Program analysis parameterized by the semantics in Maude

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Motivation

- Logical frameworks allow us to specify and analyze different logics and inference systems.
- In particular, we can represent the semantics of programming languages.
- We have a logical framework $\mathcal{L}$ where we specify the semantics $\mathcal{S}$ of programming languages.
- Then, we have programs p written for these programming languages.
- Is it possible to define generic analyses $\mathcal{A}$ so $\mathcal{A}(\mathcal{S})$ is a tool for programs p defined for $\mathcal{S}$?

Motivation

- It is possible but not straightforward.
- (Meta)Semantics of the framework vs. semantics defined for the programming language in the framework.
- We have a (declarative) debugger for logical framework that asks questions and locates bugs in the specification:

```
x = 0;
i = 1;
while i < 3 {
   x = x + 1; // It should be x = x + i
   i = i + 1;
}
```

- It locates an error in the semantics of loops.

Motivation

- However, it is useful (and usual) to use the tools for $\mathcal{L}$ to analyze programs p.
- For example, for looking for counterexamples with model checking.
- Finding a counterexample indicates that the program fails (assuming the semantics are correct).
- Interpreting the counterexample is difficult, because it does not refer to $\mathcal{S}$.

Motivation

- Particular syntax/semantics vs. another particular syntax/semantics.
- If we implement the debugger to locate problems in C-like functions (in a naïve way)...
- We would need to implement the same for Java-like functions.
- Both debuggers would be quite similar but the sorts would and particular pieces of syntax would different.

Motivation

- We choose *Rewriting Logic* as logical framework.
- We use *Maude* as implementation of rewriting logic.
- Our generic analysis will be *slicing*.
- For presentation purposes we will focus in a particular imperative language with conditional statements, loops, i/o buffer, and function calls.

Motivation

- Many researchers have specified the complete semantics of programming languages in Maude (and $\mathbb{K}$).
- Useful for theorem proving and model checking.
- Many specific tools for proving “particular” results on different languages.
- These particular results are applied to features such as classes/objects, threads, or message-passing.
- They also included refined theorem provers and modifications for improving model checking counterexamples.
- Generic analysis tools would be useful for all of the already defined languages.

Outline of the talk

1. Preliminaries
   - Rewriting Logic
   - Semantics in Rewriting Logic
   - Slicing
2. Parameterized analysis
   - Features synthesis
   - Slicing algorithm
3. Prototype
4. Conclusions and ongoing work

Membership equational logic

- Rewriting logic is parameterized by an underlying equational theory.
- In our case this logic is *membership equational logic* (MEL).
- We denote by $\Sigma \equiv (K, \Sigma_K, S)$ a *signature* where:
  - K is a set of *kinds*,
  - $\Sigma_K = \{\Sigma_{k_1 \ldots k_n, k}\}_{(k_1 \ldots k_n, k) \in K^* \times K}$ is a many-kinded signature, and
  - $S = \{S_k\}_{k \in K}$ is a pairwise disjoint K-kinded family of sets of *sorts*.
- Intuitively, terms with a kind but without a sort represent error elements.
- $T_{\Sigma,k}$ and $T_{\Sigma,k}(X)$ denote the set of ground Σ-terms and of Σ-terms over variables in X.

Membership equational logic

- The atomic formulas of MEL are:
  - *Equations* $t = t'$.
  - *Membership axioms* $t : s$.
- *Sentences* are Horn clauses of the form $(\forall X)\, A_0 \Leftarrow A_1 \wedge \cdots \wedge A_n$, with A_i either an equation or a membership axiom.
- A *specification* is a pair (Σ, E), where E is a set of sentences in MEL over the signature Σ.
- A MEL specification (Σ, E) has an initial model $\mathcal{T}_{\Sigma/E}$.
- Our MEL specifications are assumed to satisfy some executability requirements, so their equations can be oriented from left to right, $t \to t'$.

Membership equational logic

- Maude functional modules, with syntax `fmod ... endfm`, are executable MEL specifications.
- In a functional module we can declare:
  - `Sorts`.
  - `Subsort` relations between sorts.
  - Operators (`op`) for building values of these sorts, giving the arity and coarity, and which may have attributes such as `assoc` and `comm`.
  - Memberships (`mb`) asserting that a term has a sort.
  - Equations (`eq`) identifying terms.

