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# An Adaptive Cognitive Agent Model for Development of a Hoarding Disorder and Recovery from it by Therapy

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**Abstract.** In this paper, an adaptive cognitive agent model is presented that describes both the process of development of a hoarding disorder and recovery from it by therapy. The adaptive agent model was evaluated by simulation experiments and comparison of them with expected patterns known from the literature. Moreover, mathematical analysis was performed of the equilibria of the agent model and used to verify the model. The model can be the basis for a virtual agent model that may support a therapist in their training or in their professional life.

## 1 Introduction

Hoarding Disorder (HD) can be described as excessive collection and acquisition of objects and a persistent inability to discard them because of a perceived need to save them, resulting in clutter. Attempts by caregivers or family to discard the clutter can cause distress, anxiety and conflict. It can lead to fire hazards and danger for one's physical and mental health. They perceive avoidance behavior as the solution to their problems, but this causes short-term relief and long-term pain.

Rodriguez et al. [4] found that treatments for Hoarding Disorder were underutilized, because the clients did not find the available treatments acceptable. This causes a delay in seeking treatment, which in turn causes progressive worsening of the hoarding behavior. In order to improve treatment and the mental health issues and safety conditions of hoarders, it may be valuable to gain more insight in what Hoarding Disorder fundamentally is and what happens during the process of decision making when needing to discard a possession. By gaining insight in self-help treatment for Hoarding Disorder it may be utilized more to maximize treatment outcomes.

Learning to cope with emotions the right way is essential in overcoming hoarding tendencies. In order to do this, Singh, Hooper and Jones [6] wrote a self-help guide using cognitive behavioral techniques. The Cognitive Behavioral Treatment (CBT) techniques in this book deal with hoarding by gradually eliminating unhelpful rituals that people with Hoarding Disorder use to cope with their emotions.

In this paper, an adaptive cognitive agent model is shown for the underlying mechanisms. It is adaptive both for developing the disorder, and for recovery from it by therapy. It analyzes Hoarding Disorder in a computational manner and simulates the processes assumed to play a role in the disorder, its development, and recovery from it.

## 2 Background of Hoarding

Hoarding Disorder is defined as “the acquisition of, and failure to discard, a large number of possessions of limited apparent value, the presence of living spaces that are sufficiently cluttered as to preclude use of those areas for intended purposes, and significant distress or impairment in functioning caused by hoarding.” [2]. Typically, a hoarder will save items that seem invaluable or useless to any other person (e.g. old newspapers, notes or trash). When confronted with the clutter, a hoarder may experience intense distress and/or anxiety [3]. Generally, there is limited space in active living areas, which can cause safety concerns like mobility limitations for first aid, fire and of course health risks (bad hygiene, pest or mold). However, even if the clutter interferes with the hoarder’s day to day life, they may not be distressed about this at all. The lack of insight plays a role in this. “In Hoarding Disorder, insight refers to the level or degree the individual is aware of the consequences of the symptoms (e.g., safety for self and others or consequences of family members) in addition to hoarding-related beliefs (e.g., about the importance of possessions).” ([9], p. 26).

Singh found that most participants of his study stated that they have had help or support for their hoarding problems in the past, but that these had been ineffective [6]. Rodriguez supports this: “Only three treatments and services were deemed acceptable: individual CBT, professional organizing, and self-help book. However, these three just barely made the *a priori* cutoff of 6 on the Likert scale, suggesting there is an important gap between available resources and acceptability of these resources for clients with hoarding behaviors.” ([4], p. 8) This gap, combined with the lack of insight, causes a delay in seeking treatment. When treatment is delayed, the hoarding behavior will get the chance to worsen progressively [11].

Primarily, the context of the situation is an important factor to consider when we speak about the development of hoarding. This includes early life experiences, personality traits (such as impulsiveness, perfectionism and dependency), familial history, comorbidity and individual vulnerabilities (such as genetic influences or traumatic life experiences). For this thesis, these factors are out of scope, since they are based on the context of the situation.

