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An ontology of physical causation as a basis for assessing causation in fact and attributing legal responsibility

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Abstract. Computational machineries dedicated to the attribution of legal responsibility should be based on (or, make use of) a stack of definitions relating the notion of legal responsibility to a number of suitably chosen causal notions. This paper presents a general analysis of legal responsibility and of causation in fact based on Hart and Honoré's work. Some physical aspects of causation in fact are then treated within the "lite" version of DOLCE foundational ontology written in OWL-DL, a standard description logic for the Semantic Web.

Key words: causation in fact, formal ontology, legal responsibility, physical causation

1. Introduction

Reasoning about causation in fact is an essential element of attributing legal responsibility. Therefore, the automation of the attribution of legal responsibility requires a modelling effort aimed, on the one hand, at a thorough understanding of the relation between the legal concepts of responsibility and of causation in fact, and, on the other hand, at the specification of an ontology of the concepts that are required for reasoning about causation in fact. It is important to note that by its very nature such a specification should be (as) purpose-independent (as possible). It should be able to provide conceptual support to legal practitioners at any stage of causal analysis: to lawyers when building or verifying a case, to judges when assessing the presentations, etc. The ontology should specify the *conceptual* elements that are common to all these different intellectual activities when focusing on causal matters. This paper presents an attempt at specifying such a conceptual structure. Section 2 provides a legal theoretical framework for treating legal responsibility and causation in fact

according to Hart and Honoré's approach (Hart and Honore 1985), as reworked and presented in (Lehmann 2003) and (Lehmann et al. 2005). Section 3 presents a formal ontological analysis of the physical aspects of causation in fact based on results presented in (Lehmann et al. 2004) and on the "lite" version of DOLCE foundational ontology (Gangemi et al. 2005). While in (Lehmann et al. 2004) our ontology is presented in an extended first-order logic, here we introduce it in the OWL-DL language (McGuinness and van Harmelen 2004), a variety of a description logic, which is currently used as a standard for the Semantic Web[1]. The motivation for this transition is twofold:

1. The Semantic Web community has been showing a lot of interest for the use of detailed legal ontologies in the design and integration of large, distributed legal knowledge bases (Benjamins et al. 2005).
2. OWL-DL is at the same time less and more expressive than first-order logic, but has a known complexity that makes it tractable by current reasoners. For example, n-ary relations cannot be expressed in OWL-DL, therefore, reification mechanisms are needed to transform those relations either into a combination of classes and appropriate binary relations, or into individuals with a rich reification vocabulary[2]. Moreover, co-reference of variables is not allowed (in fact, OWL-DL is a propositional modal logic, hence a variable-less language), and co-reference needs special workarounds, such as naming policies, or additional rules that are outside the expressivity of OWL-DL (but eventually within a Datalog, DL-safe fragment of FOL). Other constructs, like generalized quantification and cardinality restriction, can be expressed in OWL-DL, while they cannot in standard FOL. Of course, those workarounds make the resulting ontology and models more verbose than their FOL counterparts. But the relations are more readable, and the modeller is forced, for instance, to consider all the projections of a n-ary relation. Also, the possibility of using relations polymorphically (with variable arity), while allowed in FOL, is forbidden in OWL-DL, and this results in less flexibility but more transparency in the use of predicates.

Moreover, there are similar interesting efforts to specify chunks of legal-causal knowledge while keeping an eye on tractability. (Hoekstra and Breuker 2005) and (Hoekstra and Breuker 2006) present the foundations of a demonstrator (DIRECT) dedicated to testing the validity of a process-oriented view on commonsense causation. This provides a valuable chance of comparing approaches based on different principles but specified within largely similar formal frameworks. Finally, Section 4 of this paper draws some conclusions.

2. Legal theory on responsibility and causation in fact

The question of how to attribute legal responsibility is a key issue for both legal practice and theory. At both levels there is a longing for generality and consistency that raises tough scientific problems about how to formulate general enough criteria for legal responsibility attribution. The following two examples implicitly point at these problems. They show how real cases as well as thought-experiments can represent insormountable obstacles for traditional theories of responsability attribution, which are based either on the notion of causal proximity or on the combination of legal policy considerations and counterfactuals. For a concise yet systematic overview of the shortcomings of these theories the interested reader is referred to (Lehmann et al. 2005).

EXAMPLE 1 (The air rifle). In breach of a statute forbidding the sale to an infant under the age of 16 of dangerous weapons, the defendant sold an air rifle and ammunition to a boy of 13. The boy's mother told the boy to return the weapon to the defendant and get a refund: on the defendant's refusal to take the rifle back, the boy's mother took it from the boy and hid it. Six months later the boy found it and allowed a playmate to use it, who shot and accidentally wounded the plaintiff, destroying the sight of one eye. (Henningsen v. Markovitz (1928) 132 Misc. 547, 230 NYS 313).

