

Software Engineering using Formal Methods

Verification with SPIN

Wolfgang Ahrendt

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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?

Model Checker (MC) is designed to prove the user wrong.

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⇒ **Finding no counter example proves stated correctness properties.**

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- if/do statements

- :: guardX -> ...

- :: guardY -> ...

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- ▶ explicit, local:

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- ▶ implicit, global:

scheduling of concurrent processes
(see next lecture)

Model Checker for This Course: SPIN

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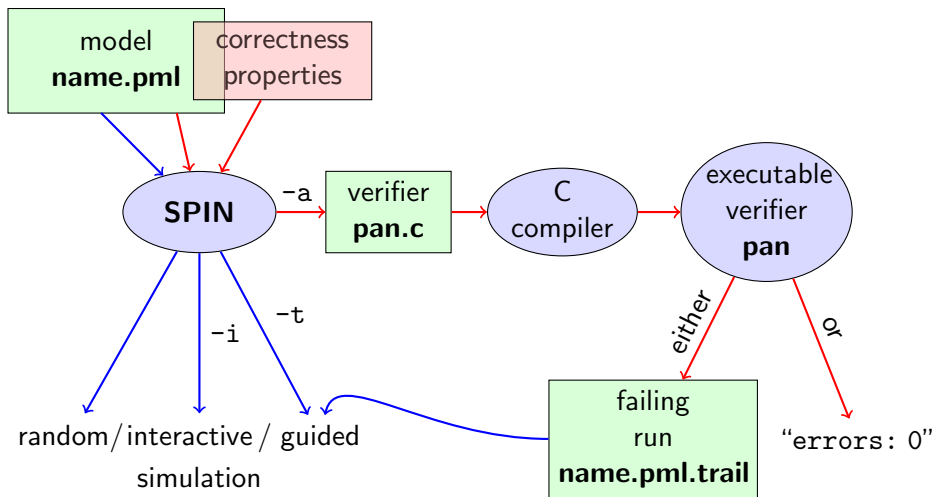
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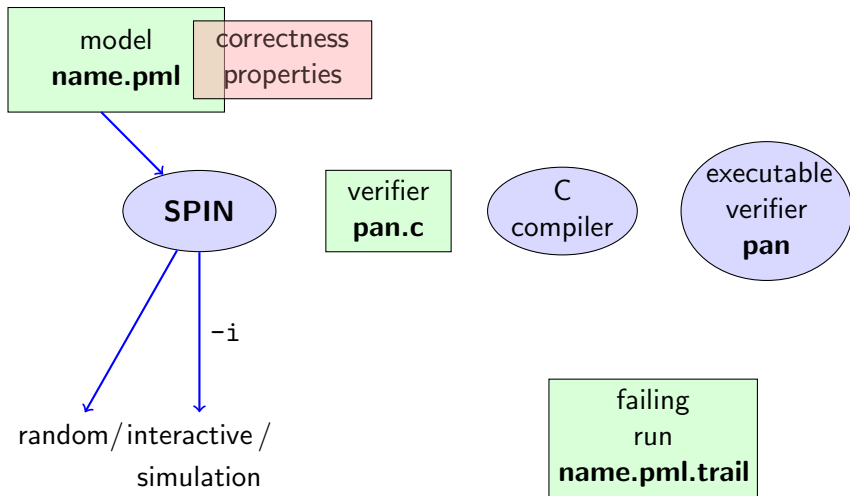
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- ▶ in case the check is negative:
generates a failing run of the model, to be simulated by SPIN

