An Adaptive Network Model of Attachment Theory

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Abstract. The interactions between a person and his or her primary caregiver shape the attachment pattern blueprint of how this person behaves in intimate relationships later in life. This attachment pattern has a lifelong effect on an individual, but also evolves throughout a person's life. In this paper, an adaptive network was designed and simulated to provide insights into how an attachment pattern is created and how this pattern then has its effects and evolves as the person develops new intimate relationships at older age.

Keywords: Attachment Theory · Adaptive Temporal Causal Network

1 Introduction

For many adults, establishing and maintaining emotionally intimate relationships with loved ones, friends or family members may raise difficulties such as problems with intimacy, dependence or abnormal emotional reactivity. The root of establishing healthy relationships can be found in the attachment theory introduced by Mary D. Salter Ainsworth and John Bowlby [5-6, 15-20], which provides a framework on how distorted personal bonds between an individual and his primary caregiver leads to a faulty development of intimate relationships later on in life.

Attachment theory has had a profound impact on changing institutional care provided for children (e.g., in care homes and in hospitals). However, the theory's wider application to adult mental health has not been investigated extensively. While the attachment patterns originating from interactions with the primary caregiver have been studied thoroughly, little attention has been paid to how these attachment styles are expressed and evolve at an older age. Modelling the expression ad evolution of adult attachment patterns may fill part of this gap by providing insight in how the concepts of attachment theory affect the individual's interactions when this person meets a securely attached person in later life and how these adult experiences may change attachment patterns.

In this study, an adaptive network model was designed to model, firstly how attachment styles are established, and secondly, how these patterns then affect the individual in later life when trying to build an intimate relationship with a securely attached

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person. For the latter situation, this model also shows how the individual's attachment style is adapted at adult age by learning from such a new relationship.

These insights behind the model and the patterns generated by it may be an helpful instrument in therapeutic settings. The model can be used in the therapeutic setting to help patients understand how the process continues, e.g., with virtual role play sessions using avatars such as pointed out in [23]. In this way, this paper provides a new perspective on the use of computational modeling [9] in a psychological context.

This paper is divided into five sections. After the current section, the second section introduces attachment theory and its main concepts. In the third section, the design of the network model will be discussed, which consists of the main attachment concepts, the individual's inner working model and the interactions with the securely attached person. The resulting simulations of the scenarios will then be laid out in the fourth section. The final section presents the conclusions for and discussion of this study.

2 Attachment Theory

The Attachment Theory concerning the relationships between humans was developed from the 1940s and 1950s on mainly by developmental psychologist Mary D. Salter Ainsworth and psychologist and psychiatrist John Bowlby [5-6, 15-20] as a successor of security Theorey developed by William E. Blatz and Mary D. Salter Ainsworth [4, 15]. The Attachment Theory explains an important evolutionary function of the relationship between the child and caregiver. This has been supported by empirical research in various settings. For example, Salter Ainsworth did research on mother-child relationships for two years from 1954 on in Uganda [16] and also Bowlby has investigated the empirical basis of the theory among humans and non-human primates [6]. The theory is often applied in therapeutical contexts; e.g., [8, 10-11].

According to Attachment theory, the first attachment relationship is between a child and its primary caregiver (PC), which has a significant effect on the child's cognitive and socio-emotional development. Research has shown that early attachment is correlated with the PC's sensitivity, reliability and responsiveness [7]. These behaviours of the PC lead to the child's development of the three principles of attachment theory: bonding as an intrinsic human survival strategy, regulation of emotion and fear to enhance resilience and vitality, and flexible adaptiveness and growth [10]. In this way, the early experiences with the PC form a main input for the child to develop the 'internal working model of social relationships' (including a 'model of self' and a 'model of other'), which continues to change with age and experience [12]. For example, if a caretaker shows high levels of parental sensitivity, reliability and responsiveness, the child will develop positive models of self and other [7].With these internal models, children predict the PC's behaviour and plan their own behaviour accordingly [7]. Important relationships later in life may be built on the quality of early attachment [20]. Accordingly, the formed relationship with the PC can be seen as a 'blueprint' for future relationships [3]; see Fig. 1 for an overview of this. The attachment behaviour of children has been classified in four patterns or styles: secure, anxious-avoidant, anxious-ambivalent, and disorganized [6, 13]. Adult attachment behaviour corresponds to these categories, but is named differently. The classification of attachment is based on the balance between intimacy and independence [3]. It is measured in levels of avoidance

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and dependence, where avoidance can be related to the ‘model of other’ and dependence can be related to the ‘model of self’. Table 1 gives an overview of the classifications, internal working models, behaviours and parental styles.

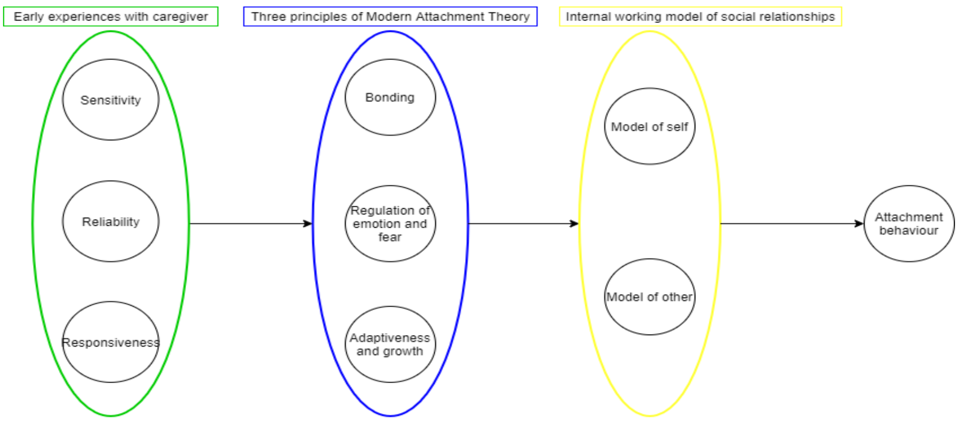

Fig. 1: How early experiences with a primary caregiver lead to the development of internal models of self and other that in turn lead to attachment behaviour.**Table 1: Overview of classifications, internal working models, behaviours and parental styles.**