The dramatic development of the events described in Example 1 raises a question of responsibility. This is due to the fact that the final event described in the example (the blinding of the plaintiff) is a harmful one. It is mostly – even though not exclusively – about undesirable events that people ask themselves "Who is to blame?". In the case of Example 1 the judge's answer was "The defendant." due to an alleged causal proximity of the seller's conduct to the harm. But the justification for this decision was all but clear or based on general criteria. It was very difficult for the judge to show that the mother's passive conduct was less proximate to the harm than then seller's. By no means can negative causation be considered in general as a weaker reason for attributing legal responsibility than positive causation. On the other hand, justifying the judge's decision in terms of legal policy plus counterfactuals could not really help: both the defendant's and the mother's conduct may constitute grounds for liability and may be considered as *sine qua non* conditions of the harm. Finally, justifications in terms of vicarious liability would not have been univocal either: the parents of the boy who shot would have come into the picture. This real case shows how difficult it can be to justify the attribution of legal responsibility to a certain individual when the causal interpretation of the case is too complex.

EXAMPLE 2 (The desert traveler). A desert traveler T has two enemies. Enemy 1 poisons T's canteen and Enemy 2, unaware of Enemy 1's action, shoots and empties the canteen. A week later, T is found dead and the two enemies confess to action and intention. ((Pearl 2000), chapter 10).

For the usually intended interpretation of this example, it must be assumed that T never drank from the canteen and that he was found dead by dehydration. This brings to the conclusion that Enemy 2 is responsible for T's death. This conclusion, though, cannot be reached by counterfactuals (had Enemy 2 not shot the canteen, T would have drunk from it and he would have died by poisoning). Therefore, like for Example 1, Enemy 2's action must be indicated as the cause of T's death in the sense that it is the most *proximate cause* of T's death. But, then again, what does this proximity amount to in general terms? Just immediate temporal precendence? This criterion is subject to many counterexamples.

The failure of counterfactuals in the analysis of this tricky and underspecified case of overdetermination shows something about the consequences of having or not having a causal interpretation of a case. From a causal viewpoint Example 2 is much less complex than Example 1. Yet, we have no simple means to pin down our simple causal intuition (i.e. Enemy 2 actually caused T's Death). This "short circuit" hinders our capacity to attribute (legal) responsibility, to the extent that someone could (reasonably?) argue in favor of Enemy 2 having saved T from poisoning, rather than having killed him.

In general terms, both Example 1 and 2 are paradoxical with respect to the inference mechanisms usually adopted in legal reasoning for analyzing them (again, proximate cause or counterfactuals). But, even though the two examples are abnormal from an inferential point of view, ontologically speaking they are not. This is especially evident when considering the *physical* chain of events described in them. The two cases contain lines of physical causation that are pretty standard. The causal relation between a bullet and a person (or a canteen) hit by it is comparable to the causal relation between two billiard balls, one of which hitting the other. Our understanding of such relations respond to the same set of intuitions about how the physical world works. Section 3 of this paper spells out and formalizes some of these intuitions. We use as reference example the following subset of Example 1:

e_1 = the bullet is shot; e_2 = the plaintiff is wounded.

It is safe to assume that the causal interpretation of this subset of the case does not deviate from the causal interpretation of standard cases. Before going into the details of physical causation, though, the rest of this section provides a general analysis of legal responsibility and of causation in fact.

2.1. LEGAL RESPONSIBILITY

In (Hart and Honore 1985) the authors propose to linearize the intricate relationships between many of the notions involved in reasoning about the attribution of legal responsibility (e.g. liability, accountability, legal policy, various causal notions). Their guiding principle is the idea that reasoning about the attribution of legal responsibility to a person involved in a case largely rests on causal reasoning. Therefore they propose a stack of definitions connecting the notion of legal responsibility to a number of causal notions. As a first step Hart and Honoré define legal responsibility as the legal status that a person acquires when the judiciary makes a decision concerning the person's liability to certain disagreeable consequences.

DEFINITION 1 (Legal responsibility). Legal responsibility is the liability of a person to be punished, forced to compensate, or otherwise subjected to a sanction by the law.

