Grounding a Cognitive Modelling Approach for Criminal Behaviour

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Abstract

This article presents a cognitive modelling approach for criminal behaviour, which is illustrated by a case study for the behaviour of three types of violent criminals as known from literature within the area of Criminology. The model can show each of their behaviours, depending on the characteristics set and inputs in terms of stimuli from the environment. Based on literature in Criminology about motivations and opportunities and their underlying factors, it is shown by a formal mapping how the model can be related to a biological grounding. This formal mapping covers ontology elements for states and dynamic properties for processes, and thus shows how the cognitive model can be biologically grounded.

Introduction

The field of Criminology, which addresses the analysis of criminal behaviour, is a multi-disciplinary area with a high societal relevance; e.g., (Cohen and Felson, 1979; Cornish and Clarke, 1986; Gottfredson and Hirschi, 1990; Raine, 1993; Towl and Crighton, 1996; Turvey, 1999). Criminal behaviour, which is shown by a minority of the overall population, typically comes in many types and variations, often related to specific individual characteristics. Not many contributions in the literature can be found that address formalisation and computational modelling of criminal behaviour; e.g., (Baal, 2004; Brantingham and Brantingham, 2004; Melo, Belchior, and Furtado, 2005; Liu, Wang, Eck, and Liang, 2005).

This paper first discusses a modelling approach at the cognitive level for different types of violent criminal behaviour. The cognitive model involves motivations (in particular desires and intentions) and beliefs in opportunities; e.g., (Georgeff and Lansky, 1987; Rao and Georgeff, 1991). Dynamical models were incorporated, addressing psychological factors relating to desires, such as levels of anxiety and excitement arousal, empathy or theory of mind (TOM), impulsiveness, and aggressiveness; e.g. (Raine, 1993; Moir and Jessel, 1995; Delfos, 2004). For example, certain types of criminal actions are more likely to be performed by persons that have a high impulsiveness, or a lack of empathy. Another part of the cognitive model addresses the generation of beliefs in opportunities, formalising the well-known Routine Activity Theory within Criminology; e.g., (Cohen and Felson, 1979). This (informal) theory assumes a certain motivation of the criminal and covers opportunities based on the perceived presence of targets (e.g., potential victims) and social control (e.g., guardians). The resulting cognitive model covers eight categories of aspects that play a role in criminal behaviour, and dynamical system models for these aspects.

To show how this cognitive model can be grounded in biological states and processes, a formal mapping was defined. This mapping relates ontology elements describing cognitive states to ontology elements describing biological states. Moreover, it relates temporal relationships between cognitive states, specified in the form of dynamic properties, to corresponding relationships between biological states. This mapping, covering both states and processes shows how the cognitive model can be grounded in the biological area.

To formalise the overall model, the language LEADSTO (Bosse, Jonker, Meij, and Treur, 2005) has been used. In LEADSTO direct temporal dependencies between two state properties in successive states are modelled by *executable dynamic properties*. The format of such dynamic properties is defined as follows. Let α and β be state properties of the form 'conjunction of ground atoms or negations of ground atoms'. In this language the notation $\alpha \twoheadrightarrow_{e, f, g, h} \beta$, means:

If state property α *holds for a certain time interval with duration g, then after some delay (between e and f) state property* β *will hold for a certain time interval of length h.*

Here atomic state properties can have either a qualitative, logical format, such as an expression desire(d) (expressing that desire d occurs), or a quantitative, numerical format, such as an expression has_value(x, v) (which expresses that variable x has value v). For more details of the language LEADSTO, see (Bosse, Jonker, Meij, and Treur, 2005).

The cognitive model as presented involves a variety of cognitive characteristics and states that affect the motivational states and hence the behaviour. A relevant, but nontrivial question is how these characteristics and states can be grounded. In (Bosse, Jonker and Treur, 2006) three ways of grounding of a cognitive state are considered: (1) by its functional role, (2) by its representation relations, (3) by its physical realisation. For the various cognitive states in the model, these types of grounding are addressed in the current paper. In the first place, the functional roles of the cognitive states are specified in a formal manner that is also used as a basis for the simulation model. Second, representation relations (Kim, 1996) can be obtained by a transitive closure of such functional role descriptions. Finally, for each of the cognitive states it is shown how it can be mapped onto a biological state that plays the role of realiser of this cognitive state; cf. (Nagel, 1961; Kim, 1996). This mapping between states has been formally defined, and extended to dynamic properties, as a variant of the concept of interpretation mapping in Logic.

