The Mopsa static analysis platform, and our quest to ease implementation & maintenance

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Prosecco
10 March 2025

Introduction

Automated Program Analysis

Motivation

Sheer quantity of programs and changes during their life:

Automated analyses will help scaling up

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Target program

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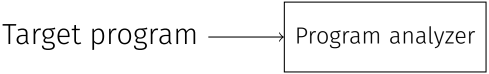

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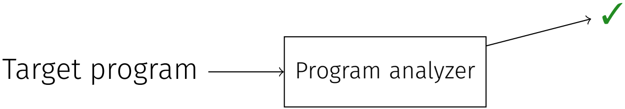

Target program

Program analyzer

✓

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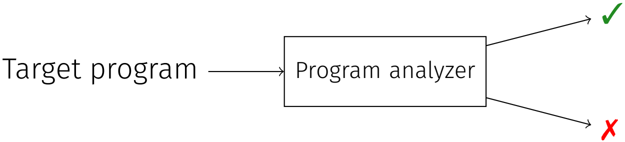

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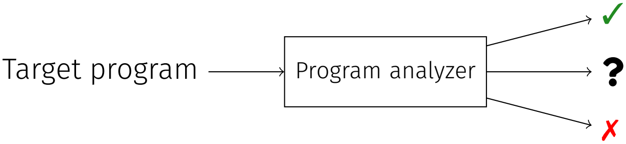

A Program Analysis Recipe

Target property φ

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Turing & Rice to the Rescue

Sound

All errors in program reported by analyzer

Turing & Rice to the Rescue

All errors reported by analyzer are replicable in program

Complete

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Guaranteed Termination

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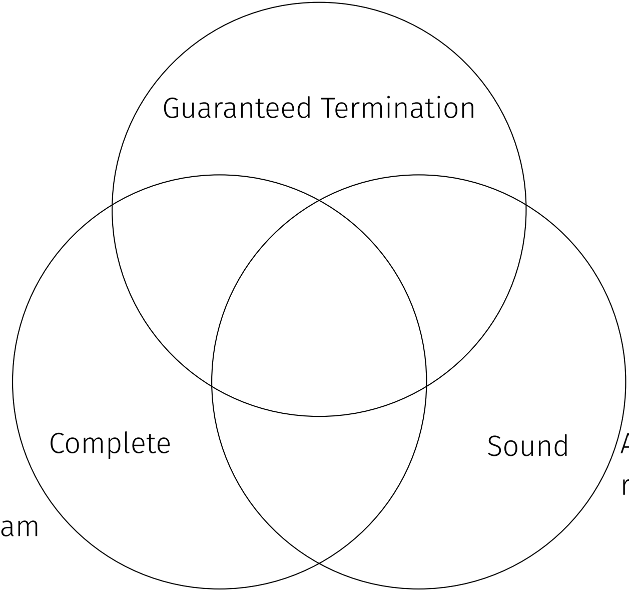

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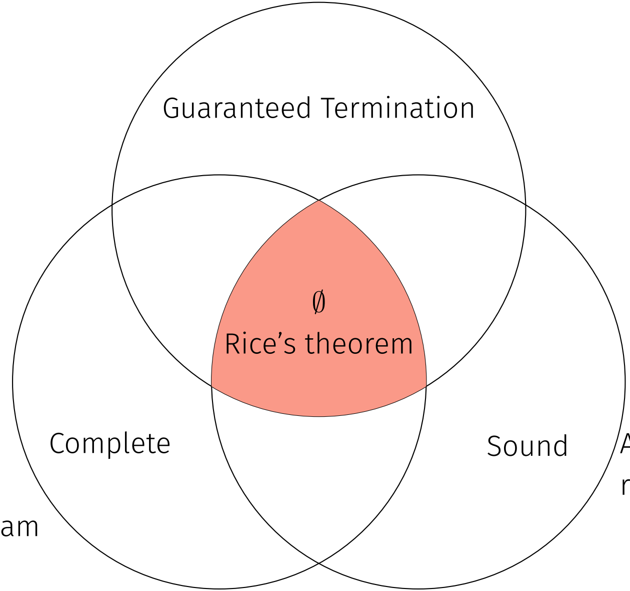

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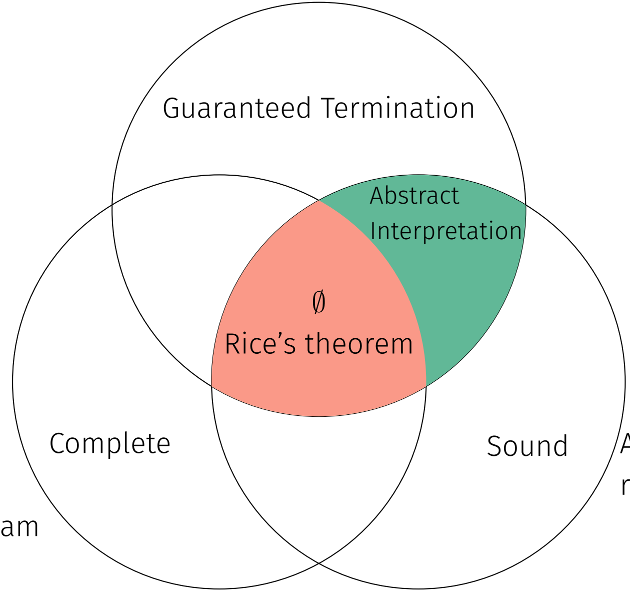

Guaranteed Termination

Abstract Interpretation

∅

Rice’s theorem

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Community Goals

Academic research around static analysis

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Ideal analyzer

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- Sound, precise and scalable

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⟹ Aiming for lowest possible implementation & maintenance costs

Outline

1. An AI primer

2. An overview of Mopsa

3. Easing maintenance and implementation

Abstract Interpretation

- Approximate analysis, ensuring soundness and termination

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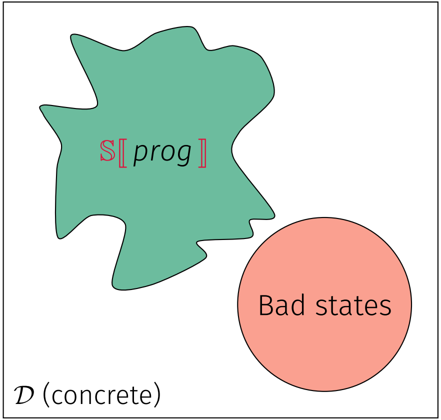
- Suggested entry-point: Miné [Min17]