Definition 1 has three advantages. Firstly, it binds the notion of legal responsibility to the notion of *liability*, marking a clear distinction between legal responsibility and any other form of responsibility (e.g. moral responsibility, political responsibility, etc.). The liability of a person may be seen as the person's relation with a (judicial) authority that has the power to make decisions that directly affect the person and her future. Secondly, Definition 1 binds the notion of legal responsibility to the notion of *accountability* of the person. To be liable, a person must be accountable, which depends on whether the person satisfies the criteria of accountability fixed by law (e.g. age or mental sanity). Finally, Definition 1 shields the definition of legal responsibility from the (legal-theoretical) debates about the existence of necessary and/or sufficient conditions for legal responsibility. Hart and Honoré propose instead to see such so-called conditions as *grounds*, which are used in *attributing* legal responsibility, rather than as defining conditions of legal responsibility itself.

DEFINITION 2 (Grounds for attribution). Grounds for the attribution of legal responsibility to a person for a given harm are: the conduct of the person; the causal connection between the conduct of the person and the given harm; the fault legally implied by the conduct of the person.

Definition 2 revolves around the notion of conduct. It considers both factual and legal elements. This is in accordance with Hart and Honoré's intention of giving equal consideration to causal issues and to legal policy in their framework definition of legal responsibility attribution. (Lehmann et al. 2005) provides a systematic treatment of the implications of Definition 2 and a typology of cases based on it. The present article focuses on the semantics

of the expression 'the causal connection'. In Legal Theory this may both refer to *causation in fact* (the actual causal relation between the events of a case, which legal experts usually take for granted and see as unproblematic) and *legal causation* (the relation between the events of a case based on a set of criteria that are applied either when a clear common sense factual interpretation of the case is missing or when, despite a clear causal interpretation, alternative legal policy considerations should be applied). In this paper we treat *only* causation in fact. Far from being unproblematic, a definition of causation in fact is crucial, especially in the perspective of automation.

2.2. CAUSATION IN FACT

There traditionally are two main families of legal theoretical approaches to causation in fact: causal maximalism (based on the notion of *causal proximity*) and causal minimalism (based on various forms of *counterfactuals*). Hart and Honoré argue against causal maximalism as well as against causal minimalism. They propose instead an analytical approach, which attempts at defining what it *concretely* means in legal settings for an agent to cause an event. They make explicit what both the maximalist and the minimalist leave implicit.

DEFINITION 3 (Causation in fact). Agent A causes an event e, that might involve agent B, if either of the following holds:

1. A starts some physical process that leads to e;
2. A provides reasons or draws attention to reasons which influence the conduct of B, who causes e;
3. A provides B with opportunities to cause e;
4. All the important negative variants of clauses 1, 2, 3.

An analysis of Example 1 according to Definition 3 yields a result that is not very different from those obtained by applying any maximalist or minimalist causal criteria. Either the mother or the seller are at the beginning of the causal chain. Contrary to most classical causal tests, though, Definition 3 provides more clarity. It explicitly distinguishes the various types of causal links that connect each of the involved agents. Rather than reducing every relevant causal relation to one type (e.g. proximate cause or *sine qua non*), Definition 3 distinguishes various types of causal roles played by the persons involved in the case. For instance, the playmate (the boy who shot) has clearly started a physical process that leads to the harm (clause 1). The boy who owns the rifle has provided opportunities to the playmate for shooting. The mother of the rifle's owner has failed to provide her child with (enough) reasons for not using the rifle and this has led him to play a causal role in the

harm. Finally, the seller – if he has played any causal role in the harm at all – has provided an opportunity for the harm to come about.

3. An ontology of physical causation

Definition 3 carves a portion of causal knowledge that is very relevant to AI&Law research. There are various alternative approaches to making the definition more rigorous and possibly useful to *automatic* classification and/or interpretation. One of such approaches is ontology, which allows to interpret Definition 3 according to an explicit and (partially) formal knowledge model. In this section we first distinguish the four main ontological elements of causation in fact: physical, agent, interpersonal and negative causation. We then present the conceptualization developed in (Lehmann et al. 2004), which defines physical causation (the only part of Definition 3 formally treated in this paper). Finally, we provide a formal account of physical causation in the OWL-DL version of DOLCE lite plus (Gangemi et al. 2005).

3.1. THE ONTOLOGICAL ELEMENTS OF CAUSATION IN FACT

Definition 3 comprises four main ontological levels, corresponding to four main types of causation, as usually described in the philosophical literature: physical causation, agent causation, interpersonal causation, negative causation. Distinguishing between varieties of causation is the pragmatic answer of Philosophy to the (temporary?) lack of stable scientific theories of some fundamental phenomena. For instance, without a stable neuropsychological solution of the mind–body problem, it is impossible to choose in a principled way between a reduction of agent causation to physical causation and a reduction of physical causation to agent causation.

