Analyzing Rsync with Mopsa

Raphaël Monat, joint exploration with Antoine Miné

rmonat.fr

AnalyzeThat @ ETAPS
12 April 2026

Inria

Outline

An Overview of Mopsa for C analyses

Framework overview

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

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

Started by ERC Consolidator Grant (2016-2021) of Antoine Miné (LIP6, SU)

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Including multi-language support

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Currently, fully context-sensitive analyses

Contributors (2018–2026, chronological arrival order)

- A. Miné
- A. Ouadjaout
- M. Journault
- A. Fromherz
- D. Delmas
- R. Monat
- G. Bau
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Maintainers in bold.

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Mopsa design

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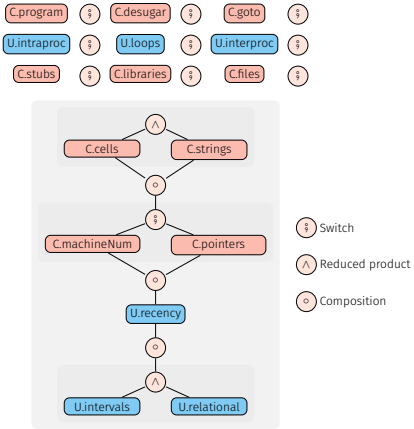

Mopsa's transparent reporting

Mopsa's approach to being transparent

- Reporting status of all proofs / checks in every analyzed context

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Stmt	Itv	Poly
x++	Safe	Safe
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Selectivity	50%	100%

An Overview of Mopsa for C analyses

C analysis

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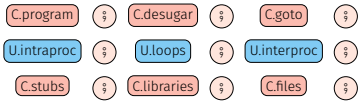
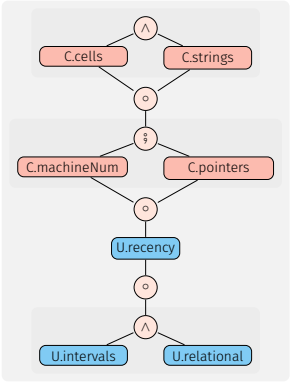
C analysis domains





- Cells [Min06] low-level memory

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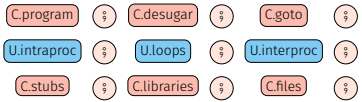

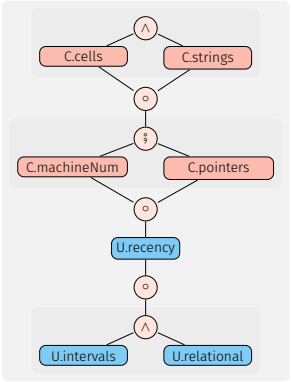

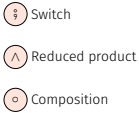

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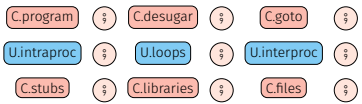

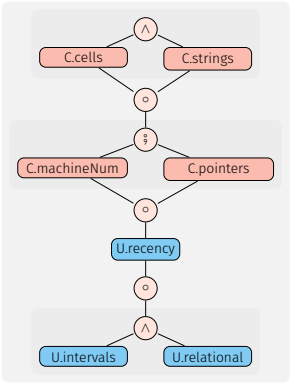

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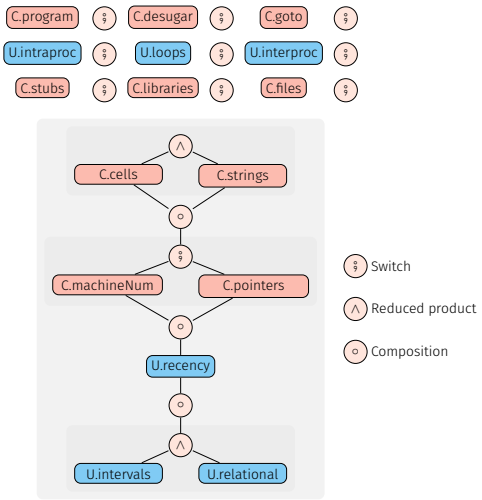

