Formal Methods for Software Development
Verification with Spin

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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?

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MC does *not* try to prove correctness properties.
It tries the opposite.

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Why can an MC also prove correctness properties?

> MC's search for counter examples is exhaustive.

⇒ Finding no counter example proves stated correctness properties.

What does 'exhaustive search' mean here?

exhaustive search
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  if/**do** statements

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

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

    ```
    :: guardX -> ...
    :: guardY -> ...
    ```

- ▶ implicit, global:
  scheduling of concurrent processes
  (see next lecture)

Model Checker for This Course: SPIN

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▶ in case the check is negative:
   generates a failing run of the model

Model Checker for This Course: Spin

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Main functionality of Spin:

- ▶ simulating a model (randomly/interactively/guided)
- ▶ 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:
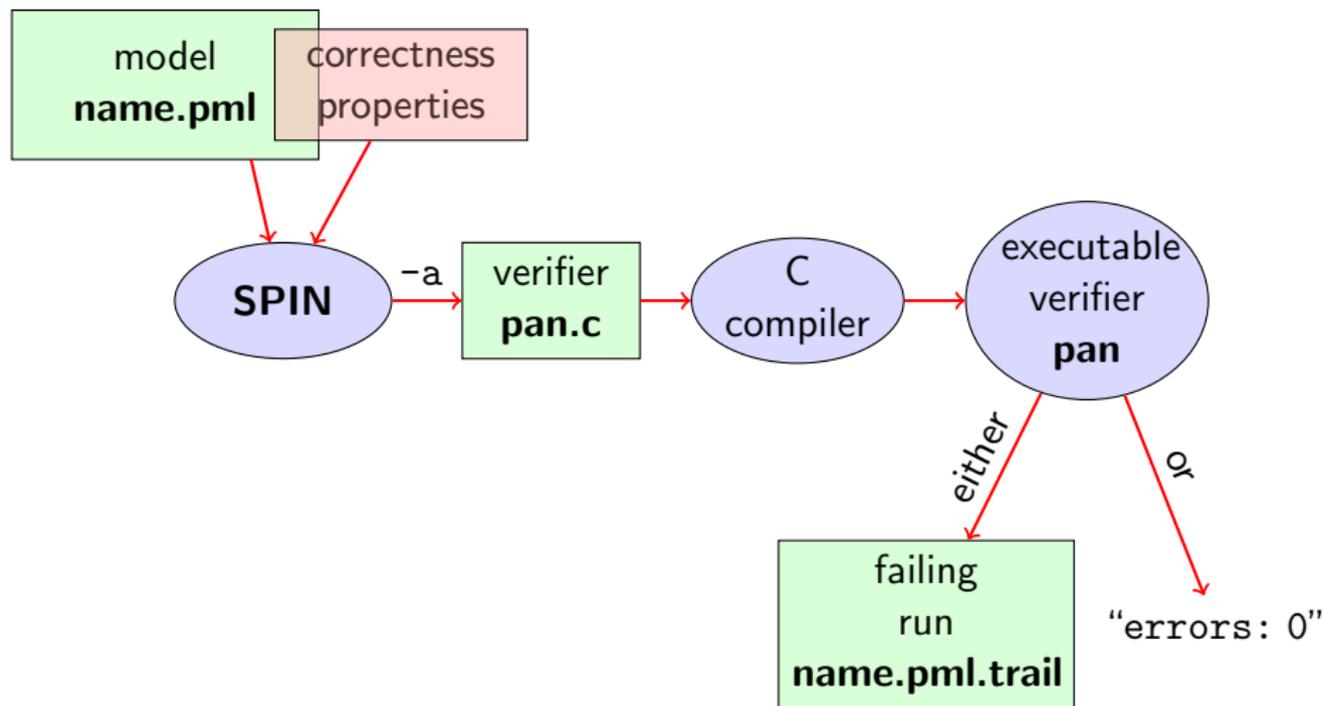 generates a failing run of the model, to be simulated by Spin
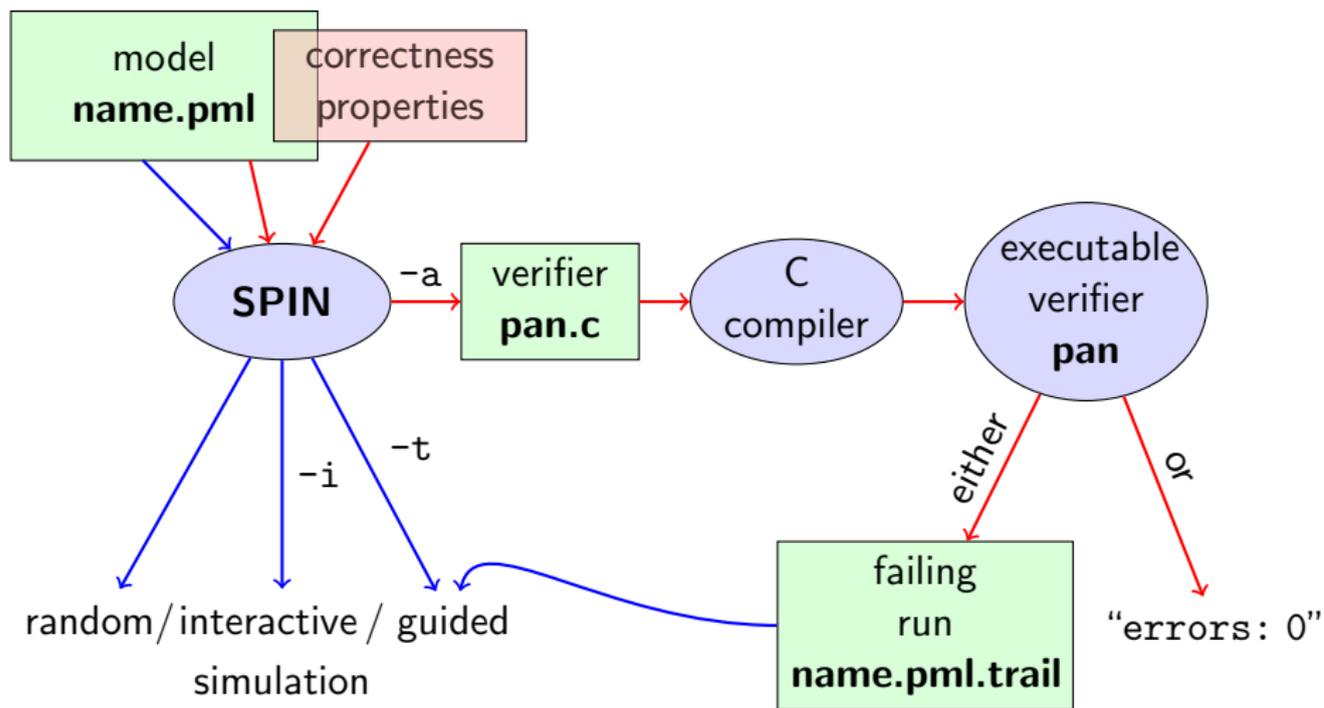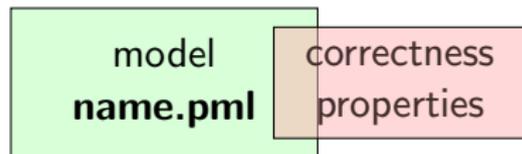
Plain Simulation with SPIN
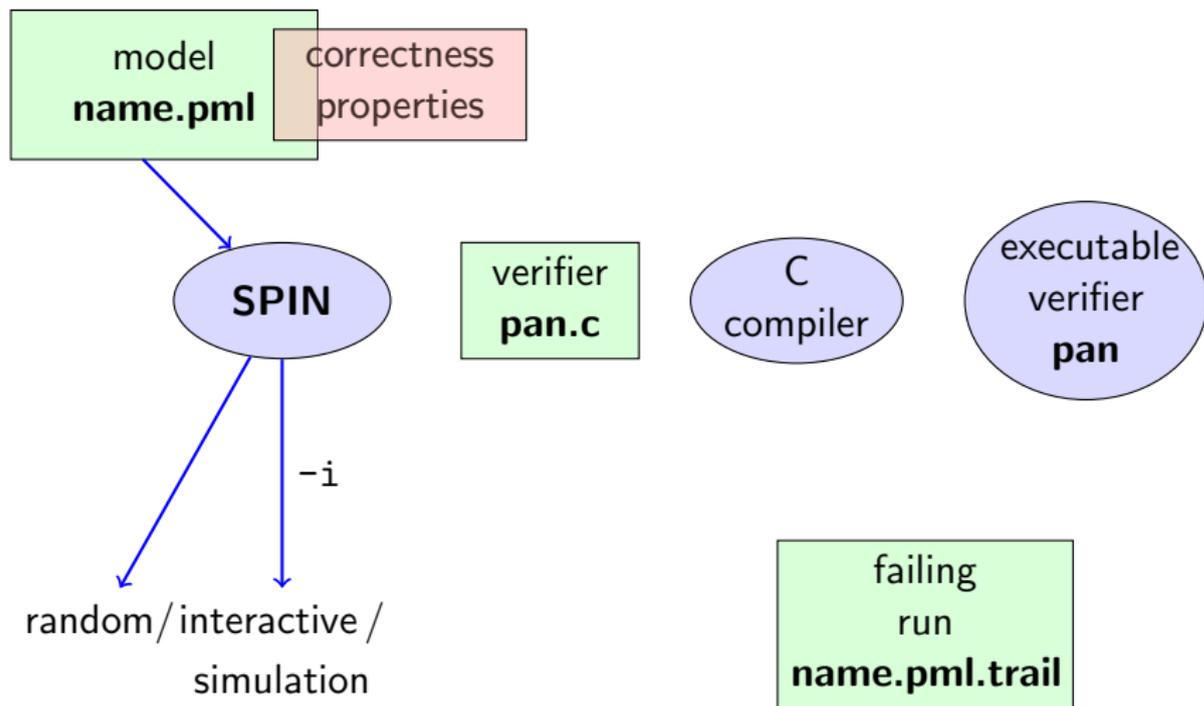
Rehearsal: Simulation Demo
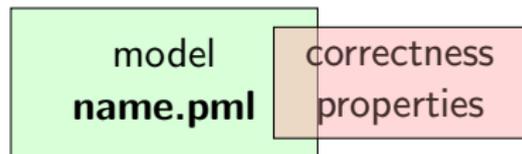
▶ run example, random and interactive
  `zero.pml`