Physical causation is described by the final part of clause 1 of Definition 3, where the definition mentions *a physical process that leads to an event*. In Example 1, the relation between the shooting of the bullet and the blinding of the plaintiff is physical causation.

Agent causation is described by the initial part of clause 1, where Definition 3 mentions *an agent starting a physical process*. The agreement around cases of agent causation is not reached as easily as in cases of physical causation. This is due to the problem of detecting the beliefs, desires and intentions of the agent that starts the physical process. In Example 1, the relation between the pulling of the trigger of the rifle by the playmate and the shooting of the bullet quite clearly is agent causation.

Interpersonal causation Things become even more complex when considering interpersonal causation, described by clauses 2 and 3. One might be tempted to

consider interpersonal causation just as a subcase of agent causation, where the psychological state of an agent exerts a causal influence on another agent. Things are not that simple, though. The causal influence that an agent may exercise on someone else may be physical in nature or psychological or a combination of the two. In Example 1, the relation between the seller's refusal to take back the rifle and the pulling of the trigger of the rifle by the playmate might be intrepreted as interpersonal causation.

Negative causation The most elusive case of causation is *negative causation*. Definition 3 refers to negative causation in clause 4 as to *all the important negative variants of the preceding clauses*. It is ontologically very difficult, almost paradoxical, to accept the general idea that something that does not occur can cause anything. In Example 1, the relation between the hiding of the rifle by the mother and the finding of the rifle by the boy might be intrepreted as negative causation.

In the following we provide a formal ontological treatment of physical causation. Adopting this as our starting point has a twofold rationale, which deserves some consideration.

On the one hand, we believe that legal causal reasoning has a *physicalistic* bias: it reconstructs the line of causation in fact primarily along the lines of physical causation. The analysis of real cases is usually based on the same reasoning pattern shown by the analysis of Example 2: in order to find the agent who caused T's death one should first look for the chain of events that killed the traveler (poisining *or* dehydration) and only after ask which agent is at the beginning of such chain (Enemy 1 *or* Enemy 2).

On the other hand, there is an issue of complexity. Defining a model for physical causation should provide important heuristics for dealing with the inherently more complex cases of agent, interpersonal and negative causation.

3.2. THE PROPOSED CONCEPTUALIZATION

Our vision of physical causation (Lehmann et al. 2004) is based on the notion of change, which in our ontology is brought about by events, like:

e_1 = the bullet is shot; e_2 = the plaintiff is wounded.

Two are the main assumptions behind our proposal. Firstly, causal relations relate very simple (types of) events that change *one single* aspect of *one single* object. For instance e_1 is *only* the change of spatial location of the bullet and nothing more than the bullet; similarly e_2 should be considered *only* as a change of, say, shape of (the body of) the plaintiff. The main rationale behind such a restrictive definition of event is methodological. The formal characterization of physical causation between *simple* events presents two main advantages: firstly, it provides valuable insight on dealing with the

intricate problem of defining physical causation between complex events; secondly, it helps in assessing the ontological correctness of models, because it forces the modeler to disentangle relevant ontological issues, while refining the model. For instance, when giving the ontological specification of e_2 one is forced to make explicit and/or to choose between a series of ontological assumptions like: what changes in a human body (considered just as an inanimate object, not as a living entity) that is wounded? Its shape, its mass, its spatial location? Which of these is primary, if any? If all of these aspects of the object change, which kind of relationships hold among them?

Secondly, our conceptualization of causal relations pivots on the distinction between *causality*, a law-like relation between minimally specified events, and *causation*, the actual causal relation that holds between maximally specified events. This distinction finds its formal characterization and embedding within DOLCE-Lite-Plus, in terms of the following dependences between *qualities types* and between *quality changes*: structural, causality and circumstantial dependences).

Structural dependences hold between a specific kind of *simple* events and a number of other kinds of *simple* events that *synchronically* change *the same* object with respect to different aspects. For instance, a structural constraint may impose that if an object changes shape (like in e_2), then it changes (simultaneously) its spatial location or its mass as well. Notice that structural constraints do not depend on the degree of the considered change, they do not depend on measuring – we might even have no measure at all. No specific information on the event is needed beside the fact that the object is changed in the given aspect (say, shape), this alone allows us to infer that the object also changed in other aspect(s) (say, spatial location or mass).

