Formal Methods for Software Development

Verification with Spin

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04 September 2020

Spin: Previous Lecture vs. This Lecture

Previous lecture

Spin appeared as a Promela simulator

This lecture

Intro to Spin as a model checker

What Does A Model Checker Do?

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MC does *not* mainly try to prove correctness properties.
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MC's search for counter examples is exhaustive.

⇒ Finding no counter example proves stated correctness properties.

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exhaustive search

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resolving non-determinism in all possible ways

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  if/**do** statements

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:: guardY -> ...
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For model checking PROMELA code,
two kinds of non-determinism to be resolved:

- explicit, local:
  if/**do** statements

```
:: guardX -> ...
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- implicit, global:
  scheduling of concurrent processes
  (see next lecture)

Model Checker for This Course: SPIN

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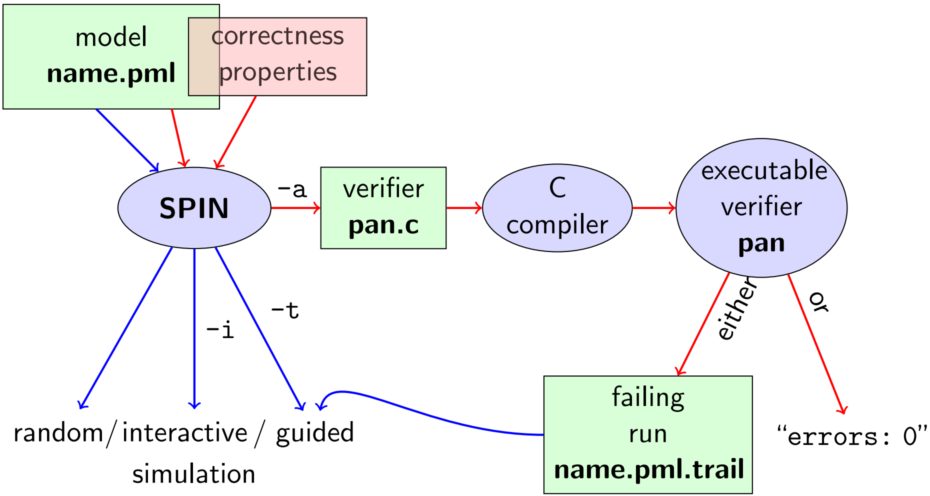
- generating a verifier

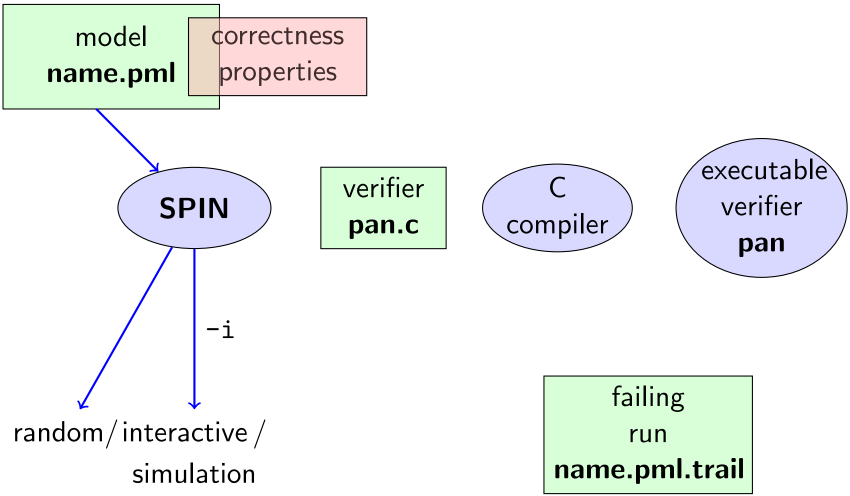
Verifier generated by Spin is a C program performing model checking:

- exhaustively checks Promela model against correctness properties
- in case the check is negative:
  generates a failing run of the model, to be simulated by Spin

SPIN Workflow: Overview



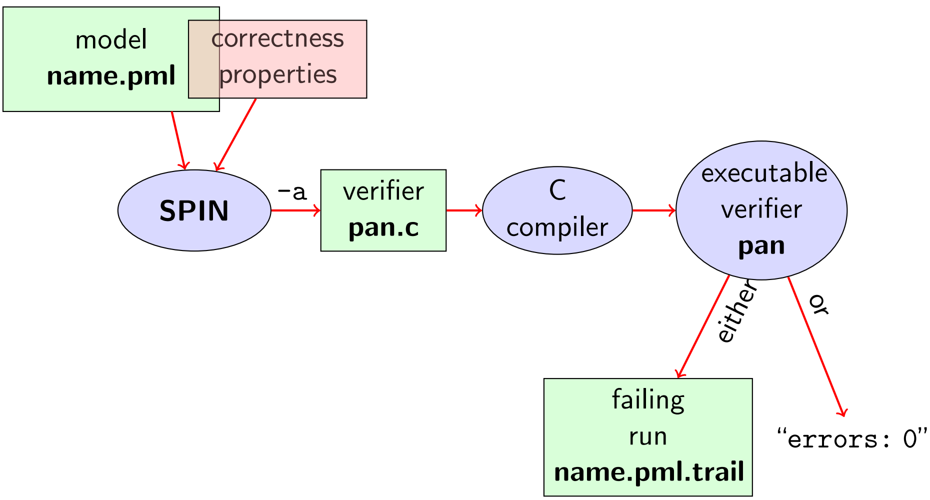
Plain Simulation with SPIN



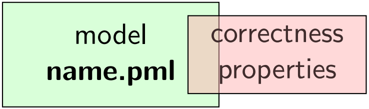
Rehearsal: Simulation Demo

- run example, random and interactive
  `zero.pml`

Model Checking with SPIN



Stating Correctness Properties



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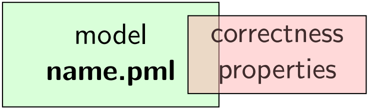

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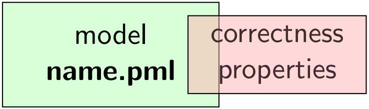

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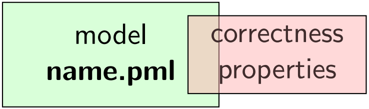

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  - `accept` labels
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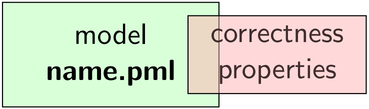

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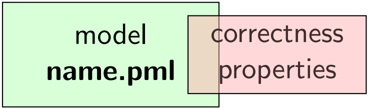

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Assertion Statements

Definition (Assertion Statements)

Assertion statements in PROMELA are statements of the form

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assert(max == a);
stmt2;
...
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assert(*expr*) can appear wherever a statement is expected.