Approximating a Complex World, with Guarantees



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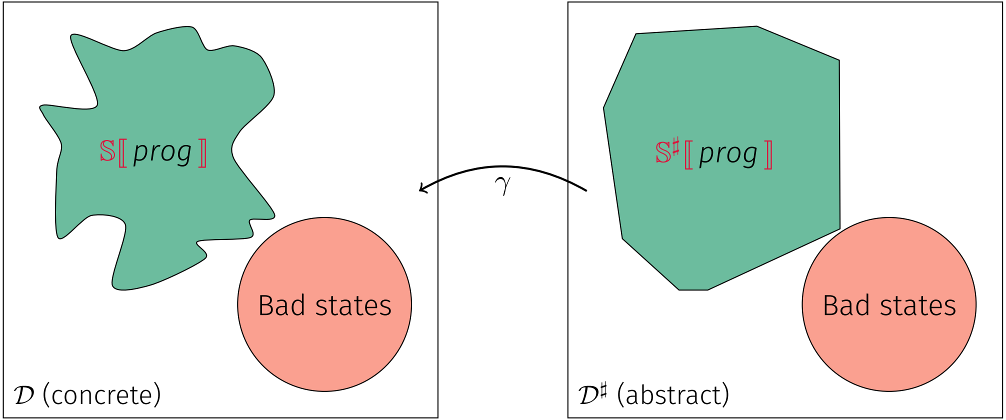
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Bad states
$\mathcal{D}$ (concrete)
γ
$\mathbb{S}^\sharp[\![\textit{prog}]\!]$
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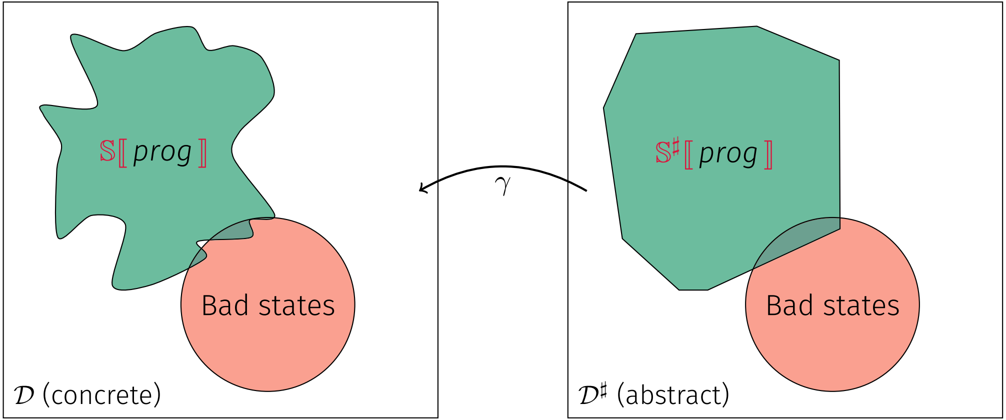
Interpret in non-standard domain

Program proved safe

Approximating a Complex World, with Guarantees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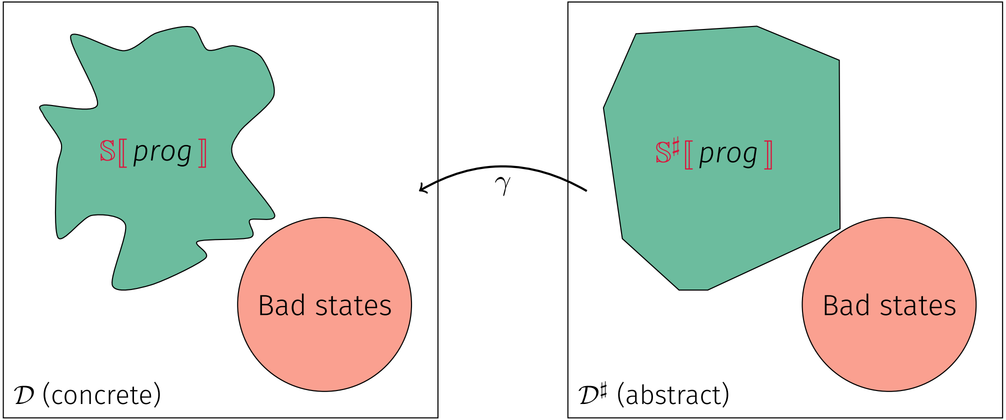
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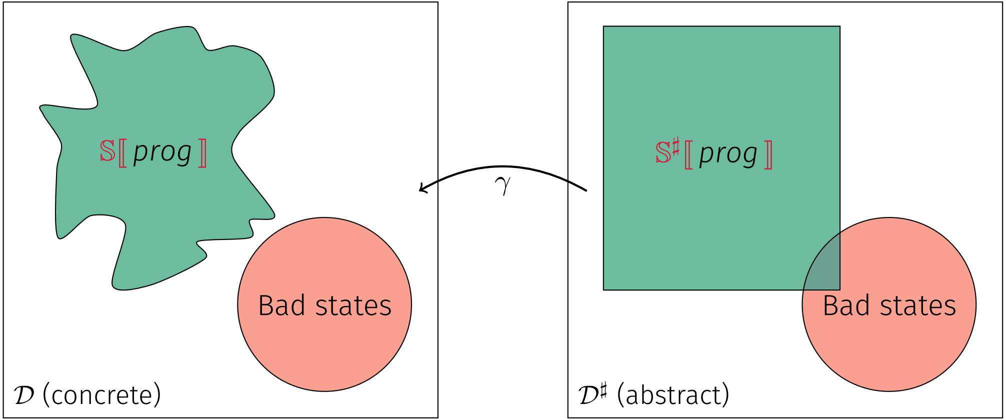
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False alarm (Abstraction too coarse)

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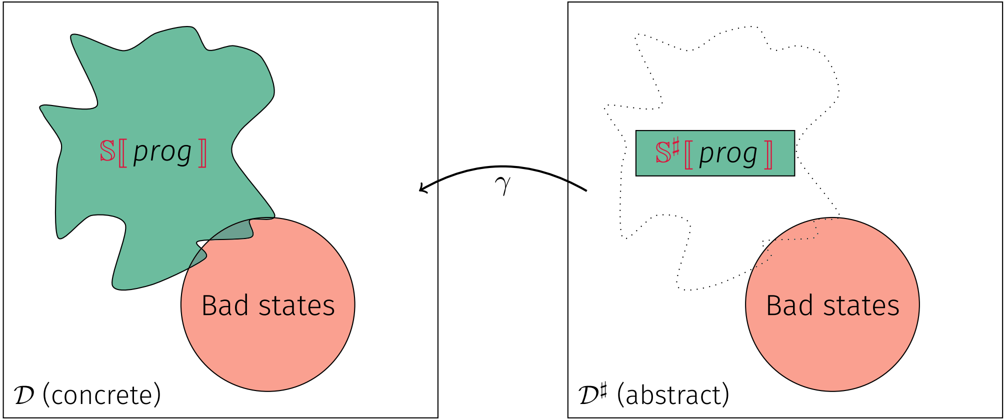
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Unsound analysis
(shouldn’t happen)

An AI primer

Key Ingredients

Merging Everything to Scale

Merging States

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  - $\sigma^\sharp = x \mapsto [0, 2147483647]$

Merging Everything to Scale (II)

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Merging can also be applied to arrays, . . .

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Precision can be recovered through decreasing iterations

$\implies \mathtt{i} = [0, 99]$

An overview of Mopsa

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Modular Open Platform for Static Analysis [Jou+19]

`gitlab.com/mopsa/mopsa-analyzer` or `opam install mopsa`

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- Ease development of relational static analyses
  - High expressivity

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Maintainers in bold.

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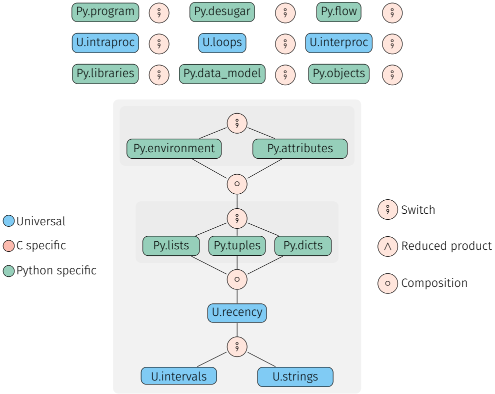

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Traditional approaches

Desugar/compile programs to an intermediate representation (IR)

Example: Infer's IR has five (!) constructors

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Mopsa

- No loss of precision from the frontend

Iterators to handle multiple languages

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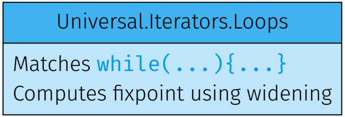
- A single AST type which can be extended for new languages