Infant attachment category	**Adult attachment category**	**Internal working model**	**Avoidance and dependence**	**Parental style**	**Behaviour**
Secure	Secure	Positive model of self	Low dependence	Sensitive Reliable Responsive	Self is worthy of love and support Others are trustworthy and reliable Seek proximity
		Positive model of other	Low avoidance		
Anxious-avoidant	Dismissing	Positive model of self	Low dependence	Insensitive Rejecting	Self is worthy of love and support Others are unreliable and rejecting Avoid proximity to protect self against disappointment
		Negative model of other	High avoidance		
Anxious-ambivalent	Pre-occupied	Negative model of self	High dependence	Unreliable Unresponsive	Self is not worthy of love and support Others are trustworthy and reliable Hesitant in seeking proximity, but strive for self-acceptance by gaining acceptance of valued others
		Positive model of other	Low avoidance		
Disorganized	Fearful	Negative model of self	High dependence	Parental abuse and neglect	Self is not worthy of love and support Others are unreliable and rejecting Avoid proximity to protect self against anticipated rejection by others
		Negative model of other	High avoidance		

Secure attachment indicates a positive model of both self and other and thus low levels of dependence and avoidance. This is the most prevalent attachment pattern [6]. Anxious-avoidant attachment, also referred to as ‘dismissing’, indicates a positive ‘model of self’, resulting in low dependence, and a negative ‘model of other’, resulting in high avoidance. Anxious-avoidant is the second most prevalent attachment style [6].

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Anxious-ambivalent attachment, also referred to as 'preoccupied', indicates a negative 'model of self', resulting in high dependence, and a positive 'model of other', resulting in low avoidance. Finally, disorganized attachment is also referred to as 'fearful' and indicates a negative model of both self and other and thus high levels of dependence and avoidance.

3 The Modeling Approach Used

For this study, the Network-Oriented Modelling approach, as described in [21, 22], was used to design a model based on a network structure which can be used to simulate and analyse attachment behaviour. The elements of such a network model are:

- the *states* Y of the network
- the *connections* from states X to Y, with their *connection weights* $\boldsymbol{\omega}_{X,Y}$ specifying different strengths for these connections
- a *speed factor* $\boldsymbol{\eta}_Y$ for each state Y to express how fast state Y can change
- a *combination function* $\mathbf{c}_Y$ for each state Y to indicate how all incoming connections for each state combine to impact that state

The designed attachment behaviour model comprises the main attachment concepts as states and relations between these concepts as connections. The numerical representation created by the available dedicated software environment is based on the following equations (where $X_1, \ldots, X_k$ are the states from which state Y gets incoming connections):

$$\mathbf{impact}_{X,Y}(t) = \boldsymbol{\omega}_{X,Y}\, X(t) \qquad (1)$$

$$\mathbf{aggimpact}_Y(t) = \mathbf{c}_Y(\mathbf{impact}_{X_1,Y}(t),\ldots,\mathbf{impact}_{X_k,Y}(t)) = \mathbf{c}_Y(\boldsymbol{\omega}_{X_1,Y}X_1(t),\ldots,\boldsymbol{\omega}_{X_k,Y}X_k(t)) \qquad (2)$$

$$\begin{aligned} Y(t+\Delta t) &= Y(t) + \boldsymbol{\eta}_Y\,[\mathbf{aggimpact}_Y(t) - Y(t)]\,\Delta t \\ &= Y(t) + \boldsymbol{\eta}_Y\,[\mathbf{c}_Y(\boldsymbol{\omega}_{X_1,Y}X_1(t),\ldots,\boldsymbol{\omega}_{X_k,Y}X_k(t)) - Y(t)]\,\Delta t \qquad (3) \end{aligned}$$

The combination functions from the library used are shown in Table 2.

For the learning, the modeling approach provides the possibility to include *self-models* in a network model. This idea is inspired by the idea of self-referencing or 'Mise en abyme' in art, sometimes also called 'the Droste-effect' after the famous Dutch chocolate brand who uses this effect in packaging and advertising of its products already since 1904[1]. This effect occurs in art when within an artwork a small copy of the same artwork is included. For Network-Oriented Modeling, this idea leads to *self-modeling networks*, also called reified networks (Treur, 2020). These are networks that represent some of the network structure characteristics by self-model states within the network. As an example used here, the weight $\boldsymbol{\omega}_{X,Y}$ of a connection from (base) state X to Y can be represented by a (first-order) self-model state $\mathbf{W}_{X,Y}$. Such a first-order self-model state is depicted in a 3D format (as in Fig. 1) in a separate (blue) plane above the (pink) plane for the base network. Like any other state, such a self-model state $\mathbf{W}_{X,Y}$ has an activation value that changes over time, based on its incoming connections from other states. Through a downward connection from $\mathbf{W}_{X,Y}$ to Y (indicated by pink arrows in Fig. 1), the weight $\boldsymbol{\omega}_{X,Y}$ of the related connection from state X to state Y within the base

[1] E.g., https://en.wikipedia.org/wiki/Mise_en_abyme, https://en.wikipedia.org/wiki/Droste_effect.

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network will adapt accordingly, which creates a form of learning for that connection. In the current paper *plasticity* is modeled by Hebbian learning and *metaplasticity* to control this learning [14]. For more details, see [2].