SPIN Workflow: Overview



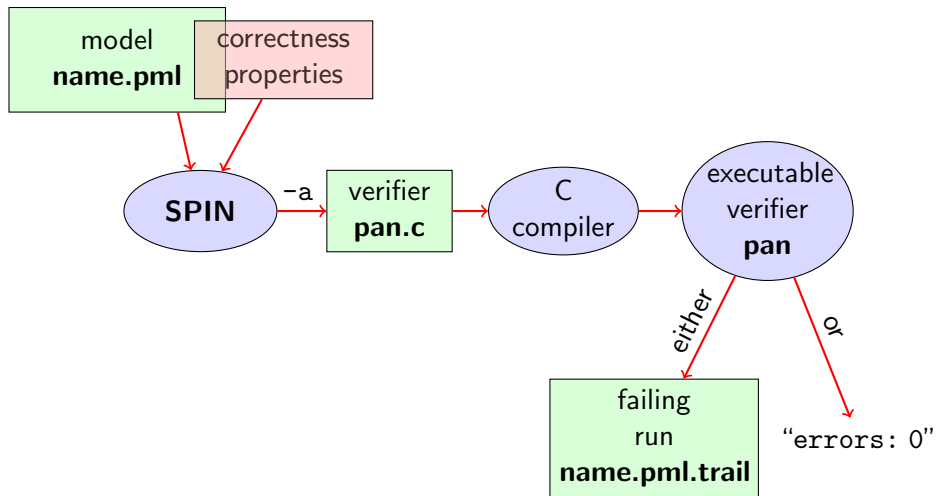
Plain Simulation with SPIN



Rehearsal: Simulation Demo

- ▶ run example, random and interactive
interleave.pml, zero.pml

Model Checking with SPIN



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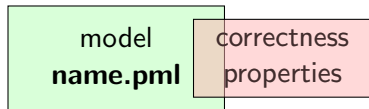
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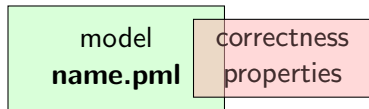
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But how to write Correctness Properties?

Stating Correctness Properties

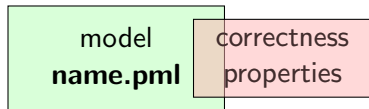


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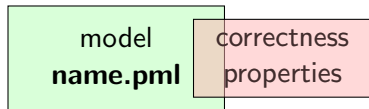


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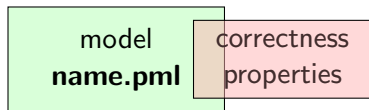