Three Types of Criminals

The case study made in this paper focuses on three types of violent offenders: the violent psychopath, the offender with an antisocial personality disorder (APD), and the offender who suffers from an intermittent explosive disorder (IED). Below, these types of criminals are briefly introduced and differences between them are discussed, based on (Raine, 1993; Moir and Jessel, 1995; Delfos, 2004):

- Violent psychopaths do not have feelings like the rest of us. They lack the normal mechanisms of anxiety arousal, which ring alarm bells of fear in most people. Their kind of violence is similar to predatory aggression, which is accompanied by minimal sympathetic arousal, and is purposeful and without emotion. Moreover, they like to exert power and have unrestricted dominance over others, ignoring their needs and justifying the use of whatever they feel compelling to achieve their goals. They do not have the slightest sense of regret.
- Persons with APD have characteristics that are similar to the psychopath. However, they may experience some emotions towards other persons, but these emotions are mainly negative: they are very hostile and intolerant.
- Persons with IED, in contrast, appear to function normally in their daily life. However, during some short periods (which will be referred to as *episodes* from now on), their brain generates some form of miniature epileptic fit. As a result, some very aggressive impulses are released and expressed in serious assault or destruction of property. After these episodes, IED persons have no recollection of their actions and show feelings of remorse.

These three types of criminals can be distinguished by taking a number of aspects into account (which are all incorporated in the model):

Anxiety Threshold: this is a threshold that needs to be passed by certain stimuli, in order to make a person anxious. Thus, when a person's anxiety threshold is high, it is very difficult for this person to become anxious (and as a result, (s)he hardly knows any fear). This is the case for the violent psychopath and the person with APD: in these persons, a notion of fear is almost completely lacking. In contrast, persons with IED have a medium anxiety threshold. Nevertheless, in some special circumstances (i.e., during episodes) the anxiety threshold of a person with IED suddenly becomes much higher.

Excitement Threshold: this is a threshold that needs to be passed by certain stimuli, in order to make a person excited. Thus, when a person's excitement threshold is high, it is very difficult for this person to become excited (and as a result, (s)he is often bored). This is the case for the violent psychopath and for persons with APD. Persons with IED have a medium excitement threshold, but under certain circumstances (during episodes) their excitement threshold becomes high, and they get bored very easily. Consequently, they will generate the desire to perform certain actions that provide strong stimuli (which are often criminal actions).

Theory of mind: the notion of theory of mind (e.g., Humphrey, 1984; Dennett, 1987; Baron-Cohen, 1995) covers two concepts: 1) having the understanding that others (also) have minds, which can be described by separate mental concepts, such as the person's own beliefs, desires, and intentions, and 2) being able to form theories as to how those mental concepts play a role in the person's behaviour. The violent psychopath has a theory of mind that is specialised in aspects that can contribute to his own goals. He is able to form theories about another person's beliefs, desires and intentions and may use these theories (e.g., to manipulate this person), but just does not care about these states. A person with APD has a less developed theory of mind. Persons with IED mostly have a normal theory of mind and can make the distinction between themselves and others, but during episode, their theory of mind decreases.

Emotional attitudes towards others: these concepts express the extent to which a person may have positive or negative feelings with respect to other persons' wellbeing. For the violent psychopath, both attitudes are low: these persons hardly show any emotion concerning other persons, so for them, both the positive and the negative emotional attitude towards others are low. For the criminal with APD, the situation is slightly different. Like the violent psychopaths, these persons do not have many positive feelings towards others, but they may have some negative feeling towards others. Finally, criminals with IED usually have a normal (medium) positive and negative emotional attitude towards others, but during episodes, all their positive feelings disappear, and substantial additional negative feelings arise.

Aggressiveness: since this paper focuses on violent criminals, by definition all considered types of criminals are aggressive. However, the criminals with IED only become highly aggressive during episodes, whereas the other two types are always aggressive.

Impulsiveness: when someone acts impulsive, this means that the action was not planned. All types of violent criminals mentioned in this paper are impulsive, but they differ in the type of impulsive action they perform. While the APD offender may lash out in disproportionate overreaction, the psychopath, with his emotional detachment, will impulsively take whatever course of action will supply him with the necessary gratification. Persons with IED normally have a medium impulsiveness but during episodes they become highly impulsive.