```
...
stmt1;
assert(max == a);
stmt2;
...
```

```
...
if
  :: b1 -> stmt3;
           assert(x < y)
  :: b2 -> stmt4
...
```

Meaning of Boolean Assertion Statements

assert(*expr*)

- has no effect if *expr* evaluates to true
- triggers an error message if *expr* evaluates to false

This holds in both, simulation and model checking mode.

Meaning of General Assertion Statements

assert(*expr*)

- has no effect if *expr* evaluates to non-zero value
- triggers an error message if *expr* evaluates to 0

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Recall:

bool **true** **false** are syntactic sugar for

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Recall:

bool	**true**	**false**	are syntactic sugar for
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⇒ general case covers Boolean case

Instead of using ‘printf’s for Debugging ...

```
/* after choosing a,b from {1,2,3} */
if
  :: a >= b -> max = a
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printf("the␣maximum␣of␣%d␣and␣%d␣is␣%d\n",
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Command Line Execution

(simulate, inject fault, simulate again)

```
> spin [-i] max.pml
```

... we can employ Assertions

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/* after choosing a,b from {1,2,3} */
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Now, we have a first example with a formulated correctness property.

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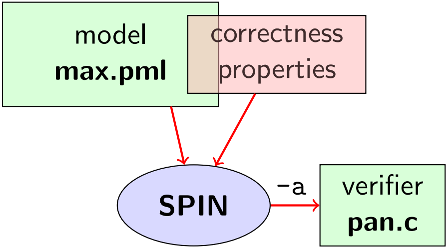
Now, we have a first example with a formulated correctness property.

We can do model checking, for the first time!

(Historic moment in the course.)

