UPPAAL TRON: Testing Real-time systems ONline

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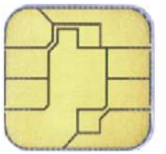


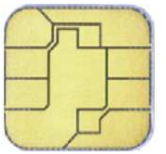
Center for Embedded Software Systems

Basic Research in Computer Science

Aalborg University

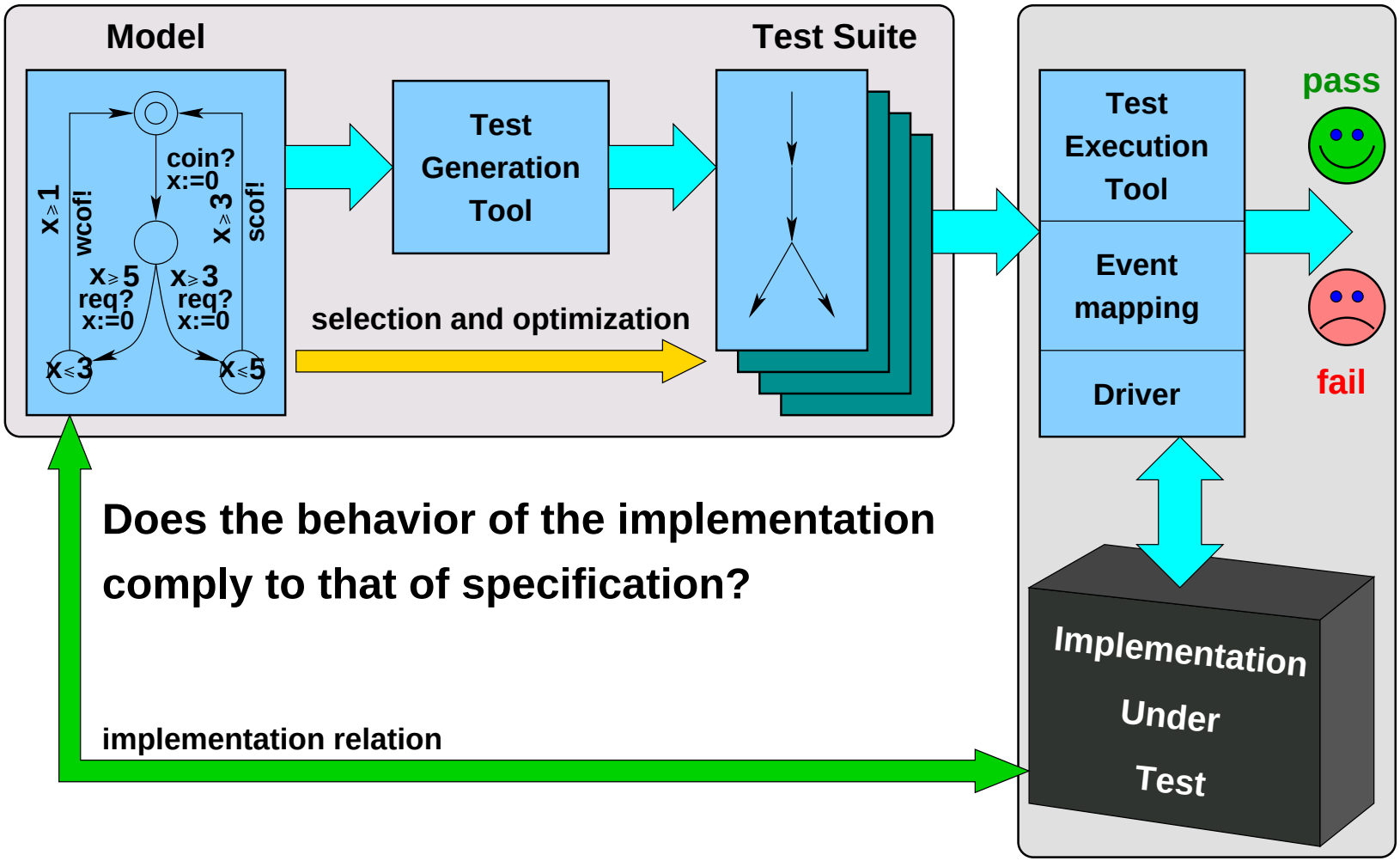
Outline

- Classical model-based testing.
- Online test setup: from specification to testing.
- UPPAAL TRON framework.
- Conformance relations: tioco and rtioco.
- Online test algorithm.
- Conclusions.
- Future work.
- Demo of Java “light controller” online test.

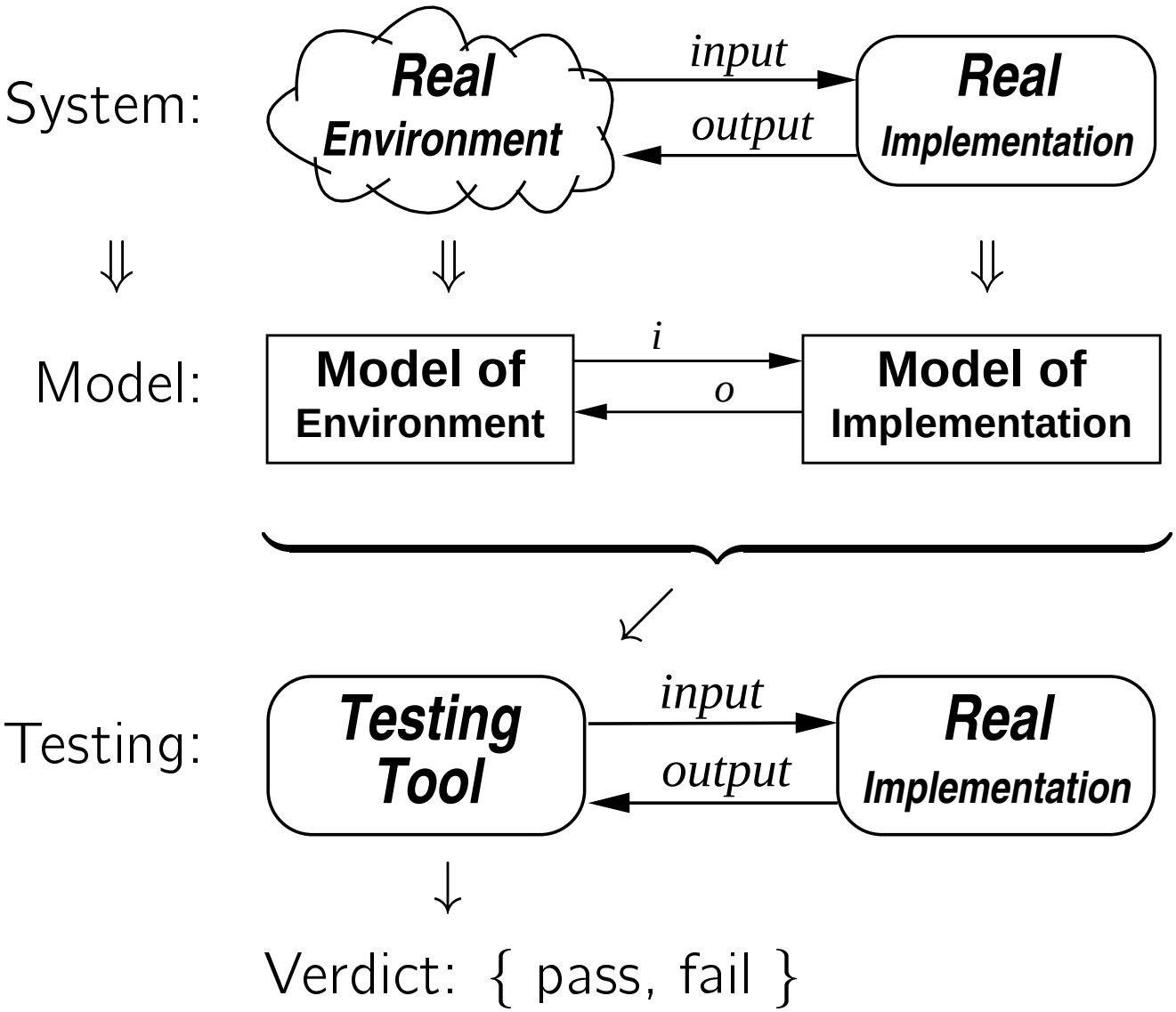


Classical Model-based Testing Framework

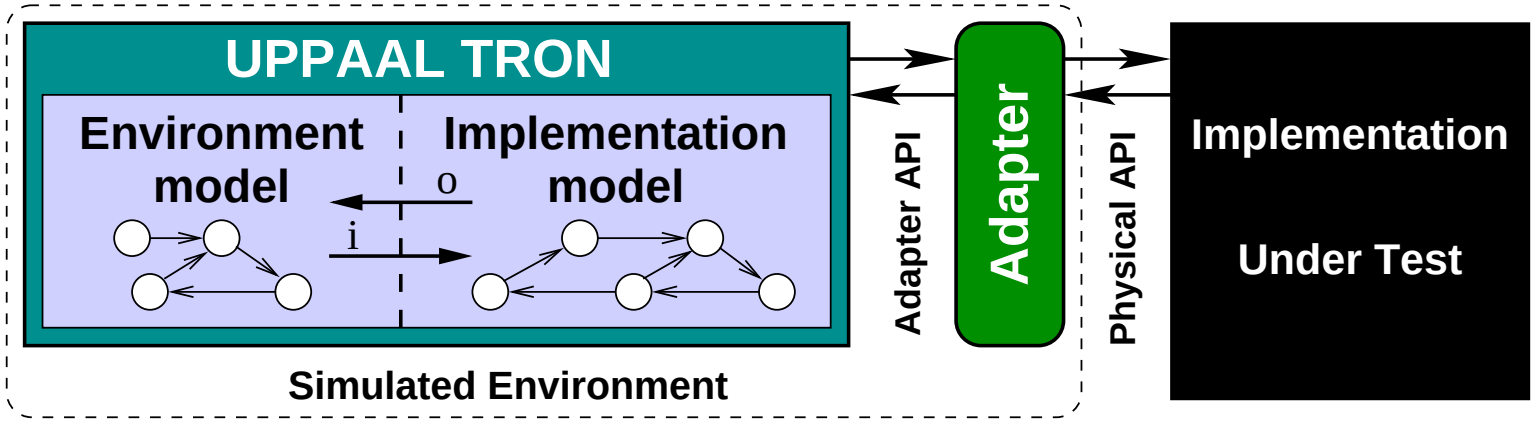
- Black-box, model-based, conformance testing offline.



Online setup: System ⇒ Model ⇒ Testing



UPPAAL TRON Framework



- UPPAAL timed automata specification:
  - Model of (requirements for) implementation,
  - Model of (assumptions about) environment,
  - Contain several concurrent non-deterministic processes.
- Online testing tool:
  - generates test primitives for stimuli (input) with timing,
  - verifies the validity of response (output) with timing,
  - while test primitives are executed online.

