Easing implementation & maintenance of academic static analyzers

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CSV
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Inria

Introduction

Motivation

Academic research around static analysis

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Ideal analyzer

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- Eases research:
  - Implementation
  - Experimental evaluation
  - Onboarding

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$\Longrightarrow$ Aiming for lowest possible implementation & maintenance costs

This talk

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Afterwards continue the conversation and increase sharing of practices

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⚠ Some things might be folklore.

Introduction

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`gitlab.com/mopsa/mopsa-analyzer`

Goals: explore new designs, ease development of (relational) analyses

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- Semantic rewriting
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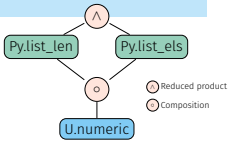
DAG of abstractions

- Relational domains
- Composition
- Cooperation



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Works around Mopsa

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C, Python

Multilanguage Python+C

WIP: Michelson, OCaml, ...

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Properties

- **Absence of RTEs**
- Patch analysis
- Endianness portability
- Non-exploitability

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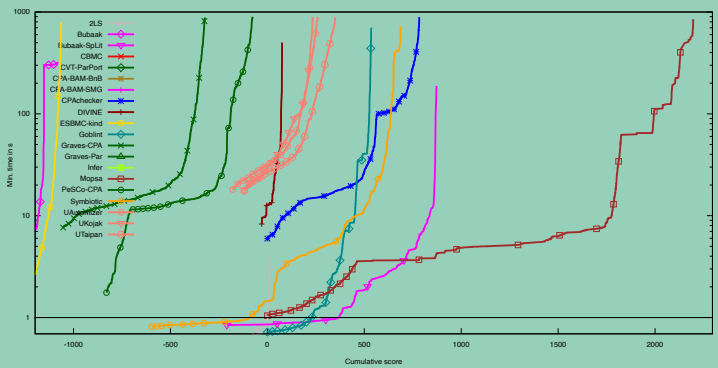
Software Verification Competition

We won the “SoftwareSystems” track of SV-Comp 2024!



Outline

1. Avoiding regressions
   - Measuring precision
   - Comparing analysis reports
2. Easing debugging
   - Developer-friendly interfaces
   - Testcase reduction
3. A plug-in system of analysis observers

Avoiding regressions

Measuring precision

The easy case of benchmarks with precision oracles

Benchmarks with precision oracles

- Know whether a given alarm should be raised
- Can provide absolute precision measure
- Based on manual analysis, not scalable
- NIST's Juliet Benchmarks, SV-Comp labeling of tasks (coarse)

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Otherwise: relative precision measures.

A good precision measure

Precision measures

Is the program safe?	Too coarse

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Our approach

Reporting status of all proofs / checks in every analyzed context

$$\text{Selectivity} = \frac{\#\text{checks proved safe}}{\#\text{checks}}$$

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1 int main() {
2   int n;
3   int y = -1;
4   for(int x = 0; x < n; x++)
5     y++;
6 }
```

Statement	
x++	
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Statement	Intervals
`x++`	Safe
`y++`	Alarm
Selectivity	50%

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Statement	Intervals	Relational
`x++`	Safe	Safe
`y++`	Alarm	Safe
Selectivity	50%	100%

A good precision measure (II)

Benefits of the approach

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Analysis of coreutils `fmt`

```
Checks summary: 21247 total, ✔ 18491 safe, ✗ 129 errors, ⚠ 2627 warnings
  Stub condition: 690 total, ✔ 513 safe, ✗ 3 errors, ⚠ 174 warnings
  Invalid memory access: 8139 total, ✔ 7142 safe, ✗ 4 errors, ⚠ 993 warnings
  Division by zero: 499 total, ✔ 445 safe, ⚠ 54 warnings
  Integer overflow: 11581 total, ✔ 10177 safe, ⚠ 1404 warnings
  Invalid shift: 163 total, ✔ 163 safe
  Invalid pointer comparison: 37 total, ✗ 37 errors
  Invalid pointer subtraction: 85 total, ✗ 85 errors
  Insufficient variadic arguments: 1 total, ✔ 1 safe
  Insufficient format arguments: 26 total, ✔ 25 safe, ⚠ 1 warning
  Invalid type of format argument: 26 total, ✔ 25 safe, ⚠ 1 warning
```

Avoiding regressions

Comparing analysis reports

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```
--- baseline/touch-many-symbolic-args-a4.json
+++ pplite/touch-many-symbolic-args-a4.json

- time: 589.0760
+ time: 675.1761

+ parse-datetime.y:1399.44-46: alarm: Invalid memory access
- parse-datetime.y:965.56-71: alarm: Invalid memory access
- parse-datetime.y:980.25-52: alarm: Invalid memory access
- parse-datetime.y:1003.23-50: alarm: Invalid memory access
- parse-datetime.y:921.56-71: alarm: Invalid memory access
- parse-datetime.c:1733.2-8: alarm: Invalid memory access
- parse-datetime.y:781.26-41: alarm: Invalid memory access
- parse-datetime.y:772.23-38: alarm: Invalid memory access
- parse-datetime.y:755.23-38: alarm: Invalid memory access
- parse-datetime.y:973.25-52: alarm: Invalid memory access
- parse-datetime.y:610.8-41: alarm: Invalid memory access
- parse-datetime.y:743.25-40: alarm: Invalid memory access
```

