

# Discrete Event Systems

## Exercise Sheet 12

This last exercise session puts somehow everything together. You will discover a simulation tool for time Petri nets, which is paramount for the evaluation of your design. You will mainly use the "stepper simulator", which randomly plays the token game. In the last part of the exercise, you will use the embedded model-checker to tune some design parameters.

### 1 Warming up: Calculating with Petri nets

In this exercise you are supposed to model a function  $f_i(x, y)$  using a Petri net. That is, the Petri net must contain two places  $P_x$  and  $P_y$  that hold  $x$  and  $y$  tokens respectively in the beginning. Additionally, the net must contain one place  $P_z$  which holds  $f_i(x, y)$  tokens when the net is dead. The Petri nets are supposed to work for arbitrary numbers of tokens in  $P_x$  and  $P_y$ .

- a)  $f_1(x, y) = 5x + y \quad \forall x, y \geq 0$
- b)  $f_2(x, y) = x - 2y \quad \forall y \geq 0, x \geq 2y$
- c)  $f_3(x, y) = x \cdot y \quad \forall x, y \geq 0$

Here you may want to use inhibitor arcs. An inhibitor arc between a place and a transition prevents the transition from firing as long as there is at least one token in the place.

**Hint** Start by creating a net that "duplicate" the number of tokens from  $P_x$  in place  $P_z$ . Then adapt this net to perform the multiplication.

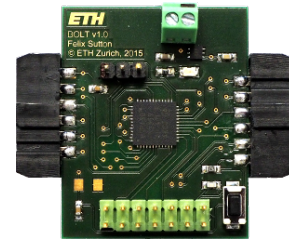
### 2 Simulate your Petri nets with TINA

In this exercise, you will learn how to use the modeling tool TINA (**T**ime petri **N**et **A**nalyzer). The objective is to implement your solutions from Exercise 1 and simulate the nets.

- a) On our course webpage you will find a simple tutorial for basic uses of the TINA software. Complete the reading of Section 1 before moving on.
- b) To practice, create new net files and implement your solutions from Exercise 1. Using the stepper, try them out for different values of  $x$  and  $y$ .

### 3 Queue sizing and overflow management of BOLT

BOLT is an ultra-low power processor interconnect that decouples arbitrary application and communication processors with respect to time, power and clock domains. BOLT supports asynchronous message passing with predictable timing characteristics. Therefore, it enables system designers to construct highly-customized platforms that are easier to design, implement, debug, and maintain. You can find more information on BOLT's webpage: [www.bolt.ethz.ch](http://www.bolt.ethz.ch)



The BOLT processor interconnect

In this exercise, we look at the practical problem of queue sizing and overflow management, using BOLT architecture as a case study.

Assume BOLT is connected on one side to a sensor, which delivers data at a given frequency and writes into BOLT queue. At the other side, a communication processor is responsible for reading those messages from BOLT and sending them through a wireless sensor network. The problem is that the network is not always available (other processes also need the bandwidth) and the communication processors have limited memory to store messages before sending them. The BOLT queues can be used as temporary buffers.

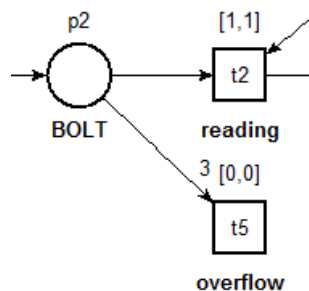
The objective is to evaluate the design parameters (queue size, resource management scheme...) such that overflows in the BOLT queue (which would result in packet losses) are avoided.

#### 3.1 The nice and pretty deterministic world

- a) This initial model (in the exercise folder) is untimed. Extend it with delays on transitions such that the net follows the earliest firing rule and knowing that:
  - The sensor produces one message every 5 time units.
  - Reading and writing from/to BOLT take one time unit each.
  - Sending a message to the network takes one time unit.
  - On average, the communication processor uses the network for 10% of the time.
- b) Play the token game using the stepper. Is the net bounded? Why is this not surprising?
- c) Assume BOLT has now a maximal capacity of two messages. How would modify the net to implement this? Why is this not a "real" solution to our problem?

On the physical system, BOLT does not prevent a write operation if its queue is full, but overwrites old messages. Hence, our previous solution to avoid overflows is not satisfying, as it yields that the write operation is forbidden if there is no more memory available in BOLT, so the systems is actually waiting for the resource to be available.

In our case, the goal is to guarantee there is enough network resource available such that there is no possible overflow in BOLT, without having to control the write operations. As a result, we need our Petri net to model the (possible) overflow of BOLT in order to test our design. Among several options, we choose to do that by adding a sink transition downstream the BOLT place, as shown thereafter.





- The processor can read and store one or several messages from BOLT before sending them.
  - When the processor accesses the network to send messages, it will keep on sending (i.e., no releasing the resource) until it has no more message left in memory.
  - It is uncertain when the network will be available again.
- a) Complete the reading of Section 2 of the TINA tutorial.

Our design question is the following:

**How much memory does one need in the communication processor  
in order to guarantee that BOLT never overflows?**

To answer this question, we will use the LTL model-checker embedded within TINA. LTL is a different logic than CTL, but for our simple purpose here, we can say the differences are the following

- the  $E$  quantifier doesn't exist,
- the  $A$  quantifier is always implied,
- $G$  writes  $\square$ ,  $F$  writes  $\diamond$ , and  $X$  writes  $\circ$ .

This is summarized in the table below:

CTL	AF a	AG a	EF a	AX a	...
LTL	$\diamond$ a	$\square$ a	$\neg$ AG $\neg$ a	$\circ$ a	...
in TINA	$\langle \rangle$ a ;	$\square$ a ;	$- \square -$ a ;	$\circ$ a ;	...

- b) What does the LTL property  $\diamond t5$  mean in natural language? Does our model verify this property? Are we happy about this?
- c) What is the LTL property our system must verify in order to guarantee that BOLT will never overflow?
- d) What is the smallest capacity for the place  $p4$  that makes this true? Do not open the stepper to generate an example trace, or be prepared to wait for a while...

**Hint** Look for a solution between 1 and 30.