The Blame Game for Property-based Testing: work-in-progress

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Property-based Testing

- A light-weight validation approach merging two well known ideas:
  1. automatic generation of test data, against
  2. executable program specifications.
- Brought together in *QuickCheck* (Claessen & Hughes ICFP 00) for Haskell
- The programmer specifies properties that functions should satisfy inside in a very simple DSL, akin to Horn logic
- QuickCheck aims to falsify those properties by trying a large number of randomly generated cases.

αCheck

- Our recently (re)released tool: `https://github.com/aprolog-lang`
- On top of αProlog, a simple extension of Prolog with nominal abstract syntax.
- Use nominal Horn formulas to write specs and checks.
- Equality coincides with $\equiv_\alpha$, $\#$ means "not free in", $\langle \mathsf{x} \rangle M$ is M with x bound, $\mathsf{И}$ is the *fresh* Pitts-Gabbay quantifier.
- αCheck searches exhaustively for counterexamples, using iterative deepening.
- Our intended domain: the meta-theory of programming languages artifacts: from static analyzers to interpreters, compilers, parsers, pretty-printers, down to run-time systems. . .

A motivating (toy) example 1/2

- This grammar characterizes all the strings with the same number of a's and $b's$:

```
S ::= .  | bA | aB
A ::= aS | bAA
B ::= bS | aBB
```

- We encode it in αProlog, inserting two quite obvious bugs, but be charitable and think of a much larger grammar:
  - viz., the grammar of $Ocaml_{light}$ consists of 251 productions

```
ss([]).
ss([b|W])  :- ss(W).
ss([a|W])  :- bb(W).

bb([b|W])  :- ss(W).
bb([a|VW]) :- append(V,W,VW), bb(V), bb(W).

aa([a|W])  :- ss(W).
```

(an ice cream to the first who finds both bugs in the next 30 secs)

- We use αCheck to debug it, splitting the characterization of the grammar into soundness and completeness:

```
#check "sound" 10: ss(W), count(a,W,N1), count(b,W,N2)
                        => N1 = N2.

#check "compl" 10: count(a,W,N), count(b,W,N) => ss(W).
```

- The tool dutifully reports (at least) two counterexamples:

```
Checking for counterexamples to
sound: N1 = z, N2 = s(z), W = [b]
compl: N = s(s(z)),       W = [b,b,a,a]
```

- Where is the bug? Which clause(s) shall we blame? Can we help the user localize the slice of program involved?

The idea: 1/3

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- Where do bugs come from? That's a huge problem.
- Did anybody say *declarative debugging*? Let's do something less heavy handed.
- We do not claim to have a general approach:
  - First, we're addressing the sub-domain of *mechanized meta-theory model-checking*, where fully declarative PL models are tested against theorems these systems should obey
  - Second, we just want to give *some* practical help to the poor user debugging a model w/o exploiting her as an oracle.

- The `#check` pragma corresponds to specs of the form that we try and refute $\forall\vec{X}.\ G \supset A$
- Take completeness of the above grammar:
  $\exists$`W. count(a,W,N), count(b,W,N), not(ss(W)).`
  A *counterexample* is a grounding substitution θ that $\theta(G)$ is derivable, but $\theta(A)$ is not
- For the above to unexpectedly succeed, two (possibly overlapping) things may go wrong:
  - MA: $\theta(A)$ fails, whereas it belongs to the intended interpretation of its definition (*missing answer*);
  - WA: a bug in $\theta(G)$ creates some erroneous bindings that make the conclusion fail (*wrong answer*).

- Our "old-school" idea consists in coupling:
  1. *abduction* to try and diagnose *MA's* with
  2. *proof verbalization*: presenting at various levels of abstraction *proof-trees* for *WA's* to explain where the bug occurred.
- Differently from declarative debugging, we ask the user only to state who she trusts:
  - built-in, certainly; libraries, most likely;
  - predicates that have sustained enough testing;
- and which are the abductable predicates:
  - some heuristics based on the dependency graph should help.

Proof verbalization

- Back to the *soundness* check: we trust unification and the auxiliary count predicate . . .

```
ss(W), count(a,W,N1), count(b,W,N2)  => N1 = N2.
sound:  N1 = z, N2 = s(z), W = [b]
```

- . . . hence it must be a case of WA, starring `ss([b])`. Verbalizing the proof tree yields:

```
ss([b])  for rule s2, since:
  ss([])   for fact s1.
```

- This points to rule s2

```
ss([b|W])  :- ss(W). % BUG
ss([b|W])  :- aa(W). % OK
```

- Clearly, proof trees tend to be longer than that and we *distill* them to hide information, up to showing only the skeleton of the proof (the clauses used).

Abduction

- Once we fix the previous bug, the second still looms:

```
count(a,W,N), count(b,W,N) => ss(W).
compl: N = s(s(z)), W = [b,b,a,a]
```

- It's a MA: putting all the grammar in the abducibles, we have:

```
ss([b,b,a,a])  for rule s2, since:
  aa([b,a,a])   for assumed.
```

- We realize that there is **no** clause head `aa([b|VW])` in the program, matching the failed leaf: we have forgot the clause:

```
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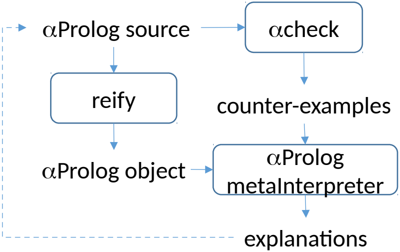
- I told you the bugs were silly, didn't I?
- That's why we implemented a tool for **mutation** testing: plenty of unbiased faulty programs to explain away!

Mutation testing

- Change a source program in a localized way by introducing a single (syntactic) *fault* — have a "mutant", hopefully not semantically equivalent.
- "Kill it" with your testing suite means finding the fault.
- A killed mutant is a good candidate for blame assignment: it contains reasonable bugs not planted by ourselves.
- We have written a mutator for αProlog by randomically applying **type-preserving** mutation operators
- and checking with αCheck (up to a bound of course) that the mutant is not equivalent to its ancestor;
- if so, we pass it to the blame tool for explanation.

Architecture of the tool

- The back-end consists of an αProlog meta-interpreter working on a reified version of the sources of an αProlog program
- The front-end is written in Prolog and is responsible for everything else:
  - The reification process and syncing the latter with the sources
  - Calling αCheck, feeding the meta-interpreter with the necessary info and doing the verbalization



Conclusions

- We are close to release a tool for explanations of bugs reported by αCheck for **full** αProlog— whose features we have not used in this talk.
- While our approach of abduction + explanations is simple-minded it tries to find a sweet spot in helping understanding bugs in PL models w/o going full steam into declarative debugging
- Experience (e.g., significant case studies) will tell if we succeeded
- The mutator is of independent interest for evaluating the effectiveness of the various strategies of αCheck in finding bugs in αProlog specifications.

Thanks!