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```

```
139 reports compared
avg. time change       +52.065s
avg. speedup               -36%
new alarms                   2
removed alarms              32
new assumptions              0
removed assumptions          0
new successes                0
new failures                 0
```

A word on continuous integration (CI)

Detecting breaking changes in the CI

- `mopsa-diff` to compare with previous results

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Language	Benchmark	Max. LoC	≃ Time	Selectivity
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Python+C[3]	ahocorasick	4,800	1.0m	98.0%
	bitarray	5,700	4.6m	94.6%

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[3] Monat, Ouadjaout, and Miné. "A Multilanguage Static Analysis of Python Programs with Native C Extensions". 2021

Easing debugging

Developer-friendly interfaces

Where static analyzers usually start from

- Analysis output

Too coarse

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- Printing abstract state using builtins — Not interactive

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- Analysis output — Too coarse
- Printing abstract state using builtins — Not interactive
- Interpretation trace — Can be dozens of gigabytes of text

```
+ S [| set_program_name(argv[0]); |]
| | + S [| add(argv0)
| | |       argv0 = argv[0]; |]
| | | + S [| add(argv0) |]
| | | | + S [| add(argv0) |] in below(c.iterators.intraproc)
| | | | | + S [| add(argv0) |] in C/Scalar
| | | | | | + S [| add(offset⟦argv0⟧) |] in Universal
| | | | | | o S [| add(offset⟦argv0⟧) |] in Universal done [0.0001s, 1 case]
| | | | | o S [| add(argv0) |] in C/Scalar done [0.0001s, 1 case]
| | | | | + S [| add(argv0) |] in below(c.memory.lowlevel.cells)
| | | | | | + S [| add(offset⟦argv0⟧) |] in Universal
| | | | | | o S [| add(offset⟦argv0⟧) |] in Universal done [0.0001s, 1 case]
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| | | o S [| add(argv0) |] done [0.0002s, 1 case]
| | | + S [| argv0 = argv[0]; |]
| | | | + S [| argv0 = (signed char *) @argv{0}:ptr; |] in below(c.iterators.intraproc)
| | | | | + S [| argv0 = (signed char *) @argv{0}:ptr; |] in C/Scalar
| | | | | | + S [| offset⟦argv0⟧ = (offset⟦@argv{0}:ptr⟧ + 0); |] in Universal
| | | | | | | + S [| offset⟦argv0⟧ = (offset⟦@argv{0}:ptr⟧ + 0); |] in below(universal.iterators.intraproc)
```

An interactive engine acting as abstract debugger

GDB-like interface to the abstract interpretation of the program

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Demo!

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- Breakpoints

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  - Alarm: jumping back to statement generating first alarm
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- Observation of the abstract state
  - Full state
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- Some scripting capabilities

DAP support

- Sibling of Language Server Protocol (LSP)

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- Debug Adapter Protocol introduced by VSCode

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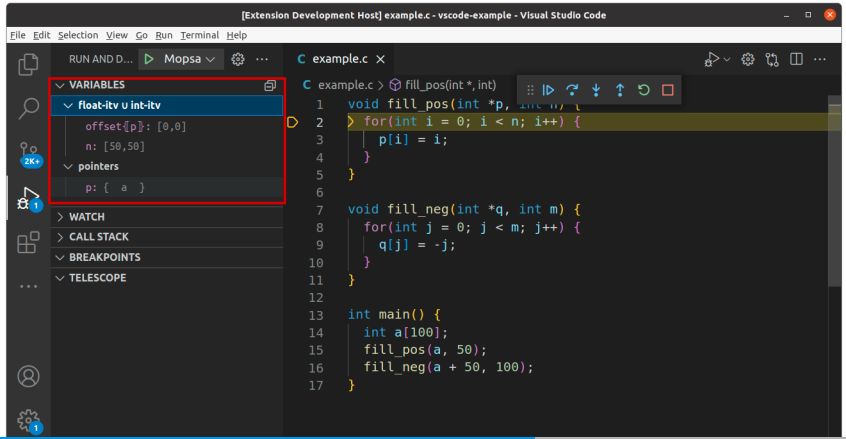