Dynamic, semantic iterators with delegation



Universal.Iterators.Loops

Matches `while(...){...}`

Computes fixpoint using widening

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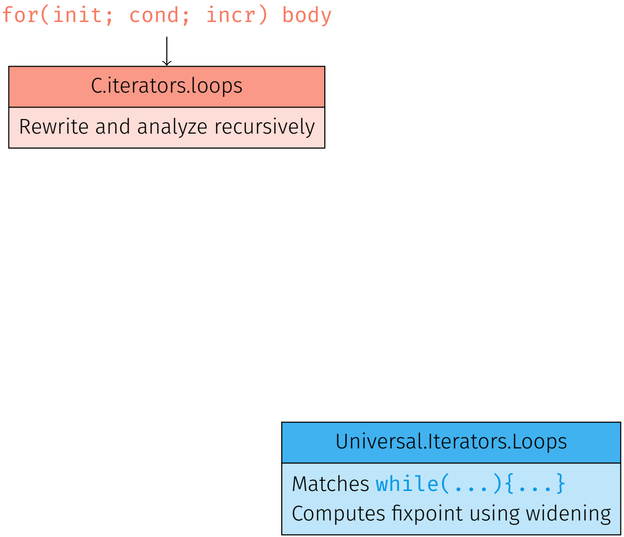

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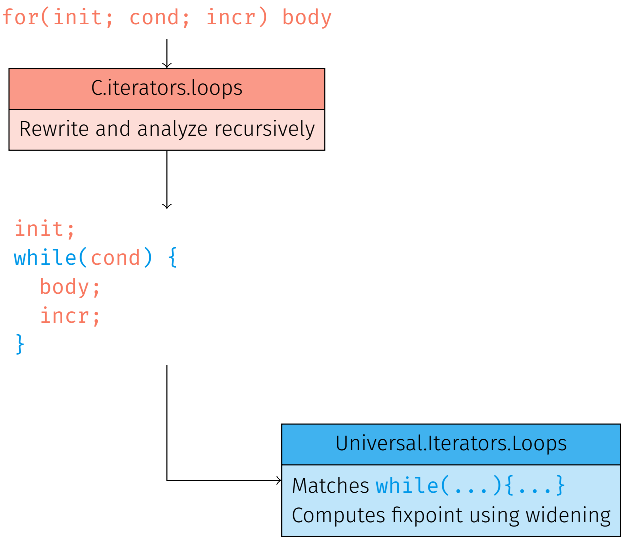

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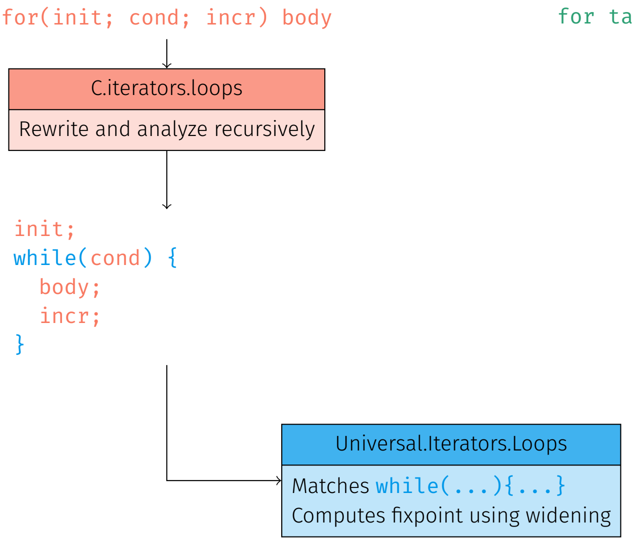

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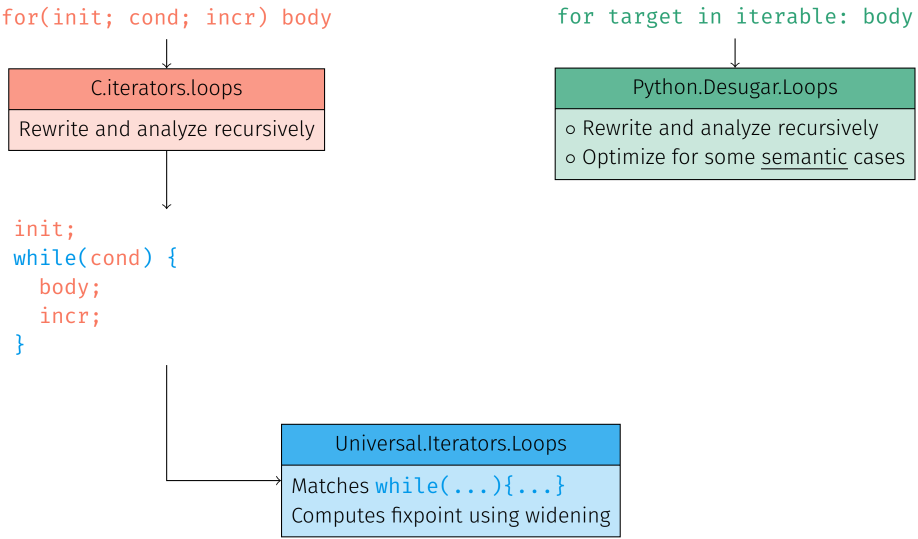

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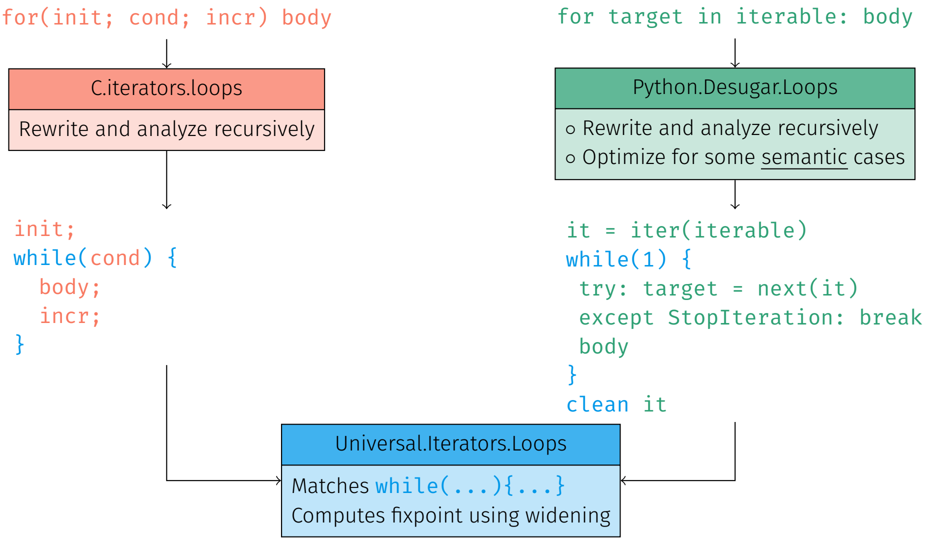

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Python.Desugar.Loops

- Rewrite and analyze recursively
- Optimize for some semantic cases

```
it = iter(iterable)
while(1) {
 try: target = next(it)
 except StopIteration: break
 body
}
clean it
```

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Expressivity through relational domains