Causality dependences hold between a specific kind of *simple* events and a number of other kinds of *simple* events that *diachronically* change *distinct* objects. The changes may be on different aspects of the objects. For instance, a causality constraint may impose a dependence between the change in shape of an object (like in e_2) and an earlier (or later) change in location of another object (like in e_1). We call these causality constraints because they state very general assertions between qualities of (different) objects taking into account the temporal relation between events. Even causality constraints define clusters of types of changes. They fix the fundamental *law-like* causal relations between such types in the world of reference (as opposed to the *actual* causal relations holding between couples of events, which are captured by the relation of physical causation). Similarly to structural constraints, causality constraints do not depend on the degree of the considered change: they do not depend on measuring – again, one might have no measure at all. It suffices to know that a change has modified the object with respect to, say, its shape, to infer that another object has changed (or will change) in some aspect(s), like its location.

Circumstantial dependences bind event types taking into account the degree of the change they bring about as well as the types of objects they change. In this sense circumstantial costraints are very different from the types of constraints presented above; they depend on how refined our measures are – i.e. one needs to measure the changes to verify if these constraints are satisfied. There are two main groups of circumstantial constraints:

1. *Intrinsic constraints* constrain two specific kinds of *simple* events to comply with restrictions either on the way the change is brought about or on the type of objects that are changed. For instance, for physical causation to hold between e_1 and e_2, on the one hand, e_1 should involve a translation and, on the other hand, e_2 should be the change of a penetrable object (like a human body);
2. *Relational constraints* constrain the relations between two specific kinds of *simple* events and/or the objects they change. For instance, for physical causation to hold between e_1 and e_2, e_1 should temporally precede e_2 and the location of the bullet at the end of e_1 should be the location of the plaintiff during e_2.

Physical causation is the relation that holds between two individual events that satisfy the causality and circumstantial constraints introduced on their types. Furthermore, the application of our framework to the assessment of physical causation is sensitive to the adopted structural constraints, which helps filtering out spurious causal relationships between a candidate effect and the events that are synchronically dependent on the candidate cause.

3.3. THE PROPOSED ONTOLOGY IN DOLCE-LITE-PLUS

This section introduces in an informal fashion the parts of DOLCE-Lite-Plus (DLP) that are relevant to the contents of this article.[3] Moreover, a formal presentation is provided of our ontology of physical causation.[4] The reader may choose either to proceed from DLP to our ontology or the other way around, i.e. simply using Section 2 as a reference for those parts of DLP on which our ontology is based. Note that our ontology is written in OWL-DL species, a language with well known complexity features. OWL-DL corresponds to the description logic *SHOIQ(D)* (Baader et al. 2002) and it is employed in many Semantic Web projects, among which the development of the Core Legal Ontology (CLO) (Gangemi et al. 2005). We introduce the ontology in OWL-DL ‘‘abstract syntax'', a variable-free notation that retains the flavour of the orginal implementation but can be translated into a logical notation through the following mapping:

`partial` means implication ($\rightarrow$).
`complete` means equivalence ($\leftrightarrow$).

`intersectionOf`, `complementOf`, `unionOf` mean the intuitively equivalent set operators.
`restriction` means an "anonymous" predicate equivalent to the axiom that follows.
`(R someValuesFrom(C))` means $\exists(y)\ R(x,y) \wedge C(y)$.
`(R allValuesFrom(C))` means $\forall(y)\ R(x,y) \rightarrow C(y)$.

3.3.1. *Relevant parts of DOLCE-Lite-Plus*

From the DOLCE-Lite-Plus (DLP) ontology library, we have reused a good amount of primitive classes and relations. DLP is written in OWL (DL species), and contains about 200 classes and 150 (binary) relations, mostly domain-independent. In particular, we have reused the following classes:

`physical-endurant` any entity located in space-time that is entirely present at any time it is present (e.g. objects, substances).
`perdurant` any entity that is only partly present at any time it is present (e.g. events, processes).
`physical-quality` any aspect of an entity that can be perceived or measured, and does not change across its life (e.g. having a color, length, energy).
`physical-region` any value (region) within a (usually dimensional) space, which encodes the appearance of a quality at any time (e.g. the appearance of a color, length, energy as measured according to some unit and device).
`description` any social, communicable entity that is used as the counterpart of a conceptualization by some agent (e.g. a regulation, a theory, a reified relation).
`concept` any component defined by a description and used to classify some other entity according to a certain conceptualization.
Examples of concepts are:

- `role` a constraint over a physical endurant, usually a natural person, for instance *plaintiff*.
- `course` a constraint on possible events, usually movements, for instance *location change*.
- `parameter` a (parametric) constraint over a region of values that is changing, for instance *changing value range*.

`situation` any setting that includes all the entities that are classified by concepts defined by the same description.

We have also reused the following binary relations (with their inverses):
`proper-part/proper-part-of` holding between any two entities.
`component` holding between any two entities (expresses functionally relevant proper part).
`(direct-)successor/predecessor` holding between any two entities (expresses abstract precedence, not necessarily a temporal one).
`participant/participant-in` holding between perdurants and physical endurants.

