

Modelling Morality with Prospective Logic

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Abstract: This paper shows how moral decisions can be drawn computationally by using prospective logic programs. These are employed to model moral dilemmas, as they are able to prospectively look ahead at the consequences of hypothetical moral judgments. With this knowledge of consequences, moral rules are then used to decide the appropriate moral judgments. The whole moral reasoning is achieved via a priori constraints and a posteriori preferences on abductive stable models, two features available in prospective logic programming. In this work we model various moral dilemmas taken from the classic trolley problem and employ the principle of double effect as the moral rule. Our experiments show that preferred moral decisions, i.e. those following the principle of double effect, are successfully delivered. Additionally we consider another moral principle, the principle of triple effect, in our implementation. We show that our prospective logic programs allow us to explain computationally different moral judgments that are drawn from these two slightly but distinctively different moral principles.

Keywords: modelling morality; computational morality; moral reasoning; trolley problem; double effect principle; triple effect principle; prospective logic; abductive stable models; ACORDA; intelligent systems.

1 INTRODUCTION

Morality no longer belongs only to the realm of philosophers. Recently, there has been a growing interest in understanding morality from the scientific point of view. This interest comes from various fields, e.g. primatology (de Waal, 2006), cognitive sciences (Hauser, 2007; Mikhail, 2007), neuroscience (Tancredi, 2005), and other various interdisciplinary perspectives (Joyce, 2006; Katz, 2002). The study of morality also attracts the artificial intelligence community from the computational perspective, and has been known by several names, including machine ethics, machine morality, artificial morality, and computational morality. Research on modelling moral reasoning computationally has been conducted and reported on, e.g. AAAI 2005 Fall Symposium on Machine Ethics (Guarini, 2005; Rzepka and Araki, 2005).

There are at least two reasons to mention the importance of studying morality from the computational point of view. First, with the current growing interest to un-

derstand morality as a science, modelling moral reasoning computationally will assist in better understanding morality. Cognitive scientists, for instance, can greatly benefit in understanding complex interaction of cognitive aspects that build human morality or even to extract moral principles people normally apply when facing moral dilemmas. Modelling moral reasoning computationally can also be useful for intelligent tutoring systems, for instance to aid in teaching morality to children. Second, as artificial agents are more and more expected to be fully autonomous and work on our behalf, equipping agents with the capability to compute moral decisions is an indispensable requirement. This is particularly true when the agents are operating in domains where moral dilemmas occur, e.g. in health care or medical fields.

Our ultimate goal within this topic is to provide a general framework to model morality computationally. This framework should serve as a toolkit to codify arbitrarily chosen moral rules as declaratively as possible. We en-

visage that logic programming is an appropriate paradigm to achieve our purpose. Continuous and active research in logic programming has provided us with necessary ingredients that look promising enough to model morality. For instance, default negation is suitable for expressing exception in moral rules, abductive logic programming (Kakas et al., 1998; Kowalski, 2006) and stable model semantics (Gelfond and Lifschitz, 1988) can be used to generate possible decisions along with their moral consequences, and preferences are appropriate for preferring among moral decisions or moral rules (Dell’Acqua and Pereira, 2005, 2007).

In this paper, we present our preliminary attempt to exploit these enticing features of logic programming to model moral reasoning. In particular, we employ prospective logic programming (Lopes and Pereira, 2006; Pereira and Lopes, 2007), an on-going research project that incorporates these features. For the moral domain, we take the classic trolley problem of Foot (1967). This problem is challenging to model since it contains a family of complex moral dilemmas. To make moral judgments on these dilemmas, we model the principle of double effect as the basis of moral reasoning. This principle is chosen by considering empirical research results in cognitive science (Hauser, 2007) and law (Mikhail, 2007), that show the consistency of this principle to justify similarities of judgments by diverse demographically populations when given this set of dilemmas. Additionally, we also employ prospective logic programming to model another moral principle, the principle of triple effect (Kamm, 2006). The model allows us to explain computationally the difference of moral judgments drawn using these two similar but distinct moral principles.

Our attempt to model moral reasoning on this domain shows encouraging results. Using features of prospective logic programming, we can conveniently model both the moral domain, i.e. various moral dilemmas of the trolley problem, the principle of double effect, and the principle of triple effect, in a declarative manner. Our experiments on running the model also successfully deliver moral judgments that conform to the human empirical research results.

We organize the paper as follows. First, we discuss briefly and informally prospective logic programming, in Section 2. Then, in Section 3 and Section 4 we explain the trolley problem and the double and triple effect principles, respectively. We detail how we model them in prospective logic programming together with the results of our experiments regarding that model, in Section 5. Finally, we conclude and discuss possible future work, in Section 6.