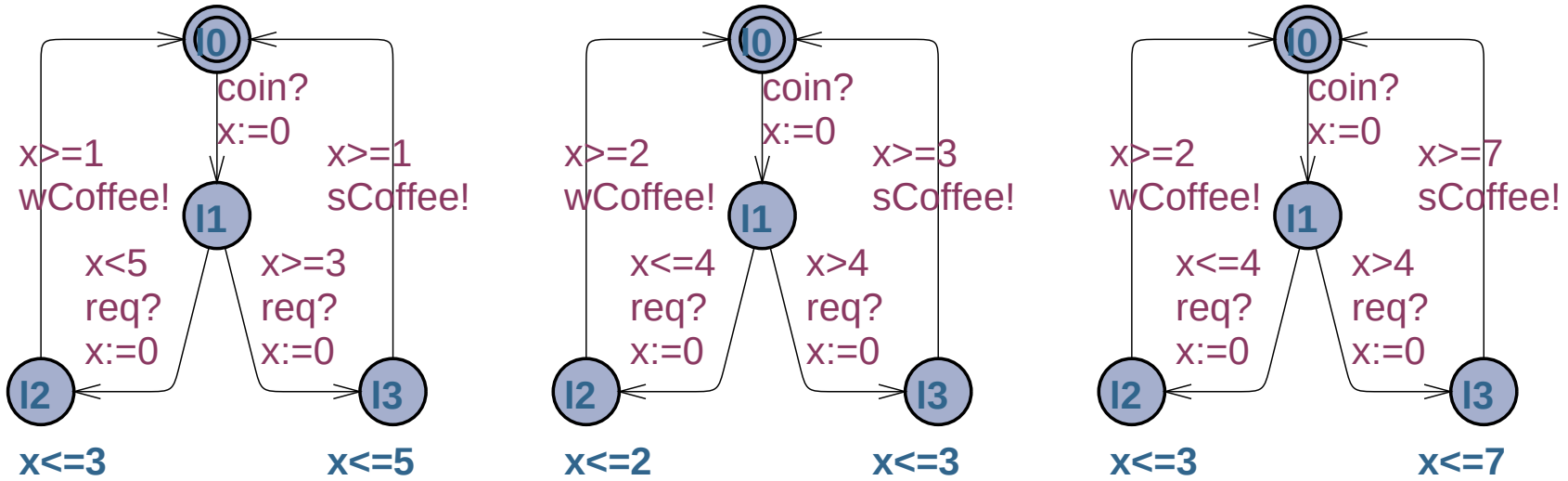
Timed I/O Conformance Relation

- Defines the correctness criteria by analyzing observable traces.
- Intuitively:
  - timed trace e.g.: $\sigma = coin? \cdot 5 \cdot req? \cdot 2 \cdot weakCoffee! \cdot 9 \cdot coin?$
  - observed output should be matched and allowed in specification,
  - timing of observed output should be allowed in specification,
  - any observation outside the specification is a fault.
- Formally:
  - *Timed traces* from state s: $\mathsf{TTr}(s) \stackrel{def}{=} \{\sigma \in (A \cup \mathbb{R}_{\geq 0})^* \mid s \stackrel{\sigma}{\Rightarrow}\}$

    Outputs: $\mathsf{Out}(S) \stackrel{def}{=} \bigcup\{\, \alpha \in (A_{out} \cup \mathbb{R}_{\geq 0}) \mid s \in S.\ s \stackrel{\alpha}{\Rightarrow} \}$
  - Timed Input/Output Conformance relation:

$$m \text{ tioco } s \stackrel{def}{=} \forall \sigma \in \mathsf{TTr}(s).\mathsf{Out}(m \text{ After } \sigma) \subseteq \mathsf{Out}(s \text{ After } \sigma)$$

Timed I/O Conformance Example



Trace, σ	Out$(s$ After $\sigma)$	Out$(i_1$ After $\sigma)$	Out$(i_2$ After $\sigma)$
$c \cdot 2$	$\mathbb{R}_{\geq 0}$	$\mathbb{R}_{\geq 0}$	$\mathbb{R}_{\geq 0}$
$c \cdot 4 \cdot r \cdot 1$	$\{wCoffee, sCoffee\} \cup [0,4]$	$[0,1]$	$[0,2]$
$c \cdot 4 \cdot r \cdot 2$	$\{wCoffee, sCoffee\} \cup [0,3]$	$\{wCoffee, 0\}$	$\{wCoffee\} \cup [0,1]$
$c \cdot 5 \cdot r \cdot 3$	$\{sCoffee\} \cup [0,2]$	$\{sCoffee, 0\}$	$[0,4]$
$c \cdot 5 \cdot r \cdot 5$	$\{sCoffee, 0\}$	$\emptyset$	$[0,2]$

Relativized Timed I/O Conformance

- Testing in *relation* to specific assumptions about *environment*.
- Relativized Timed Input/Output Conformance:

$$m \text{ rtioco}_e \ s \stackrel{def}{=} \forall \sigma \in \mathsf{TTr}(e).\mathsf{Out}\big((e,m) \text{ After } \sigma\big) \subseteq \mathsf{Out}\big((e,s) \text{ After } \sigma\big)$$

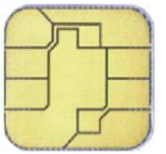
- Under certain conditions, rtioco is the same as *trace inclusion*:

$$m \text{ rtioco}_e \ s \iff \mathsf{TTr}(m) \cap \mathsf{TTr}(e) \subseteq \mathsf{TTr}(s) \cap \mathsf{TTr}(e)$$

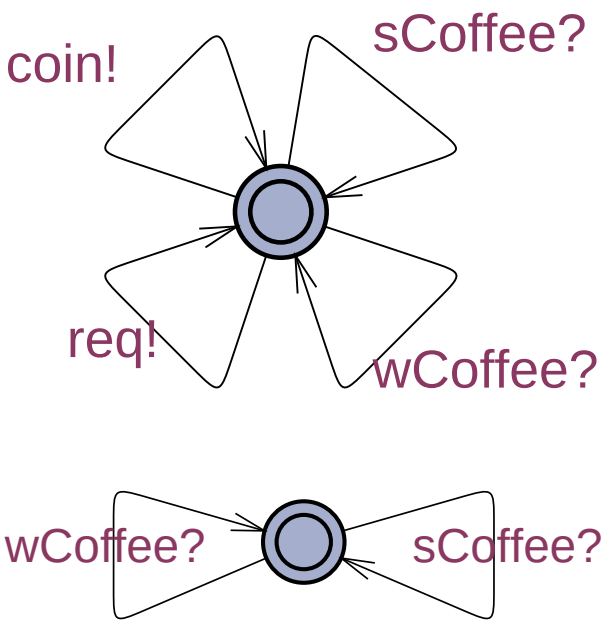
- *Ordering*: g is stronger than f:

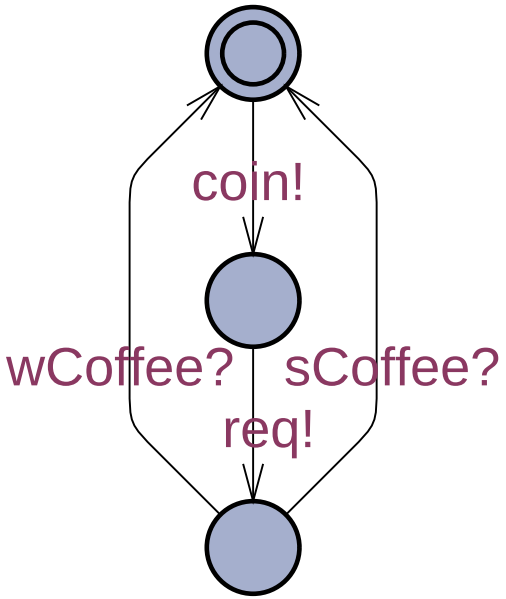
$$g \sqsubseteq f \stackrel{def}{=} \mathsf{TTr}(g) \subseteq \mathsf{TTr}(f)$$

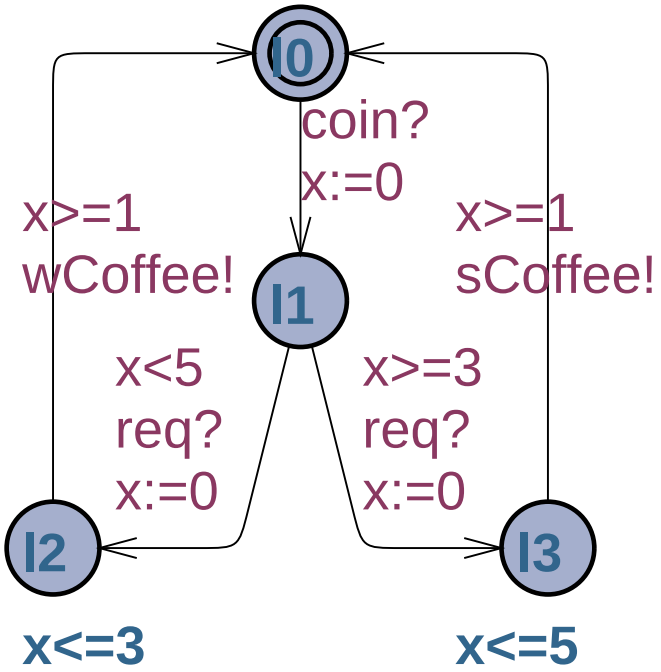
- Allows to *reuse testing effort*, assuming m rtioco$_e$ s:
  - Stronger environment e': if $e' \sqsubseteq e$ then m rtioco$_{e'}$ s.
  - Weaker specification s': if $s \sqsubseteq s'$ then m rtioco$_e$ s'.

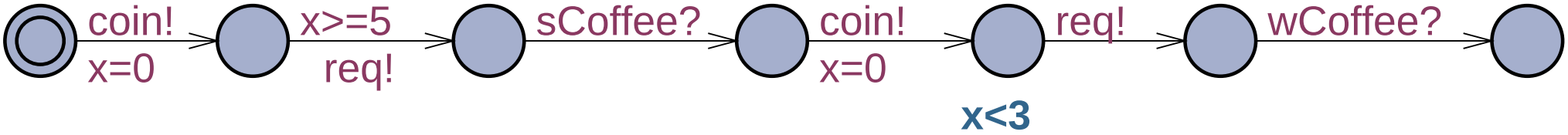


Relativized Conformance Example

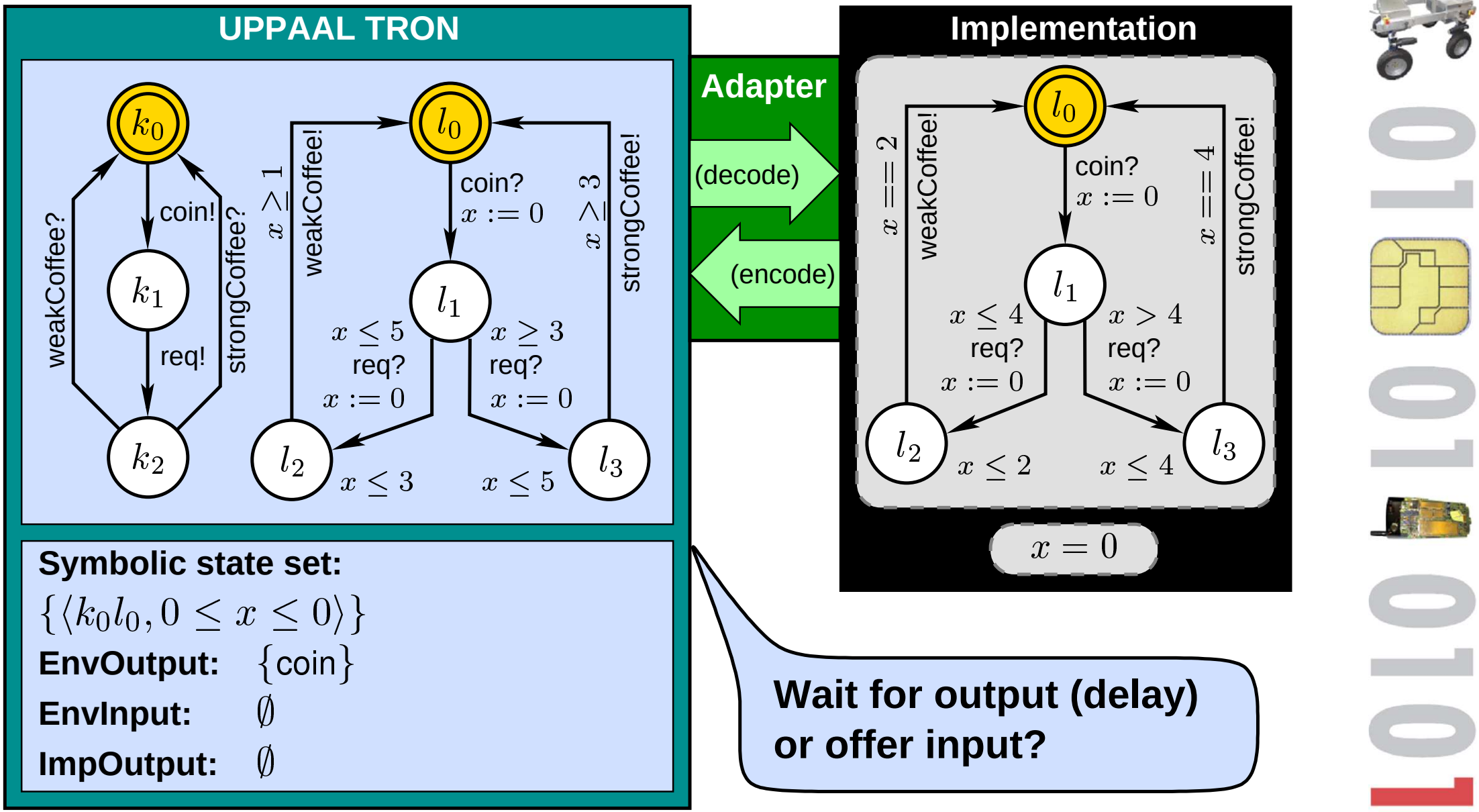








Online Test in Action



Symbolic state set:

$\{\langle k_0 l_0, 0 \leq x \leq 0 \rangle\}$

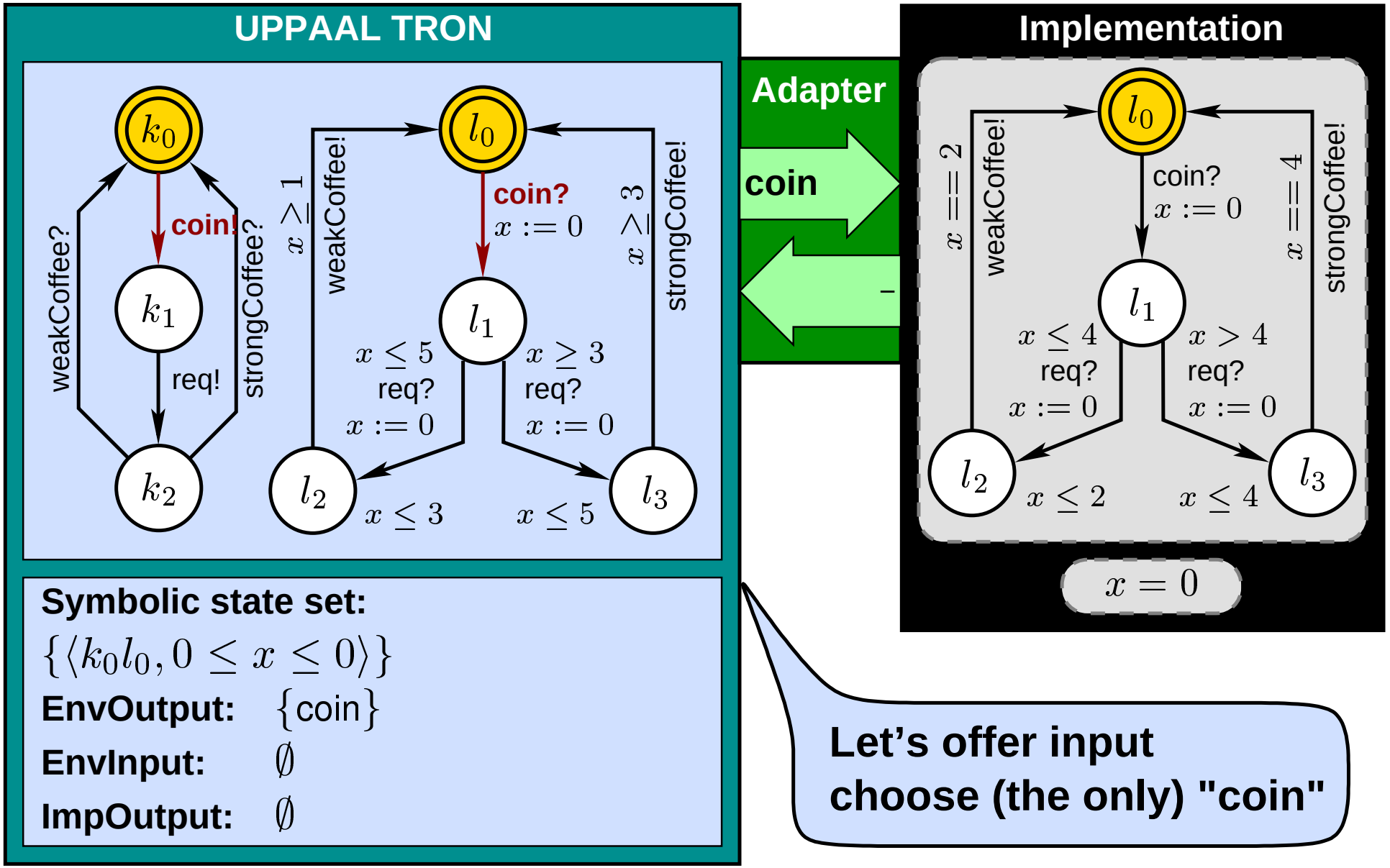
EnvOutput: $\{\text{coin}\}$

EnvInput: $\emptyset$

ImpOutput: $\emptyset$

Wait for output (delay) or offer input?

Online Test in Action



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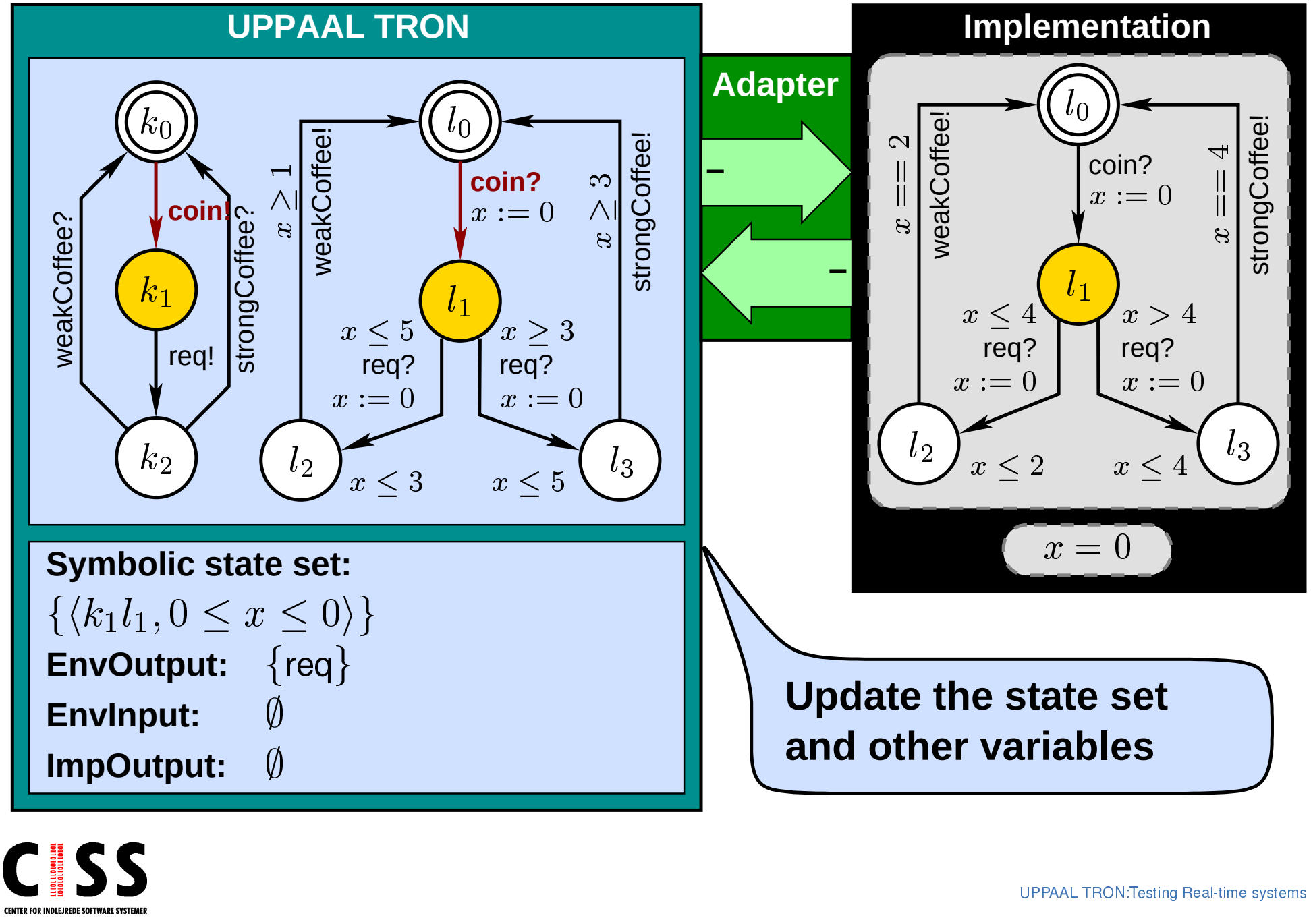

