Model Checking with Temporal Logic

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[1] Based on material from Prof. Wolfgang Ahrendt.

Model Checking

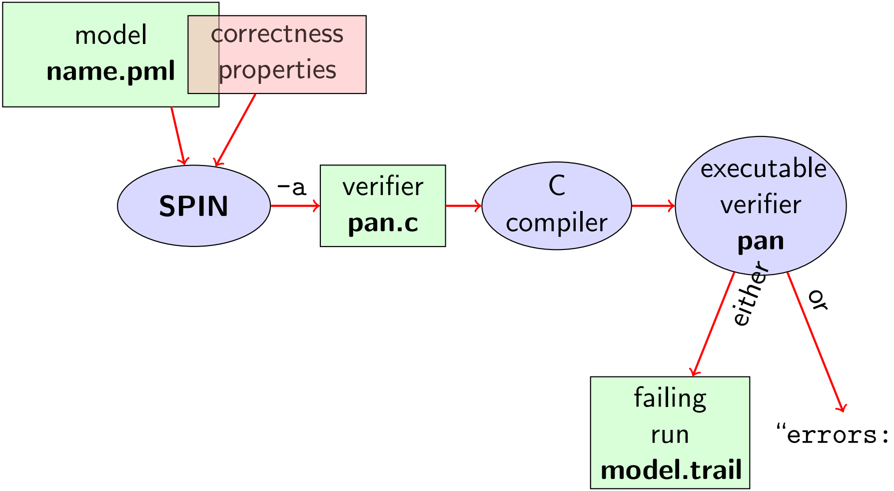
Check whether a formula is valid in all runs of a transition system.

Given a transition system $\mathcal{T}$ (e.g., derived from a PROMELA program).

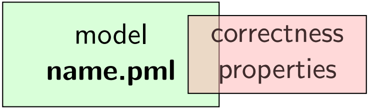
Verification task: is the LTL formula ϕ satisfied in all traces of $\mathcal{T}$, i.e.,

$$\mathcal{T} \models \phi \quad ?$$

Model Checking with SPIN



Stating Correctness Properties



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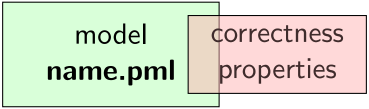

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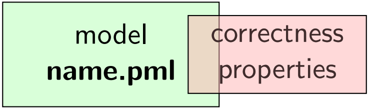

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stating properties within model using

- assertion statements ✔

stating properties outside model using

- temporal logic formulas

Preliminaries: Fairness

Does this model terminate in each run?

Simulate: `start/fair.pml`

```
byte n = 0;
bool flag = false;

active proctype P() {
  do ::  flag -> break
     ::  else -> n = 5 - n
  od
}
active proctype Q() {
  flag = true
}
```

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Termination guaranteed only if scheduling is (weakly) fair!

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Definition (Weak Fairness)

A run is called weakly fair iff the following holds:
each continuously executable statement is executed eventually.

Model Checking of Temporal Properties

Many correctness properties not expressible by assertions

- All properties that involve state changes
- Temporal logic expressive enough to characterize many (but not all) LT properties

In this course: "temporal logic" synonymous with "linear temporal logic"

Today: model checking of properties formulated in temporal logic

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Locality of Assertions

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Mutual exclusion enforced by adding assertion to each critical section

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critical++;
assert( critical <= 1 );
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Drawbacks

- No separation of concerns (model vs. correctness property)
- Changing assertions is error prone (easily out of sync)
- Easy to forget assertions:
  correctness property might be violated at unexpected locations

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- Changing assertions is error prone (easily out of sync)
- Easy to forget assertions:
  correctness property might be violated at unexpected locations
- Many interesting properties not expressible via assertions

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TL formula `[](critical <= 1)`

“It is guaranteed throughout each run that at most one process visits its critical section at any time.”

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Example

TL formula `[](critical <= 1)`

"It is guaranteed throughout each run that at most one process visits its critical section at any time."

or, equivalently:
"It will never happen that more than one process visits its critical section."

Applying Temporal Logic to Critical Section Problem

We want to verify `[](critical<=1)` as a correctness property of:

```
active proctype P() {
  do :: /* non-critical activity */
        atomic {
          !inCriticalQ;
          inCriticalP = true
        }
        critical++;
        /* critical activity */
        critical--;
        inCriticalP = false
  od
}

/* similarly for process Q */
```

Model Checking a Safety Property with SPIN

Command Line Execution

Add definition of TL formula to PROMELA file

Example `ltl atMostOne { [](critical <= 1) }`

General `ltl` *name* `{` *TL-formula* `}`

can define more than one formula

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

Demo: `target/safety1.pml`

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Example

`<>csp`

(with `csp` a variable only true in the critical section of `P`)

"in each run, process `P` visits its critical section eventually"

Applying Temporal Logic to Starvation Problem

We want to verify <>csp as a correctness property of:

```
active proctype P() {
  do :: /* non-critical activity */
        atomic {
          !inCriticalQ;
          inCriticalP = true
        }
        csp = true;
        /* critical activity */
        csp = false;
        inCriticalP = false
  od
}

/* similarly for process Q */
/* there, using csq         */
```

Model Checking a Liveness Property

1. open PROMELA file `liveness1.pml`
2. write `ltl pWillEnterC { <>csp }` in PROMELA file (as first `ltl` formula)
3. ensure that `Acceptance` is selected (SPIN will search for *accepting* cycles)
4. *for the moment* uncheck `Weak Fairness` (see discussion below)
5. select `Verify`

Verification Fails

Demo: `start/liveness1.pml`

Verification fails!

Why?

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Verification fails!

Why?

The liveness property on one process "had no chance".
Not even weak fairness was switched on!

Model Checking Liveness with Weak Fairness

Always check `Weak fairness` when verifying liveness

1. open PROMELA file
2. write `ltl pWillEnterC { <>csp }` in PROMELA file
   (as first `ltl` formula)
3. ensure that `Acceptance` is selected
   (SPIN will search for *accepting* cycles through the never claim)
4. ensure `Weak fairness` is checked
5. select `Verify`

Model Checking Liveness using SPIN directly

Command Line Execution

Make sure `ltl` *name* { *TL-formula* } is in *file*.pml

```
> spin -a file.pml
> gcc -o pan pan.c
> ./pan -a -f [-N name]
```

`-a` acceptance cycles, `-f` weak fairness

Demo: `start/liveness1.pml`

Limitation of Weak Fairness

Verification fails again!

Why?

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Weak fairness is too weak . . .

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Note that `!inCriticalQ` is not continuously executable!

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A run is called weakly fair iff the following holds:
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Note that `!inCriticalQ` is not continuously executable!

Restriction to weak fairness is principal limitation of SPIN

Here, liveness needs strong fairness, which is not supported by SPIN.

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- Specify liveness of `fair.pml` using labels

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Demo: `target/fair.pml`

- Here, weak fairness is needed, *and sufficient*

Literature for this Lecture

Ben-Ari (Principles of the Spin Model Checker) Chapter 5