SMTpp: preprocessors and analyzers for SMT-LIB

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Introduction

SMTpp = SMT pre-processor

What? source-to-source transformer and analyzer for the SMT-LIB

Why?

- SMT developer: factor simplifications found in solvers ≈ 20 % in veriT
- SMT developer: fuzzing-based tests, delta-debugging
- SMT user: factor SMT configurations from generators of verification conditions
- SMT-LIB: analyse and classify benchmarks
- SMT-COMP: scramble benchmarks

How? high-level programming language, symbolic programming (OCaml+menhir)

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Prototype release available from
`http://www.verit-solver.org`, under ISC licence.

Positioning SMTpp

- SatELite: a pre-processor for SAT
  - minimization of CNF
  - target a class of SAT encodings
- jSMTLIB: SMT-LIB for Java
  - Java-based
  - SMT-LIB parser and type-checker
  - interaction with SMT-LIB and SMT-solvers
    - Eclipse plug-in
    - API
- SMT solvers ($\supset$ SMTpp)
  - parsing
  - type inference
  - logic detection
  - simplification
- delta debugger, scrambler, fuzzer

AST

- one-to-one mapping from grammar to OCaml data type
- excerpt (commands)

```
type command_desc =
  | CmdAssert of term
  | CmdCheckSat
  | CmdDeclareConst of symbol * sort
  (* ... *)

type command = {
    command_desc : command_desc;
    command_loc  : Locations.t;
  }
```

