Formalizing a simple loan agreement in L4 and B

Joe Watt

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> This is a work in progress.
> Most of this was originally written based on the work done in mcrl2 but is now being rewritten for L4 and its connection to the modelling done in B.

Contents

1 Intro and shortcomings of DFA formalization

1.1 Intro

> **TODO**
> Write a proper introduction to the original work on formalizing the simple loan agreement as a DFA.

In [3], the authors explain that many financial contracts are inherently computational in nature. They argue that the computational structure of many such contracts can be formalized via deterministic finite automata (DFAs), with states representing various situations. Transitions between these states then correspond to events triggering a change in these situations. This is demonstrated using a simple loan agreement [3, Table 1], which they formalize directly as a DFA.

1.2 Shortcomings

While this approach is a nice proof of concept, there are various shortcomings with such a formalism, perhaps the most apparent being that the manual encoding of a contract as a DFA is a laborious process. One source of complexity arises from the fact that DFAs are a low level computational formalism that is arguably far removed from our intuitive understanding of a contract. While we can easily encode real-world events as transitions in a DFA, as done in [3], we often reason about and specify contracts in terms of normative requirements that need to be fulfilled by various actors [5]. These also come with some notion of time and deadline. These are examples of *domain-specific concepts* which are an integral part of contract drafting. Unfortunately, DFAs have no primitive notion of these, so that these must all be encoded manually, in a manner that is perhaps unnatural to many.

Another source of complexity is the state explosion problem, namely that complex contracts have large DFA representations and are thus impractical for humans to specify manually. Observe that a simplified visual representation of the automaton [3, Fig. 1] corresponding to this simple contract already contains more than 20 states and 40 transitions.

One of the main causes of this is the *concurrent interleaving* of real world events. By this, we mean that many real world events can occur in any order (including at the same time) and perhaps for the sake of simplicity, this has not been accounted for in the DFA formalization. As an example of such a scenario, consider the following. On May 31, 2015, the day before payment 1 is due, the borrower defaults on his representations and warranties. On the next day, when payment 1 becomes due, the borrower diligently repays that payment. One day later, on June 2, 2015, the lender notifies the borrower of his earlier default, which does not get cured after another 2 days. Now all outstanding

payments become accelerated, and the borrower pays off the remaining amount of \$525 in time, causing the contract to terminate. This sequence of events, when viewed as a word over the event alphabet, is unfortunately not accepted by the automaton.

Closer inspection of the DFA suggests that there is an implicit assumption being made that once an event of default occurs, the borrower will be notified by the lender soon after, with no other events like payments occurring in between. More formally, it is assumed that the default and notification events occur *within the same atomic step*. Splitting this up into separate events would increase the number of states in the DFA, especially if we account for concurrency.

> Other weaknesses to mention:
> Representation of time and deadlines. Not handled well by the DFA, but is an important notion that exists in L4. These are translated to B.
> No explicit notion of deontics, which is important to humans because that's what people are used to reasoning about and normative language shows up everywhere in legal drafting. In L4, we have a notion of deontics, though not quite the same as deontic logic. We have an operational interpretation that is made precise by the translation to B.
> The focus here is that a friendly-to-use language should provide appropriate abstractions corresponding to concepts found in the application domain. For the legal domain, these include the notions of rules, actors, events, deadlines and deontics. Another reason for modelling these explicitly is to be able to achieve a nice correspondence (more technically an isomorphism) with legal texts that are drafted in natural language.

2 The L4 approach

2.1 Intro to L4 as a language

At CCLAW, we are developing one such domain specific language (DSL) for specifying legal contracts, called L4, which addresses these issues. Along with it, we are also developing an accompanying toolset which can be used to visualize and analyze contracts written in L4.

> **TODO**
> Talk about constitutive and regulative rules.
> Constitutive rules as statics, semantics is arguably straightforward, namely some first order defeasible logic. Can be formalized using Prolog.
> Regulative rules as dynamics, trickier semantics, is the focus of this paper. Will show how the loan agreement is modelled using these.
> Give an example of a regulative rule found in the loan agreement to demonstrate the syntax. Then use this example to highlight domain specific concepts. Read [2, 9] and highlight similarities with them.