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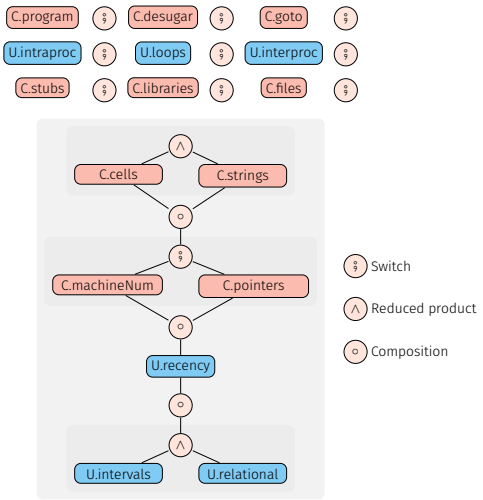

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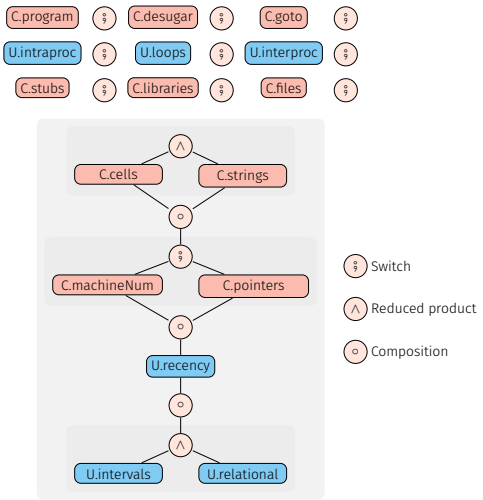

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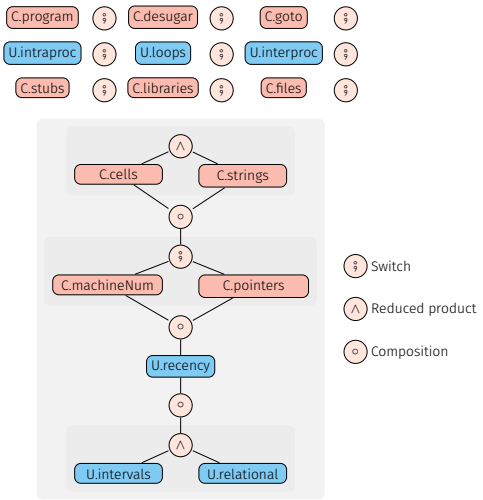

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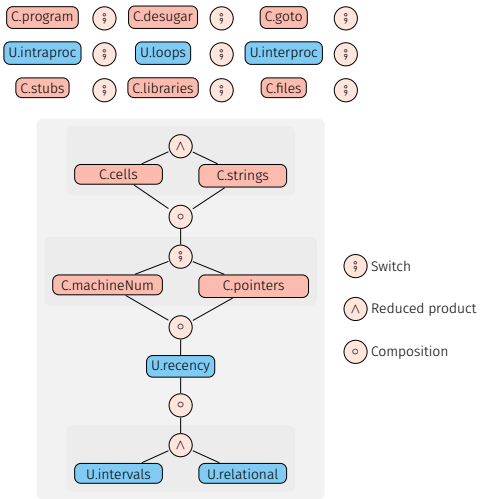

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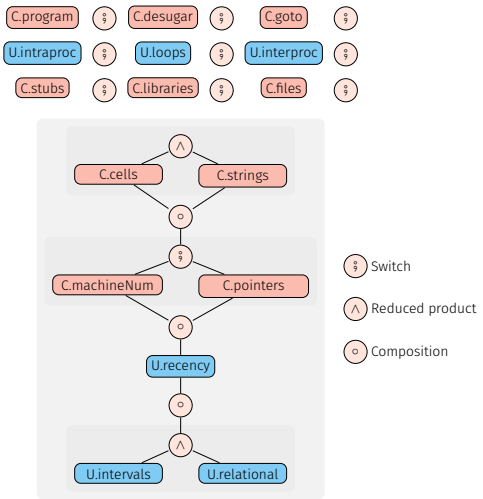

