Software Testing and Validation

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Corso di Laurea in Informatica

The Murphi Model Checker

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Murphi

- Murphi or Murφ, the simplest among "model checkers"
  - as all model checkers we will see in this course, Murphi may be freely downloaded with the source code, thus it may also be modified
  - links for download of all model checkers we will see are on the course web-page: `https://igormelatti.github.io/sw_test_val/20242025/index.html`

Murphi

- Formally, as all model checkers, Murphi needs the following input:
  1. a description of the system $\mathcal{S}$ you want to verify (i.e., the "model" you want to "check")
     - as we will see, this is essentially a Kriepke structure
  2. a property φ you want the system $\mathcal{S}$ to satisfy
- The output will be either OK or FAIL
  - if FAIL, it is possible to tell Murphi to print a *counterexample*

Murphi

- In Murphi, both the description of $\mathcal{S}$ and of φ must be written in a single text file, following a precise syntax
  - in other model checkers we will see (e.g., SPIN), this syntax has a name; but this is not the case for Murphi
  - thus, we will refer to it simply as *Murphi input language*
  - as we will see, in many points Murphi input language is similar to some imperative programming languages, especially Pascal (for statements) and C (for expressions)

Murphi

A description for $\mathcal{S}$ and φ written in the Murphi input language must be organized as follows

- 1. definitions of:
  - *constants*, also named *parameters*
  - *data types*, divided in *simple* and *composed*
    - there are only two simple types: *enumerations* and *integer subranges*
    - the *boolean* data type is predefined as an enumeration (true, false)
    - the composed types are formed using *array* and/or *records* (structs), possibly mixed, following the Pascal syntax

Murphi

- 1. (Continuing)
  - *global variables*, each having one of the types above
    - global variables are fundamental, as they define the *states space* S
    - that is, S is defined by all possible values of all global variables
    - thus, is defined by the Cartesian product of all types of all global variables defined
    - as all types are *finite*, S may be huge but it is always finite
    - see example below
  - note that such definitions may be mixed, of course keeping in mind variables scoping
    - e.g., if you need constant A to define type B of variable C, you must define constant A first, then type B and finally variable C
    - type B could also be used inline directly when declaring C

Murphi

- 2. Definitions of:
  - *functions*
    - return a value
    - may have side effects (i.e., modify a global variable)
    - may modify input arguments, but must be explicitly stated as in Pascal (parameter passed as *reference*)
  - *procedures*
    - do not return a value
    - may have side effects (i.e., modify a global variable)
    - may modify input arguments, but must be explicitly stated as in Pascal (parameter passed as *reference*)

Murphi

- For both functions and procedures:
  - Pascal-like syntax
  - it is possible to define and use *local* variables
  - local variables *must not* be considered in the definition of the state space S
- Again, you can mix them, provided scoping is respected
- E.g., if function F calls procedure G which calls function H, then G must be defined before F and H before G

- 3. Definitions (mixed as you like it) of:
  - *start states*, defined as Pascal-like statements, intended as atomically executed
    - may contain the typical statements of imperative programming languages: assignments, cycles, ifs, functions and procedures calls
    - local variables may be defined
  - *rules*, each defined by:
    - a*(n application) guard*, defining if a rule is applicable (*fired*, as Murphi says) or not
    - a *body*, again formed by atomically executed Pascal-like statements
    - an optional string, working as a short comment for the rule
    - by the way, comments may be either with C syntax (/**/) or Pascal syntax (--)

Murphi

- Of course the guard must be a boolean expression
- Only global variables and constants may occur in a guard
  - actually, also ruleset indexes, we will be back on this
- It is possible to call functions (not procedures!)
- The body may contain the typical statements of imperative programming languages: assignments, cycles, ifs, functions and procedures calls
- Local variables may be defined and used

Murphi

- 3. (Continuing):
  - *invariants*, each of them defines a property to be checked
    - same as guards: it must be a boolean expression
    - only global variables and constants may occur in a guard
    - exceptions are possible when `forall` or `exist` are used
    - it is of course possible to call functions
- Finally, at least one initial state and one rule must be present (see `00.minimal_model.m`)

Murphi

- Murphi checks that all reachable states of S satisfy all invariants
  - a state $s \in S$ is *reachable* if there exists a path in the transition graph from an initial state to s
  - that is: starting from an initial state, there exists a chain of rules, each applied to the state obtained from the preceding one, leading to s
  - this is a *safety* property