As mentioned earlier, we believe that a friendly to use language for specifying legal contracts should be situated at a higher level of abstraction than that of automata, closer to the application domain.

> **Workspace:**
> It comes with a concurrent model of computation (this is made precise by the translation to B) which allows for arbitrary interleaving of events.
> It is also friendly to use, containing ontological concepts from the legal domain that people are used to thinking about and working with.
> Discuss the precise roles of these concepts and how the execution of a contract can be viewed abstractly as a process that arises from the interaction between them.
> Mention that the precise operational interpretation of rules in L4 is tightly linked to the translation in B and this was heavily inspired by [1, 8].
> We view a rule as a wrapper around an event, a deontic (ie permission, obligation or prohibition) and an actor. Our treatment of deontics accounts for the notion of *compensability*, and is based on [5].
> Note that the difference is that instead of reasoning about deontics using deontic logic, we provide an *operational* interpretation for them.

2.2 Formalizing the loan agreement in L4

3 Formalizing contracts in B and how it relates to L4

In search for such a suitable formalism for encoding contracts, we have surveyed various approaches, using the simplified contract in [3, Fig 1.] as an example. One of these which we explored is the B language and the ProB toolset [6, 7].

In this section, we begin by providing some background on B before we discuss our formalization of the simple loan agreement. Along the way, we explain how we addressed the aforementioned shortcomings. In particular, we show how we can generate an arguably more accurate DFA that accounts for

the concurrent interleaving of real world events. Thereafter, we demonstrate how we can use ProB to help us visualize and reason about the contract.

3.1 Background on B

Techniques originating from the field of formal methods have been devised to automatically analyze the behavior of computer systems. These often rely on first modelling these systems as *labelled transition systems* (LTS), which can be seen as generalizations of nondeterministic finite automata). As with finite automata, LTSes can be seen as directed graphs, with nodes representing states that the system can be in, and labelled edges denoting transitions that change the state of a system. Where they differ from finite automata is that they are allowed to have an infinite (possibly uncountable) number of states and transitions between them. They are also not required to come with a notion of initial and final states.

While DFAs and LTSes in general are formalisms that are well suited for computers to analyze and reason about, they are cumbersome for humans to use to encode systems. This is especially so for systems like the simple loan agreement of [3] which involve concurrency, in that there are many possible ways in which events can be interleaved. Modelling concurrent systems like this directly as a transition system is often impractical as the interleaving of events gives rise to numerous states and transitions. Moreover, as previously discussed, they leave implicit many of the domain specific concepts that people directly reason about.

The toolset we use, ProB, allows us to model and analyze such concurrent systems. As with others like it, it comes equipped with a more sophisticated formalism that allow us to more conveniently specify these transition systems.

3.2 Translating from L4 to B

Use the loan agreement as an example here.

3.3 Visualizing and simulating the contract

Insert DFA of state space here.

3.4 Analyzing via model checking

Here we should mention that in [4], the author highlights an issue with using temporal logic to reason about deontics like obligations. We sidestep that issue due to the way we define rules as wrappers around events, and deontics, so that the violation of a rule corresponds directly to whether that event occured or not.

For instance, a rule of the form "Party P must do A by D" is an obligation that is violated if P does not perform A by the deadline D. In this way, we can

reason about the violation of obligations by using temporal logic to talk about whether an event occurred or not.

4   Related work

5   Limitations and future work

The current B models are not very performant and have huge state spaces. One of the main reasons is that we model time naively, with a `tick` transition denoting the passage of 1 unit of time (which can be taken to be 1 day, 1 month etc). We did this because ProB does not come with any built-in support for these notions, so we wanted an easy way to model these. Unfortunately, this considerably bloats up the state space. Again it must be emphasized that this is a proof of concept and these were designed to be as high-level and close to the syntax of L4 as possible. In the future, we intend to optimize this, among other things. We could investigate the use of other formalisms that better support modeling time and deadlines, or we could build our own abstractions to handle these more efficiently in B.

Currently, we don't yet support global variables and more sophisticated control structures like loops. Global variables would be useful to capture the notion of the outstanding amount in the loan agreement contract, which would then vary with the payments made by the borrower. B as a formalism supports these, but we currently do not support them in L4. For future work, we would like to provide syntax for these in L4 and translate them to B.

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