2 PROSPECTIVE LOGIC PROGRAMMING

Prospective logic programming enables an evolving program to look ahead prospectively into its possible future states and to prefer among them to satisfy goals (Lopes and Pereira, 2006; Pereira and Lopes, 2007). This paradigm is

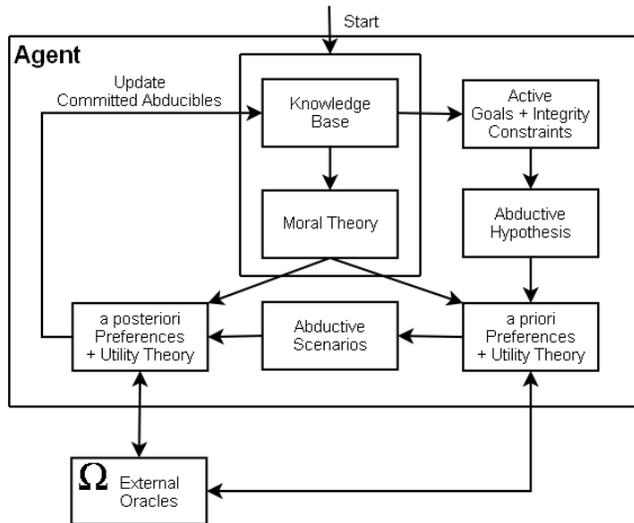


Figure 1: Prospective logic agent architecture

particularly beneficial to the agents community, since it can be used to predict an agent’s future by employing the methodologies from abductive logic programming (Kakas et al., 1998; Kowalski, 2006) in order to synthesize and maintain abductive hypotheses.

Figure 1 shows the architecture of agents that are based on prospective logic (Pereira and Lopes, 2007). Each prospective logic agent is equipped with a knowledge base and a moral theory as its initial theory. The problem of prospection is then of finding abductive extensions to this initial theory which are both relevant (under the agent’s current goals) and preferred (w.r.t. preference rules in its initial theory). The first step is to select the goals that the agent will possibly attend to during the prospective cycle. Integrity constraints are also considered here to ensure the agent always performs transitions into valid evolution states. Once the set of active goals for the current state is known, the next step is to find out which are the relevant abductive hypotheses. This step may include the application of a priori preferences, in the form of contextual preference rules, among available hypotheses to generate possible abductive scenarios. Forward reasoning can then be applied to abducibles in those scenarios to obtain relevant consequences, which can then be used to enact a posteriori preferences. These preferences can be enforced by employing utility theory and, in a moral situation, also moral theory. In case additional information is needed to enact preferences, the agent may consult external oracles. This greatly benefits agents in giving them the ability to probe the outside environment, thus providing better informed choices, including the making of experiments. The mechanism to consult oracles is realized by posing questions to external systems, be they other agents, actuators, sensors or other procedures. Each oracle mechanism may have certain conditions specifying whether it is available for questioning. Whenever the agent acquires additional

information, it is possible that ensuing side-effects affect its original search, e.g. some already considered abducibles may now be disconfirmed and some new abducibles are triggered. To account for all possible side-effects, a second round of prospection takes place.

ACORDA is a system that implements prospective logic programming and is based on the above architecture. ACORDA is implemented based on the implementation of EVOLP (Alferes et al., 2002) and is further developed on top of XSB Prolog¹. In order to compute abductive stable models (Dell’Acqua and Pereira, 2005, 2007), ACORDA also benefits from the XSB-XASP interface to Smodels².

In this section, we discuss briefly and informally prospective logic programming and some constructs from ACORDA that are relevant to our work. For a more detailed discussion on prospective logic programming and ACORDA, interested readers are referred to the original paper (Lopes and Pereira, 2006; Pereira and Lopes, 2007).

2.1 Language

Let \mathcal{L} be a first order language. A domain literal in \mathcal{L} is a domain atom A or its default negation *not* A . The latter is to express that the atom is false by default (close world assumption). A domain rule in \mathcal{L} is a rule of the form:

$$A \leftarrow L_1, \dots, L_t. \quad (t \geq 0)$$

where A is a domain atom and L_1, \dots, L_t are domain literals. An integrity constraint in \mathcal{L} is a rule of the form:

$$\perp \leftarrow L_1, \dots, L_t. \quad (t > 0)$$

where \perp is a domain atom denoting falsity, and L_1, \dots, L_t are domain literals. In ACORDA, \leftarrow and \perp are represented by `<-` and `falsum`, respectively.

A (logic) program P over \mathcal{L} is a set of domain rules and integrity constraints, standing for all their ground instances.

2.2 Abducibles

Every program P is associated with a set of abducibles $A \subseteq \mathcal{L}$. Abducibles can be seen as hypotheses that provide hypothetical solutions or possible explanations of given queries.

An abducible A can be assumed only if it is a considered one, i.e. it is expected in the given situation, and moreover there is no expectation to the contrary (Dell’Acqua and Pereira, 2005, 2007).

$$\text{consider}(A) \leftarrow \text{expect}(A), \text{not expect_not}(A).$$

The rules about expectations are domain-specific knowledge contained in the theory of the program, and effectively constrain the hypotheses which are available.

In addition to mutually exclusive abducibles, ACORDA also allows sets of abducibles. Hence, an abductive stable model may contain more than a single abducible. To enforce mutually exclusive abducibles, ACORDA provides predicate `exclusive/2`. The use of this predicate will be illustrated later, when we model morality in a subsequent section.

2.3 A posteriori Preferences

Having computed possible scenarios, represented by abductive stable models, more favourable scenarios can be preferred among them a posteriori. Typically, a posteriori preferences are performed by evaluating consequences of abducibles in abductive stable models. The evaluation can be done quantitatively (for instance by utility functions) or qualitatively (for instance by enforcing some rules to hold). When currently available knowledge is insufficient to prefer among abductive stable models, additional information can be gathered, e.g. by performing experiments or consulting an oracle.