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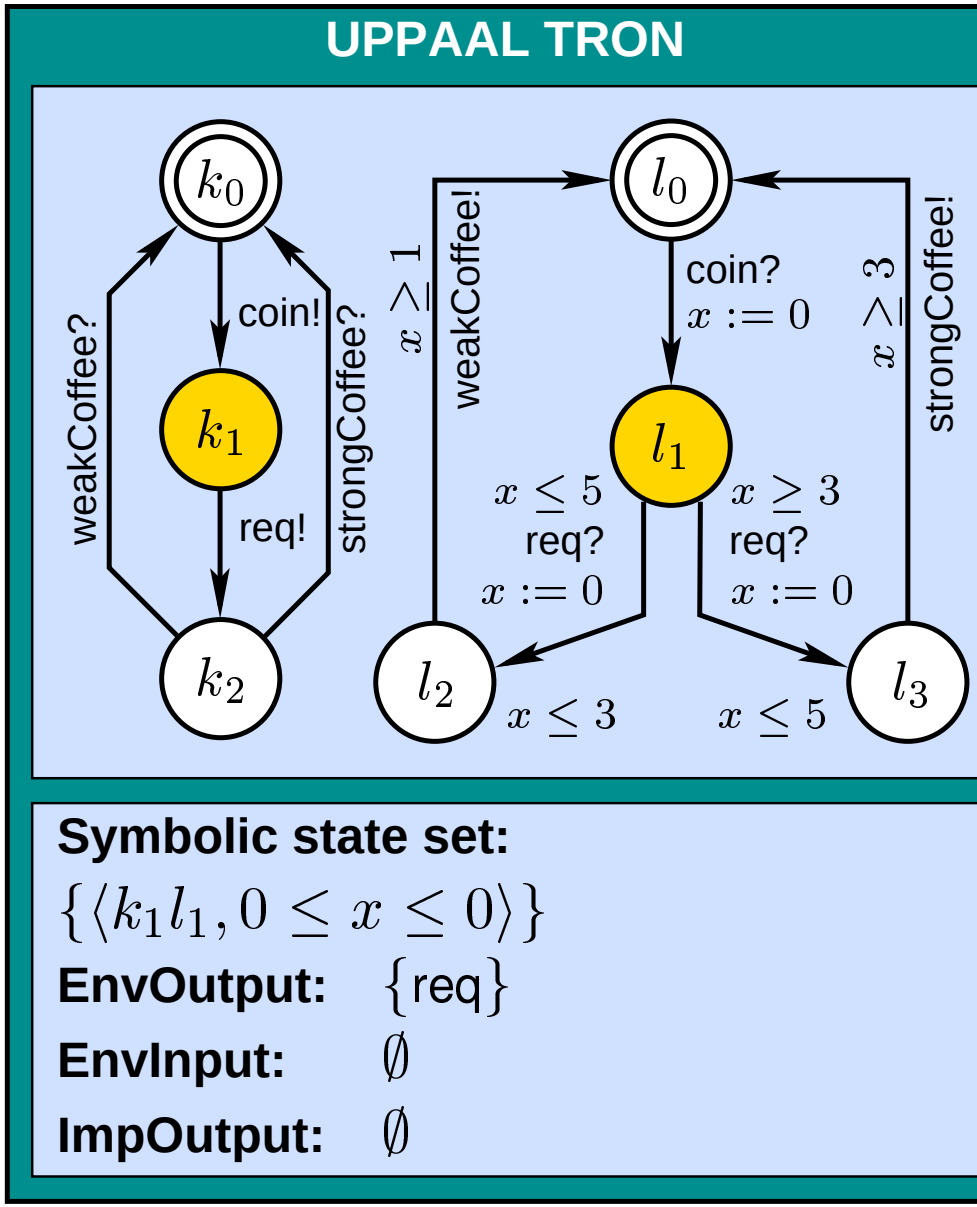
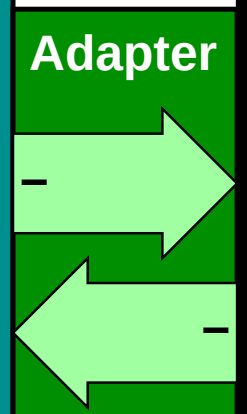
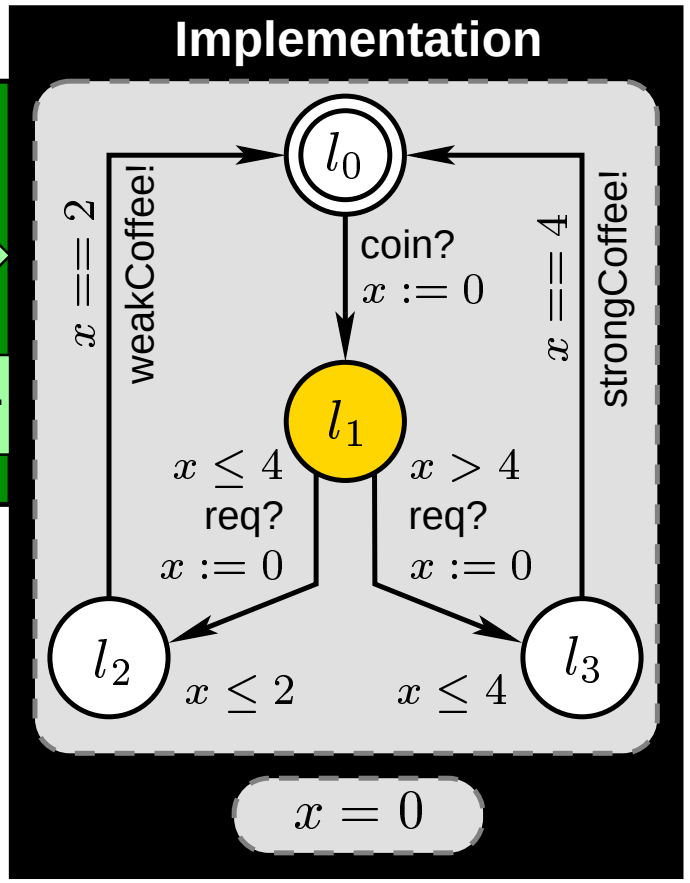
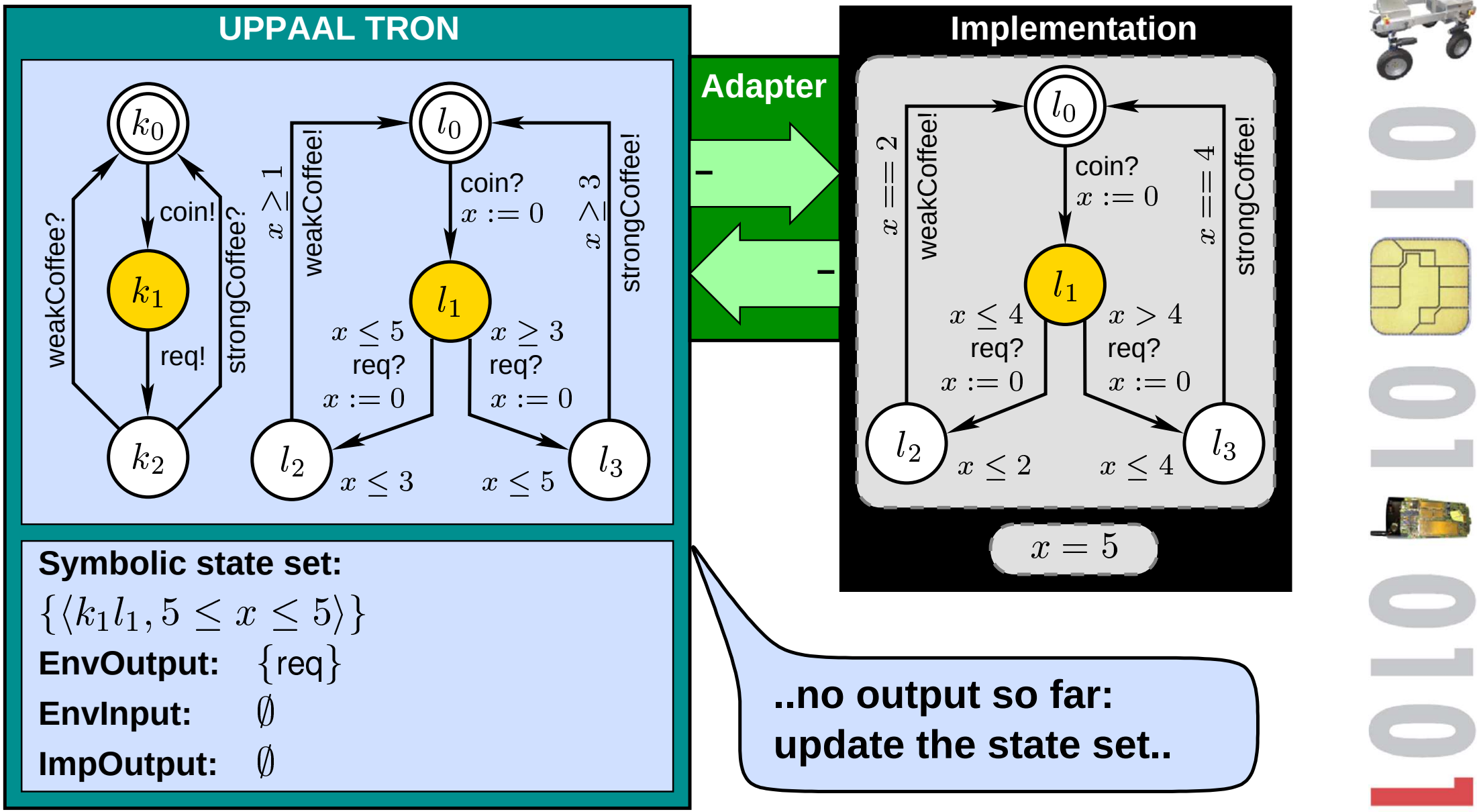






Wait or offer input?
Let's wait for 5 units

Online Test in Action



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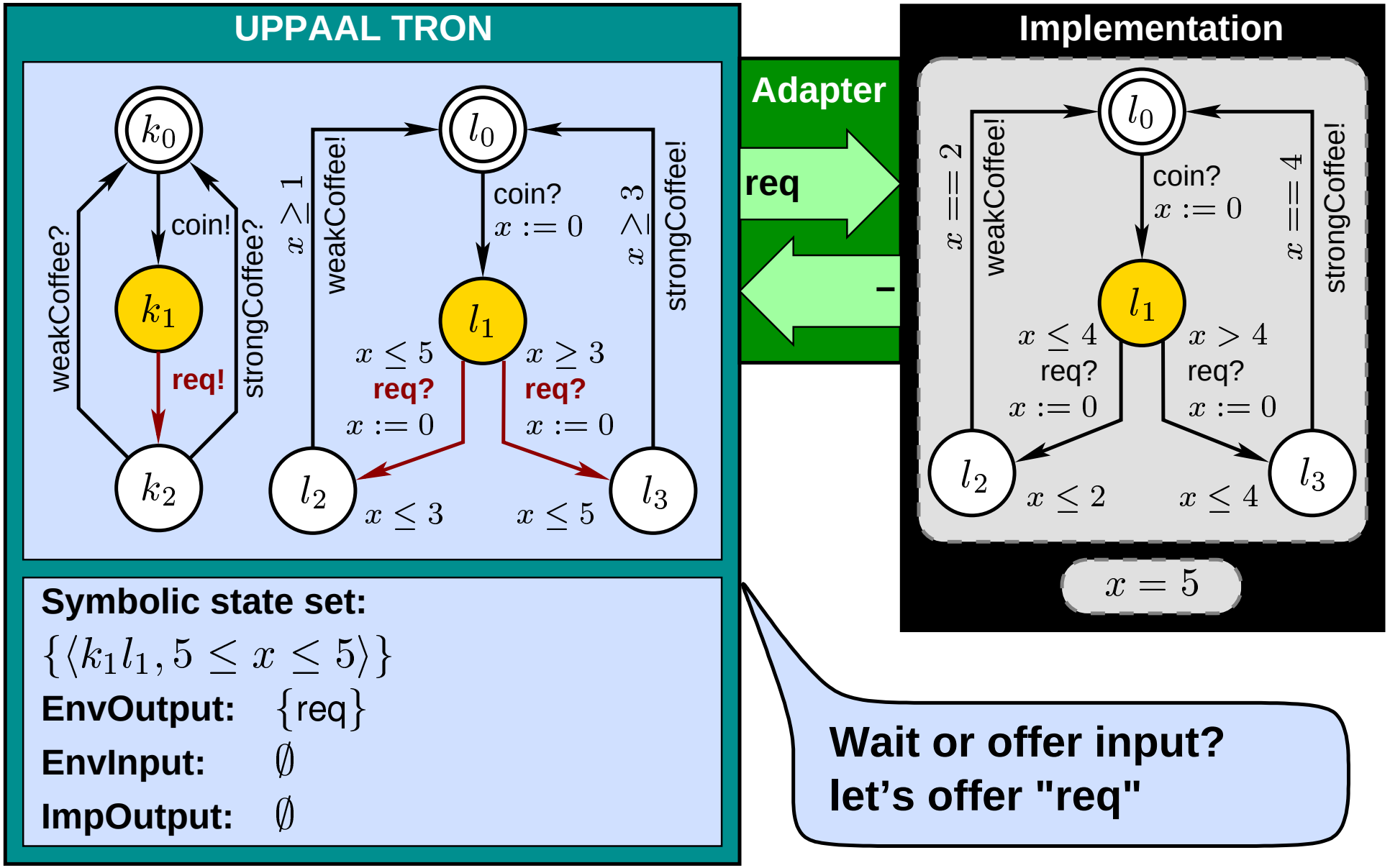