One of the most important factors of Hoarding Disorder is the ‘belief’ the hoarder has about their possessions. Individuals who hoard seem to deliberately consider each possession and assign a belief to each single one of them. This makes it more difficult for them to discard these possessions as specific conditions are set on when and why objects should be discarded. When talking about a belief, we refer to the meaning(s) a hoarder assigns to their possessions. In other words, the specific beliefs the hoarder attached to their possessions refer to the type of hoarding they are affected by. According to Frost, hoarders make decisions about their possessions based on the value of the object; it’s instrumental, intrinsic or sentimental value [1]. This paper focuses on instrumental hoarding only. Instrumental hoarders judge the likelihood of future need of their possessions as higher than non-hoarders. They think they may need the item in the future. If the needed belonging will be discarded, their beliefs about the consequences and/or wastefulness can make them feel many negative emotions such as distress, sadness, grief, anger and fear.

Emotion plays an important role in Hoarding Disorder. In [5] it is found that “fear of decision-making interacted with general emotional reactivity to predict total hoarding symptoms and difficulty discarding. These findings support the idea that HD individuals experience a wide array of negative emotions more intensely.” [5]. For people with Hoarding Disorder, most of the coping mechanisms the brain finds most optimal only bring short-term relief and long-term pain. Sometimes the ways of coping used by hoarders to help with uncomfortable emotions only perpetuate their hoarding problems, which results in a low level of tolerance of these feelings. For clarification, negative emotions (e.g., anxiety, distress, anger, sadness, helplessness and guilt) and positive emotions (e.g., happiness, emotional attraction to possessions and happy memories) are considered two different categories of emotions in this study. When an individual with HD has more trouble coping with negative emotions (e.g., during discarding possessions) it causes negative reinforcement of the hoarding behavior. A person with HD who has more difficulty coping with positive emotions (e.g., shopping online during a sale and wanting to buy many items) will lead to additional acquiring and will create a positive reinforcement pattern of the hoarding behavior.

Making any kind of decision is hard for individuals who have Hoarding Disorder. Tolin et al. [8] found that hoarding participants of his study exhibited abnormal activity in frontal and temporal regions when deciding whether to discard possessions. These brain regions are part of a network of structures that regulate decision-making and self-awareness, identify the emotional significance of a stimulus and generate an emotional response [8]. The deficits in decision-making, emotional response and emotional regulation are the core of the problem of being unable to discard possessions.

High levels of fear of decision-making combined with experiencing negative emotions more intensely can cause for an individual to have more difficulty discarding possessions and to start procrastinating. This negative reinforcement of the hoarding behavior will always lead to avoidance behavior. Behavioral avoidance is an important feature of hoarding behavior. Singh explains in his book that it “comes from a perceived fear of the intensity of the difficulty [a hoarder] may face or a prediction of how the situation will turn out, and a belief that [they] will not have the ability to deal with it or the discomfort [they] might experience.” [6]. By saving possessions, the hoarder allows him- or herself to avoid making a decision.

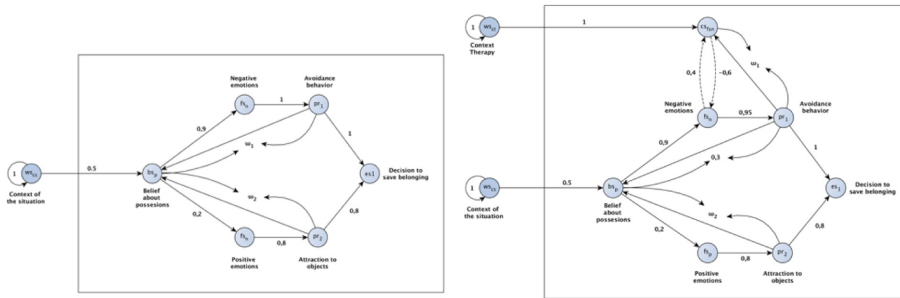
The cognitive agent models introduced here are mainly inspired by the cognitive behavioral model created by Steketee and Frost [7]. “According to a cognitive behavioral model of compulsive hoarding, manifestations of hoarding (acquisition, saving, clutter) result from basic deficits or problems in (a) information processing, (b) beliefs about and attachments to possessions, and (c) emotional distress and avoidance behaviors that develop as a result.” [7].