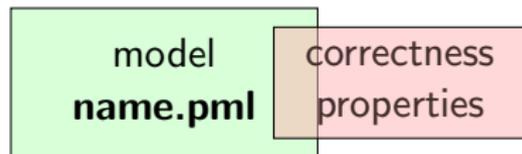# Model Checking with SPIN

Stating Correctness Properties

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Correctness properties can be stated within, or outside, the model.

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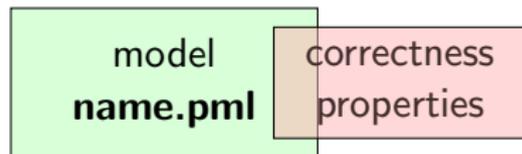Correctness properties can be stated within, or outside, the model.

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  - ▶ end labels
  - ▶ accept labels
  - ▶ progress labels

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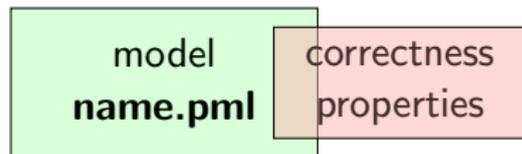


```
model          correctness
name.pml       properties
```

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> ▶ assertion statements
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Stating Correctness Properties

model **name.pml** correctness properties

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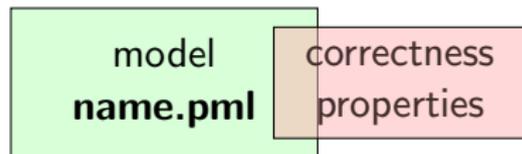
stating properties within model, using

- ▶ assertion statements (today)
- ▶ meta labels
    - ▶ end labels (today)
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Assertion Statements

Definition (Assertion Statements)

Assertion statements in PROMELA are statements of the form

$$\mathbf{assert}(\textit{expr})$$

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

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were *expr* is any PROMELA expression.