Membership equational logic

- Both membership axioms and equations can be conditional (`cmb` and `ceq`).
- Conditions can also be *matching equations* $t := t'$, which are solved by matching, thus instantiating new variables in t.
- Maude does automatic kind inference.
- Kinds correspond to the connected components of the subsort relation.

Membership equational logic

```
fmod OLIST is
 pr NAT .

 sorts List OList .
 subsort Nat < OList < List .

 op mt : -> OList [ctor] .
 op __ : List List -> List [ctor assoc id: mt] .

 vars N N' : Nat .
 var  L : List .

 cmb N N' L : OList
  if N <= N' /\
     N' L : OList .

 op |_| : List -> Nat .
 eq | mt | = 0 .
 eq | N L | = s(| L |) .
endfm
```

Rewriting Logic

- Rewriting logic extends equational logic by introducing the notion of *rewrites*.
- A rewriting logic specification, or *rewrite theory*, has the form $\mathcal{R} = (\Sigma, E, R)$, where:
  - (Σ, E) is an equational specification.
  - R is a set of *rules*.
- A rule q in R has the general conditional form

$$q : \ (\forall X)\ e \Rightarrow e' \Leftarrow \bigwedge_{i=1}^{n} u_i = u'_i \wedge \bigwedge_{j=1}^{m} v_j : s_j \wedge \bigwedge_{k=1}^{l} w_k \Rightarrow w'_k$$

Rewriting Logic

- Maude system modules, with syntax `mod ... endm`, are executable rewrite theories.
- They can contain rules (`rl`) and conditional rules (`crl`).
- Rewrite conditions instantiate variables in the righthand side.
- The strategy followed by Maude is to compute the normal form of a term w.r.t. the equations before applying a rule.
- This strategy works when the rules are *coherent* with respect to the equations.

Rewriting Logic

```
mod SHUFFLE is
 pr LIST .

 vars N N' : Nat .
 var  L : List .

 rl [shuffle] : N  L N'
 =>             N' L N .
endm
```

Rewriting Logic

- Rewriting logic is reflective.
- There is a finitely presented rewrite theory $\mathcal{U}$ that is *universal* in the sense that:
  - We can represent any finitely presented rewrite theory $\mathcal{R}$ and any terms t, t' in $\mathcal{R}$ as terms $\overline{\mathcal{R}}$ and $\overline{t}, \overline{t'}$ in $\mathcal{U}$.
  - Then we have the following equivalence

$$\mathcal{R} \vdash t \longrightarrow t' \iff \mathcal{U} \vdash \langle \overline{\mathcal{R}}, \overline{t} \rangle \longrightarrow \langle \overline{\mathcal{R}}, \overline{t'} \rangle.$$

- Since $\mathcal{U}$ is representable in itself, we get a *reflective tower*.
- In Maude reflection is accesible via the predefined `META-LEVEL` Maude module.
- It allows specifiers to handle and reason about terms that represent specifications described in Maude itself.

Semantics in Maude

- Maude is a logical framework.
- Other languages are easily defined in Maude.
- Given a programming language defined by a grammar such as

$$
\begin{array}{lcl}
\mathit{Ins} & \rightarrow & \texttt{skip} \\
 & | & \mathit{Var} \ \texttt{:=} \ \mathit{Exp} \\
 & | & \texttt{while} \ \mathit{Cond} \ \texttt{do} \ \mathit{IL} \ \texttt{od} \\
 & & \ldots \\
\mathit{Cond} & \rightarrow & \texttt{true} \mid \texttt{false} \mid \texttt{not} \ \mathit{Cond} \mid \mathit{Cond} \ \texttt{and} \ \mathit{Cond} \mid \ldots \\
\mathit{IL} & \rightarrow & \varepsilon \\
 & | & \mathit{Ins} \ \texttt{;} \ \mathit{IL}
\end{array}
$$