Motivational example

```
// Hyp: a array of size len(a) ∈ [10, 20]
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- Bindings from the convenient Apron library [JM09]

Relational domains in Mopsa

Difficulties arising from relational domains

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Mopsa relies on rewriting, symbolic expressions and ghost variables

to leverage relational domains.

A zoology of domains and combinators in Mopsa

Domain

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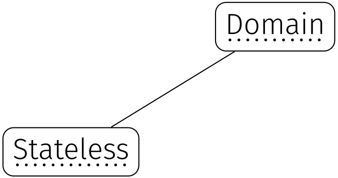

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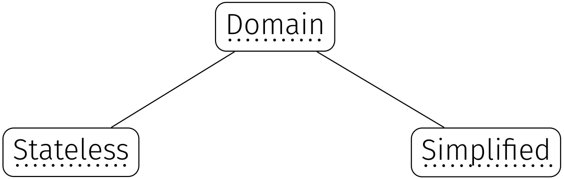

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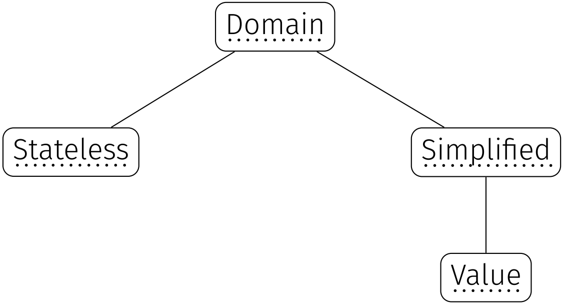

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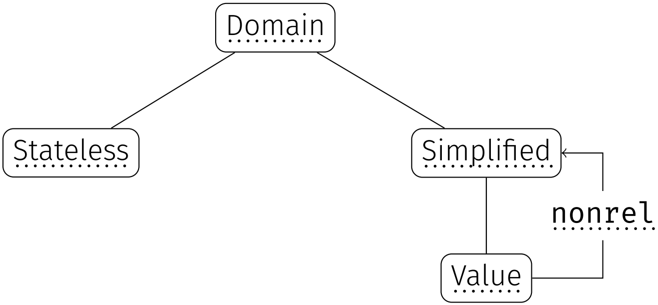

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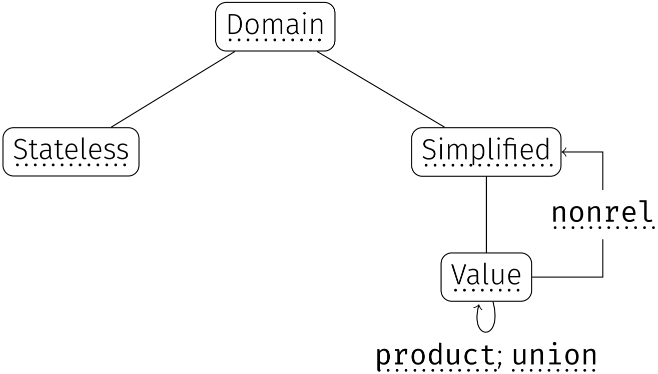

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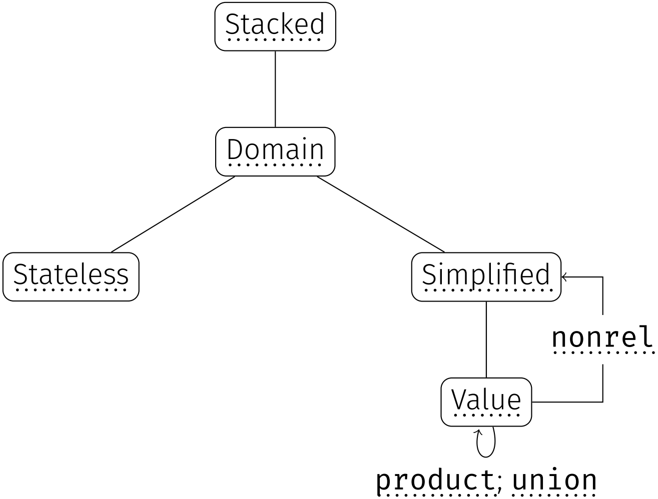

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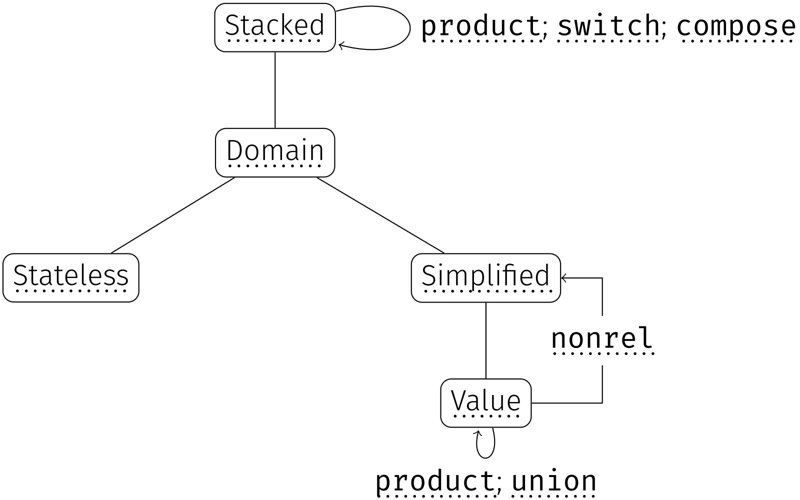

Overview of Mopsa

Modular **O**pen **P**latform for **S**tatic **A**nalysis [Jou+19]

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DAG of abstractions

- Relational domains
- Composition
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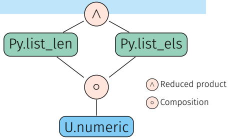

An overview of Mopsa

Works around Mopsa

Coreutils – Ouadjaout and Miné [OM20]

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Benchmark	Time	Selectivity	# checks
basename	33.79s	98.65%	11,731
dirname	21.68s	99.61%	11,307
echo	19.26s	99.43%	11,010
false	14.50s	99.72%	10,774
pwd	22.04s	99.62%	11,502
rmdir	39.00s	99.22%	11,699
sleep	23.79s	99.46%	11,546
tee	35.69s	98.76%	12,057
timeout	32.28s	98.51%	12,420
true	9.55s	99.72%	10,774
uname	20.61s	99.52%	11,943
users	20.82s	99.06%	11,668
whoami	13.03s	99.66%	11,329

Multilanguage Analysis – Monat, Ouadjaout, and Miné [MOM21]

Assessment 20% of the 200 most popular Python libraries rely on C code

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Our approach: Combined analysis of C, Python and interface code

Library	C + Py. Loc	Tests	🕒/test	$\frac{\#\text{ proved checks}}{\#\text{ checks}}$ %	# checks
`noise`	1397	15/15	1.2s	99.7%	6690
`cdistance`	2345	28/28	4.1s	98.0%	13716
`llist`	4515	167/194	1.5s	98.8%	36255
`ahocorasick`	4877	46/92	1.2s	96.7%	6722
`levenshtein`	5798	17/17	5.3s	84.6%	4825
`bitarray`	5841	159/216	1.6s	94.9%	25566

Non-exploitability – Parolini and Miné [PM24]

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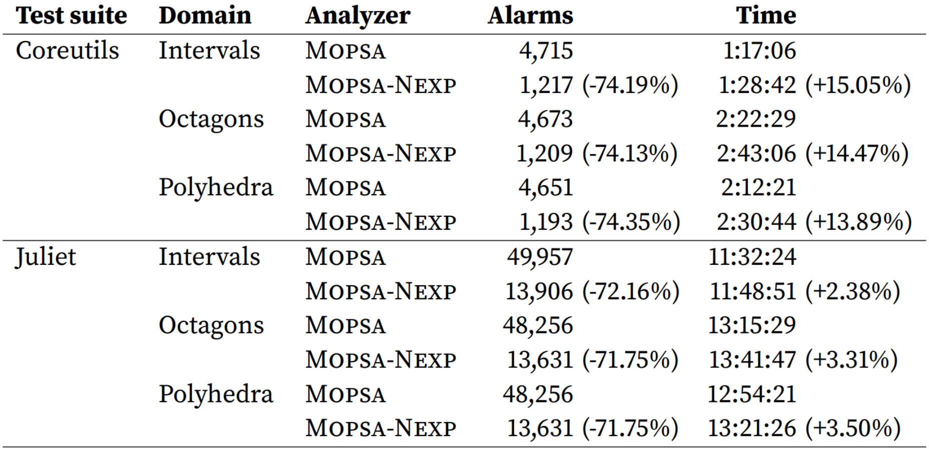

Test suite	Domain	Analyzer	Alarms	Time
Coreutils	Intervals	Mopsa	4,715	1:17:06
		Mopsa-Nexp	1,217 (-74.19%)	1:28:42 (+15.05%)
	Octagons	Mopsa	4,673	2:22:29
		Mopsa-Nexp	1,209 (-74.13%)	2:43:06 (+14.47%)
	Polyhedra	Mopsa	4,651	2:12:21
		Mopsa-Nexp	1,193 (-74.35%)	2:30:44 (+13.89%)
Juliet	Intervals	Mopsa	49,957	11:32:24
		Mopsa-Nexp	13,906 (-72.16%)	11:48:51 (+2.38%)
	Octagons	Mopsa	48,256	13:15:29
		Mopsa-Nexp	13,631 (-71.75%)	13:41:47 (+3.31%)
	Polyhedra	Mopsa	48,256	12:54:21
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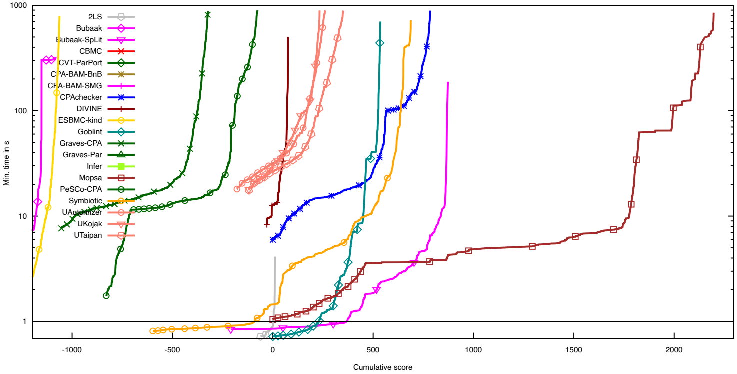

Summary of analyses

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- Sufficient precondition inference [MM24a; MM24b]

Easing maintenance and implementation

Providing transparent analysis results

Raising the bar in static analyzer transparency