Easing debugging

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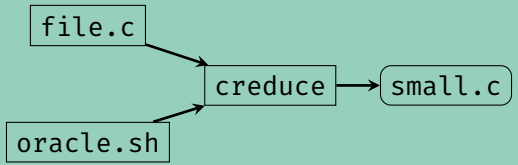
Automated testcase reduction using `creduce`[1]



[1] Regehr, Chen, Cuoq, Eide, Ellison, and Yang. “Test-case reduction for C compiler bugs”. 2012

Testcase reduction (II)

Internal errors debugging

- Highly helpful to significantly reduce debugging time of runtime errors (Apron mishandlings, raised exceptions, ...)
- Has been applied to coreutils programs, SV-Comp programs of 10,000+ LoC

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Differential-configuration debugging

```
$ mopsa-c -config=confA.json file.c
Alarm: assertion failure
$ mopsa-c -config=confB.json file.c
No alarm
```

Has been used to simplify cases in externally reported soundness issues

Handling multi-file projects

`creduce` limited to reducing a specific file

Mitigation: generate a pre-processed, standalone file

Painful operation on large projects such as `coreutils`

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- `mopsa-build`

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- `mopsa-c` leverages the compilation database

```
mopsa-c mopsa.db -make-target=fmt
```

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```
mopsa-c mopsa.db -make-target=fmt
```

- Option to generate a single, preprocessed file

A plug-in system of analysis observers

Hooks: a plug-in system of analysis observers

Hooks	
Observe analyzer state	before/after any expression/statement analysis

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Observe analyzer state — before/after any expression/statement analysis

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- Logs: trace of interpretation performed by the analysis
- Thresholds for widening
- Coverage
- Heuristic unsoundness/imprecision detection
- Profiling

Coverage hooks

Coverage

- Global metric for the analysis' results
- Good to detect issues in the instrumentation of the fully context-sensitive analysis

No symbolic argument

```
./src/coreutils-8.30/src/fmt.c:
    'main' 76% of 72 statements analyzed
    'set_prefix' 100% of 12 statements analyzed
    'same_para' 100% of 1 statement analyzed
    'get_line' 100% of 30 statements analyzed
    'fmt' 100% of 7 statements analyzed
    'base_cost' 100% of 16 statements analyzed
    'line_cost' 100% of 10 statements analyzed
    'get_prefix' 100% of 18 statements analyzed
```

Symbolic arguments

```
./src/coreutils-8.30/src/fmt.c:
    'main' 100% of 72 statements analyzed
```

Heuristic unsoundness/imprecision detection

Detection of unsound transfer functions

Bottom shouldn’t appear after some statements (such as assignments)

Detection of imprecise analysis

Warns when assignments to top are performed

Simplifies the search for sources of large imprecision

Profiling

Standard profiling

Measures which parts of Mopsa are the most time-consuming

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Abstract profiling hook

Measures which parts of the analyzed program are the most time-consuming

- Loop-level profiling
- Function-level profiling

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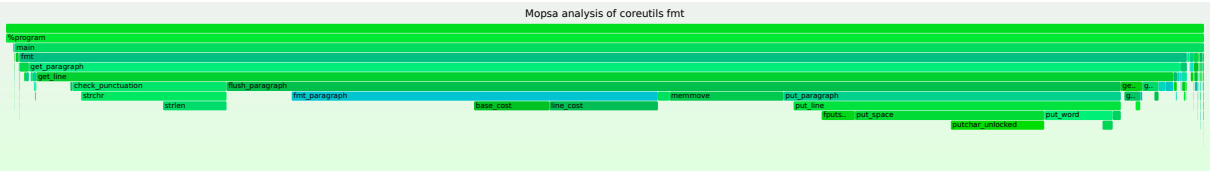

Conclusion

Lots of folklore

- Andreasen, Møller, and Nielsen. “Systematic approaches for increasing soundness and precision of static analyzers”. 2017

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- Molle, Vandenbogaerde, and Roover. “Cross-Level Debugging for Static Analysers”. 2023

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- Online availability, install-free tool testing