Semantics in Maude

$$
\begin{array}{lcl}
\mathit{Ins} & \rightarrow & \texttt{skip} \\
 & \mid & \mathit{Var}\ \texttt{:=}\ \mathit{Exp} \\
 & \mid & \texttt{while}\ \mathit{Cond}\ \texttt{do}\ \mathit{IL}\ \texttt{od} \\
 & & \ldots \\
\mathit{Cond} & \rightarrow & \texttt{true} \mid \texttt{false} \mid \texttt{not}\ \mathit{Cond} \mid \mathit{Cond}\ \texttt{and}\ \mathit{Cond} \mid \ldots \\
\mathit{IL} & \rightarrow & \varepsilon \\
 & \mid & \mathit{Ins}\ \texttt{;}\ \mathit{IL}
\end{array}
$$

- Syntactic categories are defined as datatypes (sorts in Maude).

```
sorts Ins Cond IL Exp Var ... .
```

- Grammar rules are stated as operators:

```
op skip : -> Ins [ctor] .
op _:=_ : Var Exp -> Ins [ctor] .
op while_do_od : Cond IL -> Ins [ctor] .

subsort Ins < IL .
op mtIns : -> IL [ctor] .
op _;_ : IL IL -> IL [ctor assoc id: mtIns] .
```

Semantics in Maude

- Semantics is defined by means of inference rules:

$$\frac{\langle E, st, b, fs\rangle \Rightarrow v}{\langle X := E, st, b, fs\rangle \Rightarrow \langle \texttt{skip}, st[v/X], b, fs\rangle}\ \mathrm{Asg}$$

- Inference rules are defined by conditional rewrite rules:

```
crl [Asg] : < X := e, st, b, fs >
 =>         < skip, st[v / X], b, fs >
 if < e, st, b, fs > => v .
```

- Auxiliary functions are defined by means of equations.

Semantics in Maude

- In particular we need to specify abstract, implicit notions as the memory.

```
sorts Cell Memory .
subsort Cell < Memory .

op _|->_ : Var Value -> Cell [ctor] .
op noCell : -> Memory [ctor] .
op _;_ : Memory Memory -> Memory [ctor assoc comm id: noCell] .
```

- And functions for look-up and update:

```
op _[_]   : Memory Var -> Value .
op _[_/_] : Memory Value Var -> Memory .
...
```

Semantics in Maude

$$\frac{\langle C, st, b, fs\rangle \Rightarrow \texttt{true} \quad \langle IL\ ;\ \texttt{while}\ C\ \texttt{do}\ IL\ \texttt{od}, st, b, fs\rangle \Rightarrow \langle \texttt{skip}, st', b', fs\rangle}{\langle \texttt{while}\ C\ \texttt{do}\ IL\ \texttt{od}, st, b, fs\rangle \Rightarrow \langle \texttt{skip}, st', b', fs\rangle}\ \mathrm{W}_1$$

```
crl [W1] : < while C do IL od, st, b, fs >
  =>       < skip, st', b', fs >
 if < C, st, b, fs > => True /\
    < IL ; while C do IL od, st, b, fs > => < skip, st', b', fs > .
```

$$\frac{\langle I, st, b, fs\rangle \Rightarrow \langle \texttt{skip}, st', b', fs\rangle \quad \langle IL, st', b', fs\rangle \Rightarrow \langle \texttt{skip}, st'', b'', fs\rangle}{\langle I\ ;\ IL, st, b, fs\rangle \Rightarrow \langle \texttt{skip}, st'', b'', fs\rangle}\ \mathrm{Comp}$$

```
crl [Comp] : < I ; IL, st, b, fs >
 =>          < skip, st'', b'', fs >
 if < I, st, b, fs > => < skip, st', b', fs > /\
    < IL , st', b', fs > => < skip, st'', b'', fs > .
```

Semantics in Maude

- Maude is executable, so once the semantics are specified you can write programs in your syntax and execute them.
- We use the command `rew`:

```
Maude> (rew < x := 0 ;
              y := 1 ;
              while x < 3 do
                z := x + y ;
                x := x + 1
              od, noCell, noRWB, noFuns > .)
Result: < skip, x |-> 3 ; y |-> 1 ; z |-> 3, noRWB, noFuns >
```

Slicing

- In particular, we focus on *slicing*.
- Slicing is an analysis method that takes a program and a *slicing criterion* and produces a *program slice*.
- This slicing criterion is usually a program point *pc* and a set of program variables.
- The slice consists of those instructions potentially modifying the elements in the slicing criterion.