- Full code available at:
  `https://github.com/ossanha/smtpp`

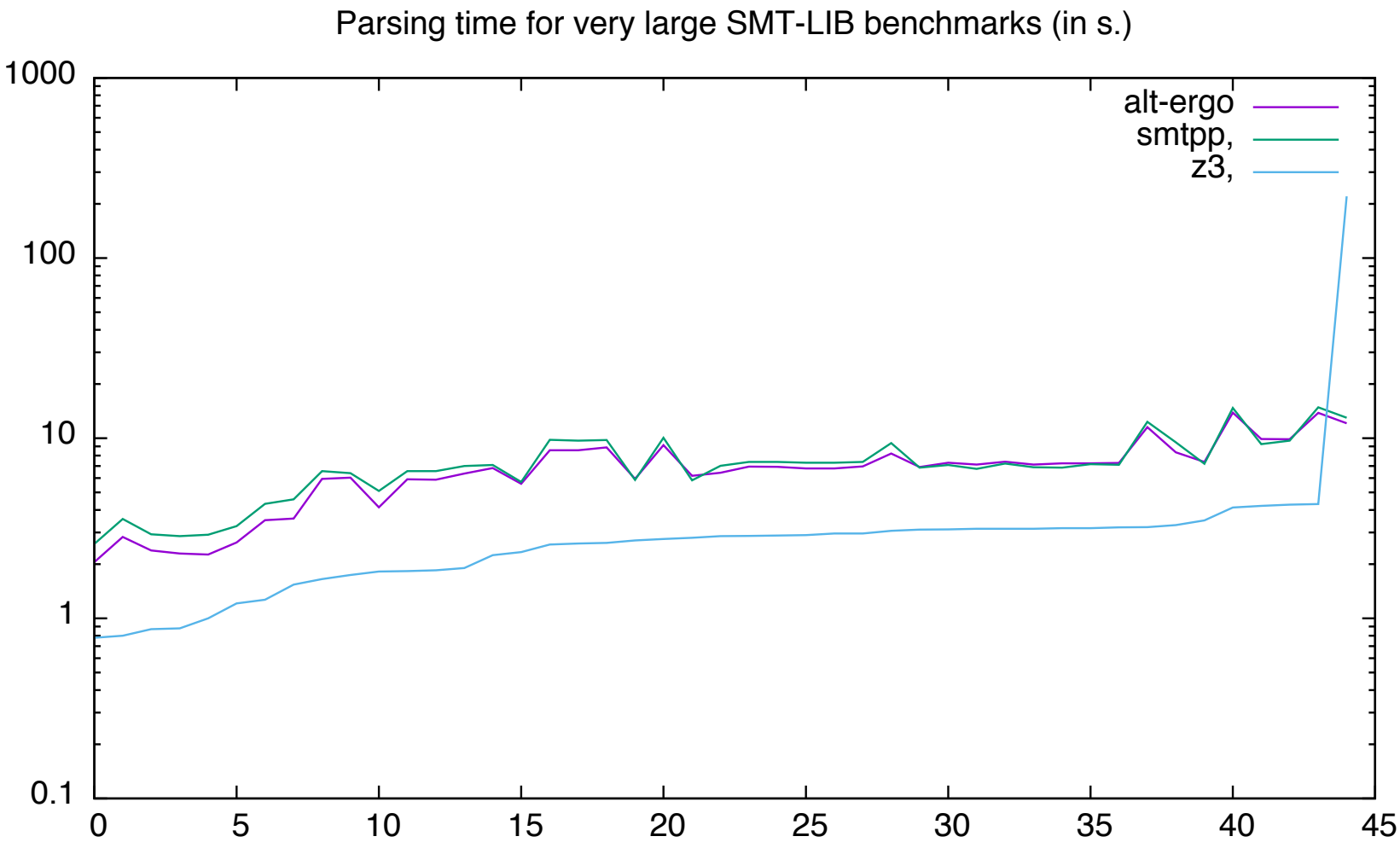
The parser module

- ocamlyacc or Menhir
  - LR(1) parser generator
  - keyword references to semantic values
  - improved debugging support

```
%inline command:
  | ASSERT t=term;
  { let loc = mk_loc $startpos $endpos in
    mk_command (CmdAssert t) loc }
  | CHECKSAT
  { let loc = mk_loc $startpos $endpos in
    mk_command CmdCheckSat loc }
  | DECLARECONST sym=symbol; so=sort;
  { let l = mk_loc $startpos $endpos in
    mk_command (CmdDeclareConst(sym, so)) l }
```

```
let mk_loc loc_start loc_end =
    { loc_start; loc_end; } ;;
```

Parser: experiments



Obfuscator module

- replace declared symbols with tool-generated names
- example input (excerpt):

```
(declare-fun x () Real)
(declare-fun f (Real) Real)
(assert (=> (> x 0) (< (f x) 0)))
```

- corresponding output:

```
(declare-fun S2 () Real)
(declare-fun S3 (Real) Real)
(assert (=> (> S2 0) (< (S3 S2) 0)))
```

Multi-script generation module

- Slice incremental benchmarks into non-incremental ones.

```
(set-logic QF_LIA)
(declare-fun w () Int)
(declare-fun x () Int)
(declare-fun y () Int)
(declare-fun z () Int)
(assert (> x y))
(assert (> y z))
(push 1)
(assert (> z x))
(check-sat)
(pop 1)
(push 1)
(check-sat)
(exit)
```

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```

Use-def analysis module

- detects:
  1. use of undefined symbols: error
  2. definition of never-used symbols: noise
     - commonplace in SMT-LIB
- results verified with grep
- application
  - simplify benchmarks
  - possible errors

Use-def analysis: experiments

- BWare project: prelude with symbols not used in all files
- a number of scripts have local bindings (`let`) for variables that are not used
- all benchmarks in LRA/keymaera have a homonymous global constant symbol and existentially quantified variable.
- QF_ABV has scripts with significant amounts (30-50% file size) of unused declarations.

Logic detection module

- Errors occur when logic is not precise enough
- Logic is too restrictive:
  - reduce choice of solvers
  - might reduce performance
  - might reduce precision of results (e.g. `unknown` vs `sat`)
- Benchmark generators often choose a default logic that is sometimes too expressive
- Approaches in existing solvers
  - have a default catch-all logic
  - inspection of AST to infer a logic

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- Approaches in existing solvers
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  - inspection of AST to infer a logic $*$
- $\Longrightarrow$ logic detector module in SMTpp.
  - Still conservative: e.g. LA benchmarks classified as NLA
  - DL: problems with non-canonical atoms, e.g. $x \leq y + 1$

Logic detection: experiments

- SMT-LIB (2014 version): 5% reported by SMTpp

  AUFLIRA 1368 scripts without `Array`.