Table 2 Combination functions from the library used in the presented model

	Notation	Formula	Parameters
Steponce	**steponce**(V)	1 if $\alpha \leq t \leq \beta$, else 0	α begin, β end time
Scaled sum	$\mathbf{ssum}_\lambda(V_1, \ldots, V_k)$	$\frac{V_1 + \cdots + V_k}{\lambda}$	Scaling factor λ>0
Advanced logistic sum	$\mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k)$	$[\frac{1}{1+e^{-\sigma(V_1+\cdots+V_k-\tau)}} - \frac{1}{1+e^{\sigma\tau}}](1+e^{-\sigma\tau})$	Steepness σ>0 Excitability threshold τ
Scaled minimum	$\mathbf{smin}_\lambda(V_1, V_2)$	$\frac{\min(V_1, V_2)}{\lambda}$	Scaling factor λ>0
Scaled maximum	$\mathbf{smax}_\lambda(V_1, \ldots, V_k)$	$\frac{\max(V_1, \ldots, V_k)}{\lambda}$	Scaling factor λ>0
Min advanced logistic	$\mathbf{minalogistic}_{\sigma,\tau}(V_1, .., V_{k+1})$	$\min(\mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k), V_{k+1})$	Steepness σ>0 Excitability threshold τ

4 Design of the Adaptive Network Model for Attachment Theory

This section describes the adaptive temporal-causal network model designed to investigate the formation of an attachment style and its impact on the individual's relationship at older age. Fig. 3 provides an overview of all the states and their connections for a person A who develops a 'blueprint' from his/her primary caregiver C and then interacts with a new person B. The connection weights, speed factors, and combination functions are labels for the nodes and arrows. These are not presented in the figure, but can be found for each scenario in [2] in the form of role matrices. Table 3 presents the nomenclature and explanation for all 47 states of the model.

Note that, triggered by when the other person is there, base states X_{10} to X_{15} are the states that become activated according to person A's model of the other, and base states X_{16} to X_{21} according to person A's model of self. If there is no person, these states are not activated. To achieve this, the persistent models of the other and of the self are represented by first-order self-model **W**-states X_{35} to X_{40} and X_{41} to X_{46}, respectively. These **W**-states represent the weights of the connections from X_3 (presence of a person) to the respective base states X_{10} to X_{15} and X_{16} to X_{21}. The specific combinations of values of these **W**-states define the attachment style, and when a person is present (i.e., X_3 is activated), the base states as mentioned get their (temporary) values accordingly. The different types of states were assigned different combination functions to ensure that incoming connections impact the state activations in a proper manner. The six different combination functions shown in Table 2 have been used as follows:

- The *steponce* combination function. The two initiating states X_1 for primary caregiver C and X_2 for other person B were assigned the steponce function. This function was used to ensure that each of them initiates the process at the specified time interval.
- The *scaled sum* combination function. This function was assigned to state X_3 and the sensor and sensory representation states X_{22} and X_{23}.

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- The *alogistic* combination function. The states for the early experiences with the primary caregiver C (X_4, X_5, X_6), the three principles of modern attachment theory (X_7, X_8, X_9) and the action, reaction and evaluation states (X_{26} to X_{31}) were assigned this function. The learning control state (X_{47}) was also assigned the alogistic combination function. By this, person A processes the arrival of a person and the possible adaptation of the attachment blueprint for the person.
- The *maximum* combination function. For the states of the internal self and other working models (X_{10} to X_{21}) this function was used.
- The *min-alogistic* combination function. The preparation states (X_{24}, X_{25}) were given a composition of two functions: first, the alogistics function is applied and then the minimum function to select the outcome with the lowest value.
- The *minimum* combination function. All **W**-states (X_{32} to X_{46}) were assigned this function.

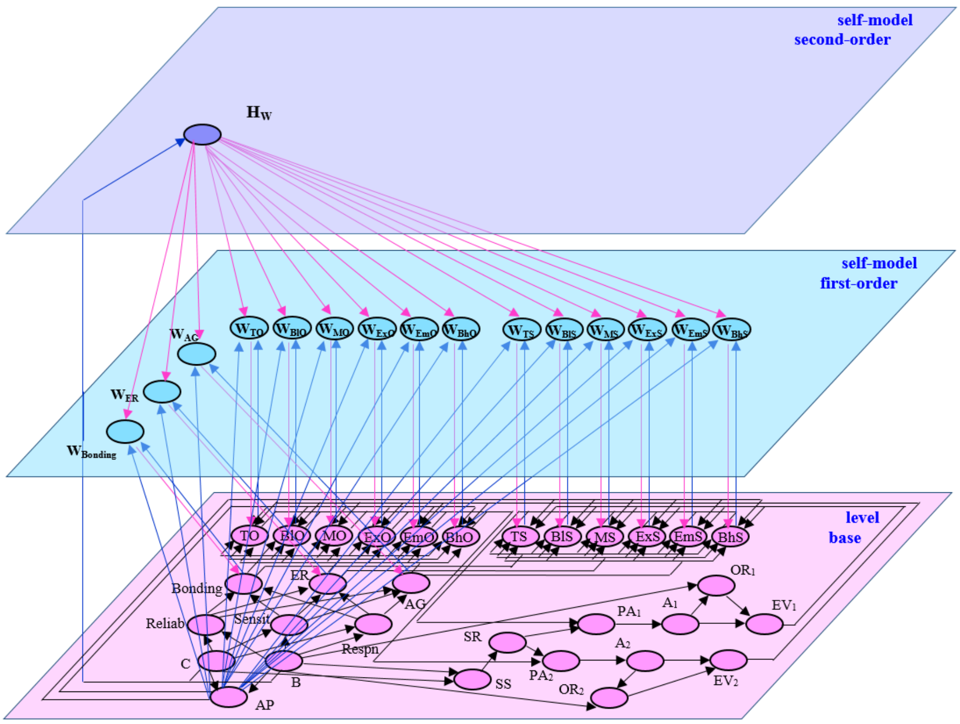

Fig. 3: Graphical representation of the connectivity of the adaptive network model for attachment behaviour.