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- Contract language for libc [OM20], inspired from Frama-C ACSL

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Benchmark	# Tests	Total LOC	Time	Precision
CWE121	2,508	234,930	3,064s	22.13%
CWE122	1,556	166,664	1,948s	25.84%
CWE124	758	93,372	961s	36.94%
CWE126	600	75,984	769s	46.83%
CWE127	758	89,022	963s	37.07%
CWE190	3,420	440,749	4,356s	78.13%
CWE191	2,622	340,884	3,236s	78.87%
CWE369	497	83,238	674s	70.42%
CWE415	190	17,990	228s	100.00%
CWE416	118	14,782	142s	67.80%
CWE469	18	1,520	22s	100.00%
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Benchmark	Time	Selectivity	# checks
basename	33.79s	98.65%	11,731
comm	42.67s	97.32%	12,654
dircolors	34.82s	99.74%	20,062
dirname	21.68s	99.61%	11,307
echo	19.26s	99.43%	11,010
false	14.50s	99.72%	10,774
getlimits	34.62s	98.54%	11,711
hostid	18.05s	99.65%	11,303
id	32.69s	99.04%	12,338
link	23.03s	99.52%	11,572
logname	20.36s	99.66%	11,307
mkfifo	34.87s	99.20%	11,807

Table 2: `coreutils` benchmarks (fully symbolic arguments, relational analysis).

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Easing implementation and maintenance

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"std. tools on the concrete execution of the *abstract interpreter*"

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$\rightsquigarrow$ "new tools on abstract execution of *target program*"

Read more in our STTT paper [MOM24]

Static analyses interfaces: traditional approaches

- Analysis output

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- 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
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| | | | | o S [| add(argv0) |] in C/Scalar done [0.0001s, 1 case]
| | | | | + S [| add(argv0) |] in below(c.memory.lowlevel.cells)
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Static analyses interface: an abstract debugger

GDB-like interface to the abstract interpretation of the program (online demo)

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- Some scripting capabilities

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Standard profiling

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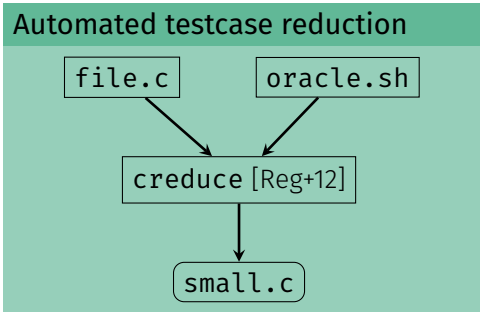
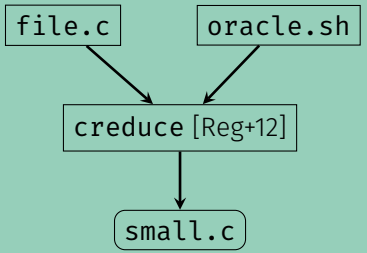
Partial results reporting supported!

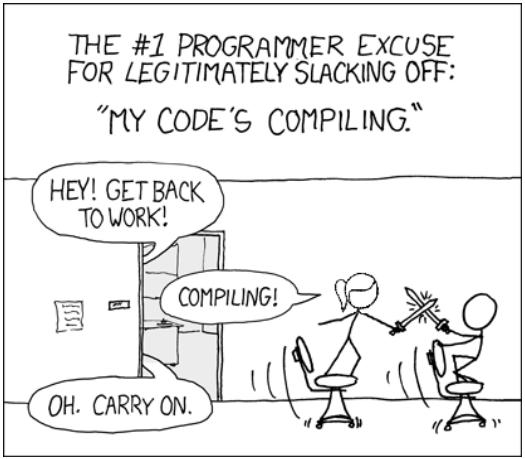
Testcase reduction



Testcase reduction

Automated testcase reduction





Testcase reduction – II

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  - Option to generate a single, preprocessed file