  UF/grasshopper propositional

  QF_UFLRA 20% do not use arithmetics

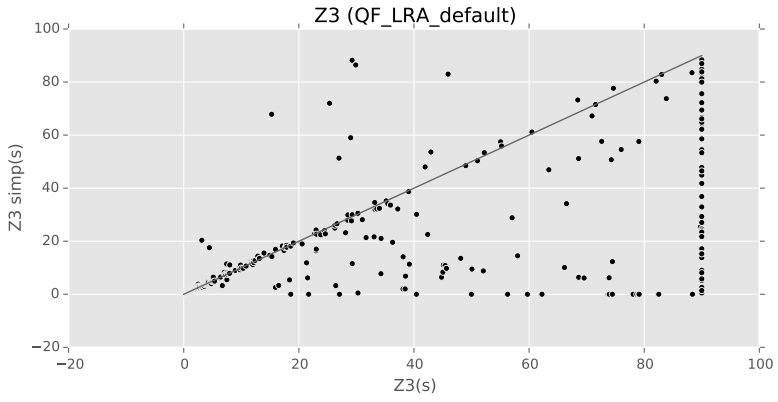
  QF_AUFLIA mostly do not use arithmetic functions, 1/4 have no free sorts and uninterpreted functions.

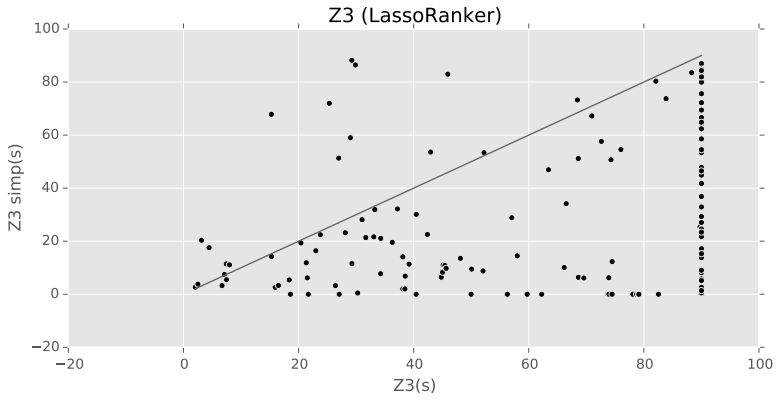
LA simplifications module

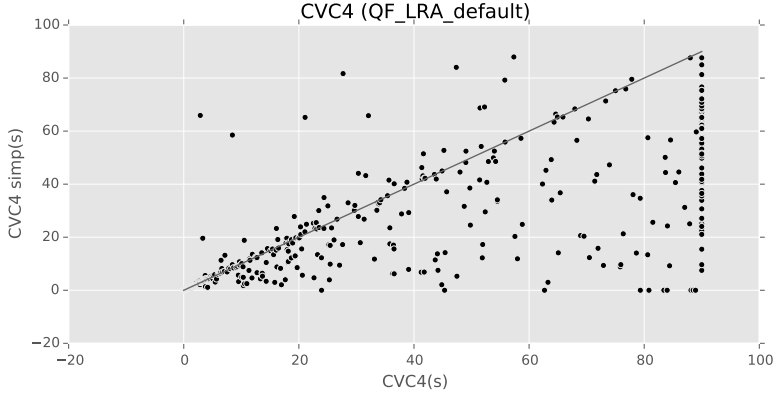
- motivated on LassoRanker subfamily
- straigthforward transformations
  - absorbing element
    - multiplication
    - logical and
    - logical or
  - neutral element
    - multiplication
    - addition
  - turn relational constraints into boolean constants (i.e. $1 > 0$)
- Local Gauss elimination
  - identify equational constraints
  - split additive expression
    - replacing monoms
    - monoms to be replaced
  - perform substitution on relational constraints