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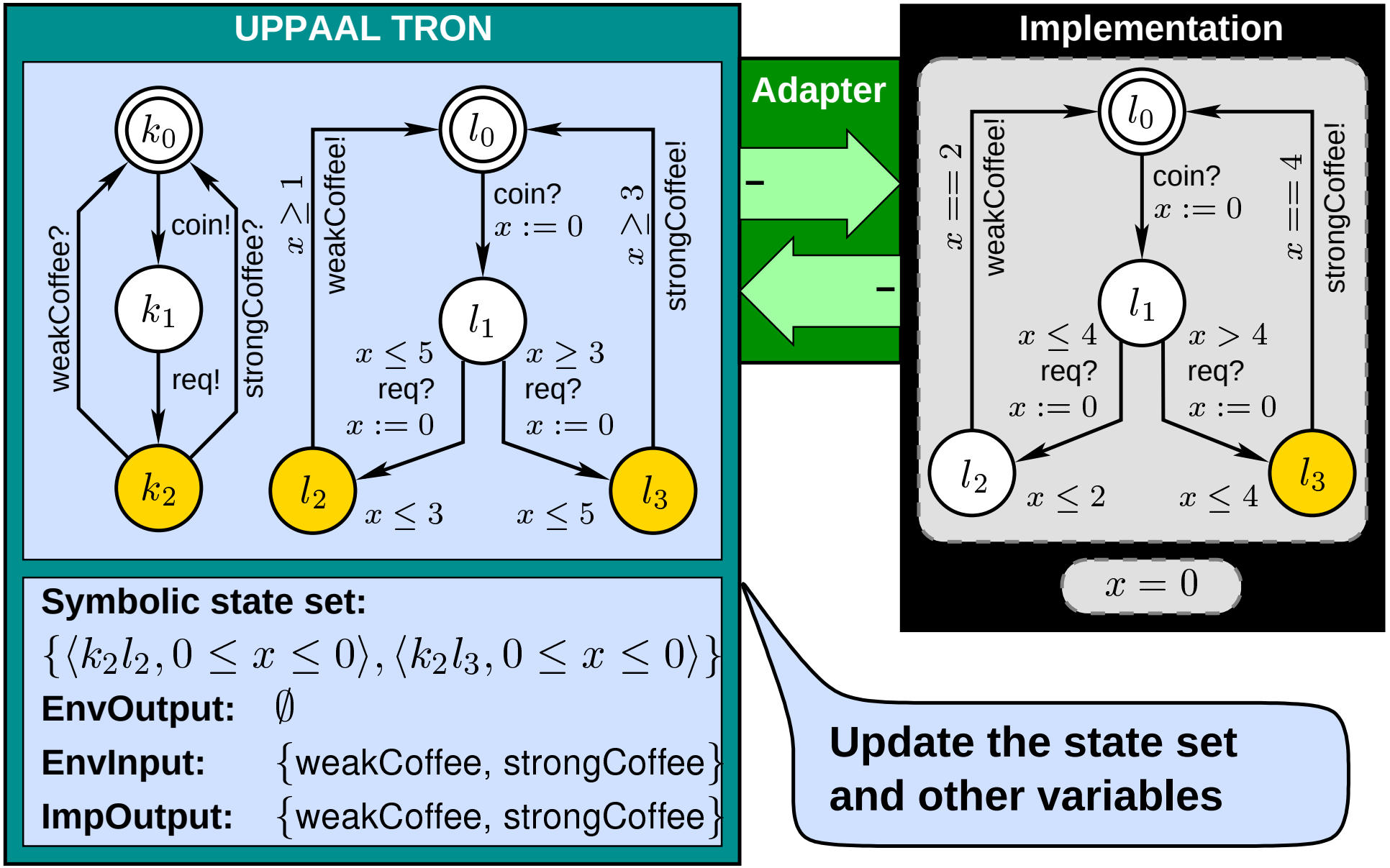

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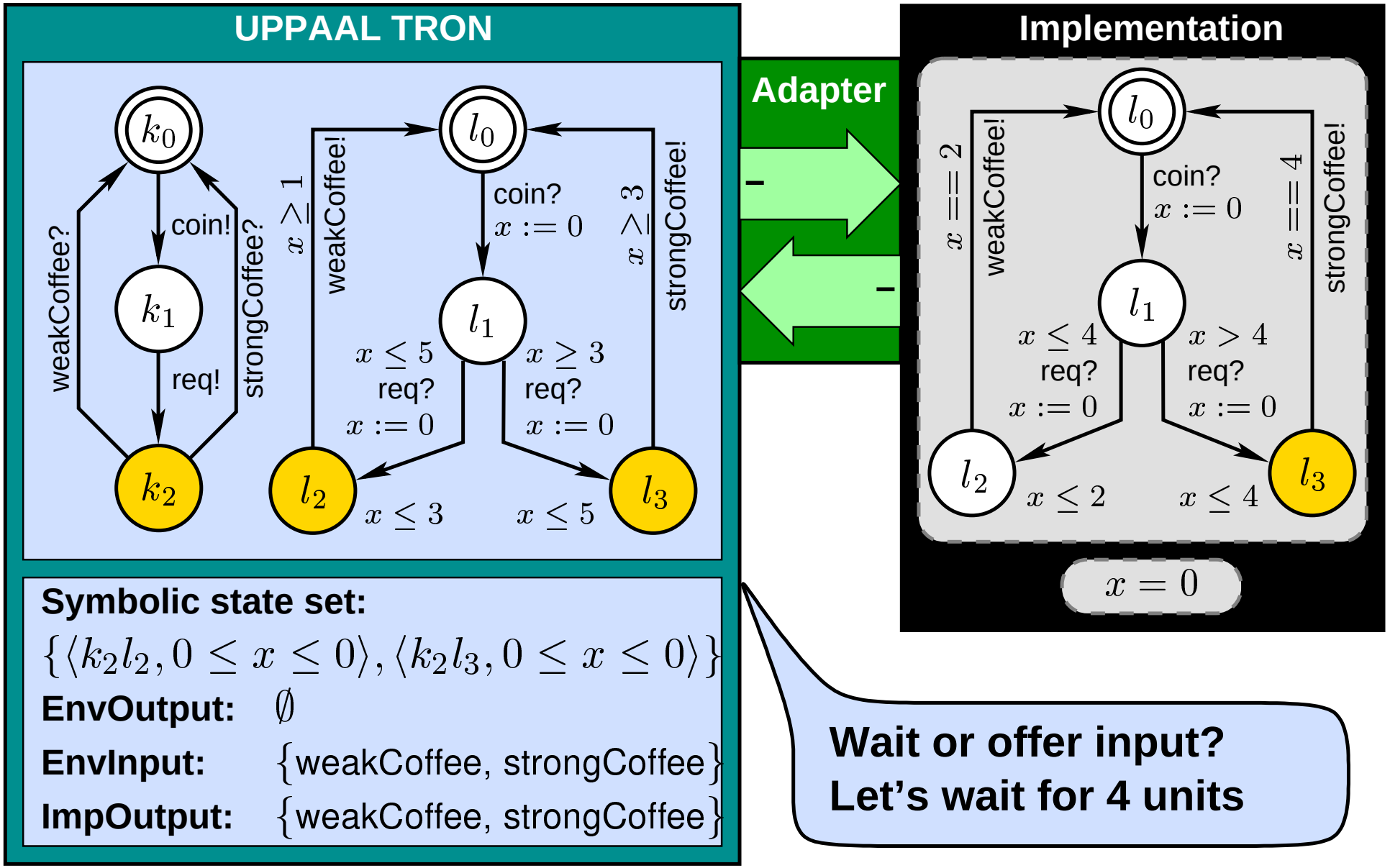

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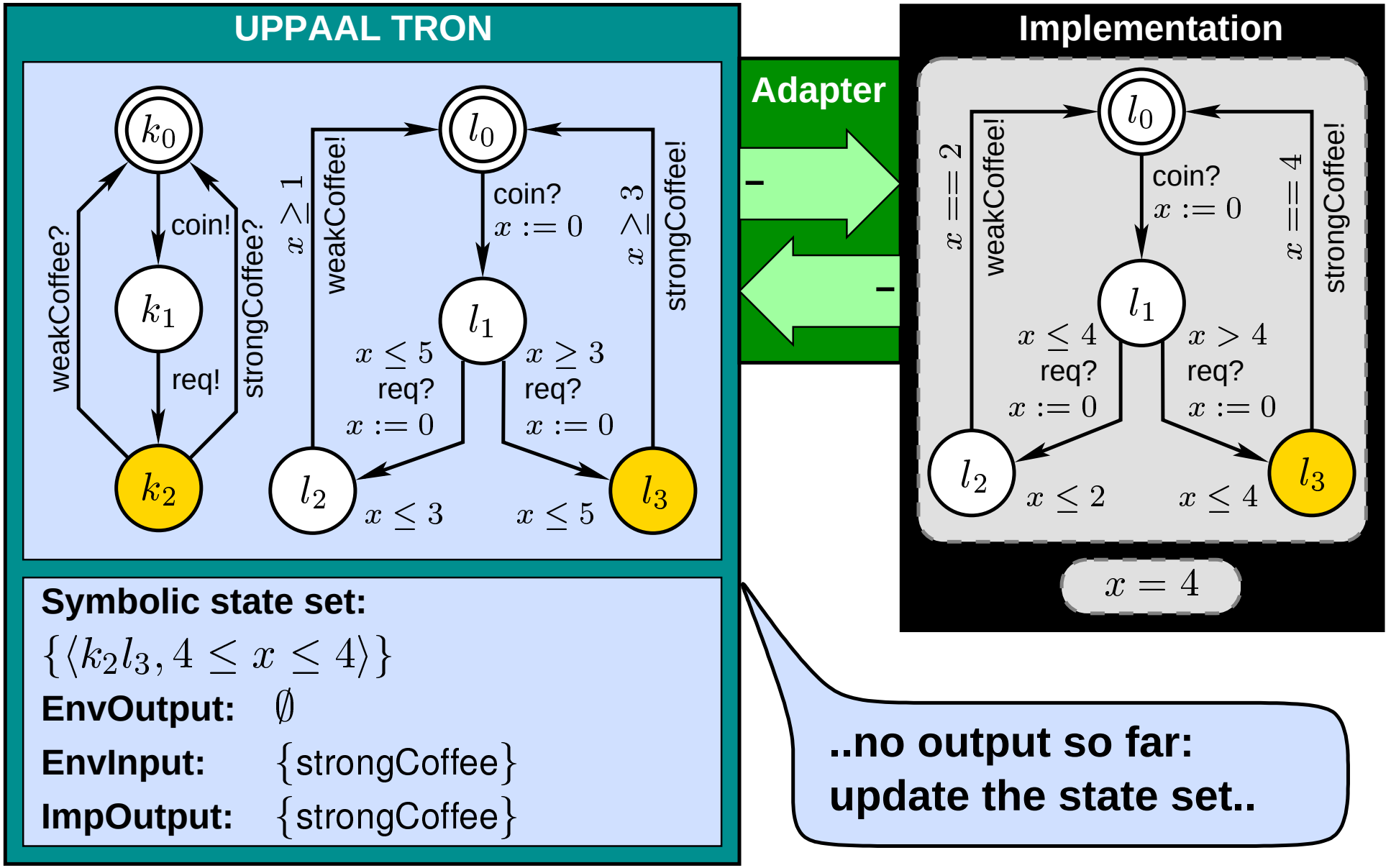