Sensitivity to alcohol: For psychopaths and persons with APD, a small amount of alcohol or drugs can result in violent behaviour. For persons with IED, episodes can be triggered by small amounts of alcohol.

The Simulation Model

In this section the simulation model that has been developed is described in more detail[1]. It has been built by composing three submodels:

[1] Appendix A in www.cs.vu.nl/~tbosse/crim/sim-model.pdf shows a complete overview of the model (both in textual and in visual representation) and some simulation traces.

1. a model to determine actions based on beliefs, desires and intentions (*BDI-model*)
2. a model *to determine desires* used as input by the BDI-model
3. a model *to determine beliefs in an opportunity* as input for the BDI-model

The BDI-model bases actions on motivational states. It describes how desires lead to intentions and how intentions lead to actions, when the appropriate opportunities are there. It needs as input desires and beliefs in opportunities, generated by the other two submodels.

The BDI-submodel

Part of the model for criminal behaviour is based on the BDI-model, a model that bases the preparation and performing of actions on beliefs, desires and intentions (e.g., Georgeff and Lansky, 1987; Rao and Georgeff, 1991; Jonker, Treur, and Wijngaards, 2003). This model shows a long tradition in the literature, going back to Aristotle's analysis of how humans (and animals) can come to actions. In this model an action is performed when the subject has the intention to do this action and it has the belief that the opportunity to do the action is there. Beliefs are created on the basis of stimuli that are sensed or observed. The intention to do a specific type of action is created if there is a certain desire, and there is the belief that in the given world state, performing this action will fulfil this desire:

desire(d) ∧ belief(satisfies(a, d)) ↠ intention(a)
intention(a) ∧ belief(opportunity_for(a)) ↠ is_performed(a)

Assuming that beliefs about how to satisfy desires are internally available, what remains to be generated in this model are the desires and the beliefs in opportunities. Generation of desires often depends on domain-specific knowledge, which also seems to be the case for criminal behaviour. Beliefs in opportunities are based on the Routine Activity Theory by (Cohen and Felson, 1979).

The Submodel to Determine Desires

To determine desires, a rather complex submodel is used incorporating various aspects. To model these, both causal and logical relations (as in qualitative modelling) and numerical relations (as in differential equations) have been integrated in one modelling framework. This integration was accomplished, using the LEADSTO language as a modelling language. A variety of aspects, which were found relevant in the literature (such as Raine, 1993; Moir and Jessel, 1995; Bartol, 2002; Delfos, 2004) are taken into account in this submodel. These aspects can be grouped as: (a) use of a *theory of mind* (e.g., understanding others), (b) desires for *aggressiveness* (e.g., using violence), (c) desires to *act* (no matter which type of action) and (d) to *act safely* (e.g., avoiding risk), (e) desires for *actions with strong stimuli* (e.g., thrill seeking), (f) desires for *impulsiveness* (e.g., unplanned action), and (g) social-emotional *attitudes with respect to others* (e.g., feel pity for someone). Note that these aspects are derived on the basis of (but not exactly equal to) the eight characteristics as described in the previous section. Different combinations of such elements lead to different types of (composed) desires, for example:

- the desire to perform an exciting planned nonaggressive nonrisky action that harms somebody else (e.g., a pick pocket action in a large crowd),
- the desire to perform an exciting impulsive aggressive risky action that harms somebody else (e.g., killing somebody in a violent manner in front of the police department)

The following LEADSTO property (LP) is used to generate a composed desire out of the different ingredients covered by (a) to (g) above; here the x1, x2, x3, x4, x5, x6, x7, x8 are qualitative labels (e.g., high, medium, low) or numerical values (integer or real numbers):

LP24 A combination of values for theory of mind, desire for aggressiveness, desire to act, desire to act safely, desire for actions with strong stimuli, desire for impulsiveness, emotional attitude towards others(pos) and emotional attitude towards others(neg) will lead to a specific composed desire, represented as d(x1, x2, x3, x4, x5, x6, x7, x8).

