is taken from the data. This is the setting used for testing all other tasks. (Error: 0.2695)
4. **Questionnaire, outcome from questionnaire:** the values for task structure, task aversiveness and the outcome are taken from the questionnaire, so they are the same for every participant. The other values are taken from data (Trait procrastination, fear of failure and self-efficacy) (Error: 0.1607)

The fact that random values result in a high error is not surprising. 'Questionnaire, outcome from questionnaire' has the lowest error. This could mean that the influence of the questionnaire on the outcome of the model is very high. Or since the outcome and two values are fixed for every participant, it is easier to learn.

The error for 'Data' is 0.2471 and this is quite low. It is important that this value is low, because it is the best set of data available: it uses all available data of the same dataset without the use of other data. When this would give bad results, it is a strong indication that something is not correct in model. Fortunately, the error is low. The error for 'Questionnaire, outcome from data' is only slightly higher. This lower error for 'Data' suggests that when there is participant-specific data, a better fit can be made to the data. The fact that the error for 'Questionnaire, outcome from data' is only slightly higher, means that the assumption to use the average values from the questionnaire is valid. It shows that it can be a good alternative to use a different dataset to fill in missing data when there is not enough data available.

Description	Overall error	Error per participant	w_Task aversiveness	w_Ego resource	w_Structure	w_Self efficacy	w_Fear of failure	w_Trait procrastination	w_Task delay
Best set of weights [a]	0.329	0.056	0.2372	0.6737	0.3315	0.6048	0.4380	0.4273	0.3965
Random values	0.48	0.115	0.413	0.555	0.524	0.492	0.42	0.342	0.558

Table 5.11: Learning weights with different parameter settings.

Task	Error overall weights	Error task-specific weights	w_Task aversiveness	w_Ego resource	w_Structure	w_Self efficacy	w_Fear of failure	w_Trait procrastination	w_Task delay
Write paper	0.2235	0.2396	0.1856	0.7097	0.3206	0.6044	0.4275	0.4335	0.4161
Study exams	0.2993	0.2942	0.2307	0.6783	0.3373	0.6042	0.4392	0.4241	0.4028
Weekly reading	0.2346	0.2398	0.1804	0.7182	0.3197	0.6206	0.4393	0.4482	0.4211
Administration	0.4606	0.3341	0.3200	0.6205	0.3463	0.5851	0.4400	0.4113	0.3667
Attendance	0.4273	0.3904	0.2691	0.6417	0.3336	0.6099	0.4438	0.4195	0.3757

Table 5.12: Weights per task

Source of the value	Overall error	Error per participant	w_Task aversiveness	w_Ego resource	w_Structure	w_Self efficacy	w_Fear of failure	w_Trait procrastination	w_Task delay
Data	0.2471	0.0292	0.168	0.559	0.368	0.712	0.589	0.432	0.444
Random	0.5241	0.1206	0.3776	0.6143	0.5108	0.4917	0.4268	0.3503	0.5814
Questionnaire, outcome from data	0.2695	0.0425	0.2103	0.5397	0.4531	0.6009	0.5857	0.2363	0.6857
Questionnaire, outcome from questionnaire	0.1607	0.0225	0.1860	0.6066	0.4290	0.5635	0.5332	0.4086	0.4421

Table 5.13: Error for 'Writing paper' using different values for task aversiveness and task structure

[a] The used values for the simulated annealing algorithm can be found in Table 5.9

Chapter 6

Discussion

In Section 2.8 it is already discussed what the limitations of the conceptual model are: for some factors, the influence is unclear, there could missed factors, or the link between factors is unclear. In this section, first, the results of the model will be discussed. Next, the limitations of the formal model and validation will be discussed, including some changes that can improve the model and validation in future work.

The results of the simulations are discussed in Section 5.2.5. The average error after learning the weights for all 5 tasks was 0.329 (on a scale from 0 to 1). The error is the (absolute) difference between the amount of procrastination found in the simulations and the amount of procrastination in the data. Some of these tasks had better results, for example 0.2235 for 'Writing paper' and 0.2346 for 'Weekly reading', while the other tasks did worse. To understand whether an average error of 0.329 is good or not, two ways of evaluation will be discussed.