Generate Verifier in C



Command Line Execution

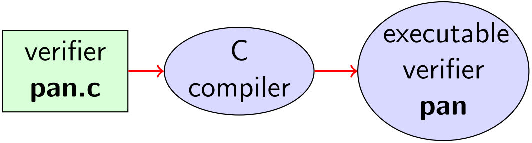
Generate Verifier in C

```
> spin -a max2.pml
```

SPIN generates Verifier in C, called **pan.c**

(plus helper files)

Compile To Executable Verifier



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```
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```

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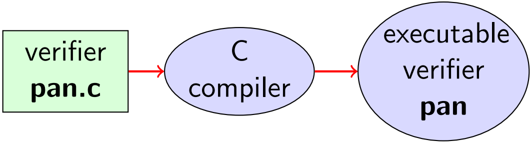

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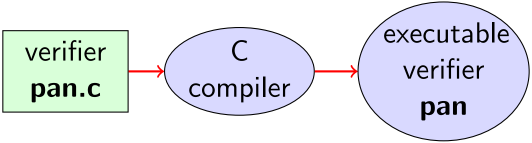

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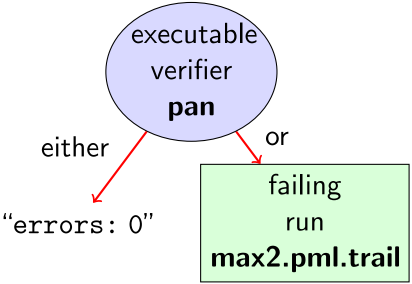
C compiler generates executable verifier **pan**

pan: historically "**p**rotocol **an**alyzer", now "**p**rocess **an**alyzer"

Run Verifier (= Model Check)



Command Line Execution

run verifier pan

> ./pan or *> pan*

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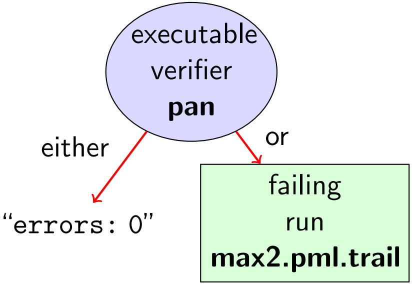

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`> ./pan` *or* `> pan`

- prints "errors: 0"

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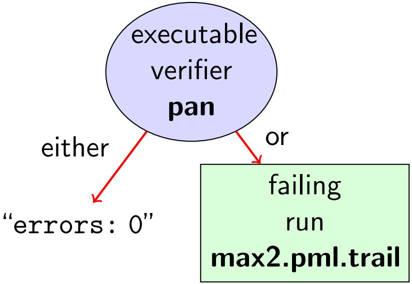


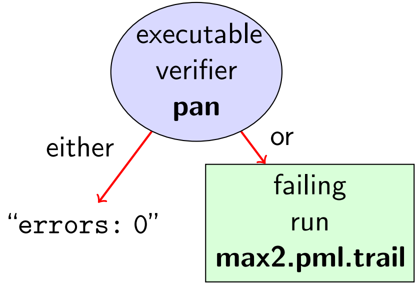
Command Line Execution

run verifier pan

> ./pan *or* *> pan*

- prints "errors: 0" ⇒ Correctness Property verified!

Run Verifier (= Model Check)



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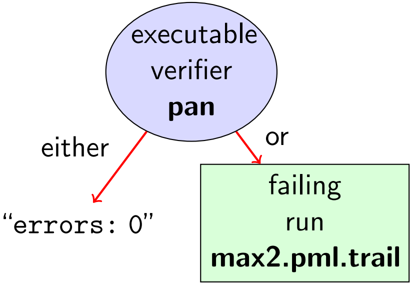

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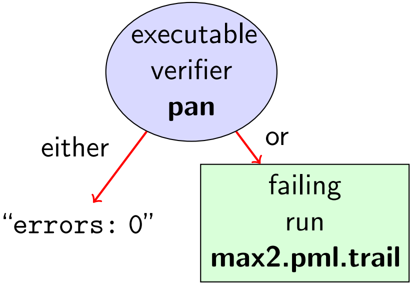