∀x1,x2,x3,x4,x5,x6,x7,x8:SCALE
theory_of_mind(x1) ∧ desire_for_aggressiveness(x2) ∧ desire_to_act(x3) ∧ desire_to_act_safely(x4) ∧ desire_for_actions_with_strong_stimuli(x5) ∧ desire_for_impulsiveness(x6) ∧ emotional_attitude_towards_others(pos,x7) ∧ emotional_attitude_towards_others(neg,x8)
↠ desire(d(x1, x2, x3, x4, x5, x6, x7, x8))

Due to space limitations, the parts of the submodel to determine each of the ingredients (a) to (g) cannot be described in detail. To give an impression, a rough sketch of part of this submodel is given. Stimuli are labeled with two aspects, indicating the strength with respect to anxiety (risk), and with respect to excitement (thrill), respectively. For both aspects, thresholds represent characteristics of the person considered. The excitement threshold depends on other aspects in the model, such as sensitivity for (and use of) drugs and alcohol, and basic sensitivity to stimuli. A stimulus with excitement strength below the excitement threshold leads to being bored, and being bored leads to a desire for actions with strong(er) stimuli (which are often criminal actions). In contrast, a stimulus with anxiety strength above the anxiety threshold leads to internal alarm bells, which (depending on another characteristic, the tendency to look for safety) leads to the desire to perform only 'safe' actions (which are usually not criminal actions).

The Submodel to Determine Opportunities

Beliefs in opportunities are based on two of the three criteria as indicated in the Routine Activity Theory by (Cohen and Felson, 1979), namely the *presence of a suitable target*, and the *absence of social control* (guardians). The third criterion of the Routine Activity Theory, the *presence of a motivated offender*, is indicated by the intention in the BDI-model. This way, the presence of the three criteria together leads to the action to perform a criminal act, in accordance with (Cohen and Felson, 1979). This was specified by the following property in LEADSTO format:

LP34 When a suitable target for a certain action is observed, and no suitable guardian is observed, then a belief is created that there is an opportunity to perform this action.

∀a:ACTION
observes(suitable_target_for(a)) ∧ not observes(suitable_guardian_for(a))
↠ belief(opportunity(a))

An Example Simulation Trace

The model described in the previous section has been used to generate a number of simulation traces for the different types of violent criminals addressed. In Figure 1, an example simulation trace is depicted, addressing the case of the criminal with APD. Here, time is on the horizontal axis; state properties are on the vertical axis. A dark box on top of the line indicates that the property is true during that time period, a lighter box below the line indicates that it is false.

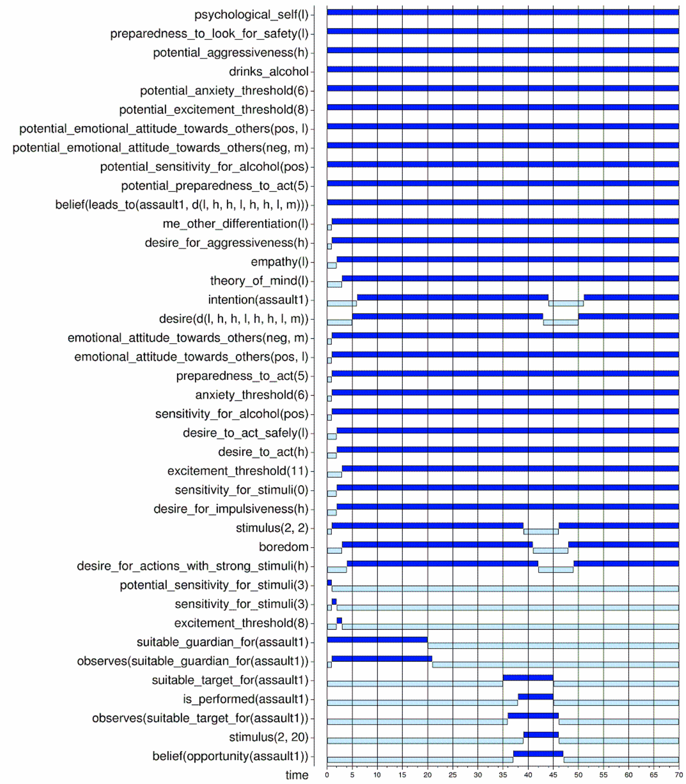

Figure 1: Example simulation trace.