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Table 3: Nomenclature and explanation of the states in the network model

Nr	Abb.	Full name	Definition
X_1	C	Primary caregiver	A being in contact with caregiver C
X_2	B	Other person	A being in contact with other person B at adult age
X_3	AP	Abstract Person	A being in contact with any person; all learned attachment patterns and personal characteristics are related to this state
X_4	Reliab	Reliability	Early experiences with reliability of C in relation to A
X_5	Sensit	Sensitivity	Early experiences with sensitivity of C in relation to A
X_6	Respn	Responsiveness	Early experiences with responsiveness of C in relation to A
X_7	Bond	Bonding	First principle of Modern Attachment Theory
X_8	ER	Emotion regulation	Second principle of Modern Attachment Theory
X_9	AG	Adaptiveness and growth	Third principle of Modern Attachment Theory
X_{10}	TO	Thoughts about other	First part of A's internal other-model of attachment
X_{11}	BlfO	Beliefs about other	Second part A's of internal other-model of attachment
X_{12}	MO	Memories about other	Third part A's of internal other-model of attachment
X_{13}	ExO	Expectations about other	Fourth part A's of internal other-model of attachment
X_{14}	EmO	Emotions about other	Fifth part of A's internal other-model of attachment
X_{15}	BhvO	Behaviours about other	Sixth part of A's internal other-model of attachment
X_{16}	TS	Thoughts about self	First part of A's internal self-model of attachment
X_{17}	BlfS	Beliefs about self	Second part of A's internal self-model of attachment
X_{18}	MS	Memories about self	Third part of A's internal self-model of attachment
X_{19}	ExS	Expectations about self	Fourth part of A's internal self-model of attachment
X_{20}	EmS	Emotions about self	Fifth part of A's internal self-model of attachment
X_{21}	BhvS	Behaviours about self	Sixth part of A's internal self-model of attachment
X_{22}	SS	Sensor state (feelings for person B)	Feelings developed by A through perceiving B.
X_{23}	SR	Sensory representation	A's sensory representation of feelings for B
X_{24}	PA1	Preparation action 1	A prepares for A's first attachment behaviour
X_{25}	PA2	Preparation action 2	A prepares for A's second attachment behaviour
X_{26}	A1	Action 1: Dependence	Degree of dependence: A's first attachment behaviour
X_{27}	A2	Action 2: Proximity seeking	Degree of proximity seeking: A's second attachment behaviour
X_{28}	OR1	Other person's reaction to action 1	Reaction of B to degree of shown dependence of A
X_{29}	OR2	Other person's reaction to action 2	Reaction of B to degree of expressed proximity seeking of A
X_{30}	EV1	Evaluation of action 1	A's evaluation of A's first attachment behaviour
X_{31}	EV2	Evaluation of action 2	A's evaluation of A's second attachment behaviour
X_{32}	$\mathbf{W}_{bond}$	**W**-state of bonding	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{bond}$
X_{33}	$\mathbf{W}_{ER}$	**W**-state of emotion regulation	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{ER}$
X_{34}	$\mathbf{W}_{AG}$	**W**-state of adaptiveness and growth	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{AG}$
X_{35}	$\mathbf{W}_{TO}$	**W**-state of thoughts about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{TO}$
X_{36}	$\mathbf{W}_{BlfO}$	**W**-state of beliefs about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{BlfO}$
X_{37}	$\mathbf{W}_{MO}$	**W**-state of memories about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{MO}$
X_{38}	$\mathbf{W}_{ExO}$	**W**-state of expectations about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{ExO}$
X_{39}	$\mathbf{W}_{EmO}$	**W**-state of emotions about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{EmO}$
X_{40}	$\mathbf{W}_{BhvO}$	**W**-state of behaviours about other	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{BhvO}$
X_{41}	$\mathbf{W}_{TS}$	**W**-state of thoughts about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{TS}$
X_{42}	$\mathbf{W}_{BlfS}$	**W**-state of beliefs about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{BlfS}$
X_{43}	$\mathbf{W}_{MS}$	**W**-state of memories about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{MS}$
X_{44}	$\mathbf{W}_{ExS}$	**W**-state of expectations about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{ExS}$
X_{45}	$\mathbf{W}_{EmS}$	**W**-state of emotions about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{EmS}$
X_{46}	$\mathbf{W}_{BhvS}$	**W**-state of behaviours about self	A's first-order self-model state for connection weight $\boldsymbol{\omega}_{BhvS}$
X_{47}	**Hw**	Learning control state	A's second-order self-model state: control state for learning of attachment patterns, representing the learning speed

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5 Simulation Scenarios

This section describes two scenarios that were simulated by the adaptive network model and the resulting simulation graphs. The first scenario concerns the secure attachment style and the second scenario the anxious-avoidant attachment style. The latter scenario was differentiated into a scenario for an attachment style that is highly adaptive to the interactions at older age and one for a pattern that is more rigid. For both scenarios the first peak illustrates the interactions of the individual with the primary caregiver C, which then leads to a persistent 'blueprint' in A for the level of bonding, emotion regulation, adaptivity, and the model of self and other. The second peak illustrates the interaction with the other person B, which either continues the learnt pattern or leads to an adaptation of person A's attachment pattern to B.

Scenario 1: Secure Attachment Style

The simulation results from the first scenario are displayed in Fig. 4.