Typically, *expr* is of type **bool**.

assert(*expr*) can appear wherever a statement is expected.

```
...                              ...
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
- ▶ triggers an error message if *expr* evaluates to 0

This holds in both, simulation and model checking mode.

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Recall:

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Recall:

bool true false   is 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
  :: a <= b -> max = b
fi;
printf("the maximum of %d and %d is %d\n",
        a, b, max)
```

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/* after choosing a,b from {1,2,3} */
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Command Line Execution

(simulate, inject fault, simulate again)

> *spin [-i] max.pml*

```
/* after choosing a,b from {1,2,3} */
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  :: a <= b -> max = b
fi;
assert( max == (a>b -> a : b) )
```

... we can employ **Assertions**

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

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We can do model checking, for the first time!
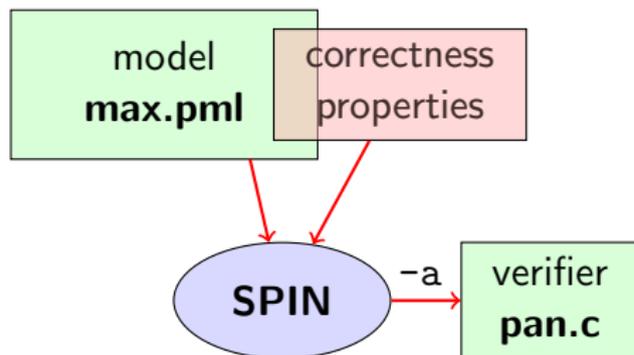
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Now, we have a first example with a formulated correctness property.

> We can do model checking, for the first time!

(Historic moment in the course.)

Generate Verifier in C

Command Line Execution
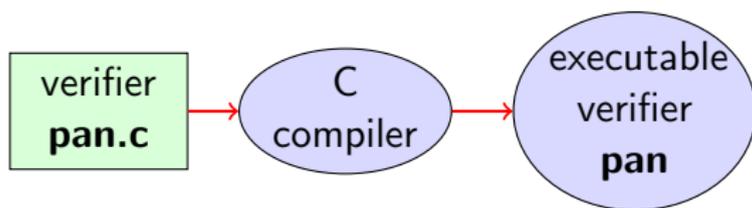
Generate Verifier in C

`> spin -a max2.pml`

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

(plus helper files)
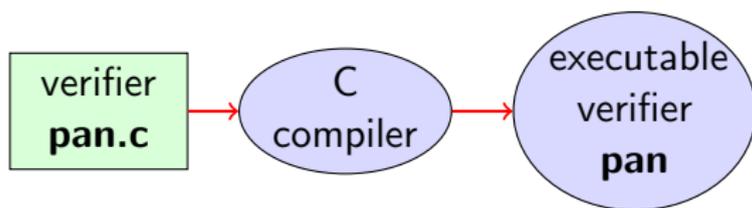
Compile To Executable Verifier

Command Line Execution

compile to executable verifier

```
> gcc -o pan pan.c
```
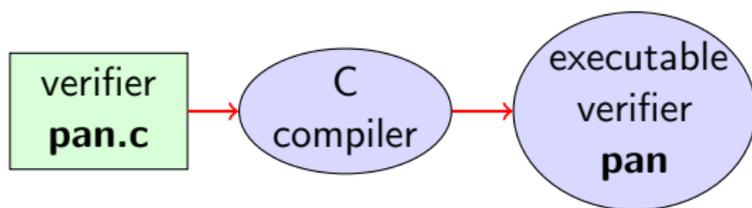
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pan: historically "**p**rotocol **an**alyzer", now "**p**rocess **an**alyzer"

Run Verifier (= Model Check)
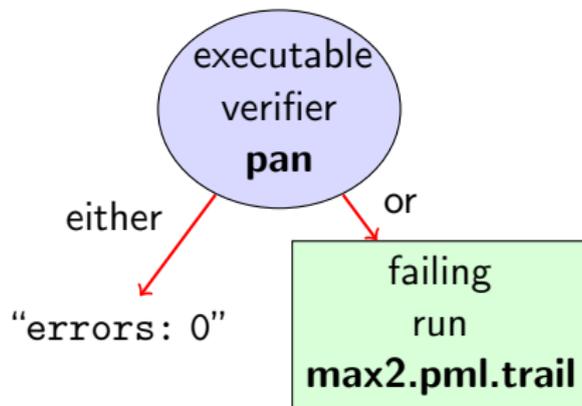
Command Line Execution

