CPSGrader: A Tutorial

Version 0.1

University of California, Berkeley

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Outline

“Grading” a Cyber-Physical System (CPS) Model Design

Purpose of grading

1. Does the design meet the assignement ?

   $\rightarrow$ Verification problem (model checking).
2. In case of imperfect design, provide a hint/explanation of what is wrong.

   $\rightarrow$ Fault identification and localization problem.

- Both are hard problems, especially for CPS.
- CPSGrader takes a simple/scalable route by reducing verification and fault identification to testing using a library of fault models
- This document describes the specification language used (Signal Temporal Logic) and how to write tests.

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- A more tractable approach: simulation + monitoring

$$\boxed{\text{Model}} \longrightarrow \text{trace:}\, aaaabbbaa \ldots \longrightarrow \boxed{\text{Property } \varphi} \longrightarrow \mathit{true}/\mathit{false}$$

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Example:

w	a	a	a	b	b	a	a	a	$\ldots$
a	$true$	$true$	$true$	$false$	$false$	$true$	$true$	$true$	$\ldots$
b	$false$	$false$	$false$	$true$	$true$	$false$	$false$	$false$	$\ldots$
$X\ b$	$false$	$false$	$false$	$true$	$true$	$false$	$false$	$?$	$\ldots$

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Xb	*false*	*false*	*true*	*true*	*false*	*false*	*false*	?	$\dots$
G a	*false*	*false*	*false*	*false*	*false*	*true?*	*true?*	*true?*	$\dots$

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F b	$true$	$true$	$true$	$true$	$true$	$false?$	$false?$	$false?$	$\dots$

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G a	*false*	*false*	*false*	*false*	*false*	*true?*	*true?*	*true?*	...
F b	*true*	*true*	*true*	*true*	*true*	*false?*	*false?*	*false?*	...
a $\mathbf{U}$ b	*true*	*true*	*true*	*false*	*false*	*false?*	*false?*	*false?*	...

From LTL to STL

Extension of LTL with real-time and real-valued constraints

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MTL G(r $=>$ F$_{[0,.5s]}$ g)

Boolean predicates, real-time

STL G($x[t] > 0$ $=>$ F$_{[0,.5s]}$ $y[t] > 0$)

Predicates over real values , real-time

STL: Syntax

Signals are functions from $\mathbb{R}^n$ to $\mathbb{R}$.

E.g.: positions (x,y,z), orientation θ, sensor values (acc. ax,ay,az), etc.

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Temporal operators are $\mathbf{F}$, $\mathbf{G}$, $\mathbf{U}$, equiped with a time interval

e.g. $\mathbf{F}_{[0,2]}(x[t] > 0.5)$, $\mathbf{G}_{[0,40]}(y[t] < 0.3)$, $\varphi\mathbf{U}_{[1,2.5]}\psi$, etc.

STL Semantics

A **formula** φ is true if it is true **at time 0**

A **subformula** ψ is evaluated on **future values** depending on temporal operators

Examples

- $\varphi = (x[t] > 0.5)$ is true iff $x[t] > 0.5$ is true when t is replaced by 0, i.e., at the first value of the signal.

- $\varphi = \mathbf{F}_{[0,1.3]}(x[t] > 0.5)$ is true iff $x[t] > 0.5$ is true when t is replaced by any value in [0,1.3].

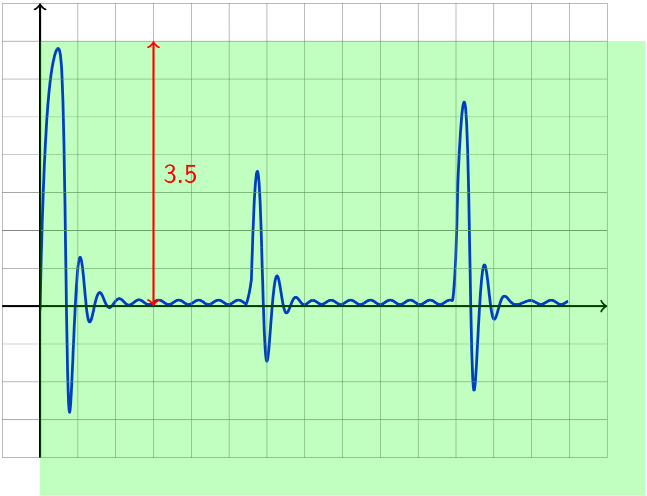
- $\varphi = \mathbf{G}_{[0,1.3]}(\psi)$ is true iff ψ is true at all time in $[0, 1.3]$, i.e., for all suffixes of signals starting at a time in $[0, 1.3]$