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

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

  - Option to generate a single, preprocessed file
  - Source-level linking

Testcase reduction – II

Mopsa supports multi-file C projects

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

  $\rightsquigarrow$ `mopsa-build make` drop-in replacement for `make`
- `mopsa-c` leverages the compilation database

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

  - Option to generate a single, preprocessed file
  - Source-level linking
- Usability: upon encountering an RTE, Mopsa helps triggering the reduction

Analyzing Rsync

Envisioned workflow

Envisioned workflow

1. Parsing fixes

Envisioned workflow

1. Parsing fixes
2. Maximize coverage

Envisioned workflow

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   - Symbolic argument modeling by default

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3. Check for soundness assumptions and issues

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3. Check for soundness assumptions and issues
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   - Heuristic hook detecting dubious cases

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4. Find sweet spot between performance and precision

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   - Manual work...

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   - Choice of other analysis options (unrolling, allocation sensitivity, ...)
5. Manually investigate some alarms
   - Manual work...
   - Can rely on the interactive engine to understand the alarm

Analyzing Rsync

What happened in practice

gitlab.com/mopsa/benchmarks/rsync-analysis/

Source code parsing

Mostly fine with the AnalyzeThat fixes.

gitlab.com/mopsa/benchmarks/rsync-analysis/

Source code parsing

Mostly fine with the AnalyzeThat fixes.

Then: a manual quest

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without sacrificing too much coverage

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Approach

Observe analysis progress and investigate using

- Interactive engine
- Profilers

Tradeoffs and simplifications

Argument parsing

- `popt` entailed analysis performance issues

Tradeoffs and simplifications

Argument parsing

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- we crafted efficient stubs equivalent in the abstract

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Large state space due to options and behaviors

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- Manual state partitioning on boolean values `am_server`, `am_sender`.

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State-space reduction

Large state space due to options and behaviors

- Manual state partitioning on boolean values `am_server`, `am_sender`.
  - Could be done in a single analysis but reduces parallelization factor

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- `popt` entailed analysis performance issues
- we crafted efficient stubs equivalent in the abstract

State-space reduction

Large state space due to options and behaviors

- Manual state partitioning on boolean values `am_server`, `am_sender`.
  - Could be done in a single analysis but reduces parallelization factor
- Set `protocol_version`=30. Same for remote version

Tradeoffs and simplifications (II)

Sidestepping other issues

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- Recursive functions

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- Logging and debug info; cleanup

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- Logging and debug info; cleanup
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Tradeoffs and simplifications (II)

Sidestepping other issues

- Recursive functions
- Logging and debug info; cleanup
- Signals
- Fork

Tradeoffs and simplifications (II)

Sidestepping other issues

- Recursive functions
- Logging and debug info; cleanup
- Signals
- Fork
- Directories...

Some bugs and improvements

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On the Mopsa side...

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On the Mopsa side...

`select` stub

```
1 * requires: __nfds >= 1;
2 * requires: null_or_valid_ptr(__exceptfds);
3 * requires: null_or_valid_ptr(__timeout);
4 * assigns: _errno;
5 * ensures: return >= -1 and return <- __nfds;
6 * unsound: "select does not check that file-descriptors are valid";
```

Found using heuristic unsoundness detection hook

Some bugs and improvements

On the Mopsa side...

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Found using heuristic unsoundness detection hook

Scalability of the interactive engine

Some bugs and improvements (II)

Callstack $\rightsquigarrow$ Control Context

Track also loop iteration numbers to roughly estimate progresss

Trace partitioning issues

`creduce/cvise` came in handy!