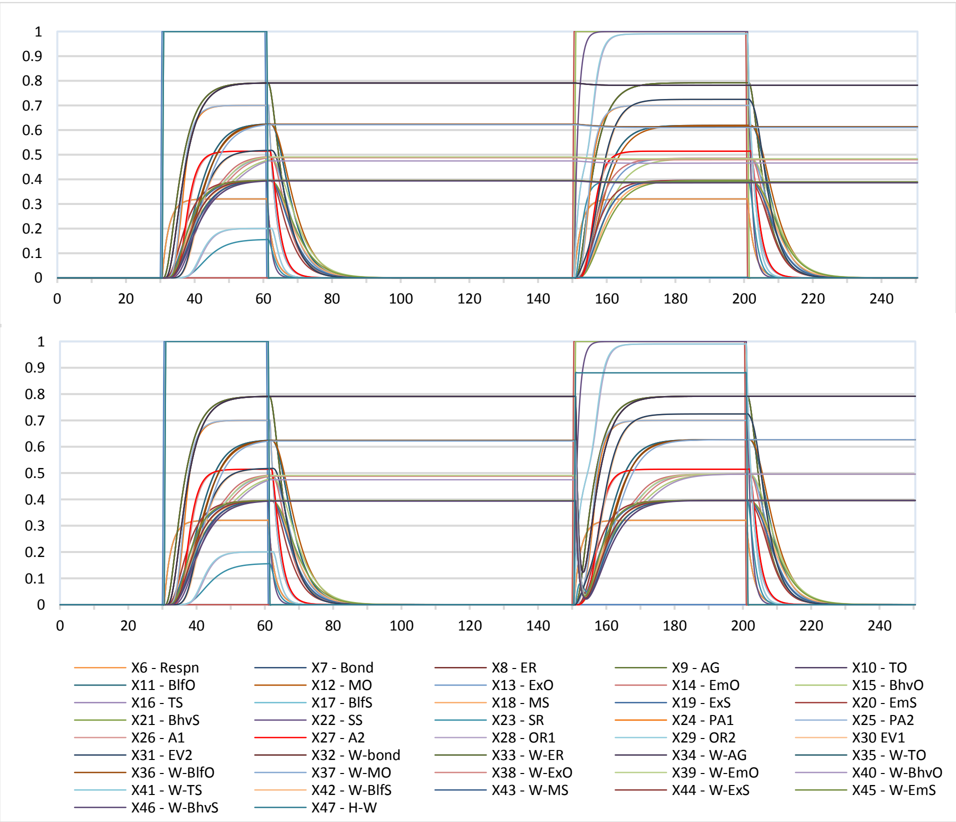

Fig. 4: Graph depicting the simulation for Scenario 1 with a secure attachment pattern and a relatively low flexibility (upper graph, 0.2) and high flexibility (lower graph, 0.5) to adapt later in life.

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In this scenario, the main character has a primary caregiver C who is sensitive, reliable and responsive. Therefore, the main character develops a secure attachment pattern. Next, at an older age, the main character encounters person B who is also sensitive, reliable and responsive. In Fig. 4 for *t* from 30 to 60, A interacts with C and these interactions lead to the formation of A's attachment style, represented by the persistent **W**-states. This comprises developing bonding, emotion regulation, adaptiveness and the construction of the 'model of self' and 'model of other'. After these interactions with C, the attachment blueprint is carried over through this person's life through the persistent **W**-states, which can be seen in the graph for *t* from 60 to 150, where the **W**-states remain at a constant level. Finally, for *t* from 150 to 200, the individual encounters B with whom he or she interacts. Since A had developed a secure attachment with C in this scenario, the blueprint, as represented by the **W**-states, does not actually adapt when meeting another securely attached person. The degree of flexibility to adapt later in life, incorporated in the model by the connection weight of X_2 to X_{47}, was given different levels. This connection weight was set to 0.2 to express a relatively low flexibility (a more rigid evolving attachment style) as shown in the upper graph and to 0.5 to simulate a higher flexibility shown in the lower graph. Note that there is a dip immediately after encountering B, which reflects how A becomes open to a certain extent to adapt his/her blueprint when meeting B. On the longer term, eventually the attachment blueprint returns to the previous values during the interactions with B, because the new person B has the same secure attachment style as the primary caregiver C.

Scenario 2 Anxious-Avoidant Attachment Style
The simulations of the second scenario are displayed in Fig. 5. In this scenario, A has a primary caregiver C who is insensitive and rejecting. To express this in the network characteristics, the connection weight for the connection from X_1 (for C) to X_4, X_5 and X_6 (sensitivity, reliability and responsiveness) was lowered from 0.4 to respectively 0.1, 0.2 and 0.2. These values represent a different ratio which would lead the main character to develop an anxious-avoidant attachment pattern. In this way, the impact from the initiating state X_1 is now much lower than in the secure attachment pattern described in Scenario 1 above, leading the main character A to develop an anxious-avoidant attachment pattern. Furthermore, again the degree of flexibility to adapt later in life, incorporated in the model by the connection weight of X_2 to X_{47}, was given different levels. This time this connection weight was set to 0.1 to simulate a very low, rigid evolving attachment style for the upper graph and to 0.9 to express a very high flexibility for the lower graph. Additionally, the threshold for X_{27} (Action 2: proximity seeking) was increased from 0.5 to 1 to ensure that the outcome of this action was lower, in accordance with this attachment style. As described in Section 2, the anxious-avoidant attachment pattern leads to more avoidance, which results in decreased proximity seeking.

Later in life, the now adult main character encounters person B who is sensitive, reliable and responsive at time point 150. Since person A's attachment blueprint from the interactions with C expresses an anxious-avoidant attachment style, A will conduct actions in accordance with this attachment style. However, A's continuous evaluations of A's actions, both based on the reaction of B and from A's own 'model of self' and 'model of other' will lead him to adapt his/her behaviour when interacting with B by selecting a different action. By doing so, the attachment blueprint will adapt and

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converge more towards a secure attachment pattern. The upper graph in Fig. 5 shows a simulation of the anxious-avoidant primary caregiver with A who expresses a low ability to adapt his attachment pattern, whereas the lower graph shows a simulation of A who has a high flexibility to change. Note that the extent of flexibility by which the attachment pattern is adapted may vary, as many other factors besides the attachment pattern may increase or suppress the ability to learn from the interactions at older age.