```
$ static-analysis-tool file
```

Raising the bar in static analyzer transparency

```
$ static-analysis-tool file
...
```

Raising the bar in static analyzer transparency

```
$ static-analysis-tool file
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No errors found
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What has been checked? What has not?

Mopsa’s approach to being transparent – at a high level

```
if $a^\# \not\sqsubseteq p^\#$ then
  add_alarm $a^\#$ $p^\#$
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```

$\rightsquigarrow$

```
if $a^\# \not\sqsubseteq p^\#$ then
  add_alarm $a^\#$ $p^\#$
else
  add_safe_check $p^\#$
```

Mopsa’s approach to being transparent – example

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Stmt
x++
y++
Selectivity

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Stmt	Itv
`x++`	Safe
`y++`	Alarm
Selectivity	50%

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Stmt	Itv	Poly
`x++`	Safe	Safe
`y++`	Alarm	Safe
Selectivity	50%	100%

Mopsa’s approach to being transparent – output

Benefits of the approach

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- Easy to implement

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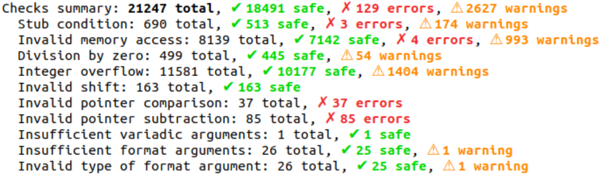
- ~~Program size~~ ⇝ “expression complexity”

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
```

Mopsa’s approach to being transparent – soundness assumptions

Soundness assumptions, through an example

```c
extern int f(int *x)
```

Mopsa’s approach to being transparent – soundness assumptions

Soundness assumptions, through an example

`extern int f(int *x)`, handling gradations

Mopsa's approach to being transparent – soundness assumptions

Soundness assumptions, through an example

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1. Crash

Mopsa’s approach to being transparent – soundness assumptions

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Soundness assumptions, through an example

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Mopsa’s approach to being transparent – soundness assumptions

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Mopsa’s approach to being transparent – soundness assumptions

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4. Assume and report: f has any effect on its parameters

Mopsa's approach to being transparent – soundness assumptions

Soundness assumptions, through an example

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5. Assume and report: f has any effect on its parameters and on globals

Mopsa's approach to being transparent – soundness assumptions

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Related topic: soundiness paper [Liv+15]

Easing maintenance and implementation

Avoiding regressions

Avoiding regressions

$\Longrightarrow$ check for precision changes

Avoiding regressions

$\Longrightarrow$ check for precision changes

Benchmarks with precision oracles

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

Avoiding regressions

$\Longrightarrow$ **check for precision changes**

Benchmarks with precision oracles

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

Otherwise: relative precision measures, rely on our selectivity computation.

Comparing analysis reports

`mopsa-diff` script, used to compare:

- analysis report(s): either single output or set of outputs
- usecases: different configurations, different versions of Mopsa

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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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- parse-datetime.y:772.23-38: alarm: Invalid memory access
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- parse-datetime.y:610.8-41: alarm: Invalid memory access
- parse-datetime.y:743.25-40: alarm: Invalid memory access
```

```
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
```

CI, tests & benchmarks

Detecting breaking changes using continuous integration

- `mopsa-diff` to compare with previous results

CI, tests & benchmarks

Detecting breaking changes using continuous integration

- `mopsa-diff` to compare with previous results
- Reusing all benchmarks from our experimental evaluations

CI, tests & benchmarks

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Benchmark selection

Our benchmarks are

CI, tests & benchmarks

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Benchmark selection

Our benchmarks are

- third-party real code
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- unmodified*
  - Underscores practicality of our approach
  - * stubs can be added in marginal cases

Easing maintenance and implementation

Easing debugging

Where static analyzers usually start from

- Analysis output Too coarse

Where static analyzers usually start from

▶ Analysis output	Too coarse
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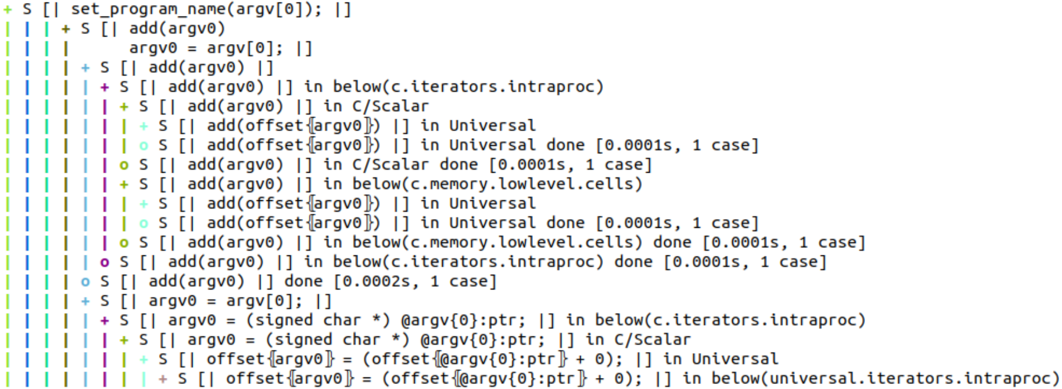
Where static analyzers usually start from

▶ 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) |] in below(c.iterators.intraproc) done [0.0001s, 1 case]
| | | | 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

An interactive engine acting as abstract debugger

GDB-like interface to the abstract interpretation of the program

Demo!

An interactive engine acting as abstract debugger

GDB-like interface to the abstract interpretation of the program

Demo!

- Breakpoints

An interactive engine acting as abstract debugger

GDB-like interface to the abstract interpretation of the program

Demo!

- Breakpoints
    - Program location

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- Breakpoints
  - Program location
  - Specific transfer function, analysis of subexpression

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- Observation of the abstract state

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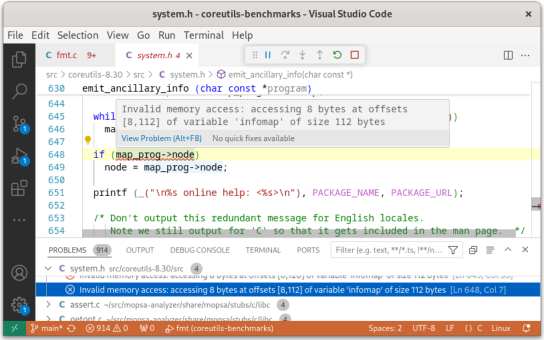
- Breakpoints
  - Program location
  - Specific transfer function, analysis of subexpression
  - Alarm: jumping back to statement generating first alarm
- Navigation
- Observation of the abstract state
  - Full state
  - Projection on specific variables
- Some scripting capabilities

IDE support

- Language Server Protocol for linters (report alarms)



system.h - coreutils-benchmarks - Visual Studio Code
File Edit Selection View Go Run Terminal Help
C fmt.c 9+
C system.h 4
src > coreutils-8.30 > src > C system.h > emit_ancillary_info(char const *)
View Problem (Alt+F8)
No quick fixes available
PROBLEMS 914
OUTPUT
DEBUG CONSOLE
TERMINAL
PORTS
Filter (e.g. text, **/*.ts, !**/n…
C system.h src/coreutils-8.30/src 4
C assert.c ~/src/mopsa-analyzer/share/mopsa/stubs/c/libc 4
C getopt.c ~/src/mopsa-analyzer/share/mopsa/stubs/c/libc 4
main* ⊗ 914 ⚠ 0 0 fmt (coreutils-benchmarks) Spaces: 2 UTF-8 LF { } C Linux