### 3 Modeling Hoarding, Its Development and Therapy

The functionality of the processes within the cognitive agent model was based on the Network-Oriented Modeling approach temporal-causal networks from [10]. Pictures can be found in Fig. 1. As the mental processes within the agent (1) contain essential cycles, and (2) are adaptive, the Network-Oriented Modeling based on temporal-causal

networks fits well to this domain. The temporal-causal model shows the process of decision making as discussed. The model has ten states that are based on the background of hoarding and the model of Steketee and Frost, which suggests that “strong negative emotional reactions to possessions (e.g., anxiety, grief, guilt) lead to avoidance of discarding and organizing, while strong positive emotions (pleasure, joy) reinforce acquiring and saving possessions.” [7]. The most prominent features of Hoarding Disorder covered here are: Problematic beliefs about possessions, Information processing deficits, Emotion processing deficits and emotional distress, Avoidance behaviors, Acquiring and saving behaviors, Decision making deficits. In addition to these states there are two adaptive connection weights for development of hoarding, and two for recovery of it by therapy. They are indicated in the pictures by the arrows pointing to an  $\omega$ .

Figure 1 shows the basic conceptual model of the process of decision-making in humans, without specific weights of the connections. Some assumptions have been made, for sake of simplicity.



**Fig. 1.** Left: Graphical conceptual model of the process and development of decision making in a person with hoarding disorder. Over time the backward connections to the belief become stronger due to the learning. Right: The adaptive cognitive agent model with therapy. During therapy, the connection from Avoidance behaviour to the control state for the negative emotions becomes stronger due to the learning. When this connection becomes strong enough, therapy is not needed anymore, as the person can regulate these emotions by him or herself.

The simulation starts when the person grabs a possession. They need to try to make an instant decision about whether to discard it or not, as explained in the Main Scenario. This triggers belief state  $bs_p$ , which quickly triggers their particular emotions the person feels about the object;  $fs_n$  and/or  $fs_p$ . Negative feelings have an impact on preparation state behavioral avoidance,  $pr_1$ , and positive feelings have an impact on the amount of the attraction they feel towards the object, which is preparation state  $pr_2$ . The complex part of this model, represented by persistence (or extinction rate), is that the belief state is influenced back by the avoidance behavior and object attraction states, which represents a reinforcement cycle that can be negative (when enforced by avoidance behavior) or positive (when enforced by the object attraction). The two preparation states determine whether the threshold will be met and, thus, the decision will be made to save the belonging, which is execution state  $es_1$ . In this case, the higher

the extinction rate, the greater the chance of not only developing, but also persisting Hoarding Behavior. Unlearning behavior with a high persistence value can be really difficult, however, can be learned to control using control states.

For therapy extra states and connections have been added to the model; see Fig. 1, right. The idea is that under guidance of the therapy the person strengthens his or her regulation skills, in particular the connection from Avoidance behavior to the control state (which suppresses the negative emotions for an object). If the therapy is successful, this connection will become strong enough to do regulation without the therapy. This is a second form of learning in the model, in addition to the learning for developing the disorder. The parameters used in the conceptual representations show some of the characteristics of the context they describe, however, they have been simplified to their essence for this study. These parameters can take the form of the connection weights, speed factors and threshold  $\sigma$  or steepness  $\tau$  in logistic sum functions and have specific constant values for a given scenario. In order to simulate different scenarios to explore different situations, in this case decision-making in humans with hoarding disorder, these constant values should be varied, but they do not change over time.

The characteristics represented by the parameters can change over time as a result of developing the disorder or of treatment. Therefore, Hebbian learning is applied for these adaptation processes. It is used not only to show how hoarding is (or is not) developed in the brain, but also to see how a certain type of therapy may affect the disorder. Hebbian learning is based on the principle that ‘neurons that fire together, wire together’ and interprets the adapting connection weight characteristics as states that now can change over time, so the characteristics become variables [10], Ch. 2. A Hebbian connection between states  $X_1$  and  $X_2$  is indicated by  $\omega_{X_1, X_2}$  or just by  $\omega$ ; it needs a *persistence rate*  $\mu$  and *learning rate* (or speed)  $\eta$ . The formula used (in differential equation format) for calculating the Hebbian learning values is

$$d\omega(t)/dt = \eta[X_1(t)X_2(t)(1 - \omega(t)) - (1 - \mu)\omega(t)]$$

Note that if an equilibrium state is reached ( $d\omega(t)/dt = 0$  and  $dY(t)/dt = 0$  for all  $\omega$  and  $Y$ ), from the above the following relation can be derived for the equilibrium values:

$$\omega = \frac{X_1 X_2}{1 - \mu + X_1 X_2} \quad \text{with a maximal value of} \quad \frac{1}{2 - \mu}$$