To realize a posteriori preferences, ACORDA provides predicate `select/2` that can be defined by users following some domain-specific mechanism for selecting favoured abductive stable models. The use of this predicate to perform a posteriori preferences in a moral domain will be discussed in a subsequent section.

3 THE TROLLEY PROBLEM

Several interesting results have emerged from recent interdisciplinary studies on morality. One common result from these studies shows that morality has evolved over time. In particular, Hauser (2007), in his recent work, argues that a moral instinct, playing the role of generating rapid judgments about what is morally right or wrong, has evolved in our species.

Hauser (2007) and Mikhail (2007) propose a framework of human moral cognition, known as universal moral grammar, analogously to Chomsky’s universal grammar in language. Universal moral grammar, which can be culturally adjusted, provides universal moral principles that enable an individual to unconsciously evaluate what actions are permissible, obligatory, or forbidden. To support this idea, Hauser and Mikhail independently created a test to assess moral judgments of subjects from demographically diverse populations, using the classic trolley problems. Despite their diversity, the result shows that most subjects widely share moral judgments when given a moral dilemma from the trolley problem suite. Although subjects are unable to explain the moral rules in their attempts at justification, their moral judgments are consistent with a moral rule known as the principle of double effect.

The trolley problem presents several moral dilemmas that inquire whether it is permissible to harm one or more individuals for the purpose of saving others. In all cases, the initial circumstances are the same (Hauser, 2007):

¹XSB Prolog is available at <http://xsb.sourceforge.net>

²Smodels is available at <http://www.tcs.hut.fi/Software/smodels>

There is a trolley and its conductor has fainted. The trolley is headed toward five people walking on the track. The banks of the track are so steep that they will not be able to get off the track in time.

Given the above initial circumstance, in this work we consider six classical cases of moral dilemmas, employed for research on morality in people (Mikhail, 2007). These six cases are described below and are visually depicted in Figure 2.

1. **Bystander.** Hank is standing next to a switch, which he can throw, that will turn the trolley onto a parallel side track, thereby preventing it from killing the five people. However, there is a man standing on the side track with his back turned. Hank can throw the switch, killing him; or he can refrain from doing this, letting the five die. Is it morally permissible for Hank to throw the switch?
2. **Footbridge.** Ian is on the footbridge over the trolley track. He is next to a heavy object, which he can shove onto the track in the path of the trolley to stop it, thereby preventing it from killing the five people. The heavy object is a man, standing next to Ian with his back turned. Ian can shove the man onto the track, resulting in death; or he can refrain from doing this, letting the five die. Is it morally permissible for Ian to shove the man?
3. **Loop Track.** Ned is standing next to a switch, which he can throw, that will temporarily turn the trolley onto a loop side track. There is a heavy object on the side track. If the trolley hits the object, the object will slow the train down, giving the five people time to escape. The heavy object is a man, standing on the side track with his back turned. Ned can throw the switch, preventing the trolley from killing the five people, but killing the man. Or he can refrain from doing this, letting the five die. Is it morally permissible for Ned to throw the switch?
4. **Man-in-front.** Oscar is standing next to a switch, which he can throw, that will temporarily turn the trolley onto a side track. There is a heavy object on the side track. If the trolley hits the object, the object will slow the train down, giving the five people time to escape. There is a man standing on the side track in front of the heavy object with his back turned. Oscar can throw the switch, preventing the trolley from killing the five people, but killing the man. Or he can refrain from doing this, letting the five die. Is it morally permissible for Oscar to throw the switch?
5. **Drop Man.** Victor is standing next to a switch, which he can throw, that will drop a heavy object into the path of the trolley, thereby stopping the trolley and preventing it from killing the five people. The heavy object is a man, who is standing on a footbridge
6. **Collapse Bridge.** Walter is standing next to a switch, which he can throw, that will collapse a foot-

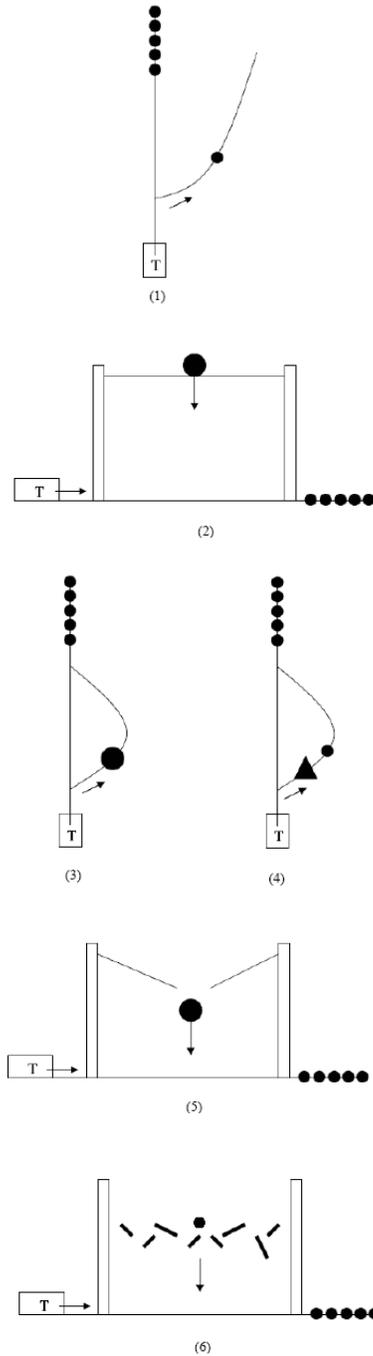


Figure 2: The six trolley cases: (1)Bystander, (2)Footbridge, (3)Loop Track, (4)Man-in-front, (5)Drop Man, (6)Collapse Bridge

overlooking the track. Victor can throw the switch, killing him; or he can refrain from doing this, letting the five die. Is it morally permissible for Victor to throw the switch?