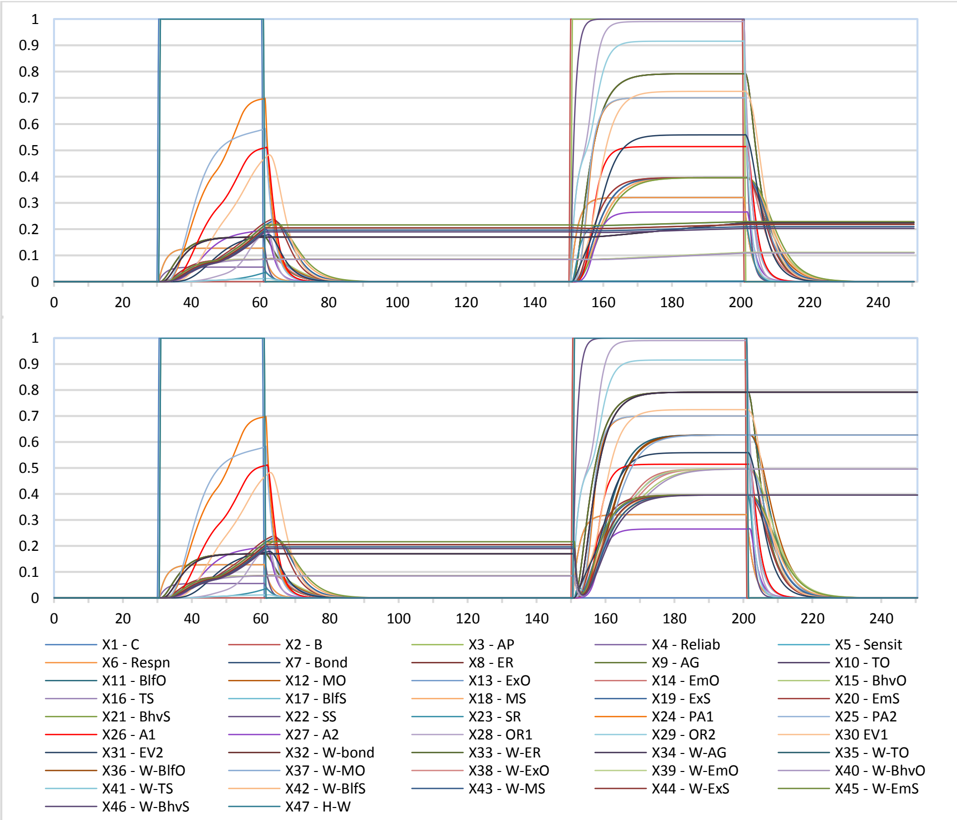

Fig. 5: Graph depicting the simulation for Scenario 2 with an anxious-avoidant attachment pattern which adapts with a low flexibility (upper graph, 0.1) and a high flexibility (lower graph, 0.9) later in life.

In the graphs in Fig. 5, this adaptation of the blueprint is visible for *t* between 150 and 200. A dip similar to Scenario 1 is visible at timepoint 150. Due to lower flexibility to adapt later in life, the upper graph shows less adaptation than the lower graph. A only slightly adapts their behavior after encountering the securely attached B, which can be seen as the **W**-states are much more rigid and only differ slightly from their previous values that originated from the interactions with the primery caregiver.

Comparing the two scenarios To compare the two scenarios and assess the impact an insensitive and rejecting parent can have on a child's development, this part provides a

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closer look into the **W**-states and the action-states for each scenario. In Fig. 6 (the double secure case) the two actions A1 for dependence (X_{26}) and A2 for proximity seeking (X_{27}) overlap (indicated in red). As found in literature, in secure attachment, the two actions are in an equilibrium. This equilibrium implies that the main character is self-confident and seeks out others. The same graph shows that the values for X_7 to X_{21} learnt from C remain at the same value when encountering a B who also gives input for a secure attachment. There is a dip shortly after meeting B, which can be explained by the fact that A needs to process encountering B and to possibly adapt some of the learnt patterns. In Fig. 7 adressing the anxious-avoidant case, action A1 for dependence (X_{26}) remains at the same level as in Scenario 1. However, action A2 for proximity seeking (X_{27}) is now at a much lower value. This is in line with literature stating that for anxious-avoidant attachment there is more avoiding behaviour and thus lower proximity seeking. Additionally, the graph shows very low levels for the learnt bonding, emotion regulation and adaptiveness (X_{32}, X_{33}, X_{34}) which increase after meeting B who is sensitive, reliable and responsive.