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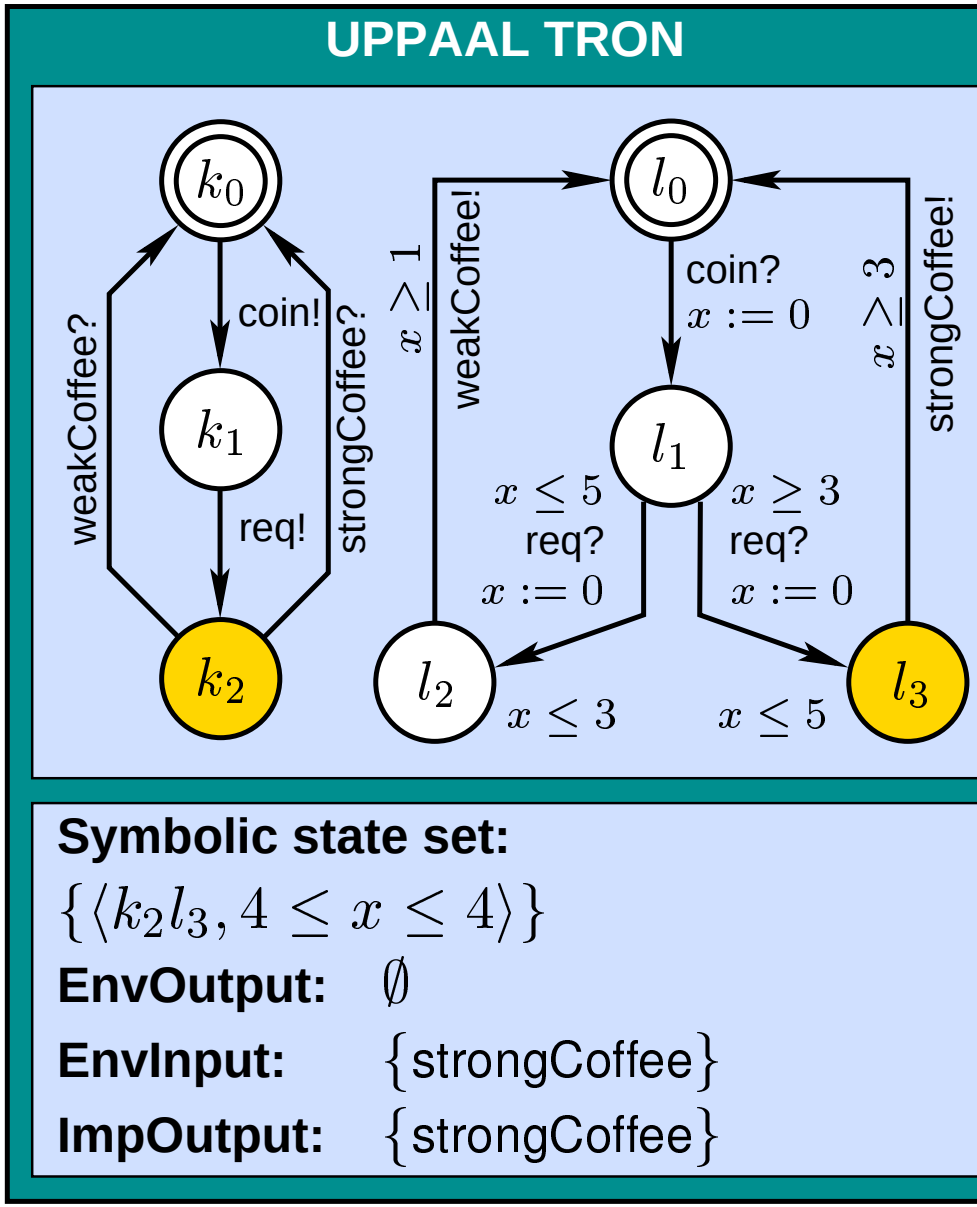
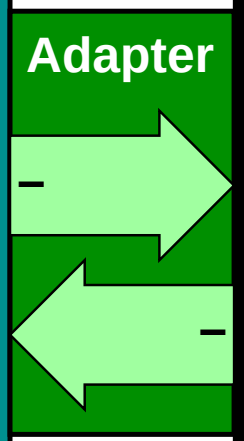
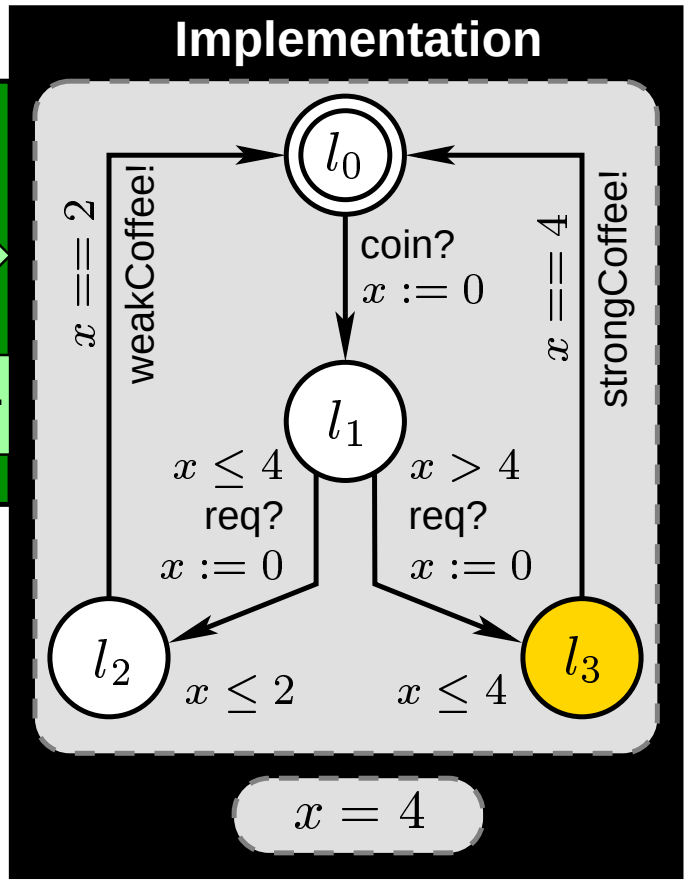
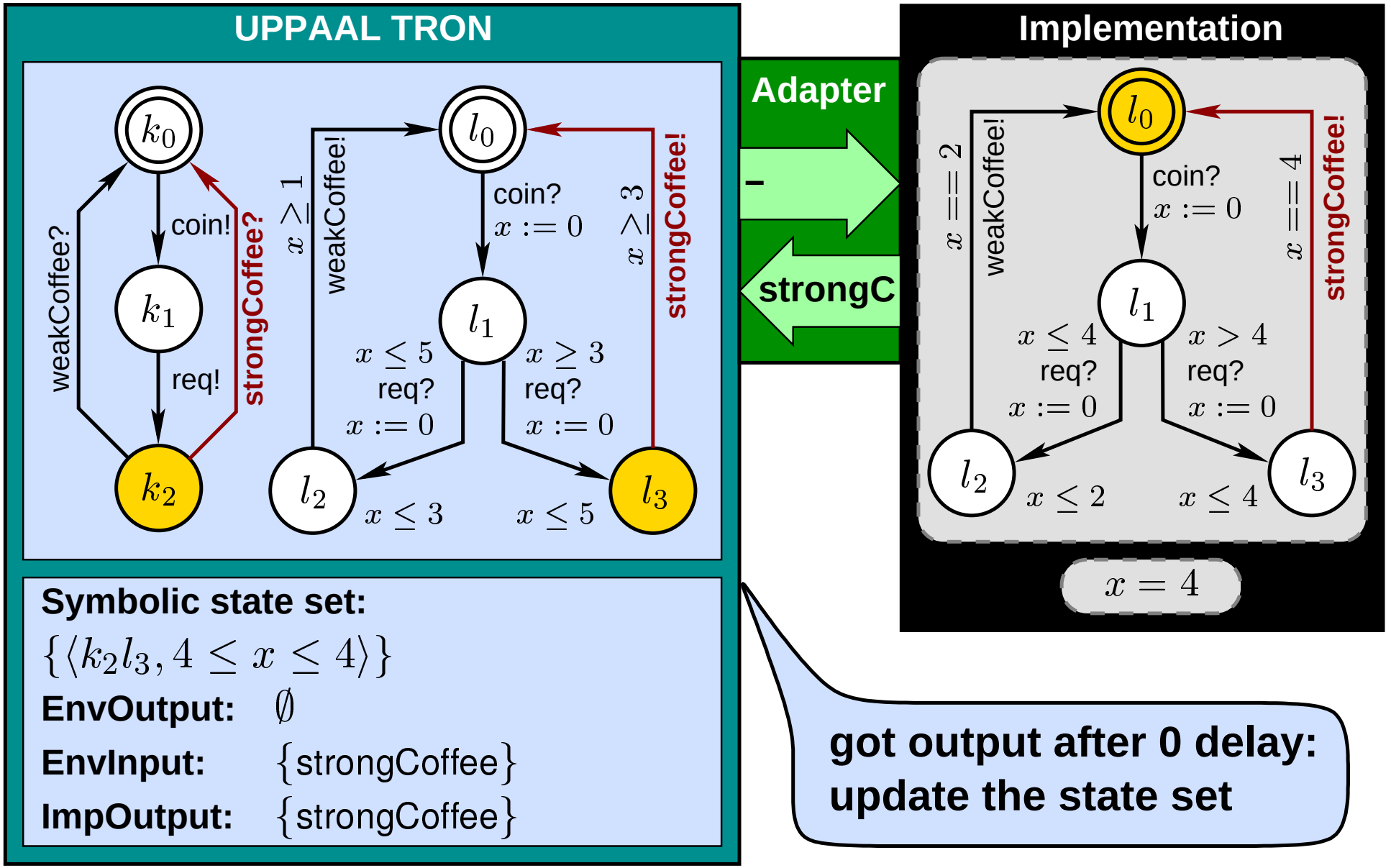






Wait or offer input?
Let's wait for 2 units

Online Test in Action



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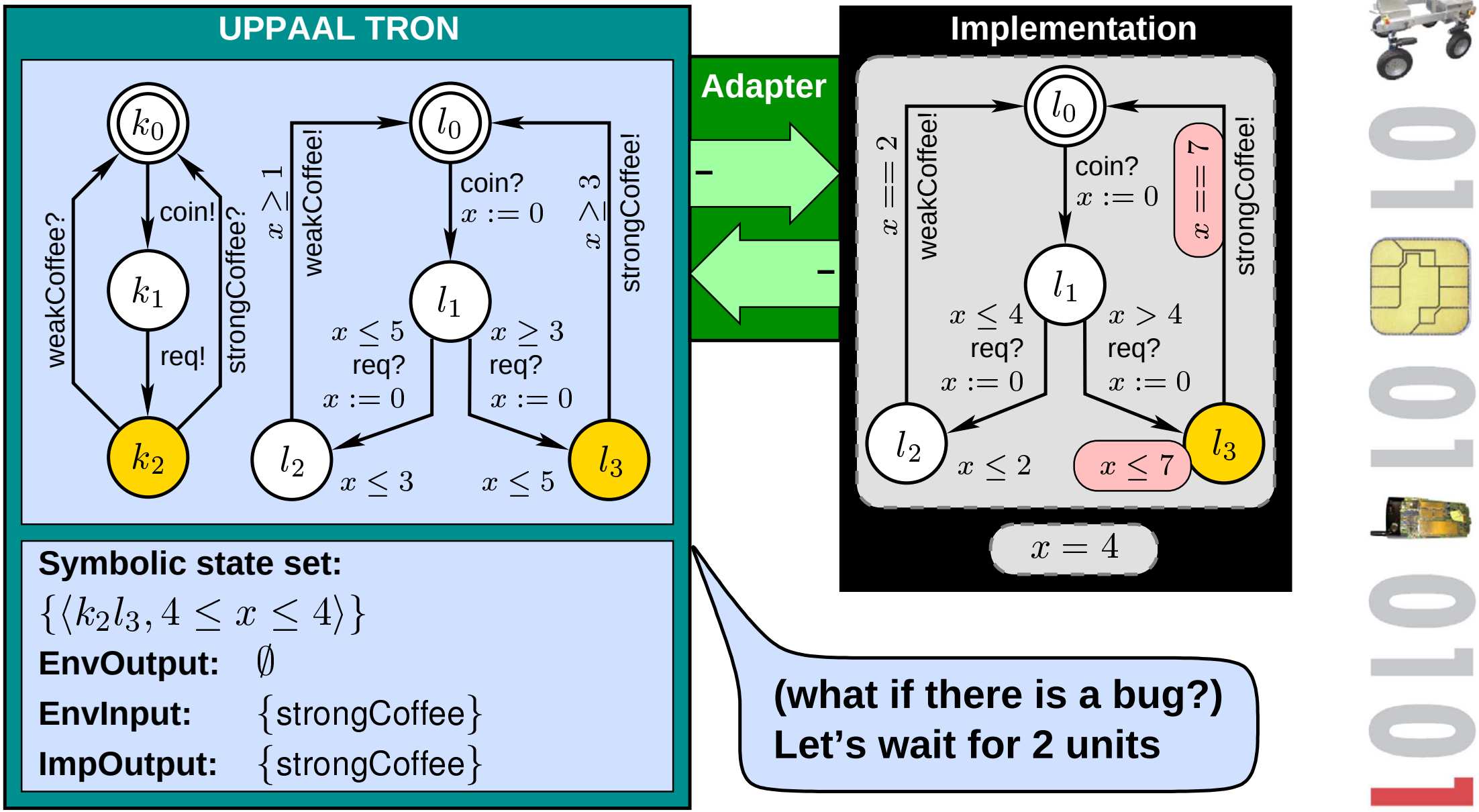