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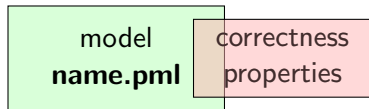
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```
...                               ...
stmt1;                             if
assert(max == a);                 :: b1 -> stmt3;
stmt2;                             assert(x < y)
...                                 :: b2 -> stmt4
...                               ...
```

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**
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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  
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Command Line Execution

(simulate, inject faults, add assertion, simulate again)

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


... we can employ **Assertions**

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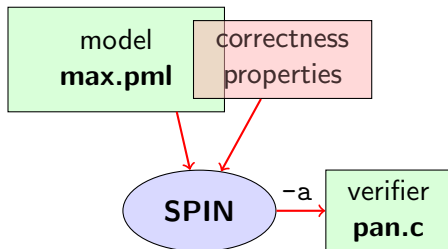
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(Historic moment in the course.)

Generate Verifier in C



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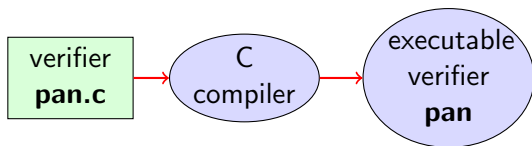
Generate Verifier in C

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

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

(plus helper files)

Compile To Executable Verifier

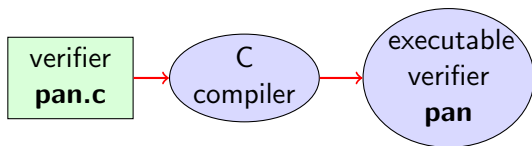


Command Line Execution

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> gcc -o pan pan.c
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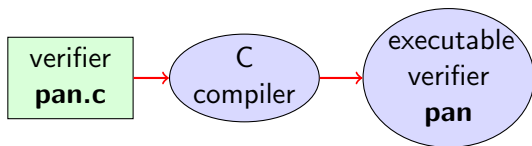
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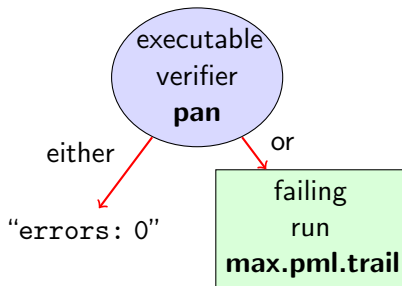
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C compiler generates **executable verifier pan**

pan: historically “**protocol analyzer**”, now “**process analyzer**”

Run Verifier (= Model Check)

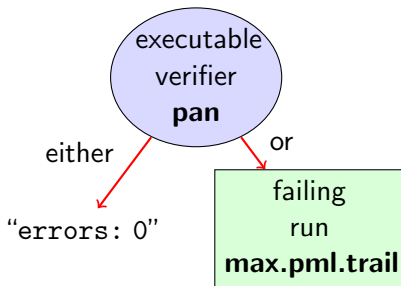


Command Line Execution

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> ./pan or > pan
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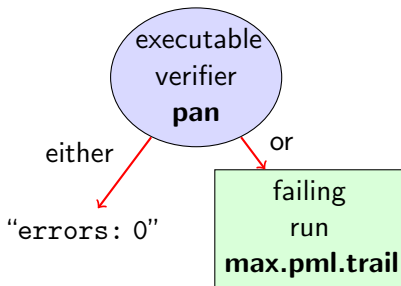
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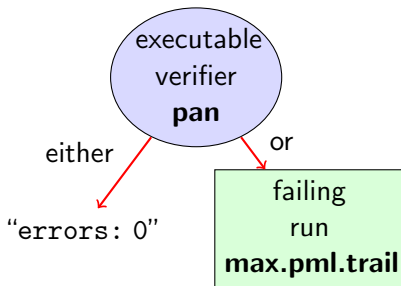
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- ▶ prints "errors: 0" ⇒ Correctness Property verified!

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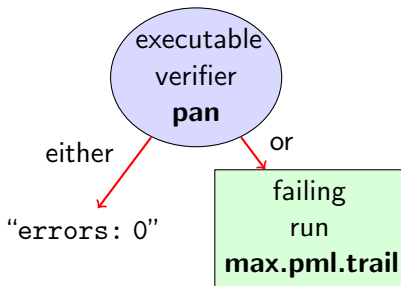
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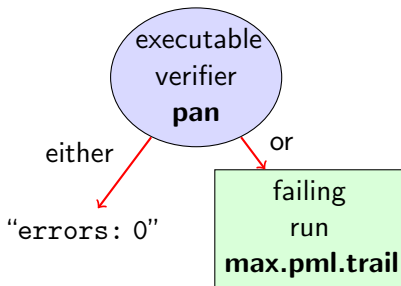
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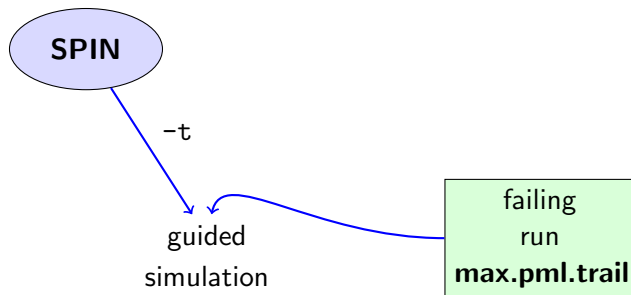
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records failing run in **max2.pml.trail**

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 ]
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2: proc 0 (P) line 14 "max2.pml" (state 7) [b = 2 ]
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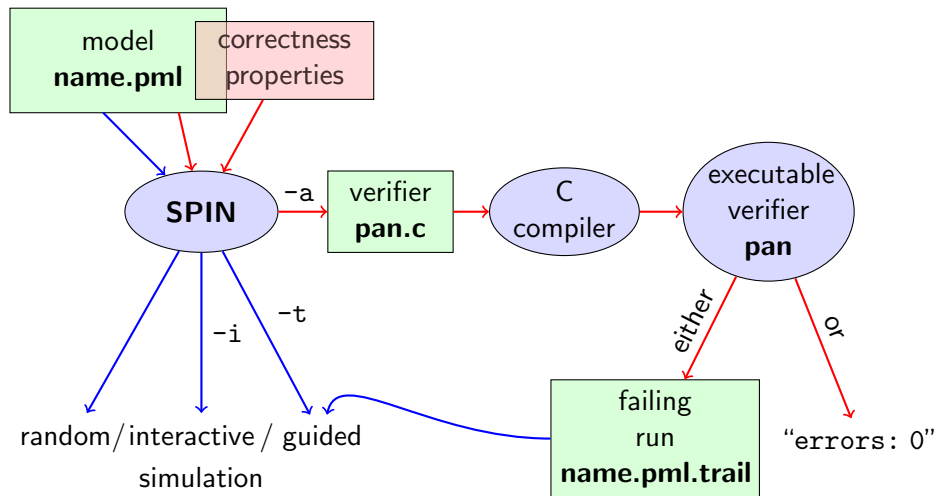
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(If output doesn't mention max variable, re-verify with ./pan -E)

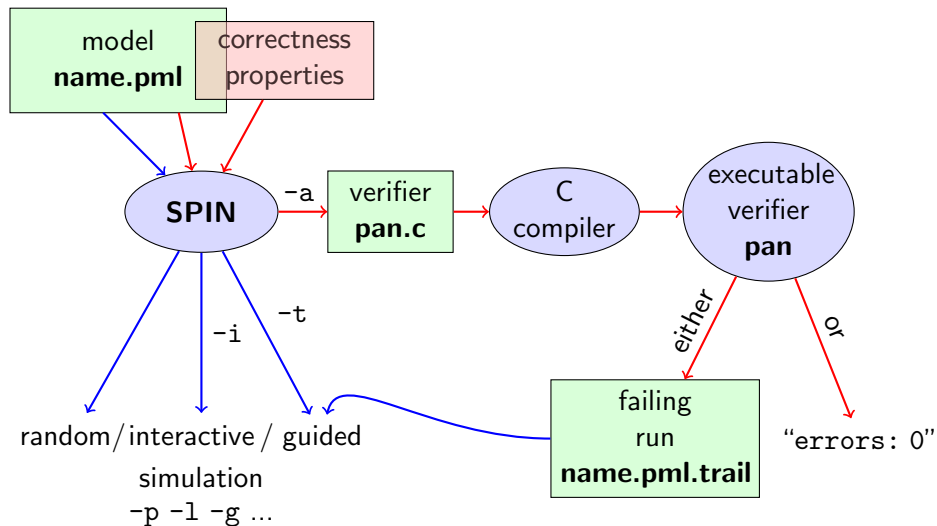
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following whole cycle (most primitive example, assertions only)



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Further Examples: Integer Division