run verifier **pan**

> `./pan`   or   > `pan`

Run Verifier (= Model Check)
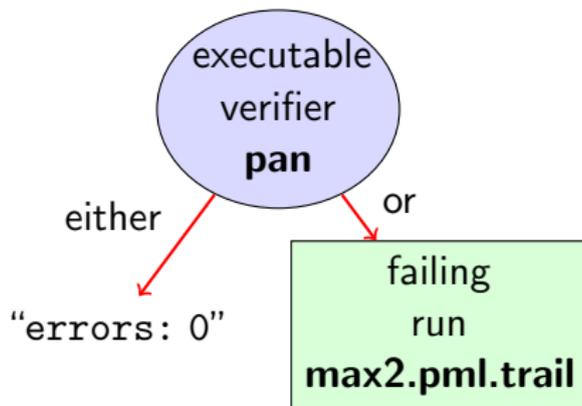
Command Line Execution

run verifier **pan**

> ./pan   or   > pan

► prints "errors: 0"

Run Verifier (= Model Check)
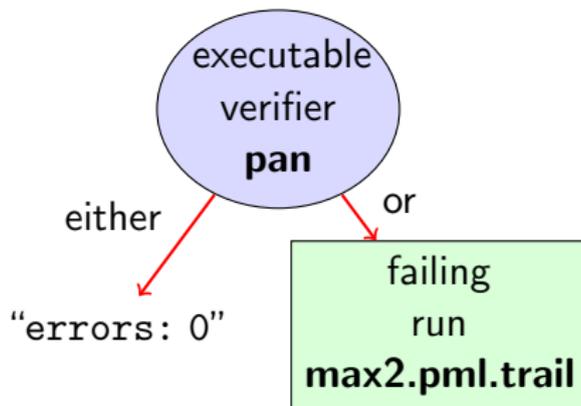
Command Line Execution

run verifier **pan**

`>  ./pan   or   >  pan`

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

Run Verifier (= Model Check)
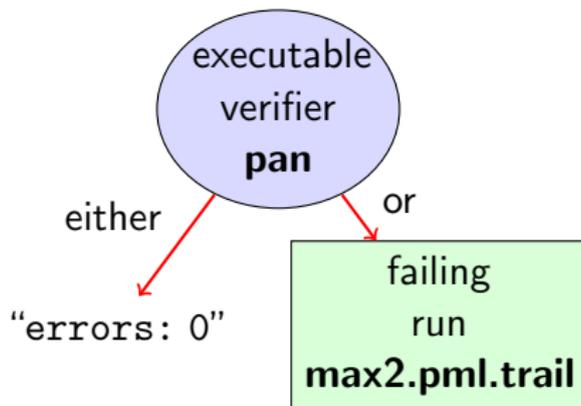
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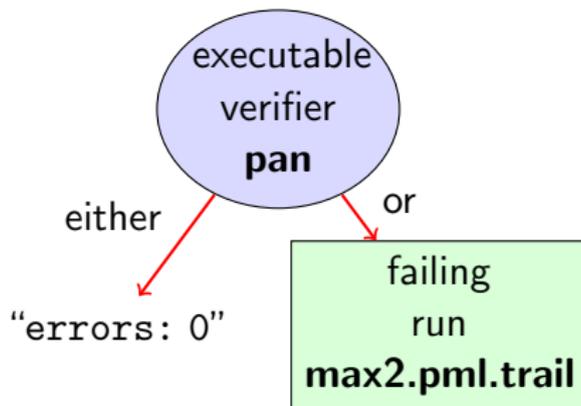
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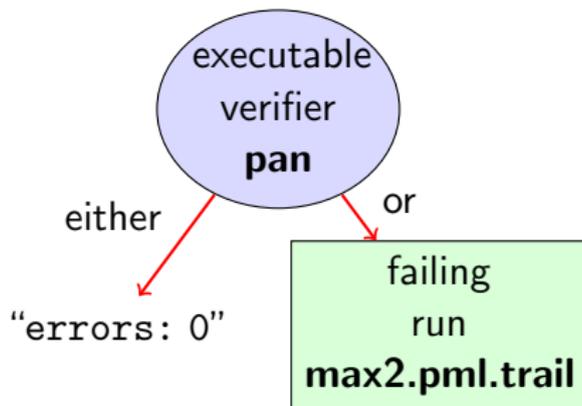
Command Line Execution