The initial state properties that have been set to model the person with APD are (see time point 0): low psychological self, low preparedness to look for safety, high potential aggressiveness, rather high potential anxiety and excitement threshold (resp. value 6 and 8), potentially a low positive and a medium negative emotional attitude towards others, a low potential sensitivity for stimuli (value 3), and (s)he drinks alcohol and is sensitive for it. These initial characteristics, combined certain world stimuli, eventually lead to a specific composed desire d(l, h, h, l, h, h, l, m) (see time point 5), characterised by the following ingredients: low theory of mind, high aggressiveness, high desire to act, low desire to act safely, high desire for actions with strong stimuli, high impulsiveness, low positive and medium negative emotional attitude towards others. As a result, the criminal generates an intention to perform a specific type of assault (denoted by assault1), and, as soon as the opportunity is there, actually performs the assault. As a result, the stimuli increase, which satisfies the desires of the criminal.

Mapping Cognitive to Biological States

The psychological concepts used within Criminology to describe criminal behaviour are often complex concepts for which it is not always easy to give a precise definition. It may even be argued that for some of these concepts, there is a risk of circularity. For example, the internal state of aggressiveness may be related to aggressive or violent behaviour[2]. To clarify such issues, it may be worthwhile to have some reflection on how these concepts are embedded in reality. In (Bosse, Jonker and Treur, 2006) three perspectives are put forward: (1) specification of functional roles, (2) specification of representation relations, cf. (Kim, 1996), and (3) specification of realisation relations. Here (1) is already covered by the LEADSTO properties of the simulation model. Moreover, (2) can be obtained from these functional role specifications by determining their transitive closure. For the third way of grounding of the cognitive model, a mapping from this model to biological concepts has been established; this maps cognitive states to anatomical, neurophysiological and biochemical states, and cognitive dynamics onto biological dynamics. In this section it is discussed how a conceptualisation based on cognitive state properties can formally be mapped onto a conceptualisation based on biological states properties. In the following section this basic mapping is extended to a mapping of dynamics based on traces, executable (LEADSTO) properties and more complex dynamic properties.

In literature within Criminology, often relationships between cognitive states and biological (anatomical, neurological, biochemical) states are discussed; e.g., (Raine, 1993; Moir and Jessel, 1995). A mapping from the cognitive to a biological conceptualisation of the case study is shown in Table 1. Here a state property a in the left hand side column corresponds to the state property φ(a) as indicated in the right hand side column; for example,

φ(desire_for_aggressiveness(v)) = chemical_state(testosterone, v).

The assumption behind the mapping is that if b = φ(a), then b is true if and only if a is true.

In the literature on reduction in Philosophy of Mind or Philosophy of Science, this mapping is called a biconditional bridge principle, sometimes denoted by a $\leftrightarrow$ b; e.g., (Kim, 1996; Nagel, 1961). Based on this mapping of state properties, cognitive states as a whole can be mapped onto biological states. A state S over state ontology Ont is characterised by an assignment of truth values S: At(Ont) $\rightarrow$ {true, false}. Each cognitive state S can be mapped onto a biological state φ(S) by φ(S)(φ(a)) = S(a) for any cognitive ground atom a (with φ(a) the corresponding biological atom). In other words, the truth value of any mapped ground atom φ(a) in the mapped state φ(S) is the truth value of the original atom in the original state. The next question to be addressed is whether this mapping of state properties preserves temporal relations. This will be done in a number of ways in the next section.

[2] A similar example is: "Opium puts people to sleep, because it contains a *dormative principle*" (Bateson, 1979).

Table 1: Mapping cognitive to biological state properties.