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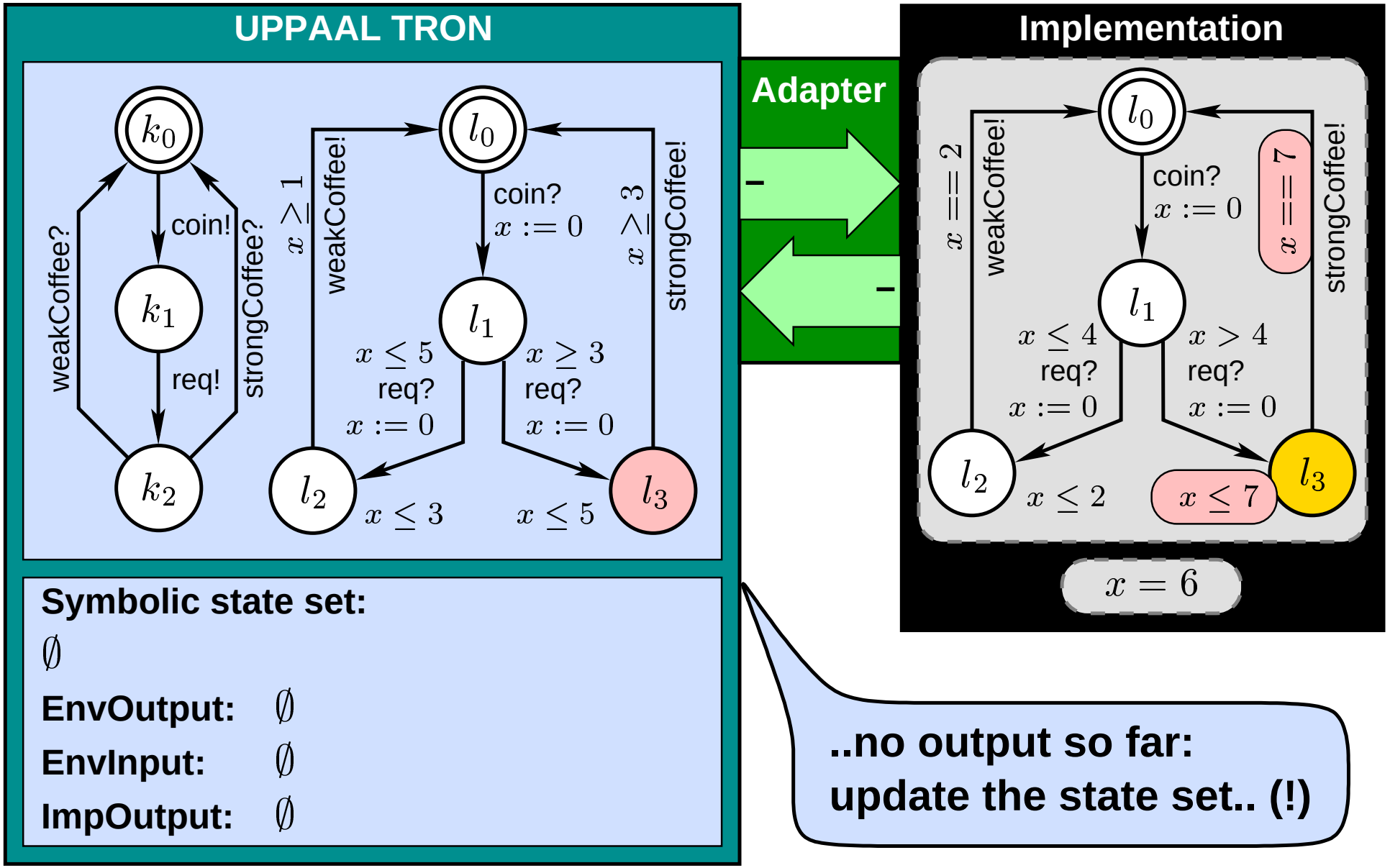
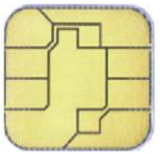


Online Test Algorithm

while $\mathcal{Z} \neq \emptyset \wedge \sharp iterations \leq T$ **do** choose randomly:

1. **if** EnvOutput$(\mathcal{Z}) \neq \emptyset$ // offer an input
   randomly choose $a \in$ EnvOutput$(\mathcal{Z})$
   send a to IUT
   $\mathcal{Z} := \mathcal{Z}$ After a
2. randomly choose $\delta \in$ Delays$(\mathcal{Z})$ // wait for an output
   sleep for δ time units and wake up on output o
   if o occurs at $\delta' \leq \delta$ **then**
      $\mathcal{Z} := \mathcal{Z}$ After δ'
      if $o \notin$ ImpOutput$(\mathcal{Z})$ **then return fail**
      else $\mathcal{Z} := \mathcal{Z}$ After o
   else $\mathcal{Z} := \mathcal{Z}$ After δ // no output within δ delay
3. $\mathcal{Z} := \{(s_0, e_0)\}$, **reset** IUT //reset and restart

if $\mathcal{Z} = \emptyset$ **then return fail else return pass**

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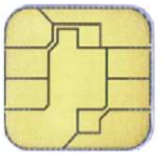
sound and complete in limit

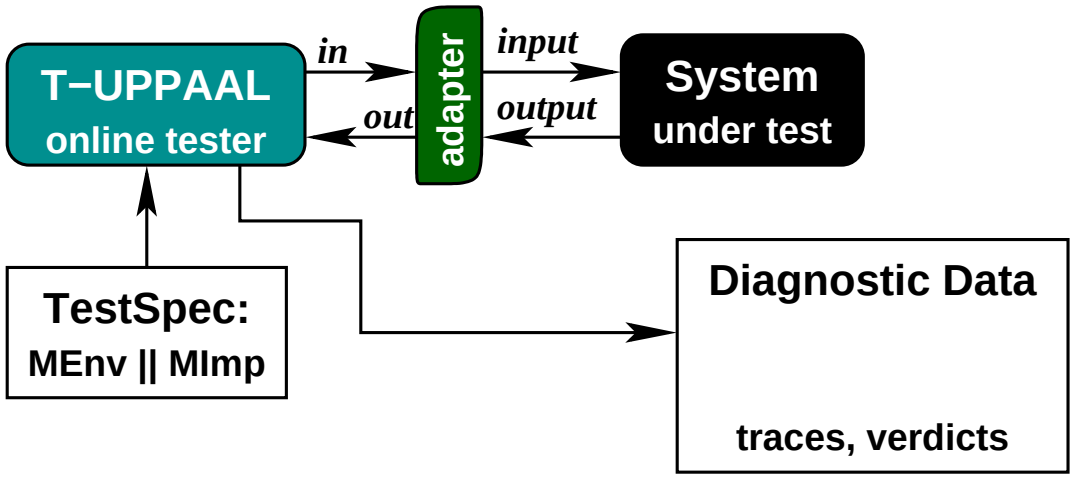



Conclusions

- Online real-time testing theoretically *sound* and *complete*.
- Relativized conformance provides:
  - Explicit environment assumptions
  - Realism and guiding
  - Separation of concerns
  - Modularity
  - Theoretical properties
- Implementation:
  - Allows *abstract* and *non-deterministic* specifications
  - Shows encouraging *error detection* capability and *performance*
  - Using UPPAAL model-checker constructs, online testing setup can also be applied to other model-checker.

Summary and Future Work



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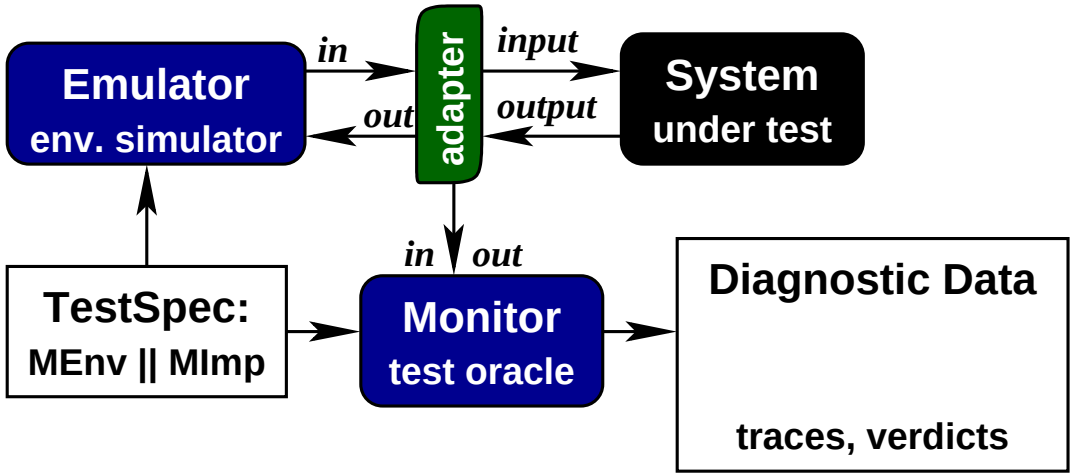

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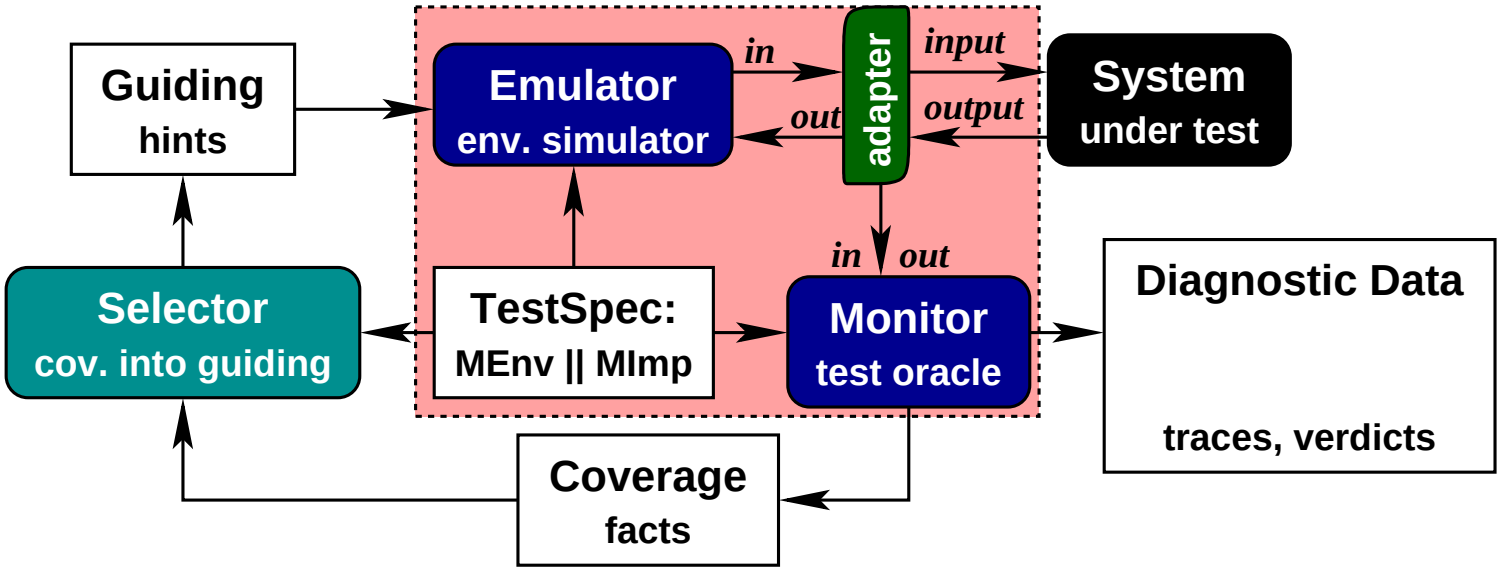