```
emit_ancillary_info (char const *program)

  whil                                                                        ))
    ma

  if (map_prog->node)
    node = map_prog->node;

  printf (_("\n%s online help: <%s>\n"), PACKAGE_NAME, PACKAGE_URL);

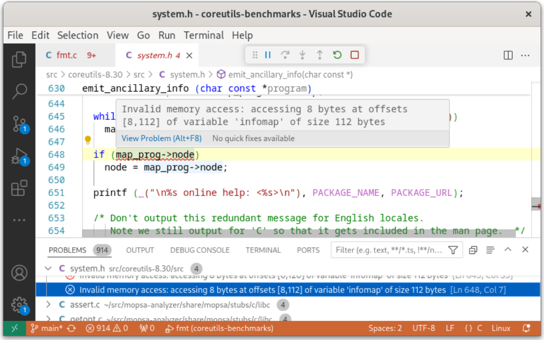
  /* Don't output this redundant message for English locales.
     Note we still output for 'C' so that it gets included in the man page.  */
```

```
Invalid memory access: accessing 8 bytes at offsets
[8,112] of variable 'infomap' of size 112 bytes
```

⊗ Invalid memory access: accessing 8 bytes at offsets [8,112] of variable 'infomap' of size 112 bytes [Ln 648, Col 7]

IDE support

- Language Server Protocol for linters (report alarms)
- Debug Adapter Protocol providing interactive engine interface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Spaces: 2 UTF-8 LF {} C Linux

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View Problem (Alt+F8) No quick fixes available

C system.h src/coreutils-8.30/src 4

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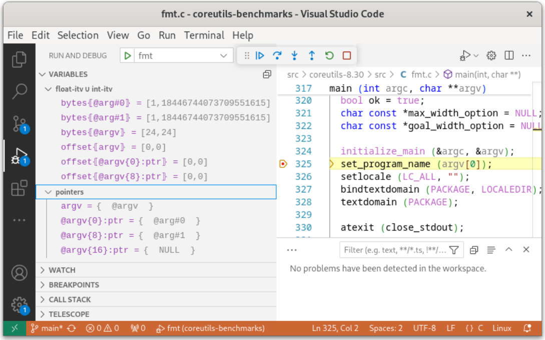
C assert.c ~/src/mopsa-analyzer/share/mopsa/stubs/c/libc 4

C getopt.c ~/src/mopsa-analyzer/share/mopsa/stubs/c/libc 4


fmt.c - coreutils-benchmarks - Visual Studio Code
File Edit Selection View Go Run Terminal Help
RUN AND DEBUG
fmt
VARIABLES
WATCH
BREAKPOINTS
CALL STACK
TELESCOPE
src > coreutils-8.30 > src > C fmt.c > main(int, char **)
Filter (e.g. text, **/*.ts, !**/...
main* ⊗ 0 ⚠ 0 0 fmt (coreutils-benchmarks)
Ln 325, Col 2 Spaces: 2 UTF-8 LF {} C Linux

```
float-itv ∪ int-itv
  bytes⟦@arg#0⟧ = [1,18446744073709551615]
  bytes⟦@arg#1⟧ = [1,18446744073709551615]
  bytes⟦@argv⟧ = [24,24]
  offset⟦argv⟧ = [0,0]
  offset⟦@argv{0}:ptr⟧ = [0,0]
  offset⟦@argv{8}:ptr⟧ = [0,0]
pointers
  argv = {  @argv  }
  @argv{0}:ptr = {  @arg#0  }
  @argv{8}:ptr = {  @arg#1  }
  @argv{16}:ptr = {  NULL  }
```

```
main (int argc, char **argv)
  bool ok = true;
  char const *max_width_option = NULL;
  char const *goal_width_option = NULL

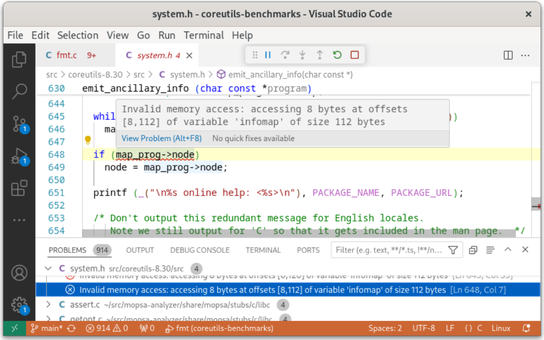
  initialize_main (&argc, &argv);
  set_program_name (argv[0]);
  setlocale (LC_ALL, "");
  bindtextdomain (PACKAGE, LOCALEDIR);
  textdomain (PACKAGE);