Slicing

- That is, the slicing criterion is updated by adding information information from those instructions producing side effects.
- For example, given `x = y;`, if `x` is in the slicing criterion we would add `y`.
- We also propagate information via parameter passing.
- If we have a call `f(a, b)`, with `a` in the slicing criterion, and the definition `f(x,y)`, then we add `x`.

Slicing

- Assume we are interested on variable z.

```
function Main (){
 sum := 0;
 Local i;
 i := 1;
 while i < 11 do
  Call A (sum, i)
}
```

```
function A (x, y) {
 Call Add (x, y);
 Call Inc (y)
}

function Add (a, b) {
 a := a + b
}
```

```
function Inc (z) {
 Local i;
 i := 1;
 Call Add (z, i)
}
```

Slicing

- Assume we are interested on variable z.
- The sliced body of Add is included in the slice of Inc.
- It also indicates that i must be added to the slice.

```
function Main (){
 sum := 0;
 Local i;
 i := 1;
 while i < 11 do
  Call A (sum, i)
}
```

```
function A (x, y) {
 Call Add (x, y);
 Call Inc (y)
}

function Add (a, b) {
 a := a + b
}
```

```
function Inc (z) {
 Local i;
 i := 1;
 Call Add (z, i)
}
```

Slicing

- Assume we are interested on variable z.
- The return statement of procedure Inc is paired with the call to Inc, in the body of A so y becomes relevant for the slice.

```
function Main (){
 sum := 0;
 Local i;
 i := 1;
 while i < 11 do
  Call A (sum, i)
}
```

```
function A (x, y) {
 Call Add (x, y);
 Call Inc (y)
}

function Add (a, b) {
 a := a + b
}
```

```
function Inc (z) {
 Local i;
 i := 1;
 Call Add (z, i)
}
```

Slicing

- Assume we are interested on variable z.
- However, in this case we distinguish the call to Add from A.
- Since b does not depend on a, x is not added to the slice.

```
function Main (){
 sum := 0;
 Local i;
 i := 1;
 while i < 11 do
  Call A (sum, i)
}
```

```
function A (x, y) {
 Call Add (x, y);
 Call Inc (y)
}

function Add (a, b) {
 a := a + b
}
```

```
function Inc (z) {
 Local i;
 i := 1;
 Call Add (z, i)
}
```

Slicing

- Assume we are interested on variable z.
- Hence, in this case sum is not included in the slice.

```
function Main (){
 sum := 0;
 Local i;
 i := 1;
 while i < 11 do
  Call A (sum, i)
}
```

```
function A (x, y) {
 Call Add (x, y);
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 a := a + b
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```
function Inc (z) {
 Local i;
 i := 1;
 Call Add (z, i)
}
```

Slicing

- Assume we are interested on variable z.
- It would be the same for other languages like C or Python.

```
void Main (){
 sum = 0;
 int i;
 i = 1;
 while (i < 11) {
  A (sum, i);
 }
}
```

```
void A (int x, int y) {
  Add (x, y);
  Inc (y);
}

void Add (int a, int b) {
 a = a + b;
}
```

```
void Inc (int z) {
 int i;
 i = 1;
 Add (z, i);
}
```

Slicing

- Assume we are interested on variable z.
- It would be the same for other languages like C or Python.

```
def Main () :
 global sum
 sum = 0
 i = 1
 while (i < 11) :
  A (sum, i)
```

```
def A (x, y) :
  Add (x, y)
  Inc (y)

def Add (a, b) :
 a = a + b
```

```
def Inc (z) :
 i = 1
 Add (z, i)
```

Slicing in Maude

- There is a slicer available for Maude specifications.
- It slices Maude programs using Maude variables.
- Hence, it can debug the semantics.
- However, it cannot slice the programs written in the specified language, it is just a term!
- We show how to implement a slicer parameterized by the semantics defined in Maude.
- It computes the slices of programs whose semantics has been specified in Maude.
- We have implemented a tool called *Chisel* that implements the ideas presented here.

Parameterized analysis

- Given the standard slicing algorithm for imperative languages, it is “easy” to apply it to the programs written for the semantics given we know:
  - The sort for the elements in the slicing criterion

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Parameterized analysis

- Given the standard slicing algorithm for imperative languages, it is “easy” to apply it to the programs written for the semantics given we know:
  - The sorts for the elements in the slicing criterion, the instructions, and the memory.