6. **Collapse Bridge.** Walter is standing next to a switch, which he can throw, that will collapse a foot-

bridge overlooking the tracks into the path of the trolley, thereby stopping the train and preventing it from killing the five people. There is a man standing on the footbridge. Walter can throw the switch, killing him; or he can refrain from doing this, letting the five die. Is it morally permissible for Walter to throw the switch?

Interestingly, although all cases have the same goal, i.e. to save five albeit killing one, subjects come to different judgments on whether the action to reach the goal is permissible or impermissible. As reported by Mikhail (2007), the judgments appear to be widely shared among diverse demographically populations, the summary being given in Table 1.

Table 1: Summary of moral judgments for the trolley problem

Case	Judgment
1. Bystander	Permissible
2. Footbridge	Impermissible
3. Loop Track	Impermissible
4. Man-in-front	Permissible
5. Drop Man	Impermissible
6. Collapse Bridge	Permissible

4 THE DOUBLE AND TRIPLE EFFECT

Although subjects have difficulties to uncover which moral rules they apply for reasoning in the above cases, their judgments appear to be consistent with the so-called the principle of double effect. The principle can be expressed as follows (Hauser, 2007):

Harming another individual is permissible if it is the foreseen consequence of an act that will lead to a greater good; in contrast, it is impermissible to harm someone else as an intended means to a greater good.

The key expression here is “intended means”. We shall refer in the subsequent sections to the action of harming someone as an intended means, as an intentional killing.

Differently from the result shown in Table 1, Otsuka (2008) in his work states that diverting the trolley in the loop track case strikes most moral philosophers as permissible. In his work, he refers to Kamm’s principle of triple effect (Kamm, 2006), to explain permissibility of diverting the trolley onto a loop side track. The triple effect principle is a revised version of the double effect principle. This moral principle refines the double effect principle, in particular on harming someone as an intended means. In this case, the triple effect principle distinguishes an action

that is performed *in order to* bring about an evil from an action performed *which directly causes* an evil to occur without production of evil being its goal. The latter is a new category of action, that neither treats the occurrence of evil as a foreseen unintended consequence nor as an action performed in order to intentionally bring about an evil. Similarly to the double effect principle, the triple effect principle classifies an action performed in order to intentionally bring about an evil as an impermissible action. But, this moral principle is more tolerant to the third effect, i.e. it is *permissible* for an action to be performed because an evil will occur, if not intended as such.

In the footbridge case, both the double and the triple effect principles arrive at the same moral judgment, i.e. it is impermissible to shove a man in order to cause the trolley to hit the man. On the other hand, different moral judgments are delivered for the loop track case when employing the double and the triple effect principles. Whereas it is impermissible by the double effect to divert the trolley, this action is *permissible* by the triple effect principle. According to the third effect principle, the action of diverting the trolley onto the loop side track is performed because it will hit the man, not in order to hit the man (Kamm, 2006). As in the other cases, the goal of the loop track case is to prevent the trolley from killing the five people. This goal can be achieved by throwing the switch to divert the trolley onto the side track. But diverting the trolley raises another problem as the side track is a loop track that will take the trolley back to the main track and will still hit the five people. The action of diverting the trolley is not necessarily intended in order to hit the man on the side track. Instead, this action is performed because it will hit the man, eliminating the new problem created by diverting the trolley (Kamm, 2006).

To better distinguish an action that is performed in order to bring about an evil and that performed because an evil will occur, the loop track case can be compared with the following case. Consider a variant of the loop track case, where the loop side track is empty. Note that, instead of only diverting the trolley onto the empty loop side track, an ancillary act of shoving a man onto the loop side track can be performed. How can this case be morally distinguished from the original loop track case? In the original loop track case the man has already been standing on the loop side track when the action of diverting the trolley being carried out, causing the death of the man. In the other case, the suffered death of the man is not merely caused by diverting the trolley (the loop side track is initially empty). Instead, the man dies as a consequence of a further action, i.e. shoving the man. This action is intentionally performed to place the man on the side track, for the trolley in order to hit the man. Hence, preventing the trolley from killing the five people.

We shall show in the subsequent sections, how we can computationally distinguish these two similar cases, in the context of the triple effect principle. In particular, we discuss a feature, available in ACORDA, to explain the above moral reasoning computationally.

5 MODELLING MORALITY IN ACORDA

It is interesting to model the trolley problem in ACORDA due to the intricacy that arises from the dilemma itself. Moreover, there are similarities and also differences between cases and between the moral principles employed. Consequently, this adds complexity to the process of modelling them in order to deliver appropriate moral decisions through reasoning. By appropriate moral decisions we mean the ones that conform with those the majority of people make, in adhering to the principle of double effect (though we also consider the principle of triple effect, as comparison to the principle of double effect).