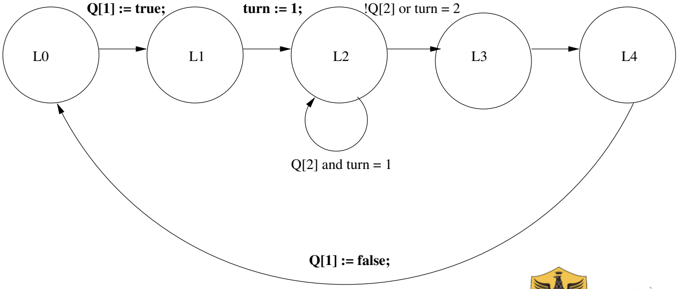
- Example: G. L. Peterson protocol for mutual exclusion of 2 processes (1981)

Peterson's Algorithm

```
boolean flag [2];
int turn;
void P0()
{
     while (true) {
          flag [0] = true;
          turn = 1;
          while (flag [1] && turn == 1) /* do nothing */;
          /* critical section */;
          flag [0] = false;
          /* remainder */;
     }
}
void P1()
{
     while (true) {
          flag [1] = true;
          turn = 0;
          while (flag [0] && turn == 0) /* do nothing */;
          /* critical section */;
          flag [1] = false;
          /* remainder */
     }
}
void main()
{
     flag [0] = false;
     flag [1] = false;
     parbegin (P0, P1);
}
```

Murphi

- Example: G. L. Peterson protocol for mutual exclusion of 2 processes (1981)
- UML-like state diagram: this is the first process; the second may be obtained exchanging 1's with 2's and viceversa



Murphi

- Example: G. L. Peterson protocol for mutual exclusion of 2 processes (1981)
  - two identical processes
  - each applies Peterson protocol to access to the critical section L3
  - the first issuing the request enters L3
  - `Q` is a global variable, defined as an array of two integers
    - each process i may modify `Q[`i`]` and read `Q[`$(i+1) \mod 2$`]`
  - `turn` is another global variable, which may be both read and modified by both processes

Murphi

- Murphi description for Peterson protocol: let's start with the variables
  - of course `turn` and `Q`, but also two variables `P` for the modality ("states" in the UML-like state diagram)
  - see `01.2_peterson.no_rulesets.no_parametric.m`
  - to this aim, we define constants and types
  - the `N` constant (number of processes) is here fictious: only 2 processes, not more
  - this version of Peterson protocol only works for 2 processes
- thus, the state space is
  $S = \texttt{label\_t}^2 \times \{\texttt{true}, \texttt{false}\}^2 \times \{1, 2\}$

Variables for Murphi Model Describing Peterson Protocol

P	$v \in \{L0, L1, L2, L3, L4\}$	$v \in \{L0, L1, L2, L3, L4\}$
Q	$v \in \{true, false\}$	$v \in \{true, false\}$
turn	$v \in \{1..N\}$	

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Murphi

- Hence, $|S| = 5^2 \times 2^2 \times 2 = 200$ (there are 200 possible states)
  - as a matter of comparison, the "state" L0 in the UML-like state diagram actually contains $5^1 \times 2^2 \times 2 = 40$ states...
- However, as we will see, *reachable* states are about 10 times less
- 2 initial states: `turn` may be initialized with any value in its domain
- Note that `01.2_peterson.no_rulesets.no_parametric.m` we have rules repeated 2 times in a nearly equal fashion
- This can be done in this very simple model, but in general descriptions must be *parametric*

Murphi

- If we want to check Peterson with 3 processes, currently we would have to add rules in the descipriou
  - very similar to the ones already present, only changing the index to 3
- Instead, it must be possible to only change the value of `N` from 2 to 3
- To write parametric descriptions in Murphi, rules are grouped with *rulesets*
  - an index will allow to describe the behavior of the generic process *i*
  - see `02.2_peterson.with_rulesets.no_parametric.m`, but invariant is still for two processes only

Murphi

- Finally, in `03.2_peterson.with_rulesets.parametric.m` also the invariant is parametric in `N`
  - `Exists` $x : T$ $E(x)$ `End` is equivalent to $\vee_{x \in T} E(x)$
  - `Forall` $x : T$ $E(x)$ `End` is equivalent to $\wedge_{x \in T} E(x)$
  - all types $T = \{x_1, \ldots, x_{|T|}\}$ are finite, thus it is a finite formula