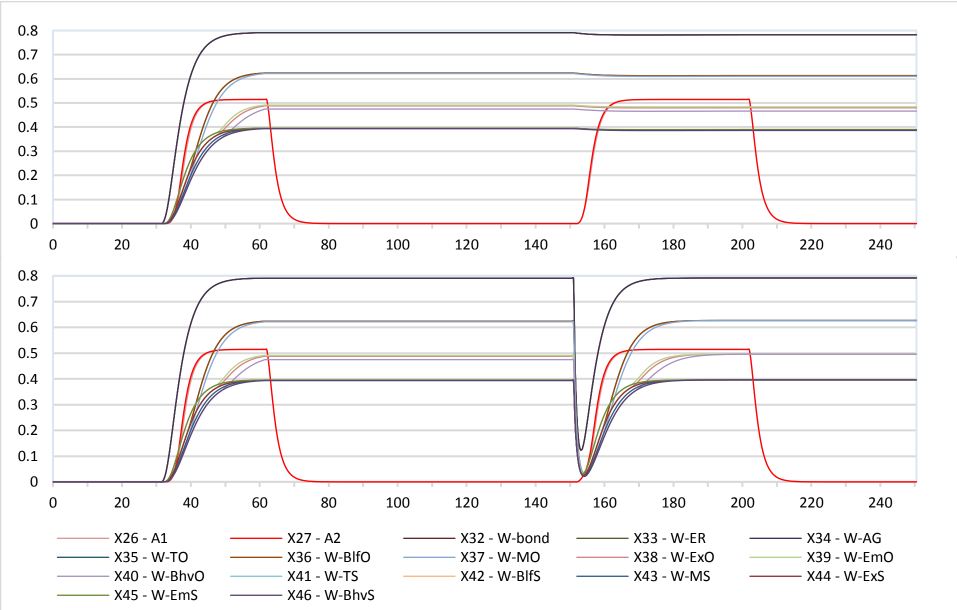

Fig. 6: Graph showing the **W**-states and action states A1 and A2 (in red) for Scenario 1 for secure attachment with a lower (upper graph, 0.2) and higher (lower graph, 0.5) adaptation flexibility.

The **W**-states for the ‘model of other’ states (X_{35} to X_{40}) are also lower. The **W**-states for the ‘model of self’ states (X_{41} to X_{46}) are also lower, but less deviant from the secure attachment scenario. When encountering B, values closer to the ‘healthy’ ones for the internal models are learnt, which results in values similar to Scenario 1. Lastly, the upper graph in Fig. 8 displays the **W**-states and action states where A’s attachment pattern remains unopen to change. Here, the **W**-states, in contrast to the lower graph in

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Fig. 7, only change slightly after meeting B, which implies that A is less affected by the new interactions. This simulation shows the difficulty that A experiences in evolving his/her attachment style to form healthy intimate relationships at older age.

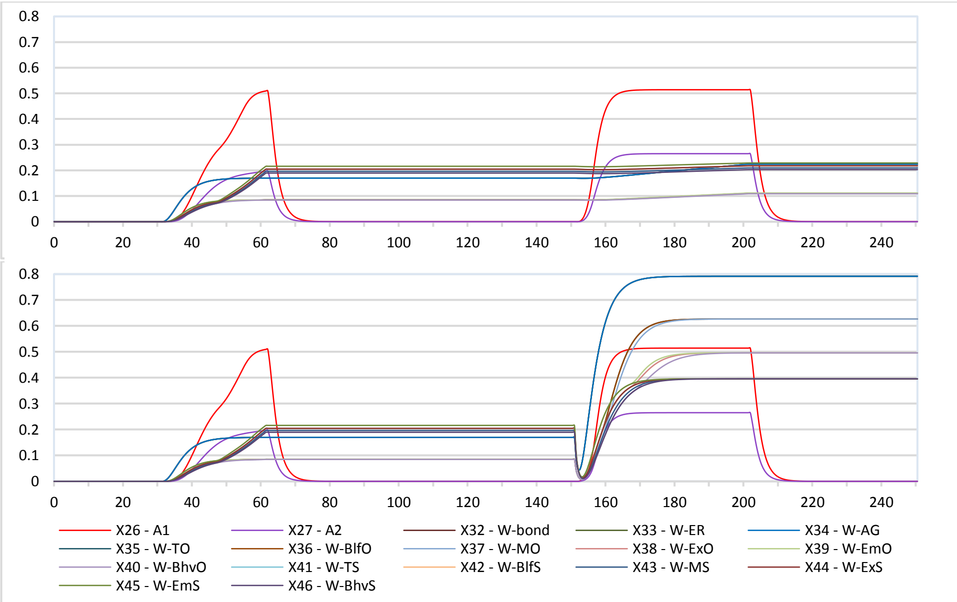

Fig. 7: Graph showing the **W**-states and action states A1 and A2 (in red and purple) for Scenario 2 anxious-avoidant attachment with a low (upper graph, 0.1) and high (lower graph, 0.9) adaptation flexibility.

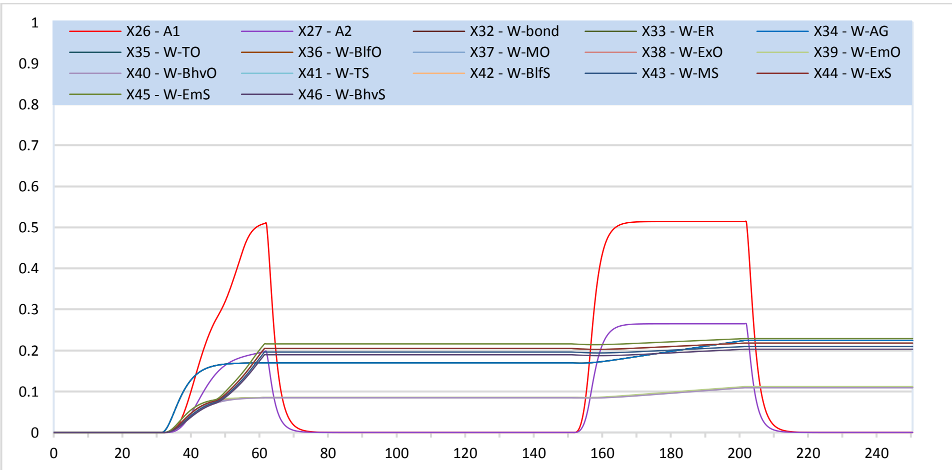

Fig. 8: Graph showing the **W**-states and action states A1 and A2 (in red and purple) for Scenario 2 anxious-avoidant attachment with a low adaptation flexibility.