Cognitive Conceptualisation	Biological Conceptualisation
potential_anxiety_threshold(v) potential_sensitivity_for_alcohol(s) potential_excitement_threshold(v) potential_emotional_attitude_towards_others(s,v)	brain_configuration_for_anxiety_threshold(v) brain_configuration_for_sensitivity_for_alcohol(s) brain_configuration_for_excitement_threshold(v) brain_configuration_for_emotional_attitude_towards_others(s, v)
potential_aggressiveness(v)	tendency_for_chemical_state(testosterone, v)
potential_sensitivity_for_stimuli(v)	tendency_for_chemical_state(serotonin, v)
potential_preparedness_to_act(v)	tendency_for_chemical_state(adrenalin, v)
psychological_self(v)	biological_self(v)
sensitivity_for_alcohol(s)	brain_state_for_sensitivity_for_alcohol(s)
anxiety_threshold(v)	brain_state_for_anxiety_threshold(v)
excitement_threshold(v)	brain_state_for_excitement_threshold(v)
sensitivity_for_stimuli(v)	chemical_state(serotonin, v)
preparedness_to_act(v)	chemical_state(adrenalin, v)
preparedness_to_look_for_safety(v)	chemical_state(oxytocine, v)
theory_of_mind(v)	brain_state_for_theory_of_mind(v)
emotional_attitude_towards_others(s, v)	brain_state_for_emotional_attitude_towards_others(s, v)
desire_for_actions_with_strong_stimuli(v)	brain_state_for_stimulation(w) and is_opposite(v,w)
desire_for_aggressiveness(v)	chemical_state(testosterone, v)
desire_to_act(v)	chemical_state(adrenalin, v)
desire_to_act_safely(v)	chemical_state(oxytocine, v)
desire_for_impulsiveness(v)	chemical_state(bloodsugar, v)
desire(d(v1, v2, v3, v4, v5, v6, v7, v8))	biological_state(v1, v2, v3, v4, v5, v6, v7, v8)

The Extended Mapping for Dynamic Properties

Above it was shown how the basic interpretation mapping can be defined as a mapping between state properties. The next question is how this mapping preserves temporal relationships, for example, in the following sense:

- if α holds at time point t in a trace γ, then also $\varphi(\alpha)$ holds at t in a corresponding trace
- if a temporal relationship $\alpha \twoheadrightarrow \beta$ holds, then also the temporal relationship $\varphi(\alpha) \twoheadrightarrow \varphi(\beta)$ holds
- if a more complex temporal relationship holds, expressed in the logical language TTL (Bosse, Jonker, Meij, Sharpanskykh, and Treur, 2006), then also this relationship holds between the mapped states

First it is addressed how a cognitive trace can be mapped onto a biological trace. This can be done as follows, based on the mapping of states defined above: a trace over state ontology Ont is a time-indexed sequence of states over Ont and is characterised by an assignment of states over Ont to time points: γ: TIME $\rightarrow$ STATES(Ont). Each cognitive trace γ can be mapped onto a biological trace $\varphi(\gamma)$ by $\varphi(\gamma)(t) = \varphi(\gamma(t))$ for any time point t. In other words, the state at t in the mapped trace $\varphi(\gamma)$ is the mapped state of γ at t.

The above mapping shows one answer to the question how temporal relationships are preserved. Another answer addresses temporal LEADSTO relationships. The mapping between state properties can be extended to a mapping between local dynamic properties in LEADSTO format as follows, where α and β are conjunctions of literals:

$$\varphi(\alpha \twoheadrightarrow \beta) = \varphi(\alpha) \twoheadrightarrow \varphi(\beta)$$
$$\varphi(\alpha1 \wedge \alpha2) = \varphi(\alpha1) \wedge \varphi(\alpha2)$$
$$\varphi(\neg\, \alpha) = \neg\, \varphi(\alpha)$$

and when α is an atom that is not an internal state property (e.g., an inequality relation or observation state)

$$\varphi(\alpha) = \alpha$$

Using this mapping, combined with the basic mapping of the state ontology elements described above, mappings between the dynamic LEADSTO properties of the case study can be found. For example:

$$\begin{aligned}
&\varphi(\text{anxiety_threshold}(y) \wedge \text{observes_stimulus}(x1, x2) \wedge x1>y \\
&\qquad\qquad \twoheadrightarrow \text{preparedness_to_act}(w)) \\
&= \varphi(\text{anxiety_threshold}(y) \wedge \text{observes_stimulus}(x1, x2) \wedge x1>y) \\
&\qquad\qquad \twoheadrightarrow \varphi(\text{preparedness_to_act}(w)) \\
&= \varphi(\text{anxiety_threshold}(y)) \wedge \varphi(\text{observes_stimulus}(x1, x2)) \wedge \varphi(x1>y) \\
&\qquad\qquad \twoheadrightarrow \varphi(\text{preparedness_to_act}(w)) \\
&= \text{brain_state_for_anxiety_threshold}(y) \wedge \text{observes_stimulus}(x1, x2) \wedge x1>y \\
&\qquad\qquad \twoheadrightarrow \text{chemical_state}(\text{adrenalin}, w)
\end{aligned}$$

The mapping of traces shows that the syntactic mapping between local properties preserves semantics: if the cognitive relationship $\alpha \twoheadrightarrow \beta$ holds in cognitive trace γ, then the corresponding biological relationship $\varphi(\alpha \twoheadrightarrow \beta)$ holds in the corresponding trace $\varphi(\gamma)$.