In the questionnaire, the average standard deviation was 0.2 (when converting it to a scale from 0 to 1). Because these answers are used in the calculations, it is unlikely that the model will be more accurate than this. So a result close to 0.2 will be considered as a good result. According to this definition, some tasks have good results, like 'Writing paper' (0.2235) and 'Weekly reading' (0.2346), while other tasks with a higher error are worse. According to this definition, an average error of 0.329(on a scale from 0 to 1) is moderate.

Another way to evaluate a model is to compare it with another model. Creating a new model is outside the scope of this thesis, but it can be compared to the model with random weights instead of learned weights. To make the comparison, the model was run 10 times with different random weights. the average error of those runs was 0.48. Using Cohen's d to calculate the effect size shows that this is 0.57, which is classified as a moderate effect. A t-test shows that there is a significant difference ($p < 0.01, t = 8.53$).

Next, a possible limitation of the formal model will be discussed and after that more on the validation. Goals, tasks and activities are the building blocks of the model. In the model, tasks and activities are different from each other. This division is added so the agent can procrastinate: in order to procrastinate there must be a mismatch between what the agent intends to do and what he does at a certain moment. The question is whether this is a realistic way to implement procrastination, because the difference between tasks and activities is a bit fuzzy. Also, people use these words interchangeable and this makes the difference a bit artificial.

The conceptual model in Chapter 2 contains many factors that influence procrastination. All factors that are in the conceptual model are also used in different formulas in the formal model (as explained in Chapter 4). Although the model is simplified for validation, there are still 7 weights to learn. When there are many weights to tune, it is possible that any set of data will reproduce any expected behavior with an acceptable error. To reduce the probability of overfitting, 5-fold cross-validation is used.

Another limitation of the validation is the used dataset. This dataset does not contain all information that was discussed in the conceptual model and used in the formal model. The model had to be simplified to make the best use of the available data (see Section 5.2.1 and further). To simplify the model, a lot of assumptions have been made, and this limits the conclusions that can be drawn from the experiments. The question is whether the results will improve (a lower error) when there is a dataset containing all information used in the formal model. A related question is whether the results will improve when all data, including task aversiveness and task structure, will be from the same dataset. These questions will be discussed in turn.

To start with the first question: using a dataset containing all values that are used in the conceptual model won't necessarily improve the results. The results will improve when the complete model is a better representation of the behavior of a person, but the results might decrease when the model is not as good of a fit as the simplified model. When using the complete model, the results will be more realistic. There are less assumptions about simplifying the complete model and because the complete model contains more factors, it gives a more realistic approximation of the world.

In addition, using a complete dataset will give more information about the factors that are currently not included in the validation (such as the separate elements of task aversiveness and trait procrastination, mood, task delay, ego depletion and the temptations). Also, using the separate elements of 'task aversiveness' and 'trait procrastination' instead of the compound factors will increase the accuracy because some of these elements will have more influence on procrastination than others and the values are used in different formulas.

In the validation, random values are used to model time (e.g. deadlines, estimated time for a task) and a fixed scenario is used because there was no more information available. Having more complete data that includes these factors specifically for a person and a task would make the model and validation a lot more realistic. In the current validation, it is assumed that all tasks require the same time[1]. This is however not very realistic as some tasks will take more time than others. Having specific data about time will be an interesting addition because it will reduce the number of assumptions and this increases the strength of the conclusions that can be drawn from the validation.

[1] More specificly: a random number of time steps, but all within the same range.