`unique-participant` expresses a participation that is unique (only *one single* physical endurant is taken into account).
`inherent-in/has-quality` holding between physical qualities and physical endurants.
`q-location/q-location-of` holding between physical qualities and physical regions.
`temporally-coincides` holding between perdurants, expresses temporal co-occurrence.
`precedes/follows` holding between perdurants, expresses temporal precedence.
`defines/defined-by` holding between a description and the concepts introduced within the description.
`d-uses/d-used-by` holding between a description and the concepts introduced in another description.
`plays/played-by` holding between a physical endurant and a role.
`sequenced-by/sequences` holding between a perdurant and a course of events.
`value-for/valued-by` holding between a physical region and a parameter.
`satisfies/satisfied-by` holding between a situation and a description.
`setting-for/setting` holding between a situation and any entity that is classified by a concept.
`involves/involved-in` holding between descriptions and physical endurants that play some role defined by them.
`expects/expected-by` holding between descriptions and perdurants that are sequenced by some course of events defined by them.

3.3.2. *Events as basic quality changes*

First of all, we show a sample encoding of the axioms for events considered as *basic quality change* situations. In order to characterize events as intended, a kind of *description* (see above) is introduced, called *change description*. A change description is a description of an event according to some sequence (a course) and parameters, which in our ontology are defined by the change description:

```
Class(change-description partial
  description
)
```

A *change course* is a complex course that classifies an event:

```
Class(change-course complete
  intersectionOf(
    course
    restriction(component someValuesFrom(intersectionOf(
      course
      restriction(direct-successor someValuesFrom(course))))
    restriction(component minCardinality(2))
    restriction(defined-by someValuesFrom(change-description)))
)
```

A *changing value range* is a parameter restricting a range of changing (new) values according to a change description. The value region must be the *q-location* of the same physical quality of the *changed value range* (see below) in the same description:

```
Class(changing-value-range partial
  parameter
  restriction(defined-by someValuesFrom(change-description))
  restriction(valued-by someValuesFrom(intersectionOf(
    physical-region
    restriction(q-location-of someValuesFrom(intersectionOf(
      physical-region
      restriction(q-location-of someValuesFrom(intersectionOf(
      physical-quality
      restriction(q-location someValuesFrom(intersectionOf(
      physical-region
      restriction(valued-by someValuesFrom(changed-value-
            range)))))))))))))
)
```

A *changed value range* is a parameter restricting a range of changing (old) values according to a change description. The value region must be the *q-location* of the same physical quality of the *changing value range* in the same description:

```
Class(changed-value-range partial
  parameter
  restriction(defined-by someValuesFrom(change-description))
  restriction(valued-by someValuesFrom(intersectionOf(
    physical-region
    restriction(q-location-of someValuesFrom(intersectionOf(
      physical-region
      restriction(q-location-of someValuesFrom(intersectionOf(
        physical-quality
        restriction(q-location someValuesFrom(intersectionOf(
          physical-region
          restriction(valued-by someValuesFrom(changing-value-
            range)))))))))))))
)
```

A *physical quality change* is a generic change of one or more physical qualities across different regions. It is any *situation* that *satisfies* a change description. In particular, a quality change is a *setting for* a perdurant having a *unique participant* that is a physical endurant that has a given physical quality and (two) physical regions:

```
Class(physical-quality-change complete
  intersectionOf(
    situation
    restriction(setting-for someValuesFrom(
      restriction(unique-participant someValuesFrom(physical-
          endurant))))
    restriction(setting-for minCardinality(2))
    restriction(setting-for someValuesFrom(physical-region))
    restriction(satisfies someValuesFrom(change-description))
    restriction(setting-for someValuesFrom(perdurant))
    restriction(change-of someValuesFrom(physical-quality)))
)
```

A *basic quality change* is a situation capturing the change of a physical endurant along just one quality type:

```
Class(basic-quality-change complete
  intersectionOf(
    physical-quality-change
    restriction(setting-for cardinality(1))
    restriction(change-of cardinality(1)))
)
```

Where *change of* is the following object-property:

```
ObjectProperty(change-of
      inverseOf(has-change-situation)
      super(setting-for)
      domain(basic-quality-change)
      range(physical-quality)
)
```

3.3.3. *Dependences between quality changes*

We now introduce various dependences between quality changes. A generic *change dependence* is a (reified) *relation* (a kind of description), which is satisfied by a situation that has exactly two quality changes as proper parts:

```
Class(change-dependence complete
  intersectionOf(
    relation
    restriction(satisfied-by someValuesFrom(intersectionOf(
      restriction(proper-part cardinality(2))
      restriction(proper-part someValuesFrom(quality-
          change))))))
)
```