We model each case of the trolley problem in ACORDA separately. The principle of double effect and triple effect are modelled via a priori constraints and a posteriori preferences. To assess how flexible is our model of the moral rule, we additionally model another variant for the cases of Footbridge and Loop Track. Even for these variants, our model of the moral rules allows the reasoning to deliver moral decisions as expected.

In each case of the trolley problem, there are always two possible decisions to make. One of these is the same for all cases, i.e. letting the five people die by merely watching the train go straight. The other decision depends on the cases, e.g. throwing the switch, shoving a heavy man, or the combination of them, with the same purpose: to save the five people, but also harming a person in the process.

In this work, these possible decisions are modelled in ACORDA as abducibles. Moral decisions are made by computing abductive stable models and then preferring among them those models with the abducibles and consequences that conform to the principle of double effect or triple effect.

In subsequent sections we detail the model for all six cases of the above trolley problem in ACORDA. We also show how to model the principle of double effect and triple effect. Then we present the results of running our models in the ACORDA system.

5.1 Modelling the Bystander Case

Facts to describe that there is a side track and a man (here, named John) is standing on that side track can be modelled simply as the following:

```
side_track.  
on_side(john).  
human(john).
```

The clauses `expect(watching)` and `expect(throwing_switch)` in the following model indicate that watching and throwing the switch, respectively, are two available abducibles, that represent possible decisions Hank has. Since the purpose of the switch is to turn the trolley onto the side track, the action `throwing_switch` is only considered as an abducible, if the side track exists. The other clauses represent the chain of actions and consequences for every abducible.

The predicate `end(die(5))` represents the final consequence if `watching` is abduced, i.e. it will result in five people dying. On the other hand, the predicate `end(save_men,ni_kill(N))` represents the final consequence whenever `throwing_switch` is abduced, i.e. it will save the five people without intentionally killing someone. The way of representing these two consequences is chosen differently, because the different nature of these two abducibles. Merely watching the trolley go straight is an omission of action that just has negative consequence, whereas throwing the switch is an action that is performed to achieve a goal and additionally has negative consequence. Since abducibles in other cases of the trolley problem also share this property, this way of representation will be used throughout them. The predicate `observed_end` is used to encapsulate these two different means of representation, useful later when we model the principle of double effect, to avoid floundering.

```
expect(watching).  
train_straight <- consider(watching).  
end(die(5)) <- train_straight.  
observed_end <- end(X).  
  
expect(throwing_switch) <- side_track.  
turn_side <- consider(throwing_switch).  
kill(1) <- human(X), on_side(X), turn_side.  
end(save_men,ni_kill(N)) <- turn_side, kill(N).  
observed_end <- end(X,Y).
```

We can model the exclusiveness of the two possible decisions, i.e. Hank has to decide either to throw the switch or merely watch, by using the `exclusive/2` predicate of ACORDA:

```
exclusive(throwing_switch,decide).  
exclusive(watching,decide).
```

Note that the exclusiveness between two possible decisions also holds in other cases.

5.2 Modelling the Footbridge Case

We represent the fact of a heavy man (here, also named John) on the footbridge standing near to Ian similarly to the Bystander case:

```
stand_near(john).  
human(john).  
heavy(john).
```

We can make this case more interesting by additionally having another (inanimate) heavy object, e.g. rock, on the footbridge near to Ian and see whether our model of the moral rule still allows the reasoning to deliver moral decisions as expected:

```
stand_near(rock).  
inanimate_object(rock).  
heavy(rock).
```


We may observe, that from the first two variants there is no need to change the whole model; only part of the model that represents the different facts need to be adapted. Moreover, the second variant shows that we do not need to have separate programs to model the fact that a man or an inanimate object is on the side track. Instead, we can have only one program and take the benefit from using an even loop over default negation to capture alternatives between objects.

Throwing the switch and shoving a man. The third variant concerns with the scenario discussed in Section 4. This variant will be useful later, when we discuss the difference between the double effect and the triple effect principles.

In this scenario, the action of throwing the switch, to divert the trolley, can be followed by the action of shoving a man, to place the man onto the empty loop side track. There is only one loop side track, which we can represent by using a simple fact `side_track`. To represent that either there has already been a man standing on the loop side track or the loop side track is initially empty, we can use the following even loop over default negation:

```
man_stand_sidetrack <- not empty_sidetrack.
empty_sidetrack <- not man_stand_sidetrack.
```

We have three actions available, represented as abducibles, with the chain of consequences modelled as follows. For simplicity, without loss of generality, we assume that the man standing on the side track or the man shoved, is heavy.

```
expect(watching).
train_straight <- consider(watching).
end(die(5)) <- train_straight.
observed_end <- end(X).
```

```
expect(throwing_switch) <- side_track.
turn_side <- consider(throwing_switch).
end(save_men,standing_hitting) <-
  man_stand_sidetrack,
  turn_side.
```

```
expect(shoving) <- empty_sidetrack,
  consider(throwing_switch).
```

```
freely_goto_maintrack <- empty_sidetrack,
  turn_side,
  not consider(shoving).
end(die(5)) <- freely_goto_maintrack.
```

```
place_man_sidetrack <- consider(shoving).
end(save_men,placing_hitting) <-
  place_man_sidetrack,
  turn_side.
```

```
observed_end <-end(X,Y).
```

The above model can be read declaratively. The action `watching` together with its consequence is similar as in other cases.

