Modelling and analysis of a cyber-physical system

Practical Assignment 1

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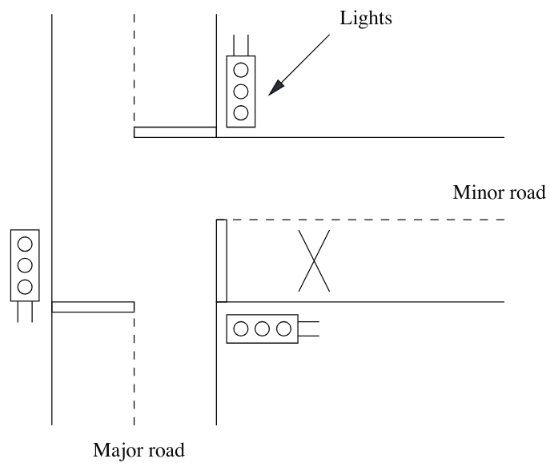
First Part

The first goal of the assignment is to *model* and *analyse* a system that ensures the *correct* functioning of traffic lights at a T-junction. The latter connects a “major” and a “minor” road and is depicted below (together with the respective traffic lights):



In this scenario vehicles drive on the left side of the road and the cross in the picture represents a sensor that tells whether a car is waiting in the minor road or not.

In order to guarantee a reasonable traffic flow, the system has the following constraints:

1. The lights on the major road will be always set on green, and red on the minor road *unless* a vehicle is detected by the sensor.
2. In the latter case, the lights will switch in the standard manner and allow traffic to leave the minor road. After a suitable time interval (30s), the lights will revert to their default position so that traffic can flow on the major road again.
3. Finally, as soon as a vehicle is detected by the sensor the latter is disabled until the minor-road lights are on red again.

The system also respects the following *temporal* constraints:

1. Interim lights stay on for 5s.
2. There exists 1s delay between switching one light off and the other on.

3. The major-road light must stay on green for at least 30s in each polling cycle, but must respond to the sensor immediately after that.

The first part of the students' assignment:

1. Model in UPPAAL the system of traffic lights described previously;
2. Express in CTL the following *reachability* properties and test them in UPPAAL: (1) the minor-road light can go green; (2) the major-road light can go red.
3. Express in CTL the following *safety* properties and test them in UPPAAL: (3) the system never enters in a deadlock state; (4) the minor-road and major-road lights cannot be green at the same time.
4. Express in CTL the following *liveness* property and test it in UPPAAL: (5) if there are cars waiting they will *eventually* have green light.
5. Can you think of other desirable properties? If so please register them and check whether they hold or not.

Second Part

The previous system of traffic lights works reasonably well under the assumption that one of the roads has more traffic than the other. But such an assumption is often *too strong*: it may be the case that both roads have the same amount of traffic, or even that their traffic flow varies drastically throughout the day. The second part of this assignment (more exploratory) aims to address precisely this problem which is well-known to have significant impact in the economy and the environment [1]. To this effect, we can now assume that each traffic light has a smart sensor attached to it. The sensor informs whether the traffic near the light is high, low, or simply non-existent.

The second part of the assignment:

1. Adapt your previous UPPAAL model to take into account the information provided by the sensors. One expects, for example, that if the rightmost sensor outputs high and the other sensors output no then the rightmost traffic light should be on green at least until the sensors provide new information.
2. Verify that all the properties mentioned in the first part of the assignment still hold.
3. (Valorisation) Note that the second part of the assigment is of a more exploratory nature, and thus we give freedom to adjust sensor parameters as seen fit in order to promote different and creative solutions. We will value properties expressed in CTL that say something about the efficiency of the system developed by the students. Such a property can be for example, "If the rightmost sensor always detects high traffic and the others detect no traffic at all, then we will observe at most one change in the traffic lights".
4. Write a report for the first and second part of the assignment that explains (1) your design choices, (2) your models, (3) the formulae that you used for benchmarking your systems, and (4) the conclusions obtained.

[1] `https://ourworld.unu.edu/en/green-idea-self-organizing-traffic-signals`

Submission instructions

What to submit: The report in PDF *and* the respective UPPAAL models. Send by email (nevrenato@gmail.com) a unique zip file "`cpp2324-N1_N2.zip`", where `N1` and `N2` are your student numbers. The subject of the email should be "`cpp2324 N1 N2`".

Deadline: 07 Apr 2024 @ 23h59