Command Line Execution

run verifier pan

```
> ./pan    or    > pan
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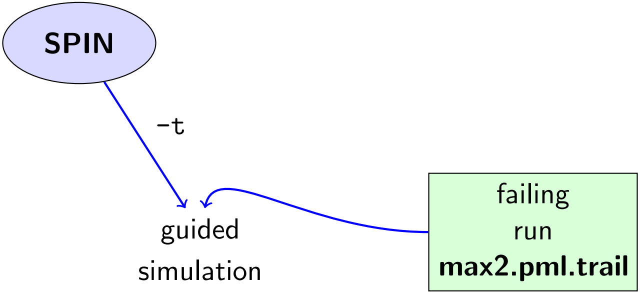
- prints "errors: 0", or
- prints "errors: n" ($n > 0$) $\Rightarrow$ counter example found!
  records failing run in **max2.pml.trail**

Guided Simulation

To examine failing run: employ simulation mode, "guided" by trail file.



Command Line Execution

inject a fault, re-run verification, and then:

```
> spin -t -p -l max2.pml
```

Output of Guided Simulation

can look like:

```
Starting P with pid 0
1: proc 0 (P) line  8 "max2.pml" (state 1) [a = 1 ]
                P(0):a = 1
2: proc 0 (P) line 14 "max2.pml" (state 7) [b = 2 ]
                P(0):b = 2
3: proc 0 (P) line 23 "max2.pml" (state 13) [((a<=b))]
3: proc 0 (P) line 23 "max2.pml" (state 14) [max = a ]
                P(0):max = 1
spin: max2.pml:22, Error: assertion violated
spin: text of failed assertion:
      assert((max==( ((a>b)) -> (a) : (b) )))
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assignments in the run
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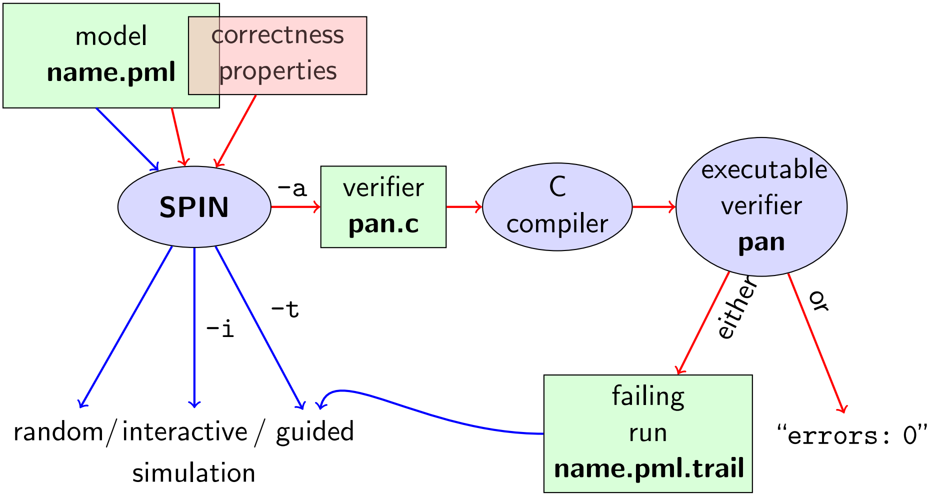
(If output doesn't mention `max` variable, re-verify with `./pan -E`)

What did we do so far?

following whole cycle (most primitive example, assertions only)



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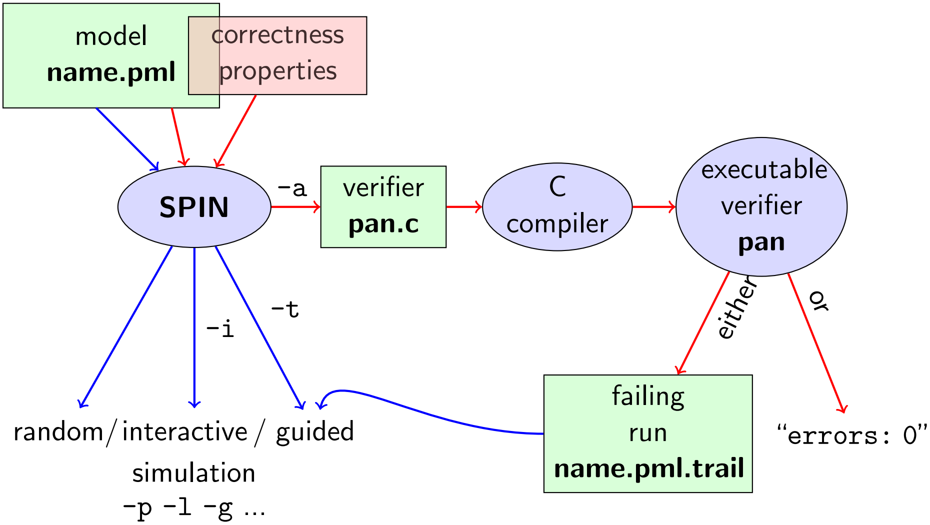