In addition, it is possible to extend the mapping to the wider class of temporal relationships expressed in the dynamic modelling language TTL (Bosse, Jonker, Meij, Sharpanskykh, and Treur, 2006). TTL expressions are predicate logical formulae, built on atoms of the form state(γ, t) |= p, which indicates that state property p is true in trace γ at time point t. By the basic mapping the cognitive state property p can be mapped onto $\varphi(p)$ in the biological conceptualisation, and cognitive trace γ can be mapped onto the corresponding biological trace $\varphi(\gamma)$. Then the extended interpretation mapping for state(γ, t) |= p is defined by $\varphi(\text{state}(\gamma, t) \models p) = \text{state}(\varphi(\gamma), t) \models \varphi(p)$. After these TTL-atoms have been mapped, TTL expressions as a whole can be mapped in a straightforward compositional manner:

$$\varphi(A \,\&\, B) = \varphi(A) \,\&\, \varphi(B) \qquad \varphi(A \vee B) = \varphi(A) \vee \varphi(B)$$
$$\varphi(\neg\, A) = \neg\, \varphi(A) \qquad \varphi(A \Rightarrow B) = \varphi(A) \Rightarrow \varphi(B)$$
$$\varphi(\forall v\, A(v)) = \forall v'\, \varphi(A(v')) \qquad \varphi(\exists v\, A(v)) = \exists v'\, \varphi(A(v'))$$

Discussion

In this paper, a method to analyse criminal behaviour based on cognitive modelling has been proposed and applied, in a case study, to three types of violent criminals: violent psychopaths, criminals with an antisocial personality disorder (APD), and criminals who suffer from an intermittent explosive disorder (IED). A cognitive model has been developed that indeed can show the behaviour as known for the three types of criminals. Within the model, various psychological aspects as found in the literature are taken into account; e.g., (Raine, 1993; Moir and Jessel, 1995; Delfos, 2004). By means of this model, it was shown how the internal process within the criminal subjects can be conceptualised and formalised from a cognitive perspective. However, as a main contribution, it was also shown how this model can be biologically grounded. To this end it was shown how an ontological mapping from the cognitive model to a biological formalisation can be formally defined. For example, the fact that under certain circumstances states of impulsiveness and aggressiveness that play a role in the cognitive model, may lead to an impulsive, violent crime can be described in terms of biological states concerning high testosterone and low blood sugar. It has been shown in detail how ontology elements for such psychological states can be formally mapped onto ontology elements for biological states. Moreover, this formal ontology mapping has been extended to a formal mapping of temporal dynamic properties. Thus it is shown how the process description at the cognitive level relates to a process description at the biological level. Having a mapping as described above allows one on the one hand to explain behaviour in terms of psychological concepts, but on the other hand to relate it to a biological grounding.

In principle, validation can address both the dynamics of the cognitive model and the dynamics of the underlying biological model. Moreover, the mapping between the cognitive and the underlying biological model can be validated. All of these have been validated positively against literature on the specific types of criminals addressed. Here one remark can be made on validation of the mapping. For some of the cognitive states used in the cognitive model, it is not clear how they would be defined without reference to underlying biological states. Within literature on reduction, such as (Nagel, 1961; Kim, 1996) such reduction relations are called definitional, in contrast to those that are empirical.

Concerning related work, only a handful of other papers address computational modelling of criminal behaviour. However, most of the existing papers concentrate more on social and environmental aspects (e.g., Baal, 2004; Bosse, Gerritsen, and Treur, 2007b), whereas the current article focuses on cognitive aspects and their relation to biology. Cognitive models for criminal behaviour as presented in this paper are very useful for case analysis, i.e., given a certain crime case, to find out which type of person has performed this crime. For more information about this topic, see (Bosse, Gerritsen, and Treur, 2007a).

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