Parameterized analysis

- Given the standard slicing algorithm for imperative languages, it is “easy” to apply it to the programs written for the semantics given we know:
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  - The instructions generating side-effects (e.g. assignments).

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  - The sorts for the elements in the slicing criterion, the instructions, and the memory.
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  - The data-flow information (e.g. `a := b` generates $\overset{\curvearrowleft}{\texttt{a b}}$).

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  - The instructions generating side-effects (e.g. assignments).
  - The data-flow information (e.g. `a := b` generates $\overset{\curvearrowleft}{a\ b}$).
  - The instructions in charge of context-updates (e.g. function calls).

Parameterized analysis

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  - The data-flow information (e.g. `a := b` generates $\overset{\curvearrowleft}{\texttt{a b}}$).
  - The instructions in charge of context-updates (e.g. function calls).
  - The parameter-passing policy.

Parameterized analysis

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  - The sorts for the elements in the slicing criterion, the instructions, and the memory.
  - The instructions generating side-effects (e.g. assignments).
  - The data-flow information (e.g. `a := b` generates $\overset{\curvearrowleft}{\texttt{a}\,\texttt{b}}$).
  - The instructions in charge of context-updates (e.g. function calls).
  - The parameter-passing policy.
  - The memory policies about references (e.g. pointers).

Parameterized analysis

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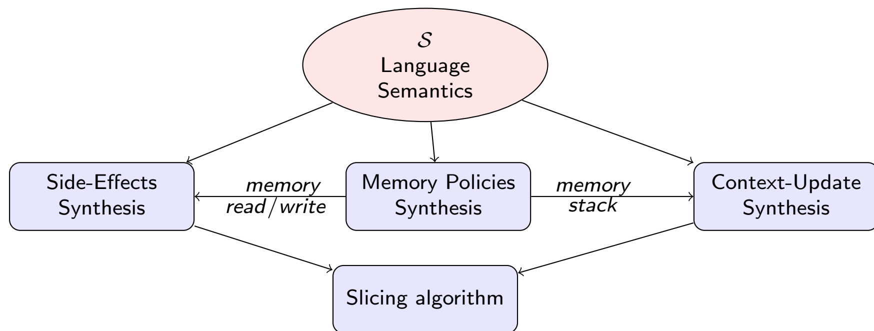
  - The for the elements in the slicing criterion
  - The instructions generating side-effects (e.g. assignments).
  - The data-flow information (e.g. `a := b` generates $\overset{\curvearrowleft}{\texttt{a b}}$).
  - The instructions in charge of context-updates (e.g. function calls).
  - The parameter-passing policy.
  - The memory policies about references (e.g. pointers).
  - How to deal with parallelism.

Parameterized analysis

- We should not force the user to provide all this information.
- We only support *call-by-value* parameter passing.
- We *do not* support pointers.
- We *do not* parallelism.
- We infer the sort for the elements in the slicing criterion from the initial command.
- We infer the rest of information (over-approximations).

Chisel



Chisel: Memory policies synthesis

- We start the analysis by classifying the sorts.
- We distinguish between them depending on how terms of these sorts are used in rules:
  - Terms being read and manipulated. Values obtained from these terms are used to access and manipulate terms of other sorts: *instructions*.
  - Terms used to store and access information: *memory, i/o buffer, registers, etc.*
  - Terms containing instructions and only read: *function definitions*.
  - Auxiliary sorts, which cannot be classified in any of the categories above: *program counter*.

Chisel: Memory policies synthesis

- Given the sorts for the memory, we can:
  - Find the functions accessing and modifying it.
  - Find its constructors.
- Functions accessing and modifying the memory show the data-flow information.
- The constructors allow us to detect *stack structures* used when changing context.

Chisel: Memory policies synthesis

```
op _[_]   : Memory Var -> Value .
op _[_/_] : Memory Value Var -> Memory .
```

- We know from the first analysis that `Memory` is the sort for the memory.
- Operators with `Memory` as coarity update it.
- Operators with it in the arity (and not in the coarity) access it.