Further Examples: Integer Division

```
int dividend = 19;
int divisor  = 6;
int quotient, remainder;

quotient = 0;
remainder = dividend;
do
  :: remainder > divisor ->
     quotient++;
     remainder = remainder - divisor
  :: else ->
     break
od;
printf("%d␣divided␣by␣%d␣=␣%d,␣remainder␣=␣%d\n",
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simulate, add assertion, ...

Further Examples: Greatest Common Divisor

greatest common divisor of x and y

```
int a, b;
a = x; b = y;
do
  :: a > b -> a = a - b
  :: b > a -> b = b - a
  :: a == b -> break
od;
printf("The GCD of %d and %d = %d\n", x, y, a)
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⇒ typical for model checking

Typical Command Lines

typical command line sequences:

random simulation

```
spin name.pml
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random simulation

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spin name.pml
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interactive simulation

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spin -i name.pml
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interactive simulation

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model checking

```
spin -a name.pml
gcc -o pan pan.c
./pan
```

Typical Command Lines

typical command line sequences:

random simulation

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spin name.pml
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interactive simulation

```
spin -i name.pml
```

model checking

```
spin -a name.pml
gcc -o pan pan.c
./pan
```

and in case of error

```
spin -t -p -l -g name.pml
```

Spin Reference Card

Ben-Ari produced Spin Reference Card, summarizing

- typical command line sequences
- options for
  - Spin
  - gcc
  - pan
- Promela
  - datatypes
  - operators
  - statements
  - guarded commands
  - processes
  - channels
- temporal logic syntax

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Ben-Ari produced Spin Reference Card, summarizing

- typical command line sequences
- options for
  - Spin
  - gcc
  - pan
- Promela
  - datatypes
  - operators
  - statements
  - guarded commands
  - processes
  - channels
- temporal logic syntax

⇒ available from course page (see 'Links, Papers, and Software')

Why SPIN?

- SPIN targets software, instead of hardware verification
("Formal Methods for *Software* Development")
- 2001 ACM Software Systems Award (other winning systems include: Unix, TCP/IP, WWW, Tcl/Tk, Java, GCC, TEX, Coq)
- used for safety critical applications
- distributed freely as research tool, well-documented, actively maintained, large user-base in academia and in industry
- annual SPIN user workshops series held since 1995
- based on standard theory of (ω-)automata and linear temporal logic

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- availability of good course book (Ben-Ari)
- availability of front end jSpin (also Ben-Ari)

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- PROMELA and SPIN are rather simple to use
- availability of good course book (Ben-Ari)
- availability of front end JSPIN (also Ben-Ari)
- and: availability of our own web interface

What is jSpin?

- graphical user interface for Spin
- developed for pedagogical purposes
- written in Java
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- supports graphics output of transition system
- makes back-end calls transparent

jSpin Demo

Command Line Execution

calling jSpin

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> java -jar /usr/local/jSpin/jSpin.jar
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(with path adjusted to your setting)

or use shell script:

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play around with similar examples ...

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- M is correct wrt. $C_1, \ldots, C_n$ iff $R_M \subseteq (R_{M,C_1} \cap \ldots \cap R_{M,C_n})$.
- If M is not correct wrt. $C_1, \ldots, C_n$, then
  each $r \in (R_M \setminus (R_{M,C_1} \cap \ldots \cap R_{M,C_n}))$ is a counter example.

Catching A Different Type of Error

quoting from file **max3.pml**:

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generate and execute **pan**
⇒ reports "`errors: 1`"

Note: no assert in **max3.pml**.

Catching A Different Type of Error

Further inspection of **pan** output:

```
...
pan: invalid end state  (at depth 1)
pan: wrote max3.pml.trail
...
```

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Can get SPIN to ignore 'invalid end state' error: `./pan -E`

Literature for this Lecture

Ben-Ari Chapter 2, Sections 4.7.1, 4.7.2