Profiling-directed simplifications

Function	Total time	Self time	Count
%program	19582.7525s	0.8358s	1
main	19581.7933s	0.6412s	1
start_client	19537.7848s	0.7921s	1
client_run	19386.0082s	0.9445s	2
send_files	14713.8498s	4.1589s	2
read_buf	14118.5177s	40.2160s	115
read_a_msg	13454.5005s	76.4954s	279
perform_io	11979.7325s	4204.6916s	8836
start_socket_client	10030.5979s	0.4299s	1
read_ndx_and_attrs	8883.6031s	3.1239s	6
raw_read_int	7557.4465s	37.7534s	2511
raw_read_buf	7007.3097s	76.1009s	4367
receive_sums	5230.0320s	2.2389s	4
read_ndx	5195.5426s	2.0533s	8
read_int	5139.1159s	1.1859s	35
write_buf	3402.1354s	67.0873s	1436
read_sum_head	2683.9100s	0.7428s	4
match_sums	2639.4841s	2.2675s	4
read_final_goodbye	2497.0366s	0.2859s	2
_exit_cleanup	2476.6955s	2476.6955s	152816

Investigating spurious loop iterations

```
$ stat -c "%y %n" -- sender.226.{1,2}
2026-04-07 12:02:50.152871307 +0200 sender.226.1
2026-04-07 13:07:52.679079724 +0200 sender.226.2
```

```
<       phase:./sender.c:210.1-14 -> [0,2147483647],
---
>       phase:./sender.c:210.1-14 -> [-2147483648,2147483647],
```

Investigating spurious loop iterations

```
$ stat -c "%y %n" -- sender.226.{1,2}
2026-04-07 12:02:50.152871307 +0200 sender.226.1
2026-04-07 13:07:52.679079724 +0200 sender.226.2
```

```
<     phase:./sender.c:210.1-14 -> [0,2147483647],
---
>     phase:./sender.c:210.1-14 -> [-2147483648,2147483647],
```

```c
void send_files(int f_in, int f_out) /* Sliced version */
{
  int phase = 0, max_phase = protocol_version >= 29 ? 2 : 1;
  while (1) {
    /* ... */
    if (ndx == NDX_DONE) {
      if (++phase > max_phase)
        break;
    }
  }
```

Analyzing Rsync

Current results

Current results

Hardware details

- Core i7-12700 desktop

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- Core i7-12700 desktop
- Single-threaded analysis

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- RAM usage: few GBs

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⚠ rough experimental data

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Analysis

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Analysis

- Intervals

Current results

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Analysis

- Intervals
- Tracking string length

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Analysis

- Intervals
- Tracking string length
- Reduced allocation sensitivity

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Analysis

- Intervals
- Tracking string length
- Reduced allocation sensitivity
- Widening with thresholds

Current results

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Analysis

- Intervals
- Tracking string length
- Reduced allocation sensitivity
- Widening with thresholds

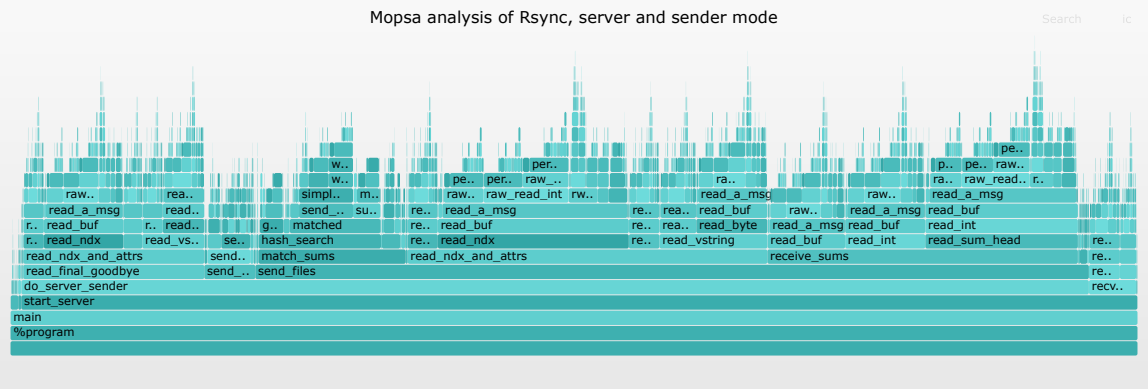
sender? \ server?	1	0
1	2h25m	5h26m
0	> 36h	24h11m