The action `throwing_switch` is possible, if there is a side track, to which the switch is connected. Throwing the switch will turn the trolley to the side track. If a (heavy) man has already been standing on the side track and the trolley also turns to the side track, then the five people are saved, but also killing the man standing on the side track.

Following our scenario, the action of `shoving` is available, if there is nothing on the side track (`empty_sidetrack`) and the action of throwing the switch is performed. This is modeled by the above clause:

```
expect(shoving) <- empty_sidetrack,
  consider(throwing_switch).
```

This means that the action of shoving is a further action following the action of throwing the switch.

If the side track is empty, the trolley has turned to the side track, but the action of shoving is not abduced, then the trolley will freely go to the main track where the five people are walking. This results in the suffered death of the five people.

On the other hand, if shoving is abduced (as an ancillary action of throwing the switch) then this will result in placing a (heavy) man on the side track. If the trolley has turned to the side track and the man has been placed on the side track, then the five people are saved with the cost of killing the man placed on the side track as the consequence of shoving.

5.4 Modelling the Man-in-front Case

Recall that in the case of Man-in-front, there is a side track where the trolley can turn onto. On this side track, there is a heavy (inanimate) object, e.g. rock. There is also a man standing in front of the heavy object. We can model these facts in ACORDA as follows:

```
side_track.
on_side(rock).
inanimate_object(rock).
heavy(rock).
in_front_of(rock,jack).
human(jack).
```

In order to prevent the trolley from killing the five people, a switch can be thrown to turn the trolley onto the side track. The following clauses are used to model the throwing switch action as an abducible together with the consequences that follow:

```
expect(throwing_switch) <- side_track.
turn_side <- consider(throwing_switch).
kill(1) <- turn_side, on_side(X),
  in_front_of(X,Y), human(Y).
slowdown_train(X) <- turn_side, on_side(X),
  heavy(X).
```

```

end(save_men,ni_kill(N)) <- inanimate_object(X),
    slowdown_train(X),
    kill(N).
end(save_men,i_kill(N)) <- human(X),
    slowdown_train(X),
    kill(N).
observed_end <- end(X,Y).

```

5.5 Modelling the Drop Man Case

The following facts model the scenario of the Drop Man case:

```

switch_connected(bridge).
human(john).
heavy(john).
on(bridge,john).

```

The above facts state that there is a switch connected to the bridge, where there is a heavy man, John, standing on the bridge. As in other cases, it is straightforward to model in ACORDA the throwing switch actions along with its consequences:

```

expect(throwing_switch(Z)) <-
    switch_connected(Z).

drop(X) <- consider(throwing_switch(Z)), on(Z,X).
kill(1) <- human(X), drop(X).
stop_train(X) <- heavy(X), drop(X).
end(save_men,ni_kill(N)) <- inanimate_object(X),
    stop_train(X),
    kill(N).
end(save_men,i_kill(N)) <- human(X),
    stop_train(X),
    kill(N).
observed_end <- end(X,Y).

```

In the above model, the fact that the switch is connected to the bridge is the condition for the action of throwing the switch to be reasonable to perform.

5.6 Modelling the Collapse Bridge Case

The Collapse Bridge case is a variation from the Drop Man case. In this case, the footbridge itself is the heavy object which may stop the train when it collapses and prevent the train from killing the five people. There is also a man, John, standing on the footbridge, as in the Drop Man case. These facts can be modelled in ACORDA as follows:

```

switch_connected(bridge).
heavy(bridge).
inanimate_object(bridge).
human(john).
on(bridge,john).

```

With slight variation of consequences from the Drop Man case, the following clauses model the throwing switch action as an abducible together with the consequences that follow:

```

expect(throwing_switch(X)) <-
    switch_connected(X).

collapse(X) <- consider(throwing_switch(X)).
stop_train(X) <- heavy(X), collapse(X).
kill(1) <- human(Y), on(X,Y), collapse(X).
end(save_men,ni_kill(N)) <- inanimate_object(X),
    stop_train(X),
    kill(N).
end(save_men,i_kill(N)) <- human(X),
    stop_train(X),
    kill(N).
observed_end <- end(X,Y).

```

5.7 Modelling the Principles of Double and Triple Effect

The principles of double effect and triple effect can be modelled by using a combination of integrity constraints and a posteriori preferences.

Integrity constraints are used for two purposes. First, we need to observe the final consequences or endings of each possible decision to enable us later to morally prefer decisions by considering the greater good between possible decisions. This can be achieved by specifying the following integrity constraint:

```
falsum <- not observed_end.
```

This integrity constraint enforces all available decisions to be abducted together with their consequences, by computing all possible observable hypothetical endings using all possible abductions. Indeed, to be able to reach a moral decision, all hypothetical scenarios afforded by the abducibles must lead to an observable ending. Second, we also need to rule out impermissible actions, i.e. actions that involve intentional killing in the process of reaching the goal. This can be enforced by specifying the integrity constraint `falsum <- intentional_killing`. Depending on whether we employ the double effect or the triple effect principle, intentional killing can be easily defined. For the double effect principle, it can be modelled as follows:

```
intentional_killing <- end(save_men,i_kill(Y)).
```

Similarly, intentional killing for the triple effect principle can be modelled as follows:

```
intentional_killing <-
    end(save_men,placing_hitting).
```

The above integrity constraints serve as the first filtering function of our abductive stable models, by ruling out impermissible actions (the latter being coded by abducibles). In other words, integrity constraints already afford us with just those abductive stable models that contain only permissible actions.