run verifier **pan**

> `> ./pan   or   > pan`

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

Guided Simulation

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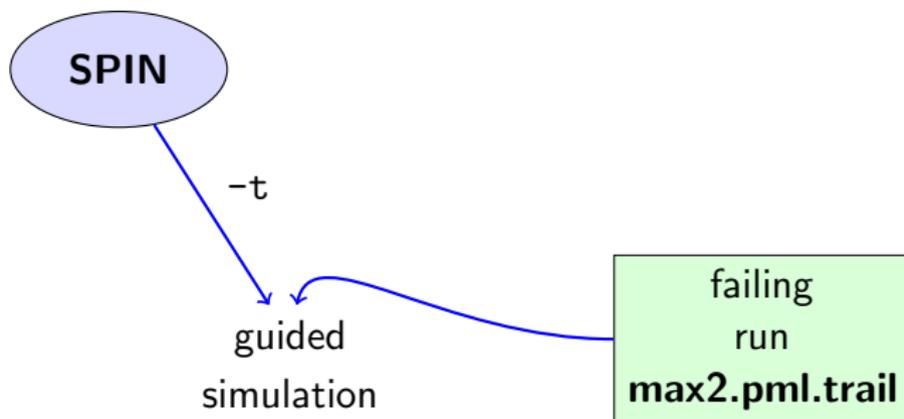
Command Line Execution

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
values of variables whenever updated