A *synchronic dependence* is a dependence between two change descriptions involving the same participant, at the same time:

```
Class(synchronic-dependence complete
  intersectionOf(
    physical-change-dependence
    restriction(expects someValuesFrom(intersectionOf(
      restriction(temporally-coincides someValuesFrom(perdu
           -rant))
      restriction(participant someValuesFrom(physical-endu
           -rant)))))
    restriction(expects cardinality(2))
    restriction(involves someValuesFrom(physical-endurant))
    restriction(involves cardinality(1))
    restriction(satisfied-by someValuesFrom(intersectionOf(
      restriction(proper-part someValuesFrom(basic-quality-
           change))))))
)
```

A *diachronic dependence* is a dependence that is satisfied by a situation that: i) has as proper parts exactly two basic quality changes that are temporally disconnected, ii) involves exactly two different physical endurants in the setting of the two quality changes:

```
Class(diachronic-dependence complete
  intersectionOf(
    physical-change-dependence
    restriction(expects cardinality(2))
    restriction(involves someValuesFrom(physical-endurant))
    restriction(involves cardinality(2))
    restriction(expects someValuesFrom(intersectionOf(
      restriction(precedes someValuesFrom(perdurant))
      restriction(participant someValuesFrom(physical-endu
           -rant))))))
)
```

A *multiple diachronic dependence* combines several diachronic dependences.

```
Class(multiple-diachronic-dependence complete
  intersectionOf(
    diachronic-dependence
    restriction(satisfied-by someValuesFrom(
      restriction(proper-part someValuesFrom(physical-quality-
           change))))
    restriction(satisfied-by minCardinality(2)))
)
```

A sibling of diachronic dependence is *analytic diachronic dependence*, which combines two basic quality changes that are synchronically dependent on two other quality changes.

```
Class(analytic-diachronic-dependence complete
  intersectionOf(
    physical-change-dependence
    restriction(proper-part someValuesFrom(synchronic-depen-
      dence))
    restriction(proper-part someValuesFrom(diachronic-depen-
      dence))
    restriction(satisfied-by someValuesFrom(intersectionOf(
    restriction(proper-part someValuesFrom(basic-quality-
      change)))))
)
```

A *structural dependence* is a synchronic dependence that must hold for the entire class of physical endurants (it is a general law). Since this axiom is a second order one, our OWL-DL axiomatization makes use of an extension of DOLCE called theory of *collections* (Bottazzi et al. 2006), which reifies qualified sets as non-physical endurants that are *unified by* a description. In this case, the so-called *collection of (all) physical endurants* is unified by any instance of structural dependence:

```
Class(structural-dependence complete
  intersectionOf(
    synchronic-dependence
  restriction(unifies   someValuesFrom(collection-of-physical-
    endurants)))
)
```

A *physical causality dependence* is a diachronic dependence that holds for the entire class of physical endurants (it is a general law). Since this axiom is a second order one, our OWL-DL axiomatization makes again use of the theory of *collections*, which reifies qualified sets as non-physical endurants that are *unified by* a description. In this case, the so-called *collection of (all) physical endurants* is unified by any instance of causality dependence:

```
Class(physical-causality-dependence complete
  intersectionOf(
    diachronic-dependence
    restriction(satisfied-by someValuesFrom(intersectionOf(
      restriction(proper-part someValuesFrom(basic-quality-
        change)))))
    restriction(unifies someValuesFrom(collection-of-physical-
        endurants)))
)
```

A *circumstantial dependence* is a diachronic dependence that is not a causality dependence; in other words, it states *local* dependences:

```
Class(circumstantial-dependence complete
  intersectionOf(
    diachronic-dependence
    complementOf(physical-causality-dependence)
    restriction(satisfied-by someValuesFrom(
      restriction(proper-part someValuesFrom(basic-quality-
         change)))))
)
```

3.3.4. *Physical causation*

We introduce here the class of *physical causation relations* as a kind of physical change dependence that has as proper part at least one of the following change dependencies: i) any diachronic dependence, ii) any indirect diachronic dependence, iii) any transitive application of a diachronic or indirect diachronic dependence

```
Class(physical-causation-relation complete
  intersectionOf(
    physical-change-dependence
    unionOf(diachronic-dependence analytic-diachronic-depen
          dence intersectionOf(
      physical-change-dependence
      restriction(involves someValuesFrom(intersectionOf(
        restriction(involved-in someValuesFrom(physical-causa
          tion-relation))
        restriction(involved-in minCardinality(2))))))))
)
```

