CS4052 Coursework 2: A Simple Model Checker

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This practical is worth 50% of the coursework component for this module and is **due 21:00 on Friday 19 November, 2021**.

The practical involves developing a simple model checker for an *action* and *state-based logic asCTL* interpreted over transition systems. The model checker supports fairness in the sense that you can add any constraints to the model to restrict the set of paths being considered for verification. To make it easier, some components (such as a parser and a model builder) are provided. There is also a readme file with further information on how to get started with the practical.

Logic *asCTL*

In the lectures we have seen two state-based logics, namely *LTL* and *CTL*. Neither of the logics is suitable for making statements about the sequences of actions carried out before reaching a particular state. One example of a property we may want to be able to express is *it is always the case that after action α or β occurs the system is in a state where p holds.* Or *the system will eventually reach a goal state by only performing legal actions.*

Similarly to *CTL*, in *asCTL* we distinguish between state and path formulae. Let Φ be a state formula, ϕ a path formula, $p \in AP$ an atomic proposition, $\alpha \in Act$ an action, and $A, B \subseteq Act$ subsets of actions.

The *action* and *state-based logic asCTL* has a grammar defined as follows.

State formulae are given by:

$$\Phi ::= true \mid p \mid \neg\Phi \mid \Phi \wedge \Phi \mid \exists\phi \mid \forall\phi$$

A *path formula* is given by:

$$\phi ::= \Phi\ \mathcal{U}_B\ \Phi \mid \Phi_A\mathcal{U}_B\ \Phi \mid \Phi_A\mathcal{U}\ \Phi \mid \Phi\ \mathcal{U}\ \Phi$$

The temporal operator *until* (given by $\mathcal{U}$) in a path formula is indexed by $A, B \subseteq Act$. Let a path be given by

$$\pi \equiv s_0 \xrightarrow{\alpha_1} s_1 \xrightarrow{\alpha_2} s_2 \ldots s_{i-1} \xrightarrow{\alpha_i} s_i \ldots$$

The intended meaning of a path formula over a path π is as follows:

$\pi \models \Phi_1 {}_A\mathcal{U}_B\ \Phi_2$	holds iff there is a state s_i in π such that $s_i \models \Phi_2$, $\alpha_i \in B$, and until then all states s_k with $0 \leq k < i$ are such that $s_k \models \Phi_1$ and $\alpha_1, \ldots, \alpha_{i-1} \in A$.

In other words, just before Φ_2 holds a B action must occur, and until then Φ_1 holds and only A actions can occur. Notice that A, B are subsets of the overall sets of actions. You need to think about what it means (or in your opinion it should mean) for A or B to be $\emptyset$ or Act.

If one of the sets is missing, like in $\Phi_1\ \mathcal{U}_B\ \Phi_2$ or $\Phi_1 {}_A\mathcal{U}\, \Phi_2$ then we are effectively imposing fewer restrictions:

$\pi \models \Phi_1\ \ \mathcal{U}_B\ \Phi_2$	holds iff there is a state s_i in π such that $s_i \models \Phi_2$, $\alpha_i \in B$, and until then all states s_k with $0 \leq k < i$ are such that $s_k \models \Phi_1$.
$\pi \models \Phi_1 {}_A\mathcal{U}\ \Phi_2$	holds iff there is a state s_i in π such that $s_i \models \Phi_2$, and until then all states s_k with $0 \leq k < i$ are such that $s_k \models \Phi_1$ and $\alpha_1, \ldots, \alpha_{i-1} \in A$.

Finally, $\Phi_1\ \mathcal{U}\ \Phi_2$ has the same meaning as in CTL.

You will need to think about and define equivalences between formulae and the meaning of all uses of the until operator. Further, how can you for instance obtain path formulae with X (next), F (eventually) and G (always), and what kinds of action-indexed operators X, F and G make sense? In the case of the next operator, for instance, we may only allow $X_B\Phi$ to denote that in the next state Φ holds and a B action occurred.

Main Task

Develop a model checker for the logic *asCTL*, an action and state-based version of CTL described above. Consider the model of a system to be a labelled transition system $\mathcal{M}$. In addition, we can specify a constraint η (e.g., a fairness constraint) in *asCTL* which is used to constrain the set of traces of $\mathcal{M}$ used by the verifier. Your model checker should allow us to check both $\mathcal{M} \models_\eta \varphi$ and $\mathcal{M} \models \varphi$ for a given $\mathcal{M}$, η and φ.

To help you with your implementation some components are provided for you in studres. You are given a model builder, a parser for *asCTL*, and an automation

tool to generate test reports. There is also a readme file that explains in detail how the parser works, and how you need to specify the formulae.

A labelled transition system as covered in lectures is a tuple (S, Act, T, I, AP, L) where S is a finite set of states, Act is a finite set of actions, $T \subseteq S \times Act \times S$ is a set of transitions, $I \subseteq S$ denotes the set of initial states, AP is a finite set of atomic propositions and $L : S \to 2^{AP}$ is a labelling function which associates to each state a set of valid atomic propositions on that state.

In the implementation, a model is given as a `json` object where states and transitions are given explicitly, and AP and L implicitly by the information associated to states.

An *asCTL* formula

$$\forall_A \mathcal{F}_B (p \wedge q)$$

with $A = \{act_1, act_2\}$ and $B = \{act_3, act_4\}$ is written in `json` as:

```
{
 "formula":  "AaFb (p && q)",
 "a":  ["act1", "act2"],
 "b":  ["act3", "act4"]
}
```

Both fairness constraints and properties that we want to check are written in the same way as a `formula`.

You are required to implement the method `check()` which takes as arguments a model, a fairness constraint (which can be just `True`) and a formula that we want to check. If this fails, you will need to return a counterexample, in other words, a path in the model that shows how the formula is not satisfied. *You can restrict the implementation of the algorithm to asCTL formulae which have a counterexample.*

To show that your implementation works correctly you should provide a realistic model such as the mutual exclusion example treated in the lectures. You can use the model as given in the lectures, add fairness constraints and check different properties over that model. At least one property used should have actions.

Submission

You should write a report discussing the semantics of *asCTL* as supported by your model checker, assumed logic equivalences with justifications, and any design and implementation decisions of the model checker for the logic *asCTL*. Include evidence of testing and explain (the rationale of) any decisions taken in your implementation. Please submit a single `.zip` archive containing all your code and your report as a `.pdf` to MMS by the specified deadline. Note that MMS is definitive for deadlines and coursework weights.

Marking

For a mark above 14, a good solution to the main task is required, with well structured code for the model checker achieving most of the functionality, a clear and detailed report showing insight and understanding of the logic $asCTL$ and how to verify it.

For a mark above 16, a solid solution to the main task is required: well structured code for the model checker with all the functionality required, a detailed illustration of how the model checker works on a realistic example, accompanied by a well-written, informative and complete report reflecting thorough understanding.

For a mark of 18 or above, in addition to a solid solution to the main task as described above, some reflection on any additional features or mechanisms for improving the scalability and/or efficiency of the model checker is expected.

For further information see the standard mark descriptors in the School Student Handbook.

Lateness

The standard penalty for late submission applies (Scheme B: 1 mark per 8 hour period, or part thereof).

Good Academic Practice

The University policy on Good Academic Practice applies.