  atexit (close_stdout);
```

No problems have been detected in the workspace.

IDE support

- Language Server Protocol for linters (report alarms)
- Debug Adapter Protocol providing interactive engine interface
- Both protocols introduced by VSCode, supported by multiple IDEs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- system.h src/coreutils-8.30/src 4
  - Invalid memory access: accessing 8 bytes at offsets [0,120] of variable 'infomap' of size 112 bytes [Ln 645, Col 33]
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- assert.c ~/src/mopsa-analyzer/share/mopsa/stubs/c/libc 4
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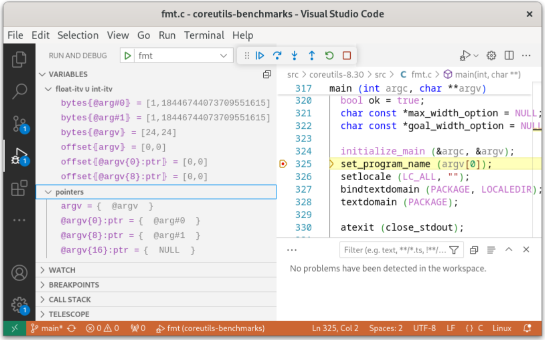
main*
⊗ 914 ⚠ 0
0
fmt (coreutils-benchmarks)
Spaces: 2
UTF-8
LF
{} C
Linux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Testcase reduction

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- Static analyzers are complex piece of code and may contain bugs

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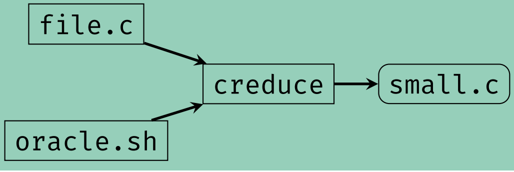
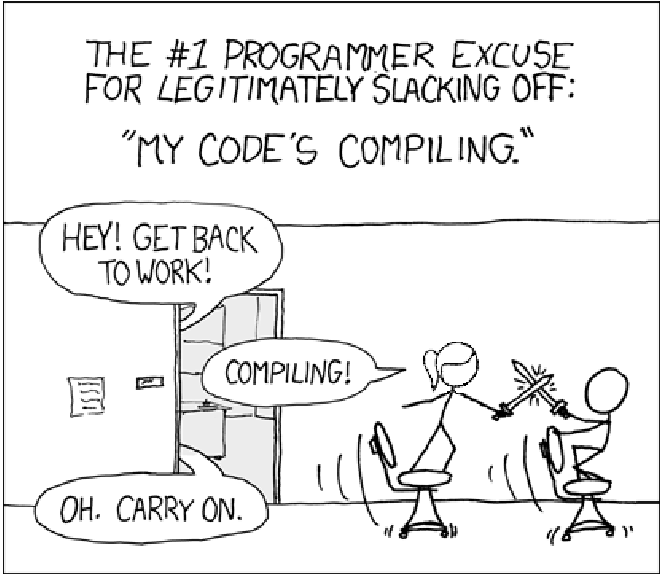
- Debugging extremely difficult: size of the program, analysis time

Automated testcase reduction using `creduce` [Reg+12]



Testcase reduction – II



Testcase reduction – III

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

Testcase reduction – III

Internal errors debugging

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- Has been applied to coreutils programs, SV-Comp programs of 10,000+ LoC

Reference	Origin	Original LoC	Reduced LoC	Reduction
Issue 76	SV-Comp	28,737	18	99.94%
Issue 81	SV-Comp	15,627	8	99.95%
Issue 134	SV-Comp	17,411	10	99.94%
Issue 135	SV-Comp	7,016	12	99.83%
M.R. 130	`coreutils`	77,981	20	99.97%
M.R. 145	`coreutils`	77,427	19	99.98%

Testcase reduction – IV

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-build make` drop-in replacement for `make`

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  - Records compiler/linker calls and their options
  - Creates a compilation database

  ⇝ `mopsa-build make` drop-in replacement for `make`
- `mopsa-c` leverages the compilation database

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

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-c mopsa.db -make-target=fmt
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- Option to generate a single, preprocessed file

Easing maintenance and implementation

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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- Logs: trace of interpretation performed by the analysis
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- **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 top expressions are created

Simplifies the search for sources of large imprecision (esp. with rewritings)

Profiling

Standard profiling

Measures which parts of Mopsa are the most time-consuming

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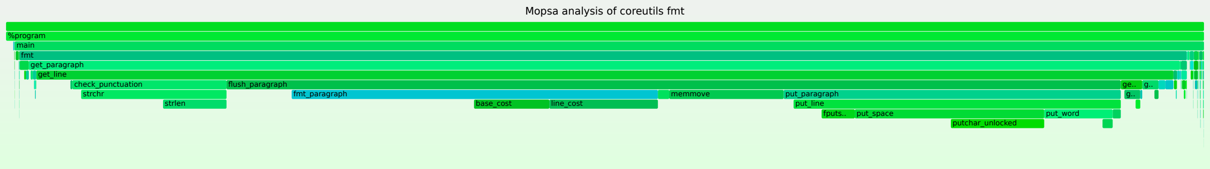
Mopsa analysis of coreutils fmt

Profiling – II

Apron vs PPLite on Coreutils touch

- PPLite is 14% slower but more precise (11 alarms removed). Why?

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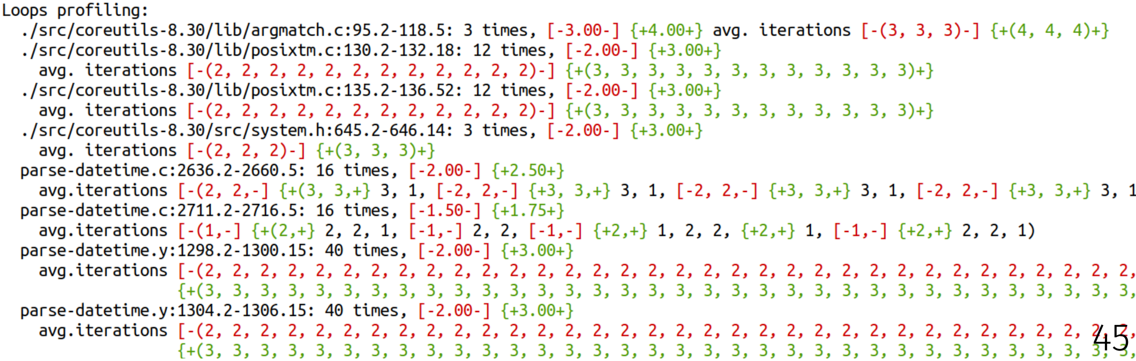

```
Loops profiling:
  ./src/coreutils-8.30/lib/argmatch.c:95.2-118.5: 3 times, [-3.00-] {+4.00+} avg. iterations [-(3, 3, 3)-] {+(4, 4, 4)+}
  ./src/coreutils-8.30/lib/posixtm.c:130.2-132.18: 12 times, [-2.00-] {+3.00+}
    avg. iterations [-(2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2)-] {+(3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3)+}
  ./src/coreutils-8.30/lib/posixtm.c:135.2-136.52: 12 times, [-2.00-] {+3.00+}
    avg. iterations [-(2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2)-] {+(3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3)+}
  ./src/coreutils-8.30/src/system.h:645.2-646.14: 3 times, [-2.00-] {+3.00+}
    avg. iterations [-(2, 2, 2)-] {+(3, 3, 3)+}
  parse-datetime.c:2636.2-2660.5: 16 times, [-2.00-] {+2.50+}
    avg.iterations [-(2, 2,-] {+(3, 3,+} 3, 1, [-2, 2,-] {+3, 3,+} 3, 1, [-2, 2,-] {+3, 3,+} 3, 1, [-2, 2,-] {+3, 3,+} 3, 1
  parse-datetime.c:2711.2-2716.5: 16 times, [-1.50-] {+1.75+}
    avg.iterations [-(1,-] {+(2,+} 2, 2, 1, [-1,-] 2, 2, [-1,-] {+2,+} 1, 2, 2, {+2,+} 1, [-1,-] {+2,+} 2, 2, 1)
  parse-datetime.y:1298.2-1300.15: 40 times, [-2.00-] {+3.00+}
    avg.iterations [-(2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
                   {+(3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
  parse-datetime.y:1304.2-1306.15: 40 times, [-2.00-] {+3.00+}
    avg.iterations [-(2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
                   {+(3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
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Easing maintenance and implementation

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  - Sound abstract debugger in Goblint [Hol+24a; Hol+24b]

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References – I

[AMN17] Esben Sparre Andreasen, Anders Møller, and Benjamin Barslev Nielsen. **“Systematic approaches for increasing soundness and precision of static analyzers”.** In: ed. by Karim Ali and Cristina Cifuentes. ACM, 2017, pp. 31–36. DOI: `10.1145/3088515.3088521`.

[Bau+22] Guillaume Bau et al. **“Abstract interpretation of Michelson smart-contracts”.** In: ed. by Laure Gonnord and Laura Titolo. ACM, 2022, pp. 36–43. DOI: `10.1145/3520313.3534660`.

[BBY17] S. Blazy, D. Bühler, and B. Yakobowski. **“Structuring Abstract Interpreters Through State and Value Abstractions”.** In: LNCS. Springer, 2017, pp. 112–130.

References – II

[Ber+10] J. Bertrane et al. “Static analysis and verification of aerospace software by abstract interpretation”. In: AIAA-2010-3385. 2010.

[BHZ08] Roberto Bagnara, Patricia M. Hill, and Enea Zaffanella. “The Parma Polyhedra Library: Toward a complete set of numerical abstractions for the analysis and verification of hardware and software systems”. In: Sci. Comput. Program. 1-2 (2008), pp. 3–21.