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6 Discussion

This paper presented an adaptive network model of attachment theory [5-6, 15-20] which simulates how an individual can develop his or her attachment pattern and adapt this through social interactions later in life. The model was built according to the Network-Oriented Modelling approach for adaptive networks from [21, 22]. Such a computational model of attachment patterns has not been created before as far as the authors are aware of. Additionally, the role of attachment patterns in adult relationships has not been extensively investigated.

A literature review on attachment theory was conducted to understand which factors influence the formation and adaptation of attachment styles and which internal processes play a role in this development [5-6, 15-20]. This literature study resulted in a total of 47 states which play a causal role in attachment patterns and which were used for the model. Two scenarios were explored; secure attachment to the primary caregiver as a child, and anxious-avoidant attachment to the primary caregiver as a child. In both scenarios the main character encounters a securely attached other person at an adult age. The distinction between the two scenarios was made by adjusting the connection weights for the connections from the primary caregiver to the characteristics of the primary caregiver (i.e., sensitivity, reliability and responsiveness). Additionally, the extent to which an attachment pattern can evolve later in life was also differentiated for Scenario 2, leading to personal differences from highly flexible and rigid adjustment of the attachment pattern.

While the simulations of the model do correspond with what is described in the literature, it should be noted that simulating social interactions remains complex. The model does not and could not include all the elements that may influence social interaction and which might play a role in forming and adapting attachment patterns. This means that the model is still not reality but a simplified version of reality, as any model necessarily is. Furthermore, it takes time to adapt one's attachment style. In the presented scenarios, for the sake of simplicity of these scenarios, the main character quickly adapts when meeting one other person. In reality, this adaptation requires more time and may need multiple interactions with different persons. As the model has certain personal characteristics that determine the strength of adaptation, weaker settings for these characteristics enable the model to simulate these slower forms of adaptation as well.

This model can serve as a basis for further investigation of the role of attachment patterns and how they can be altered through adaptive learning. Future research could explore the other two attachment patterns that have not been simulated here (i.e., anxious-ambivalent and disorganized attachment). Based on the literature review as described in Section 2, it is hypothesized that in the anxious-ambivalent scenario simulation the behaviour would show heightened levels of dependence and balanced levels of proximity seeking. In the disorganized scenario, the simulation would show behaviour with heightened levels of dependence and lowered levels of proximity seeking. Finally, in future studies, scenarios could be explored where the other person who is encountered later in life is not securely attached; the interactions between two insecurely attached persons has not been investigated yet in the current study.

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References

1. Abraham, W.C., Bear, M.F.: Metaplasticity: the plasticity of synaptic plasticity. Trends in Neuroscience **19(4)**, 126-130 (1996).
2. Appendix: URL: https://www.researchgate.net/publication/348402591 (2021).
3. Bartholomew, K., Horowitz, L.M.: Attachment styles among young adults: a test of a four-category model. Journal of personality and social psychology **61(2)**, 226-244 (1991).
4. Blatz, W.E.: Human Security: Some Reflections. Toronto, Canada: University of Toronto Press (1966).
5. Bowlby, J.: Forty-four juvenile thieves: Their characters and their home life. International Journal of Psycho-Analysis **25**, 19-52, 107-127 (1944).
6. Bowlby, J.: Attachment. Basic books (2008).
7. Bretherton, I.: The origins of attachment theory: John Bowlby and Mary Ainsworth. Developmental Psychology **28**, 759-775 (1992).
8. Fonagy, P.: Attachment theory and psychoanalysis. New York: Random House (2001).
9. ICCM: International Conferences on Cognitive Modeling. URL https://iccm-conference.github.io/previous.html (2020).
10. Johnson, S.M.: Attachment theory in practice: Emotionally focused therapy with individuals, couples, and families. New York, NY: Guilford (2019).
11. Marmarosh, C., Markin, R., Spiegel, E.: Attachment in group psychotherapy. Washington, D.C.: The American Psychological Association (2013).
12. Mercer, J. (2006). Understanding attachment: Parenting, child care, and emotional development. Greenwood Publishing Group.
13. Parkes, C.M., Stevenson-Hinde, J., Marris, P. (eds.): Attachment across the life cycle. Routledge (2006).
14. Robinson, B.L., Harper, N.S., McAlpine, D.: Meta-adaptation in the auditory midbrain under cortical influence. Nat. Commun. **7**, e13442 (2016).
15. Salter, M.D.: An Evaluation of Adjustment Based on the Concept of Security. Ph.D. Thesis, University of Toronto Studies, Child Development Series **18**, 72 (1940).
16. Salter Ainsworth, M.D.: Infancy in Uganda. Baltimore: Johns Hopkins (1967).
17. Salter Ainsworth, M.D.: Security and Attachment. In: Volpe, R. (ed.), The Secure Child: Timeless Lessons in Parenting and Childhood Education, pp. 43-53. Charlotte, NC: Information Age Publishing (2010).
18. Salter Ainsworth, M.D., Blehar, M., Waters, E., Wall, S.: Patterns of Attachment. Hillsdale, NJ: Erlbaum (1978).
19. Salter Ainsworth, M.D., Bowlby, J.: Child Care and the Growth of Love. London: Penguin Books (1965).
20. Salter Ainsworth, M.D., Bowlby, J.: An ethological approach to personality development. American Psychologist **46(4)**, 333-341 (1991).
21. Treur, J.: Network-Oriented Modeling: Addressing Complexity of Cognitive, Affective and Social Interactions. Springer Nature, Cham (2016).
22. Treur, J.: Network-Oriented Modeling for Adaptive Networks: Designing Higher-Order Adaptive Biological, Mental and Social Network Models. Springer Nature, Cham (2020).
23. Treur, R.M., Treur, J., Koole, S.L.: From Natural Humans to Artificial Humans and Back: An Integrative Neuroscience-AI Perspective on Confluence. Proc. of the First International Conference on Being One and Many: Faces of the Human in the 21st Century (2021).

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