Additionally, one can prefer among permissible actions those resulting in greater good. This can be realized by a posteriori preferences that evaluate the consequences of

permissible actions and then prefer the one with greater good. The following definition of `select/2` achieves this purpose. The first argument of this predicate refers to the set of initial abductive stable models to prefer, whereas the second argument refers to the preferred ones. The auxiliary predicate `select/3` only keeps abductive stable models that contain decisions with greater good of consequences. In the trolley problem, the greater good is evaluated by a utility function concerning the number of people that die as a result of possible decisions. This is realized in the definition of predicate `select/3` by comparing final consequences that appear in the initial abductive stable models. The first clause of `select/3` is the base case. The second clause and the third clause together eliminate abductive stable models containing decisions with worse consequences, whereas the fourth clause will keep those models that contain decisions with greater good of consequences.

```
select(Xs,Ys) :- select(Xs,Xs,Ys).

select([],_,[]).
select([X|Xs],Zs,Ys) :-
    member(end(die(N)),X),
    member(Z,Zs),
    member(end(save_men,ni_kill(K)),Z), N > K,
    select(Xs,Zs,Ys).
select([X|Xs],Zs,Ys) :-
    member(end(save_men,ni_kill(K)),X),
    member(Z,Zs),
    member(end(die(N)),Z), N <= K,
    select(Xs,Zs,Ys).
select([X|Xs],Zs,[X|Ys]) :- select(Xs,Zs,Ys).
```

Recall the variant of the Footbridge case, where either a man or an inanimate object is on the footbridge next to Ian. This exclusive alternative is specified by an even loop over default negation and we have an abductive stable model that contains the consequence of letting die the five people when a rock next to Ian. This model is certainly *not* the one we would like our moral reasoner to prefer. The following replacement definition of `select/2` accomplishes this case.

```
select([],[]).
select([X|Xs],Ys) :-
    member(end(die(N)),X),
    member(stand_near(rock),X),
    select(Xs,Ys).
select([X|Xs],[X|Ys]) :- select(Xs,Ys).
```

It is important to note that in this case, since either a man or a rock is near to Ian, and the model with shoving a man is already ruled out by our integrity constraint, there is no need to consider greater good in terms of the number of people that die. This means, as shown subsequently, that only two abductive stable models are preferred, i.e. the model with watching as the abducible whenever a man is standing near to Ian, the other being the model with shoving the rock as the abducible.

There is an interest to be able to specify a posteriori preferences more declaratively, i.e. by encapsulating the details of predicate `select/2` from the viewpoint of users. Although this may depend on the domain where moral reasoning is applied, some kind of generic macros can be defined. Our subsequent work has evidenced preliminary results (Pereira and Saptawijaya, 2007). In those results, we extend the syntax of ACORDA by introducing the predicates `elim/1` and `exists/1`. We provide two types of generic macros for the purpose of specifying a posteriori preferences.

The first type of macros allows us to realize a posteriori preferences by eliminating abductive stable models containing abducibles with worse consequences. This can be done by comparing some consequences among initial abductive stable models. The definition of predicate `select/3` above is an example of this type. Instead of using the above definition of `select/3`, the same a posteriori preferences can now be expressed more declaratively as follows:

```
elim([end(die(N))]) <-
    exists([end(save_men,ni_kill(K))]), N > K.
elim([end(save_men,ni_kill(K))]) <-
    exists([end(die(N))]), N <= K.
```

The first clause is used to eliminate abductive stable models containing the literal `end(die(N))`, if there exists other abductive stable models containing the literal `end(save_men,ni_kill(K))` and $N > K$. The second clause can be read similarly.

The second type of macros deals with a posteriori preferences, where an abductive stable model is eliminated based only on some literals it contains. This is in contrast with the first type of macros, where the elimination of an abductive stable model is performed through comparison with other abductive stable models. The latter definition of predicate `select/2` above (in dealing with the variant of the Footbridge case) falls into this type. This definition of `select/2` can be replaced with the following line:

```
elim([end(die(N)),stand_near(rock)]).
```

This simple clause eliminates abductive stable models that contain both literals `end(die(N))` and `stand_near(rock)`. Recall that the abductive stable model containing these two literals together is not the one a moral reasoner should prefer, since it may shove the rock to avoid the consequence of letting die the five people.

5.8 Running the Models in ACORDA

We report now on the experiments of running our models in ACORDA. Table 2 gives a summary of all cases of the trolley problem. Column Initial Models contains info about the abductive stable models obtained before a posteriori preferences are applied, whereas column Final Models

those after a posteriori preferences are applied. Here, only relevant literals are shown. These results comply with the results found for most people in morality laboratory experiments.

Note that entry Footbridge(a) refers to the variant of Footbridge where both a man and a rock are near to Ian, and Footbridge(b) where either a man or a rock is near to Ian. Loop Track(a) refers to the variant of Loop Track where there are two loop tracks, with a man on the left loop track and a rock on the right loop track. Loop Track(b) only considers one loop track where either a man or a rock is on the single loop track. Loop Track(c) is another variant considering the triple effect principle, where the ancillary act of shoving a man is available, following the action of throwing the switch. Note that, both cases of Loop Track(a) and Loop Track(b) employ the double effect principle. Consequently, there is no initial model (of these two cases) that contains the abducible throwing the switch whenever a man is on the side track. This model has been ruled out by the integrity constraint, as this is considered impermissible in the double effect principle. To the contrary, Loop Track(c), that employs the triple effect principle, does have an initial model with a man on the side track and throwing the switch as an abducible. This model is not ruled out by the integrity constraint, as it is deemed permissible by the triple effect principle.