Chisel: Data-flow synthesis

- This stage receives the set of rules modifying the memory, as well as the sets of functions modifying and accessing the memory, respectively.
- When facing a rule that modifies the memory, we take the instruction and slice the rule w.r.t. the variables for each element to see whether it accesses or modifies the memory.
- For example, in `X := e` we find that `e` accesses the memory.
- The value thus obtained is used to update the memory for the position `X`.
- This stage returns a set of elements of the form $\mathtt{x} \curvearrowleft \mathtt{s}$, indicating that the variable `x` is modified by the variables in `s`.

Chisel: Data-flow synthesis

```
crl [Asg] : < X := e, st, b, fs > => < skip, st[v / X], b, fs >
 if < e, st, b, fs > => v .
```

- From the previous analysis we know that the X is the value being modified and v is the new value.
- From Maude slicing, we see that v depends on e and st.
- From the first analysis we know that X and e are part of the instruction.
- So e is modifying X.

Chisel: Context-update synthesis

- This stage receives the stack constructors and identifies the rules for context-updates.
- However, some languages (e.g. assembly) do not rely on building a stack of environments when a function is called.
- In this case we use a test-case generator to analyze how the execution sequence varies and identify those rules that are in charge of these variations.
- This stage is under development, our random test-case generator does not provide good results so we need to rely in an external tool.

Program slicing as term slicing: algorithm

- The algorithm has two phases:
  - The initialization of the data structures.
  - The loop implementing the fixpoint.
- The initialization part computes a hyper-tree following the structure of the program.
- The fixpoint loop discovers the call graph in an on-demand fashion using the context-update set, which directs the fixpoint iteration.

Program slicing as term slicing: algorithm

- This fixpoint iteration is composed of three parts:
  - Updating the slice by using the called functions.
  - Updating the slice by using the calling functions.
  - Updating the slice by applying intraprocedural with the new variables.
- The algorithm terminates because there exists a finite set of function skeleton subterms, a finite set of data flow graphs, a finite set of edges in the call graph for each function, and any loop in the call graph is solved based on the data flow graph ordering.
- It produces a valid slice because it exhaustively saturates the slicing criterion.
- It might not be minimal, although it produces better results than many standard techniques.

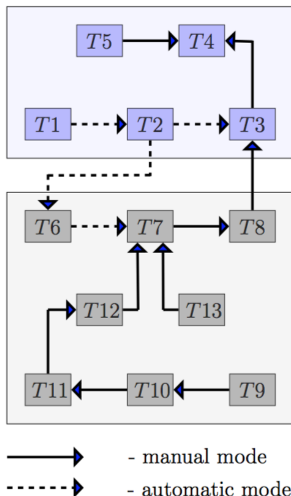
Prototype

- We test our proposed method for slicing on a set of benchmarks addressing embedded and real-time applications.
- We have compiled them into C and MIPS (assembly).
- The C code has been tested with different implementations.
- Disclaimer: we have the semantics for a small subset of C, not for the whole language.

https://github.com/ariesco/chisel

Prototype

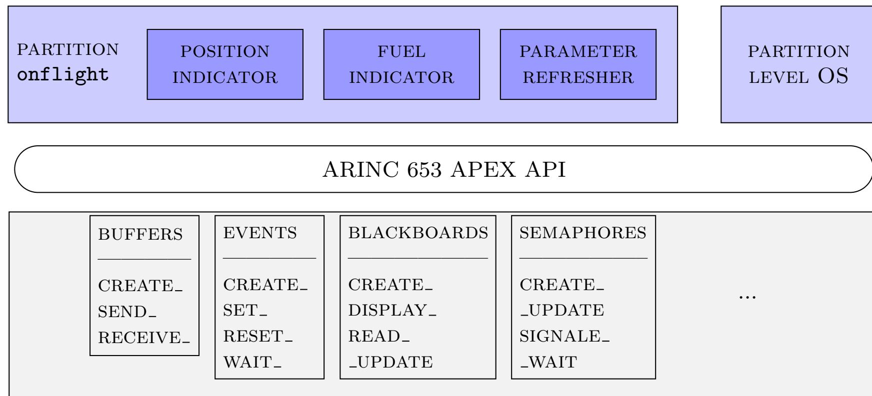
Tasks : fbw and autopilot		
T1	-	receive_radio_commands
T2	-	send_data_to_autopilot
T3	-	receive_data_from_autopilot
T4	-	transmit_servos
T5	-	check_failsafe
T6	-	manage_radio_commands
T7	-	control_stabilization
T8	-	send_data_to_fbw
T9	-	receive_gps_data
T10	-	control_navigation
T11	-	control_altitude
T12	-	control_climb
T13	-	manage_reporting