```
int dividend = 15;
int divisor  = 4;
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",
       dividend, divisor, quotient, remainder)
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simulate, put assertions, verify, change values, ...

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
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od;
printf("The GCD of %d and %d = %d\n", x, y, a)
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Further Examples: Greatest Common Divisor

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⇒ **typical for model checking**

Typical Command Lines

typical command line sequences:

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```
gcc -o pan pan.c
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```

and in case of error

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

Ben-Ari produced [Spin Reference Card](#), summarizing

- ▶ typical command line sequences
- ▶ options for
 - ▶ SPIN
 - ▶ gcc
 - ▶ pan
- ▶ PROMELA
 - ▶ datatypes
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⇒ [available from course page](#) (see 'Links, Papers, and Software')

Why SPIN?

- ▶ SPIN targets software, instead of hardware verification (“*Software Engineering using Formal Methods*”)
- ▶ 2001 ACM Software Systems Award (other winning software systems include: Unix, TCP/IP, WWW, Tcl/Tk, Java)
- ▶ 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

Why SPIN? (Cont'd)

- ▶ PROMELA and SPIN are rather simple to use
- ▶ good to understand a few systems really well, rather than many systems poorly
- ▶ availability of good course book (Ben-Ari)
- ▶ availability of front end JSPIN (also Ben-Ari)

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- ▶ availability of front end JSPIN (also Ben-Ari)
- ▶ brand new: availability of Bart's web interface

What is JSPIN?

- ▶ graphical user interface for SPIN
- ▶ developed for pedagogical purposes
- ▶ written in JAVA
- ▶ simple user interface
- ▶ SPIN options automatically supplied
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- ▶ makes back-end calls transparent

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 ...

Catching A Different Type of Error

quoting from file **max3.pml**:

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generate and execute **pan**

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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  
...
```


Legal and Illegal Blocking

A process may legally block, **as long as some other process can proceed.**

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in **max3.pml**, there exists a blocking run where no process can take over.

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Definition (Valid End State)

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End labels not useful in **max3.pml**, but elsewhere, they are.

Example: `end.pml`

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