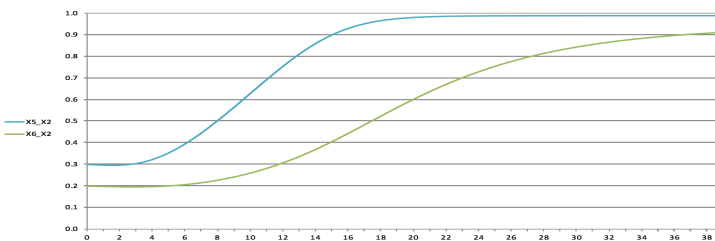
This relation was used for verification of the model by checking the different values from a simulation. For example, for  $\mu = 0.99$ , as often was set, the maximal value would be 0.9901. It can be seen in the simulations that indeed the values of the adaptive connection weights stayed below this value.

## 4 The Simulation Experiments

Four simulation experiments were done in order to test the model and run simulations of the treatment; two of them are discussed in Sect. 4. More can be found at <https://www.researchgate.net/publication/335473135>. The first shows how Hoarding Disorder gets developed by showing a reinforcement process underlying hoarding behavior. The second scenario shows a simulation of the treatment on the reinforcement cycle, by strengthening an emotion regulation cycle.

First, some background and context of the situations of the individuals involved in the simulations. Person Y is based on the patient who was covered in the case study by [11]. Person Y is a classic example of an individual who developed Hoarding Disorder, specifically instrumental disorder, but did not seek for help for a long period of time until it got out of hand. Person  $Y_{neg}$  is how we call person Y from now on, the individual from the case study by Vilaverde. Person  $Y_{neg}$  has problematic beliefs about his possessions, specifically about the possible use of these items in the future, which was the reason he could not discard them. This is a common belief among instrumental hoarders. Person  $Y_{neg}$  gets anxious whenever somebody else discards his possessions. This indicates deficits in information processing and emotion processing.

Scenario 2 (Figs. 2 and 3) concerns a simulation of the process of decision making in person  $Y_{neg}$ , which, if this behavioral pattern would be repeated for a long period of time, can make them develop instrumental hoarding. An instrumental hoarder has strong beliefs on not only the future usability, but also the wastefulness and consequences of discarding such an item. “Heightened general emotional reactivity and more intense emotional reactions to imagined discarding were associated with both difficulty discarding and acquisition.” [5]. The beliefs combined with a fear of decision making and deficits in emotion processing can cause strong emotional reactions to the discarding of possessions, since an instrumental hoarder not only has trouble coping with negative emotions, but also experiences emotions more intensely than non-hoarders. The strong emotional reactions result in avoidance behavior regarding discarding and organizing, which can turn into a negative reinforcement cycle of acquiring items, but not discarding them when the persistence rate is high enough.



**Fig. 2.** The learnt connection weights of hoarding in person  $Y_{neg}$ : the connection from positive feeling state  $fs_p$  to belief  $bs_p$  (blue) and from negative feeling state  $fs_n$  to belief  $bs_p$  (green) (Color figure online)

For person  $Y_{neg}$ , the Hebbian persistence value is very high, that is 0.99, with speed factor 0.8. This entails that  $Y_{neg}$ 's brain has a strong tendency to learn from their negative reinforcement cycle as shown in Fig. 2. As can be seen it comes very close to 1 but not exact, as predicted by the analysis at the end of Sect. 3.