The related question was whether the results will improve when all values, including 'task aversiveness' and 'task structure', are taken from the same dataset. In the current validation, a dataset was used that only contained the values for 'task aversiveness' and 'task structure' for one task ('Writing paper'). The dataset was extended by taking the average values found in a questionnaire (see Section 5.2.2). This was also done for the task 'writing paper'. Comparing the results of using the values of task structure and task aversiveness for the task 'writing paper' from the dataset (error: 0.2471) and from the questionnaire (error: 0.2695) showed that the results are slightly better when all data is taken from the same dataset (see Section 5.2.5). The error for this task was already low, so the results for the task with higher errors could improve even more when using all data from the same dataset.

6.1 Future work

As discussed in the previous section, having a more extensive dataset will be more informative, and more conclusions can be drawn from the validation. This would be interesting to do in future work. There are also some interesting extensions to the formal model possible, for example adding something on planning or including the making of goals inside the model. In this section, some of these extensions will be discussed.

As discussed in the previous section, the validation can be improved by having a complete dataset. Another validation step would be to have the trained model make predictions on the likelihood of a person procrastinating under certain conditions. This can be done by conducting an experiment for a fixed amount of time and monitoring what a person is doing at every time point. In the past, an experiment like this was done by Pychyl et al. (2000), where students carried around pagers in the five days before a deadline. Eight times a day they were asked what they were doing, whether it was procrastination and what their affective state was. This experiment was done to gather information about the relation between mood and procrastination.

Now it's 14 years later and most of the students carry around smart phones and these can be used to gather data in psychological experiments (Miller, 2012). With the appropriate use of smart phones, information about time, current mood and ego resources can be gathered. Also, other information about the tasks that should be done, the person's goals and personality traits should be collected. In the model, these values can be used to calculate the utilities of all activities and whether this matches the plans of the students. With this information it can be seen whether there is a mismatch and this could lead to procrastination. The model could return the probability for procrastination and the most likely causes to the experimenter. Of course, the gathered information can also be used to improve validation.

As already mentioned in the introduction, procrastination is problematic for many people and it is interesting to find ways to reduce procrastination. The trained model can, as described in the previous paragraph, be used to predict the likelihood of procrastination. When a person has more knowledge about his weaknesses, he can adjust his behavior, environment or tasks to reduce this probability. For example, when a person has to do a very boring task, this person is more likely to procrastinate. When this person knows this is a pitfall, he can use the matching coping strategies (see Section 2.4) to reduce procrastination.

Also, the trained model might be used to find new interventions and coping strategies. When, for example, there is a very strong connection from a certain factor to procrastination or between two factors, it will be very useful to have a good intervention to reduce procrastination. When no such intervention is known yet, they can be developed specifically for a major factor. It can also be used the other way around: to test the effects of interventions through simulations.

Chapter 7

Conclusion

Procrastination is a phenomenon influenced by many factors. One of the questions in this thesis was 'What are the different personality and task related factors influencing procrastination and in what way do they influence procrastination and each other?'. This question was answered in Chapter 2 by making an conceptual model including the prominent factors in literature.

Another question discussed in this thesis was 'Is it possible to make a generic computational model of procrastination?'. This question was answered by making a formal model in Chapter 4, implementing it as a computational model and validating it with a dataset. The implemented model gives the expected behavior of an agent that is procrastinating. For example, an agent is more likely to procrastinate on an aversive task than on a very nice one and this behavior can be seen within the computational model.

For further validation, the model was simplified to make the best use of a dataset (see Chapter 5). The dataset was used to learn the weights that are used in the model. After learning all the weights, the average error was 0.329 (on a scale from 0 to 1) for all tasks. The error is the (absolute) difference between the amount of procrastination found in the simulations and the amount of procrastination in the data. As discussed in the previous chapter, these results are moderate. This step can be improved by having a more extensive dataset so the complete model can be used instead of a simplified one. This also gives more information about which parts of the model need improvement.

Other models on procrastination (in Chapter 3) lacked implementation and relation to psychological concepts. The model discussed in this thesis makes the use of psychological factors very explicit and makes it very clear how they are used. This can give more understanding about what the important factors causing procrastination are. The model is also implemented and validated, making the assumptions that are made very explicit.

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