STL Examples

STL Examples

The signal is never above 3.5

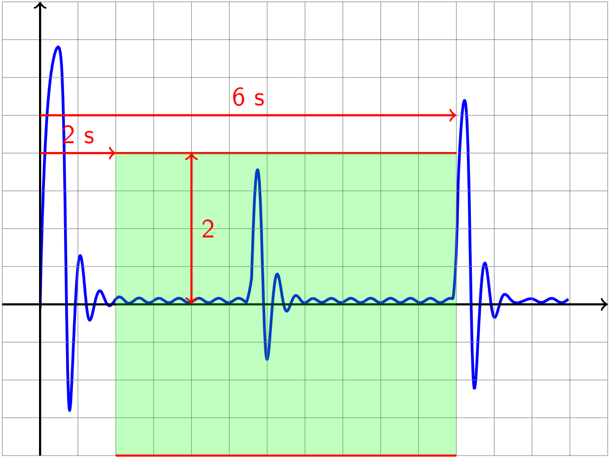
$$\varphi := \mathsf{G}\ (x[t] < 3.5)$$



STL Examples

Between 2s and 6s the signal is between -2 and 2

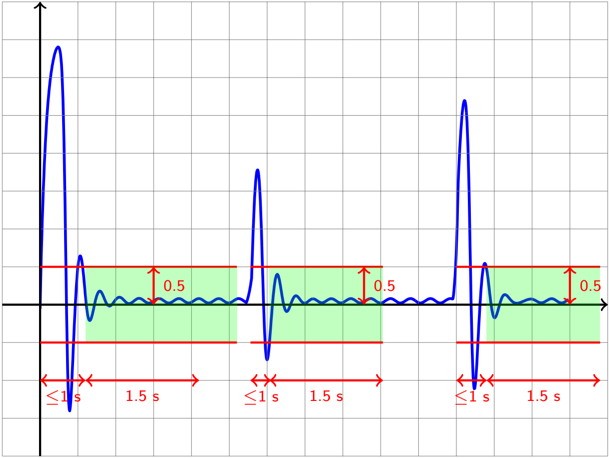
$$\varphi := \ \mathsf{G}_{[2,6]} \ \ (|x[t]| < 2)$$



STL Examples

Always $|x| > 0.5 \Rightarrow$ *after 1 s,* $|x|$ *settles under 0.5 for 1.5 s*

$$\varphi := \mathsf{G}(x[t] > .5 \rightarrow \ \mathsf{F}_{[0,.6]} \ \ (\ \mathsf{G}_{[0,1.5]}\ x[t] < 0.5))$$



Some Theoretical Background

Using CPSGrader

CPSGrader Test Plans

Grading is based on test plans comprizing:

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  System traces obtained in a specific environment setting.
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  STL properties characterizing faults in the design.
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Note that “known faults” should include “not satisfying the design requirement”.

CPSGrader test plans

The general structure of a test plan is as follows:

```
# signal, parameters and formula declarations
...
# test declarations
test test1 {
   fault1 { ...
   fault2 { ...
   ...
}
test test2 {  ...
}
...
test testN { ...
}
```

CPSGrader: Executing Test Plans

CPSGrader will execute test plans as follows

For each test trace
  Get trace $\mathbf{x}$ from simulator
  For each fault with STL formula φ
    Check whether $\mathbf{x} \models \varphi$
    Print feedback
    If fault is critical **then** return
  end
end

CPSGrader: Writing a Test Plan

First, declare signals, parameters and STL formulas and subformulas:

```
# declare signals used in formulas
signal x,y

# Defines some parameters
param y_min= 3., x_max = 5.

# sub formula: defining an (x,y) region which goal is to leave
in_region_to_leave := (y[t]<y_min) or (x[t]>x_max)

# top formula
phi_goal_missed  := alw_[0, 20] (in_region_to_leave)
```

CPSGrader: A concrete example with CyberSim

- Second, define tests and faults. E.g., with CyberSim:

```
# Defining a test
test nav1:"Environment - obstacle south left.xml",20.1,true
{
  fault_goal_missed                     #name of fault
  {phi_goal_missed,                     #formula to monitor
   "PROBLEM:Couldn't avoid obstacle",   #feedback if true
   "",                                  #feedback if false
   true                                 #feedback is critical?
  }
}
```

- Here, `"Environment - obstacle south left.xml,20.1,true"` is a configuration file for CyberSim environment, simulation time and Boolean related to visualization in the CyberSim GUI.
- Using the program `CPSFileGrader` in the `Simulators` folder, a file name for a trace can be specified instead of an XML file.

CPSGrader: Trace Format

Traces in CPSGrader are time-data series in column format, e.g.:

```
0.0  -1.514648  2.5648     0  -3
0.05 -1.514648  3.514648   1  -2
0.15 -1.662522 -21.662522 2  -1
0.25 -1.746353 -3.746353  3   0
0.35 -1.600062 -55.600062 4   10
...
```

where the first column is time.

- The declaration `signal x,y,q,r` means that column 2 is `x[t]`, column 3 is `y[t]`, etc.
- Note: For CyberSim, signals are implicitely declared as `signal x,y,z,pitch,roll,yaw,dist,angle,ax,ay,az,bump_l,...` i.e., the signal declaration is optional.

CPSGrader: Testing with CyberSim

Instruction on how to program CyberSim using C or Statecharts are given in `http://leeseshia.org/lab/`

CyberSim executable is in `Simulators\EECS149lab\CyberSim`

Test plans for CyberSim are located in `Simulators\EECS149lab\CyberSim\data`.

They are executed when Check Grade is pressed.

To test a new test plan, simply (backup and) replace the file `feedback_nav.stl` by a the file with the new test plan.

To test new test plans based on a custom simulator, see instructions in `README.md` file at the root of CPSGrader distribution.

Web sites and contact information

Write to `cpsgrader-dev@lists.eecs.berkeley.edu` for any question.
CPSGrader: `cpsgrader.org`

Another toolbox (Matlab required) with STL support:
Breach: `www.eecs.berkeley.edu/~donze/breach_page.html`