In order to cognitively restructure the beliefs hoarders have about their items, some of the techniques in [6] deal with emotion regulation. As we discussed in Sect. 2, people with Hoarding Disorder have deficits in the processing and regulating of their emotions. Using the Network-Oriented Modeling approach, emotion regulation can be simulated using control states. This can be done by modeling the processes involved in the detection of perceiving an undesired amount of emotional feeling and reacting to that with inhibition of the feeling state. Scenario 4 shows a simulation of the process of decision making in person  $Y_{neg}$ , as in Scenario 2, however, in this scenario the CBT treatment is incorporated (Fig. 4).

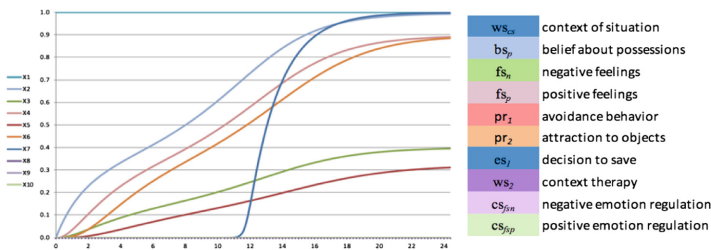


Fig. 3. Simulation of Scenario 2: how instrumental hoarding develops in person  $Y_{neg}$

For  $Y_{neg}$ , the Hebbian persistence value is very high, that is 0.99 with speed factor 0.8. This entails that  $Y_{neg}$ 's brain has a strong tendency to learn from their negative reinforcement cycle of acquiring items, but not discarding them. The decision is made a little late, due to the avoidance behavior.

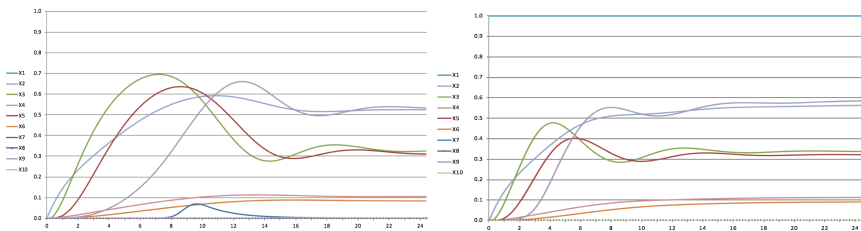


Fig. 4. Left Simulation of Scenario 4: treatment of instrumental hoarding in person  $Y_{neg}$  Right: Simulation of Scenario 4: test of treatment effect of instrumental hoarding in person  $Y_{neg}$  (Color figure online)

Person  $Y_{neg}$  picked up the treatment very well. The explanation for this may be that his lack of insight was not too bad, since they at least acknowledged that their collection of items was exaggerated. As seen in Fig. 4, the dark blue line (which represents the execution state of the decision) does not get activated, since it falls just below 0.1.



## 5 Discussion

There is not one single reason for why people hoard. The disorder can express itself in many ways. However, the reason that individuals with Hoarding Disorder experience a strong connection to possessions and a perceived need to save them is mainly due to decision-making deficits, information processing deficits, problematic beliefs about possessions and deficits in processing emotions. High levels of fear of decision making combined with experiencing negative emotions more intensely causes an inability or difficulty in discarding possessions. Avoidance behavior and/or a strong connection to the possessions causes for a hoarder's brain to develop coping mechanisms that bring temporary relief, but with that also comes reinforcement of the hoarding behavior.

Training the brain to eliminate unhelpful rituals using the cognitive behavioral therapy by Singh may work as self-treatment for people with Hoarding Disorder, when used to cope with their anxiety and other uncomfortable emotions that they encounter when confronted with their clutter. However, this research needs to be repeated to support this theory, for example with the use of a moderator or clean-up sessions.

Results of this study should be interpreted in light of several (theoretical and practical) limitations. Some concepts were left out of scope to prevent the models from getting too complex. The brain processes have been simplified to their core. Assumptions have been made about how Hoarding Disorder actually works in the brain, since this process, as any other process that happens in the brain, is extremely complicated. More research needs to be done regarding this domain. Treatment should be extended to additional help in order to lessen the emotional reactions. The patient will benefit from additions to the therapy, including psychoeducation, motivational interviewing, classic cognitive techniques focused on dysfunctional beliefs, and exposures targeting sorting and discarding, and they could also benefit from pharmacological interventions.

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