Prototype

Name	# Funs	# Calls	LOC (WhileFun)	red (%) (WhileFun)	LOC (MIPS)	red (%) (MIPS)
scheduler_fbw	14	18	103	72.8 %	396	44.4 %
periodic_auto	21	80	225	73.3 %	779	36.3 %
fly_by_wire	**41**	**110**	**638**	**91.1 %**	**1913**	**41 %**
T1	10	26	119	76.5 %	534	36.2 %
T2	9	9	59	69.5 %	329	44.4 %
T3	9	24	82	76.5 %	501	43.6 %
T4	9	14	50	61.5 %	235	34.5 %
T5	7	22	66	67 %	453	51 %
autopilot	**95**	**214**	**1384**	**92 %**	**5639**	**41.5 %**
T6	36	71	306	77.2 %	1329	54 %
T7	9	13	57	70 %	426	42 %
T8	7	15	54	69.2 %	219	38 %
T9	15	30	87	75 %	617	36.5 %
T10	18	27	102	71.1 %	1002	42.2 %
T11	3	2	15	63.4 %	90	70.6 %
T12	4	3	49	66.2 %	363	50 %
T13	37	93	240	79.7 %	1535	42 %

Prototype



Prototype

Functionality	Vars	# LOC (WhileFun)	# LOC (MIPS)	red (%) (WhileFun)	red (%) (MIPS)
GLOBAL_PROCESS_MANAGER	28	377	7020	90.7 %	33.6 %
GLOBAL_SEMAPHORE_MANAGER	6	114	6949	97.2 %	34.2 %
GLOBAL_EVENT_MANAGER	6	95	6944	97.6 %	34.3 %
GLOBAL_BLACKBOARD_MANAGER	6	90	6942	97.7 %	34.3 %
GLOBAL_BUFFER_MANAGER	6	147	6945	96.4 %	34.3 %
GLOBAL_SAMPLINGPORT_MANAGER	7	87	6971	97.8 %	34 %
CREATE_COMPONENTS	17	366	6945	91 %	34.3 %
PRESENT_SIGNALS	35	372	7054	90.9 %	33.2 %
INITIALIZATION_SIGNALS	2	78	6937	98 %	34.3 %
NORMAL_SIGNALS	1	83	6933	97.9 %	34.4 %
POSITION_INDICATOR	10	276	6931	93.2 %	34.4 %
FUEL_INDICATOR	12	221	6949	94.5 %	34.2 %
PARAMETER_REFRESHER	12	233	6949	94.3 %	34.2 %

Prototype

- What is happening?

Prototype

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- In WhileF we have `x = 0;`
- `x` is a variable and `0` a value.

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- In WhileF we have `x = 0;`
- `x` is a variable and `0` a value.
- In MIPS we have `mv Ri RZ`.
- `Ri` is a register and `RZ` a register as well.
- `RZ`, which behaves as a constant, is added to the slice.

Conclusions

- We have presented a generic algorithm for interprocedural slicing based on results of meta-level analysis of the language semantics.
- In summary, the slicing prerequisites are:
  - Context-update rules and side-effect sorts.
  - Call-by-value parameter passing.
  - No parallelism.
- The actual program slicing computation is done through term slicing and is meant to set the aforementioned set of prerequisites.
- Specific problems for some languages worsen the performance.

Conclusions

- We have worked with many different languages and different Maude specifications for them.
- We have also used Maude for other parameterized analyses.
- We have a generic declarative debugger for big-step and small-step semantics
- We also transform the counterexample obtained from the model checker to correspond to the semantics of the particular programming language.

Ongoing work

- We are interested on studying how the technique works for languages with pointers and parallelism.
- We are also interested on call-by-name parameter passing.
- From the prototype point of view, we also plan to investigate how to infer the parameter passing pattern.
- We intend to improve our test-case generator to detect context-updates.
- We want to slice the counterexample obtained from the model checker.
- Finally, we aim to develop the method for language semantics defined in Maude but also in $\mathbb{K}$.