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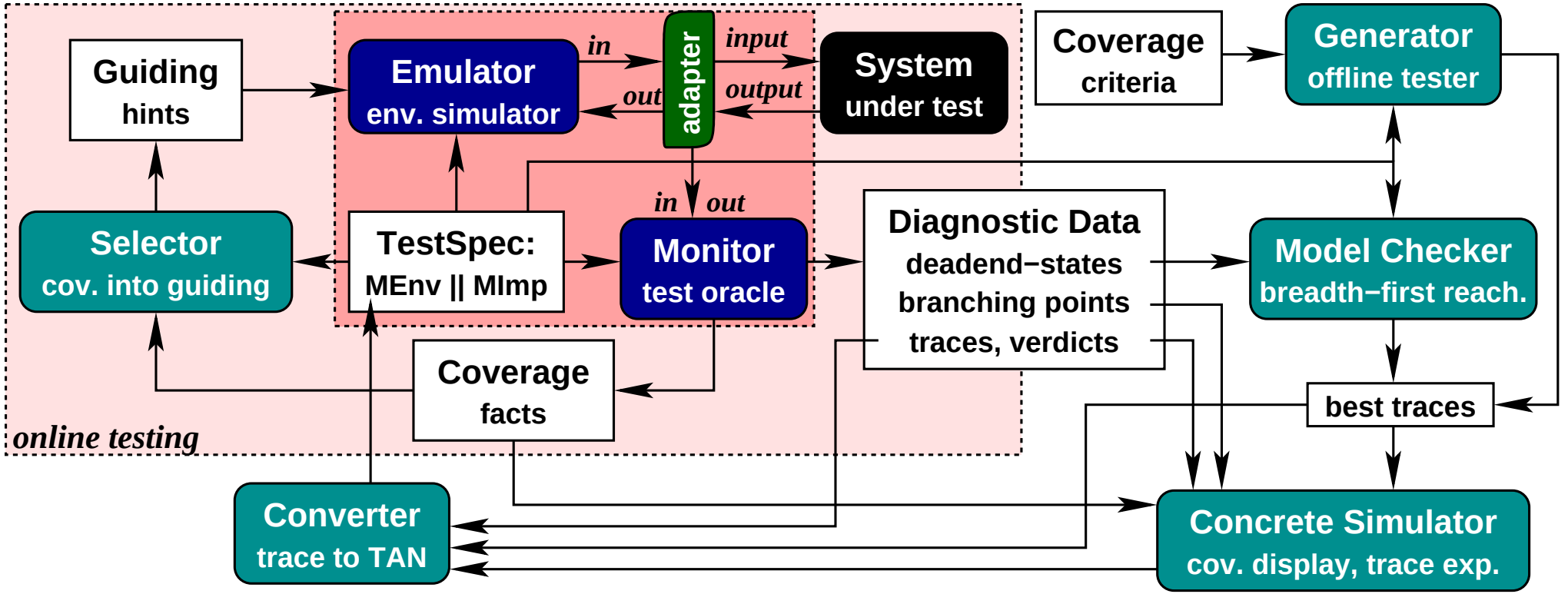

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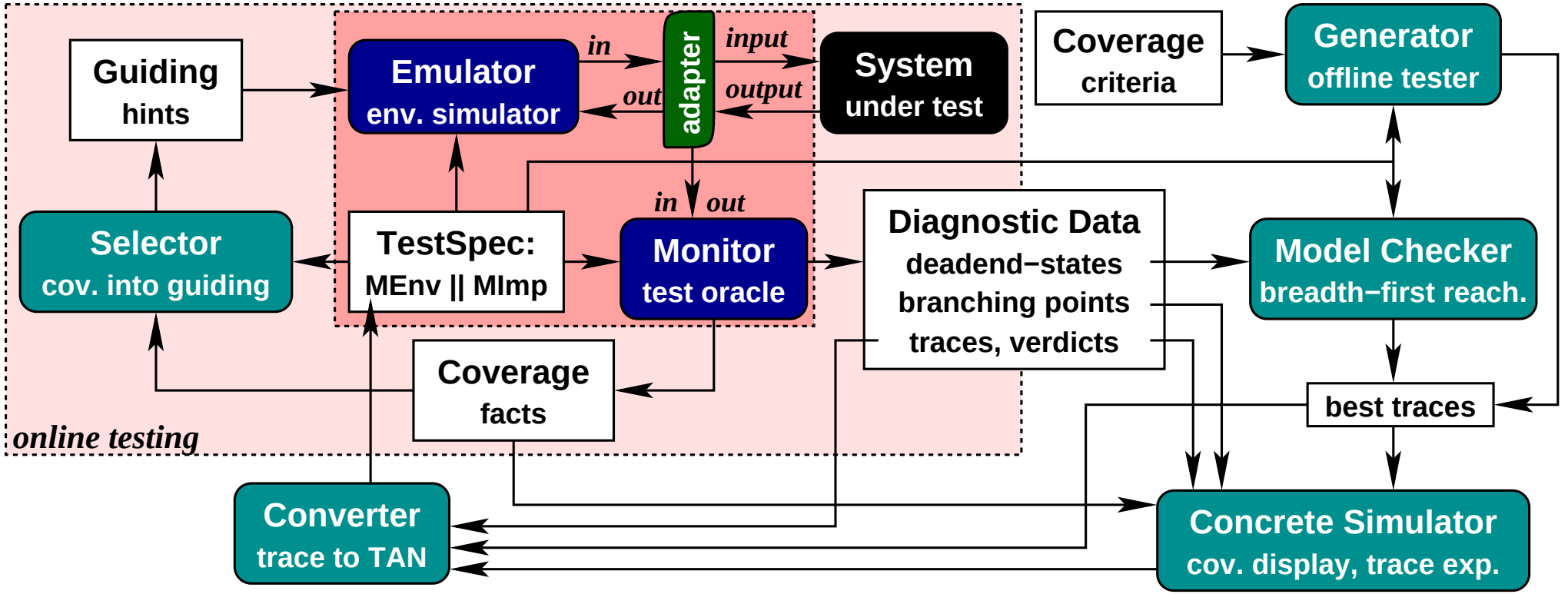
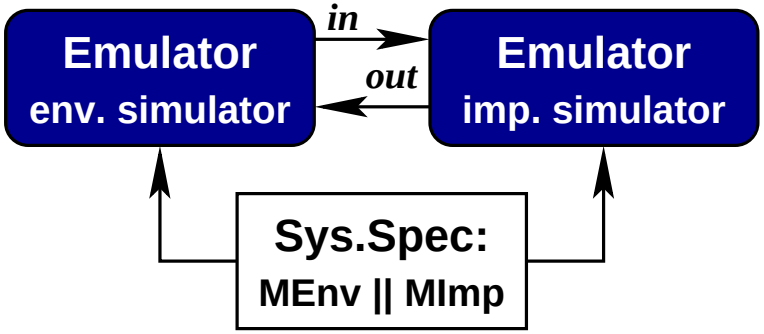
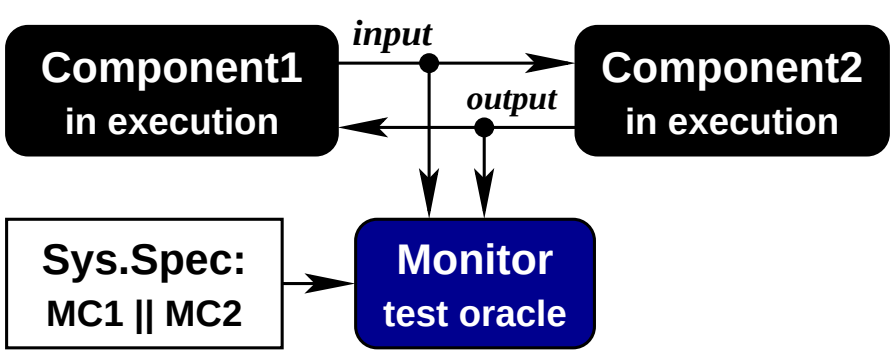


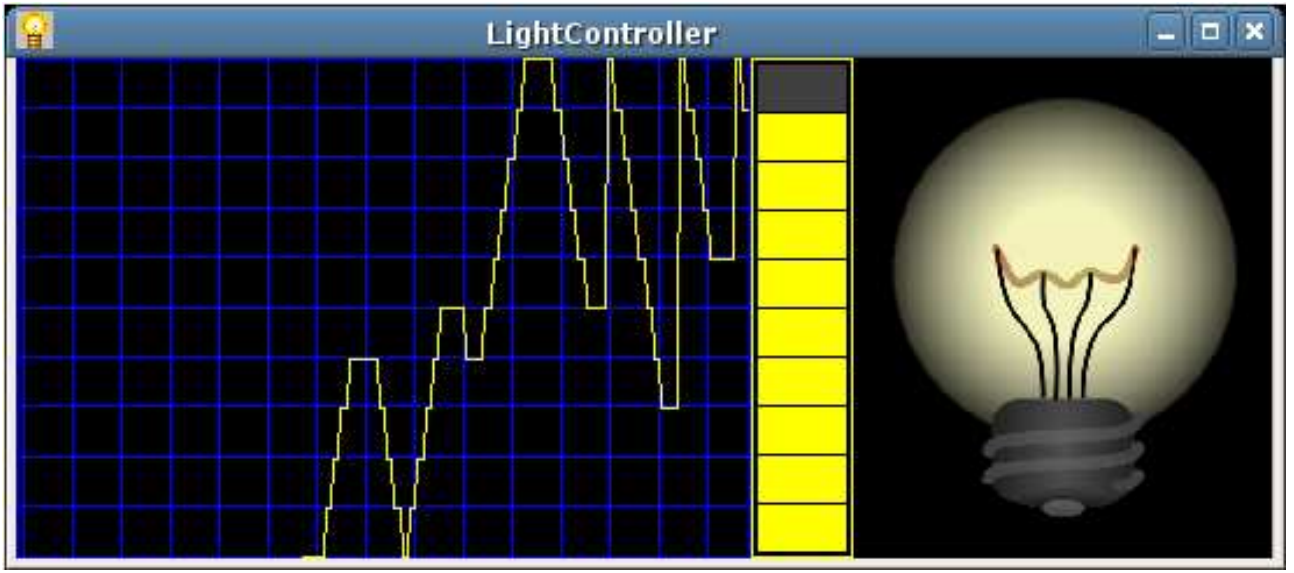
Prototyping via simulation:



Execution monitoring:



Demo of Java "Light Controller"



Supported Platforms

Compiled for the following operating systems:

- POSIX: Linux on Intel and Sun Solaris on Sparc
- Windows 2000/XP (and probably will work on others)

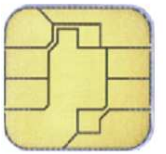
Currently available adapters:

- C dynamically linked library
- Text via standard input-output streams
- TCP/IP client-server sockets:
  C/C++ and Java implementations

Danfoss Refrigeration Controller

Beyond timed automata...

- From EKC manual: controller calculates the current temperature about every second via: $T_n = 80\% \cdot T_{n-1} + 20\% \cdot T_{sensor}$
- New manual: sensor values are calibrated during deployment to increase the precision from $0.5°$ to $0.1°$ using new Pt sensors.
- Display temperature can be roughly described by:
  $\frac{dT}{dt} = 0.2 \cdot (T_s - T) \qquad \Rightarrow \qquad T(t) = T_0 + \alpha_{T_s} \cdot e^{-\beta_{T_s} \cdot t}$
- The display temperature update interval varies and sampling is performed on a soft-real-time system $\Rightarrow$ difficult to model accurately (in timed automata with integers).
- PHAVer is more natural in modeling the dynamic behavior:
  $T_{sensor} > T: \quad 0.15 \cdot (T_{sensor} - T) \leq T' \leq 0.6 \cdot (T_{sensor} - T)$
  $T_{sensor} < T: \quad 0.6 \cdot (T_{sensor} - T) \leq T' \leq 0.15 \cdot (T_{sensor} - T)$

Monitoring EKC as HS using PHAVer