Server & sender case (2h25m)

```
Checks summary: 916479 total, ✔ 881015 safe, ✗ 639 errors, ⚠ 34825 warnings (selectivity: 96.14%)
  Stub condition: 21789 total, ✔ 15447 safe, ✗ 83 errors, ⚠ 6259 warnings
  Invalid memory access: 180065 total, ✔ 166598 safe, ✗ 489 errors, ⚠ 12978 warnings
  Division by zero: 15965 total, ✔ 15452 safe, ⚠ 513 warnings
  Integer overflow: 422425 total, ✔ 407905 safe, ✗ 2 errors, ⚠ 14518 warnings
  Invalid shift: 33077 total, ✔ 33059 safe, ⚠ 18 warnings
  Invalid pointer comparison: 693 total, ✔ 321 safe, ⚠ 372 warnings
  Invalid pointer subtraction: 838 total, ✔ 699 safe, ⚠ 139 warnings
  Double free: 65 total, ✗ 65 errors
  Insufficient format arguments: 4688 total, ✔ 4674 safe, ⚠ 14 warnings
  Invalid type of format argument: 4639 total, ✔ 4625 safe, ⚠ 14 warnings
  Incorrect number of arguments: 232235 total, ✔ 232235 safe

384 assumptions:
```

Server & sender case (2h25m)



Server & sender case

Impact of analysis options?

⚠ (very) early results

Abstract domains	Allocation Policy	Analysis Time	Selectivity
Cell Itv	Range	2h10m	96.0108%
Cell StrLen Itv	Range	2h25m	96.1304%
Cell StrLen Itv	Range Callstack	5h27m	96.4447%
Cell StrLen Itv Oct	Range	5h23m	96.2272%
Cell StrLen Itv Oct	Range Callstack	16h20m	96.5900%
Cell StrLen Itv Poly	Range	†19h50m	96.2294%
Cell StrLen Itv Poly	Range Callstack	†30h16m	96.5897%

Client & sender case (5h26m)

```
Checks summary: 2186352 total, ✔ 2097262 safe, ✗ 1122 errors, ⚠ 87968 warnings (selectivity: 95.93%)
  Stub condition: 54835 total, ✔ 36596 safe, ✗ 700 errors, ⚠ 17539 warnings
  Invalid memory access: 417177 total, ✔ 382810 safe, ✗ 328 errors, ⚠ 34039 warnings
  Division by zero: 38720 total, ✔ 37578 safe, ⚠ 1142 warnings
  Integer overflow: 993399 total, ✔ 960289 safe, ✗ 4 errors, ⚠ 33106 warnings
  Invalid shift: 78408 total, ✔ 77404 safe, ⚠ 1004 warnings
  Invalid pointer comparison: 1343 total, ✔ 696 safe, ⚠ 647 warnings
  Invalid pointer subtraction: 1809 total, ✔ 1488 safe, ⚠ 321 warnings
  Double free: 90 total, ✗ 90 errors
  Insufficient variadic arguments: 2 total, ⚠ 2 warnings
  Insufficient format arguments: 15283 total, ✔ 15199 safe, ⚠ 84 warnings
  Invalid type of format argument: 15255 total, ✔ 15171 safe, ⚠ 84 warnings
  Incorrect number of arguments: 570031 total, ✔ 570031 safe

600 assumptions:
```

Conclusion

Conclusion

Mixed bag...

- Not enough time spent?

Conclusion

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- Not enough time spent?
  - Investigative step of the ideal workflow not reached...

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Future considerations

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Future considerations

- Modular function analyses, require memory model overhaul

Conclusion

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- Not enough time spent?
  - Investigative step of the ideal workflow not reached...
- Scalability issues
- $\simeq$ 8 improvements to be added in Mopsa

Future considerations

- Modular function analyses, require memory model overhaul
- How to identify and sidestep scalability issues? Identify progress blockers?

References – I

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