Selective literals in an abductive stable model, e.g. the literals shown in Table 2, can be inspected in ACORDA. The feature of inspection enables us to examine whether some literals are true in the context of adopted abducibles, without further abduction. It is useful, in particular, to explain computationally the moral reasoning in scenario Loop Track(c), where the triple effect principle is employed. We simply inspect that the man, an obstacle to the trolley, has already been standing on the side track, since only the action of throwing the switch is abduced. No additional action need to be abduced to prevent the trolley from hitting the five people. On the other hand, in the models containing `empty_sidetrack`, mere inspection is not enough as an extra abducible is required to shove the man onto the track in order to deliberately make him an obstacle where there was none. Hence, it prevents the trolley from hitting the five people. However, the abductive stable model containing this further action is already ruled out by our integrity constraint. This conforms with the triple effect principle, as intentionally shoving the man, in addition to the act of throwing the switch, and in order the trolley to hit the man for the purpose of stopping the trolley, is impermissible. Indeed, simple inspection does not allow further abduction in order to make actively it true.

6 CONCLUSIONS AND FUTURE WORK

We have shown how to model moral reasoning using prospective logic programming. We use various dilemmas of the trolley problem and the principle of double effect

and triple effect as the moral rules. Possible decisions in a dilemma are modelled as abducibles. Abductive stable models are then computed which capture abduced decisions and their consequences. Models violating integrity constraints, i.e. models that contain actions involving intentional killing, are ruled out. Finally, a posteriori preferences are used to prefer models that characterize more preferred moral decisions, including the use of utility functions. These experiments show that preferred moral decisions, i.e. the ones that follow the principle of double effect, are successfully delivered. They conform to the results of empirical experiments conducted in cognitive science and law. Regarding the triple effect principle, the inspection feature of ACORDA can be employed to detect mere consequences of abducibles. Hence, we can distinguish computationally two moral judgments in line with the triple effect principle, i.e. whether an action is performed in order to bring about an evil or just because an evil will occur.

Much research has emphasized using machine learning techniques, e.g. statistical analysis (Rzepka and Araki, 2005), neural networks (Guarini, 2005), case-based reasoning (McLaren, 2006) and inductive logic programming (Anderson et al., 2006) to model moral reasoning from examples of particular moral dilemmas. Our approach differs from them as we do not employ machine learning techniques to deliver moral decisions.

Powers (2006) proposes to use nonmonotonic logic to specifically model Kant’s categorical imperatives, but it is unclear whether his approach has ever been realized in a working implementation. On the other hand, Bringsjord et al. (2006) propose the use of deontic logic to formalize moral codes. The objective of their research is to arrive at a methodology that allows an agent to behave ethically as much as possible in an environment that demands such behaviour. We share our objective with them to some extent as we also would like to come up with a general framework to model morality computationally. Different from our work, they use an axiomatized deontic logic to decide which moral code is operative to arrive at an expected moral outcome. This is achieved by seeking a proof for the expected moral outcome to follow from candidates of operative moral codes.

To arrive at our ultimate research goal, we envision several possible future directions. We would like to explore how to express metarule and metamoral injunctions. By metarule we mean a rule to resolve two existing conflicting moral rules in deriving moral decisions. Metamorality, on the other hand, is used to provide protocols for moral rules, to regulate how moral rules interact with one another. Another possible direction is to have a framework for generating precompiled moral rules. This will benefit fast and frugal moral decision making which is sometimes needed, cf. heuristics for decision making in law (Gigerenzer and Engel, 2006), rather than to have full deliberative moral reasoning every time.

We envision a final system that can be employed to test moral theories, and also can be used for training moral

reasoning, including the automated generation of example tests and their explanation. Finally, we hope our research will help in imparting moral behaviour to autonomous agents.

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Table 2: Summary of experiments in ACORDA

Case	Initial Models	Final Models
Bystander	[throwing_switch],[watching]	[throwing_switch]
Footbridge(a)	[watching],[shove(rock)]	[shove(rock)]
Footbridge(b)	[watching,stand_near(john)], [watching,stand_near(rock)], [shove(rock)]	[watching,stand_near(john)], [shove(rock)]
Loop Track(a)	[throwing_switch(right)], [watching]	[throwing_switch(right)]
Loop Track(b)	[watching,side_track(john)], [watching,side_track(rock)], [throwing_switch(rock)]	[watching,side_track(john)], [throwing_switch(rock)]
Loop Track(c)	[watching,empty_sidetrack], [watching,man_stand_sidetrack], [throwing_switch,empty_sidetrack], [throwing_switch,man_stand_sidetrack]	[watching,empty_sidetrack], [throwing_switch,man_stand_sidetrack]
Man-in-front	[watching], [throwing_switch(rock)]	[throwing_switch(rock)]
Drop Man	[watching]	[watching]
Collapse Bridge	[watching], [throwing_switch(bridge)]	[throwing_switch(bridge)]