A *physical causation fact* is a situation that satisfies a physical causation relation.

```
Class(physical-causation-fact complete
  intersectionOf(
    situation
    restriction(satisfies someValuesFrom(physical-causation-
          relation)))
)
```

3.3.5. *A model of the Air Rifle example*

We show here a part of a simple model that encodes the physical causation underlying Example 1. Firstly, we introduce a very simple causality dependence between shape and location changes. In this case, the general law states a *backward dependence* of a shape change of a physical endurant from a

location change of another physical endurant. Given e.g. the introduction of a description for *shape change*, as a change course having a location change as a direct predecessor:

```
Individual(shape-change
  type(change-course)
  value(direct-predecessor location-change))
```

The description of *shape location backward dependence* is introduced as a causality dependence that reuses the descriptions: *shape change* and *location change*, which must be in a direct succession relationship between one another:

```
Individual(shape-location-backward-dependence
  type(diachronic-dependence)
  type(restriction(d-uses someValuesFrom(intersectionOf(
    oneOf(shape-change)
    restriction(direct-predecessor
      someValuesFrom(oneOf(location-change)))))))
  value(d-uses location-change)
  value(d-uses shape-change))
```

Now we are in the position of introducing a model for the Air Rifle case. Only a sample of the model is presented here, in order to proof the concept. The *air rifle case* is introduced as a situation that is a *setting* for several entities: a bullet, its location quality, its shooting, a child, the shape quality of one of its body parts, and its being wounded:

```
Individual(air-rifle-case
  type(situation)
  value(setting-for bullet-x)
  value(setting-for x-location)
  value(setting-for shooting-z)
  value(setting-for child-y)
  value(setting-for y-shape)
  value(setting-for being-wounded-w))
```

Our aim is to infer that the air rifle case is a physical causation fact, given the following assertions: (i) the location quality is inherent in the bullet, (ii) the shape quality is inherent in the child, (iii) the child-y plays the *plaintiff* role, (iv) the shooting is *sequenced by* the location change course, has the bullet as its unique participant and it precedes the being wounded state, (v) the being wounded state is sequenced by the shape change and has the child as its unique participant:

```
Individual(x-location
  type(spatial-location-q)
  value(inherent-in bullet-x))
```

```
Individual(y-shape
  type(shape)
  value(inherent-in child-y))

Individual(child-y
  type(natural-person)
  value(plays plaintiff))

Individual(shooting-z
  type(shooting)
  value(sequenced-by location-change)
  value(unique-participant bullet-x)
  precedes(being-wounded-w))

Individual(being-wounded-w
  type(being-wounded)
  value(sequenced-by shape-change)
  value(unique-participant child-y))
```

By running an automatic classifier on the OWL model, we can infer that the air rifle case satisfies the shape location backward dependence; since such dependence is a diachronic dependence, which is one of the dependence classes within the *physical causation relation* class, it is possible to conclude that the air rifle case is an instance of *physical causation fact*:

```
Individual(air-rifle-case
type(physical-causation-fact))
```

The model we have presented is very simple, and the reification framework we have exemplified might appear a bit redundant compared to its simplicity, but, besides its capability of being represented in languages with known complexity features, another interesting feature of our framework is its scalability: once the descriptions (dependences, norms, regulations) and situations (cases, conflicts, etc.) are set, the amount of elements in them can increase without seriously affecting the overall complexity of the model, the reified laws, and the ontology itself.

4. Conclusions

We have discussed the role of causal issues in reasoning about legal responsibility. Based on Hart and Honoré's work, we have provided a legal theoretical framework for defining legal responsibility and causation in fact. A preliminary ontological analysis of causation in fact has yielded four main components of such relation: physical, agent, interpersonal and negative

causation. We have provided a conceptualization of physical causation in terms of a number of dependeces. We have then provided a formal account of physical causation in an OWL-DL version of DOLCE-Lite-Plus and exemplified it by a relevant subset of the Air Rifle example.

Further research objectives are the specification of (detailed) circumstantial constraints (intrinsic and relational), the validation of the proposed relation of physical causation, as well as the extension of the overall structure to the cases of agent, interpersonal and negative causation.

Notes

[1] http://www.semanticweb.org
[2] See (Gangemi and Mika 2003) and (Masolo et al. 2004) for worked-out examples of such vocabularies based on the Descriptions and Situations paradigm – which is also used in this article.
[3] For a formal presentation of the introduced concepts and relations the reader may refer to http://www.loa-cnr.it/DOLCE.html, download DOLCEx.x-Lite-Plus.
[4] Online version on http://www.loa-cnr.it/ontologies/Causality.owl

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