(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)
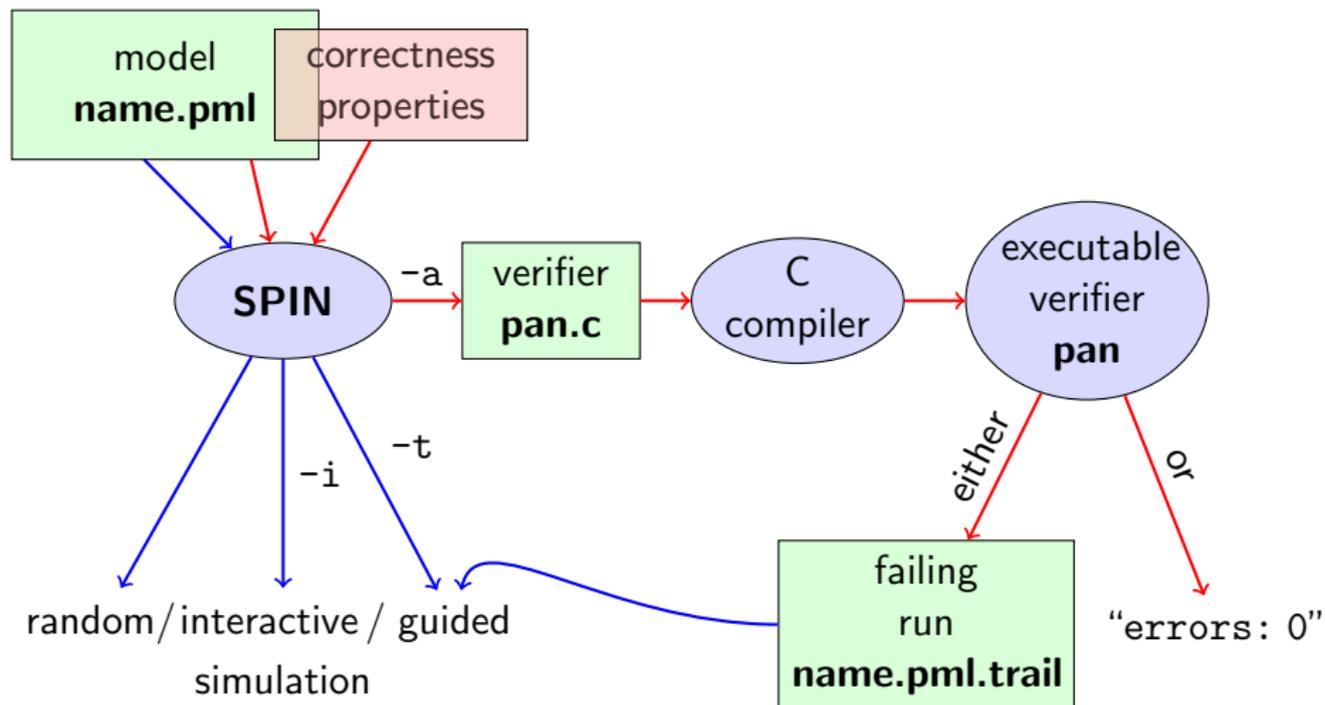
What did we do so far?
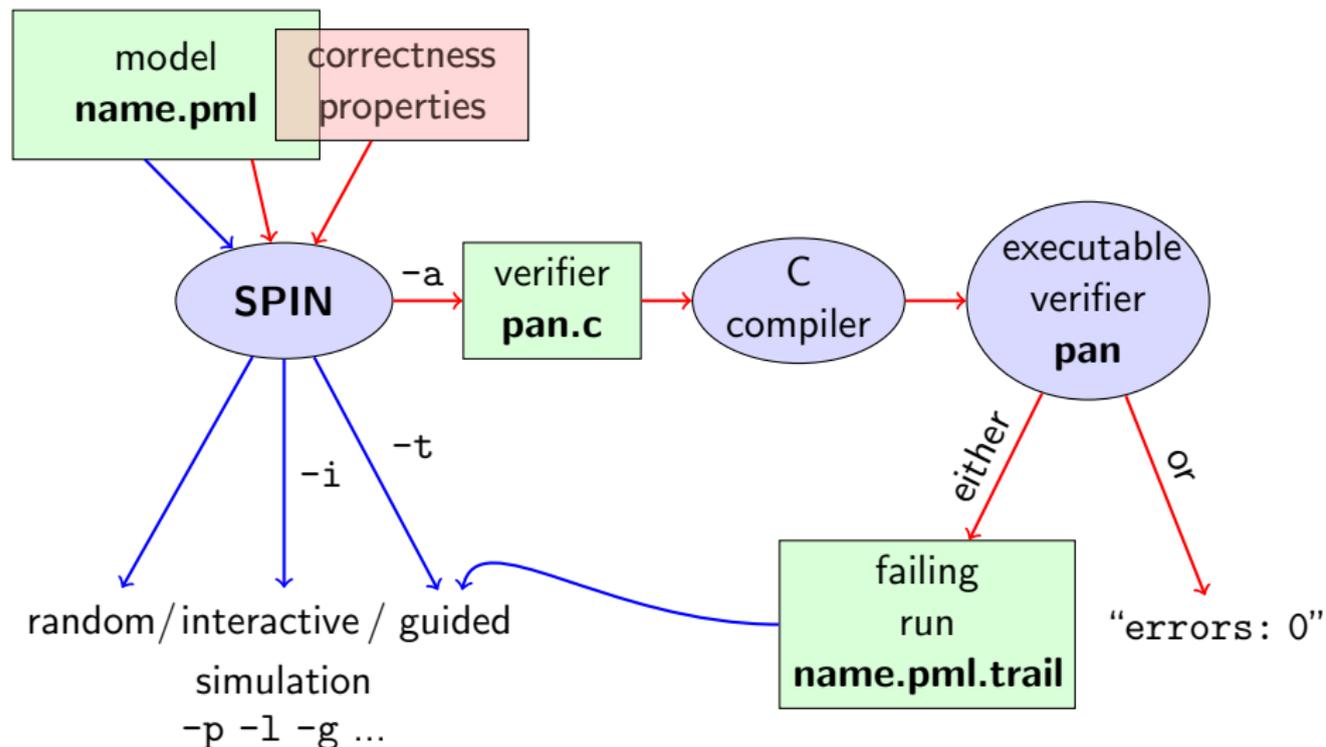
following whole cycle (most primitive example, assertions only)

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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printf("%d divided by %d = %d, remainder = %d\n",
       dividend, divisor, quotient, remainder)
```

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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typical command line sequences:

random simulation

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interactive simulation

           `spin -i name.pml`

Typical Command Lines

typical command line sequences:

random simulation

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interactive simulation

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spin -i name.pml
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model checking

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

Typical Command Lines

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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
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- temporal logic syntax

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⇒ 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

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)

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)
- ▶ and: availability of our own web interface

What is JSPIN?

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- developed for pedagogical purposes
- written in JAVA
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JSPIN **Demo**

Command Line Execution

calling JSPIN

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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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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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(Fix error)

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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