[BZ20] Anna Becchi and Enea Zaffanella. “PPLite: Zero-overhead encoding of NNC polyhedra”. In: Inf. Comput. (2020), p. 104620. DOI: 10.1016/J.IC.2020.104620.

[CH78] Patrick Cousot and Nicolas Halbwachs. “Automatic Discovery of Linear Restraints Among Variables of a Program”. In: 1978.

References – III

[DM19] David Delmas and Antoine Miné. **“Analysis of Software Patches Using Numerical Abstract Interpretation”.** In: ed. by Bor-Yuh Evan Chang. Lecture Notes in Computer Science. Springer, 2019, pp. 225–246. DOI: `10.1007/978-3-030-32304-2_12`.

[DOM21] David Delmas, Abdelraouf Ouadjaout, and Antoine Miné. **“Static Analysis of Endian Portability by Abstract Interpretation”.** In: Lecture Notes in Computer Science. Springer, 2021, pp. 102–123.

[Fle+24] Markus Fleischmann et al. **“Constraint-Based Test Oracles for Program Analyzers”.** In: ed. by Vladimir Filkov, Baishakhi Ray, and Minghui Zhou. ACM, 2024, pp. 344–355. DOI: `10.1145/3691620.3695035`.

References – IV

[Hol+24a] Karoliine Holter et al. **"Abstract Debuggers: Exploring Program Behaviors using Static Analysis Results".** In: Onward! '24. Pasadena, CA, USA: Association for Computing Machinery, 2024, pp. 130–146. DOI: `10.1145/3689492.3690053`.

[Hol+24b] Karoliine Holter et al. **"Abstract Debugging with GobPie".** In: ed. by Elisa Gonzalez Boix and Christophe Scholliers. ACM, 2024, pp. 32–33. DOI: `10.1145/3678720.3685320`.

[JM09] Bertrand Jeannet and Antoine Miné. **"Apron: A Library of Numerical Abstract Domains for Static Analysis".** In: Lecture Notes in Computer Science. Springer, 2009, pp. 661–667. DOI: `10.1007/978-3-642-02658-4_52`.

References – V

[JMO18] Matthieu Journault, Antoine Miné, and Abdelraouf Ouadjaout. **“Modular Static Analysis of String Manipulations in C Programs”.** In: ed. by Andreas Podelski. Lecture Notes in Computer Science. Springer, 2018, pp. 243–262. DOI: `10.1007/978-3-319-99725-4_16`.

[Jou+19] M. Journault et al. **“Combinations of reusable abstract domains for a multilingual static analyzer”.** In: New York, USA, July 2019, pp. 1–17.

[Kai+24] David Kaindlstorfer et al. **“Interrogation Testing of Program Analyzers for Soundness and Precision Issues”.** In: ed. by Vladimir Filkov, Baishakhi Ray, and Minghui Zhou. ACM, 2024, pp. 319–330. DOI: `10.1145/3691620.3695034`.

References – VI

[KCW19] Christian Klinger, Maria Christakis, and Valentin Wüstholz. **“Differentially testing soundness and precision of program analyzers”.** In: ed. by Dongmei Zhang and Anders Møller. ACM, 2019, pp. 239–250. DOI: 10.1145/3293882.3330553.

[LDB19] Linghui Luo, Julian Dolby, and Eric Bodden. **“MagpieBridge: A General Approach to Integrating Static Analyses into IDEs and Editors (Tool Insights Paper)”.** In: ed. by Alastair F. Donaldson. LIPIcs. Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2019, 21:1–21:25. DOI: 10.4230/LIPICS.ECOOP.2019.21.

[Liv+15] Benjamin Livshits et al. **“In defense of soundiness: a manifesto”.** In: Commun. ACM 2 (2015), pp. 44–46. DOI: 10.1145/2644805.

References – VII

[MFM24] Raphaël Monat, Aymeric Fromherz, and Denis Merigoux. **“Formalizing Date Arithmetic and Statically Detecting Ambiguities for the Law”.** In: ed. by Stephanie Weirich. Lecture Notes in Computer Science. Springer, 2024, pp. 421–450. DOI: `10.1007/978-3-031-57267-8_16`.

[Min17] Antoine Miné. **“Tutorial on Static Inference of Numeric Invariants by Abstract Interpretation”.** In: Found. Trends Program. Lang. 3-4 (2017), pp. 120–372.

[MM24a] Marco Milanese and Antoine Miné. **“Generation of Violation Witnesses by Under-Approximating Abstract Interpretation”.** In: ed. by Rayna Dimitrova, Ori Lahav, and Sebastian Wolff. Lecture Notes in Computer Science. Springer, 2024, pp. 50–73. DOI: `10.1007/978-3-031-50524-9_3`.

References – VIII

[MM24b] Marco Milanese and Antoine Miné. “Under-Approximating Memory Abstractions”. In: ed. by Roberto Giacobazzi and Alessandra Gorla. Lecture Notes in Computer Science. Springer, 2024, pp. 300–326. DOI: 10.1007/978-3-031-74776-2_12.

[MOM20a] R. Monat, A. Ouadjaout, and A. Miné. “Static Type Analysis by Abstract Interpretation of Python Programs”. In: LIPIcs. 2020.

[MOM20b] R. Monat, A. Ouadjaout, and A. Miné. “Value and allocation sensitivity in static Python analyses”. In: ACM, 2020, pp. 8–13. DOI: 10.1145/3394451.3397205.

[MOM21] R. Monat, A. Ouadjaout, and A. Miné. “A Multilanguage Static Analysis of Python Programs with Native C Extensions”. In: 2021.

References – IX

[Mon+24] Raphaël Monat et al. “Mopsa-C: Improved Verification for C Programs, Simple Validation of Correctness Witnesses (Competition Contribution)”. In: Lecture Notes in Computer Science. Springer, 2024, pp. 387–392.

[MVR23] Mats Van Molle, Bram Vandenbogaerde, and Coen De Roover. “Cross-Level Debugging for Static Analysers”. In: ed. by João Saraiva, Thomas Degueule, and Elizabeth Scott. ACM, 2023, pp. 138–148. DOI: 10.1145/3623476.3623512.

References – X

[NP18] Kedar S. Namjoshi and Zvonimir Pavlinovic. **“The Impact of Program Transformations on Static Program Analysis”.** In: ed. by Andreas Podelski. Lecture Notes in Computer Science. Springer, 2018, pp. 306–325. DOI: `10.1007/978-3-319-99725-4_19`.

[OM20] A. Ouadjaout and A. Miné. **“A Library Modeling Language for the Static Analysis of C Programs”.** In: ed. by David Pichardie and Mihaela Sighireanu. Lecture Notes in Computer Science. Springer, 2020, pp. 223–247. DOI: `10.1007/978-3-030-65474-0_11`.

[PM24] Francesco Parolini and Antoine Miné. **“Sound Abstract Nonexploitability Analysis”.** In: Lecture Notes in Computer Science. Springer, 2024, pp. 314–337.

References – XI

[Reg+12] John Regehr et al. “Test-case reduction for C compiler bugs”. In: ed. by Jan Vitek, Haibo Lin, and Frank Tip. ACM, 2012, pp. 335–346. DOI: 10.1145/2254064.2254104.

[TLR20] Jubi Taneja, Zhengyang Liu, and John Regehr. “Testing static analyses for precision and soundness”. In: ACM, 2020, pp. 81–93. DOI: 10.1145/3368826.3377927.

[VMM23] Milla Valnet, Raphaël Monat, and Antoine Miné. “Analyse statique de valeurs par interprétation abstraite de programmes fonctionnels manipulant des types algébriques récursifs”. In: ed. by Timothy Bourke and Delphine Demange. Praz-sur-Arly, France, Jan. 2023, pp. 211–242.