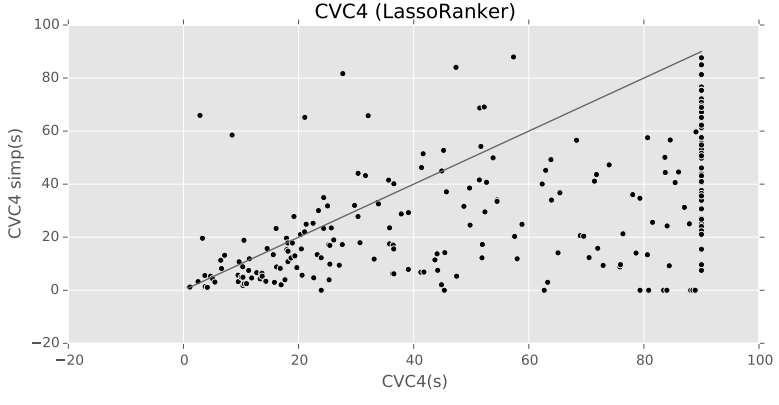
LA simplifications: experiments

Comparison of execution times



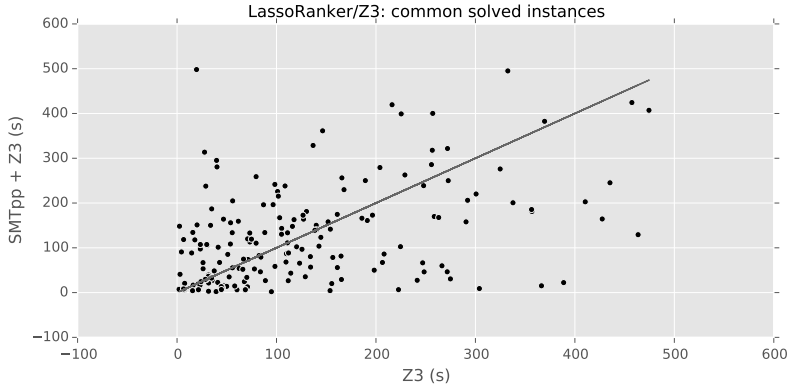


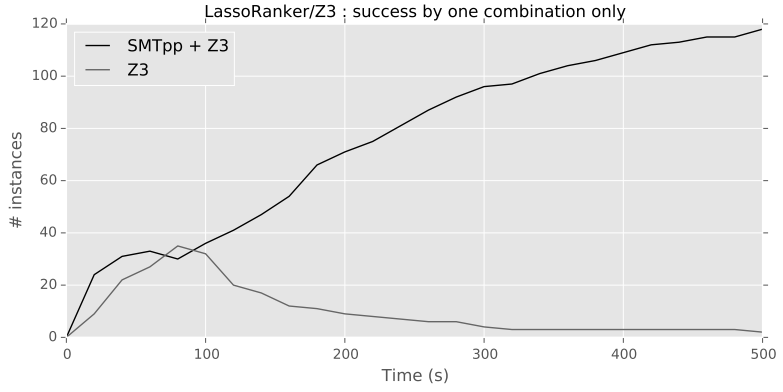


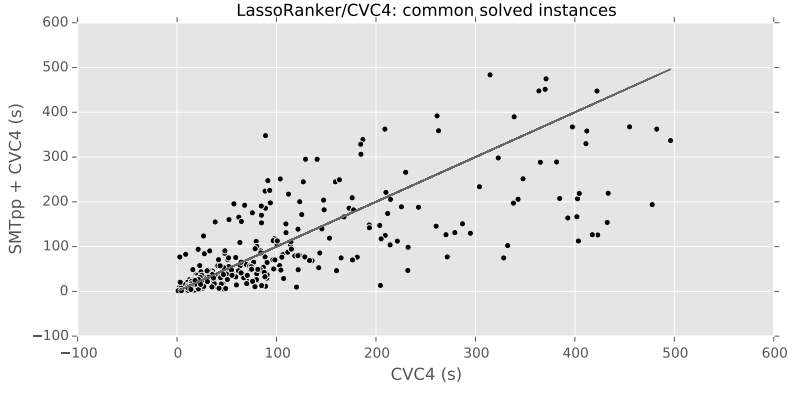


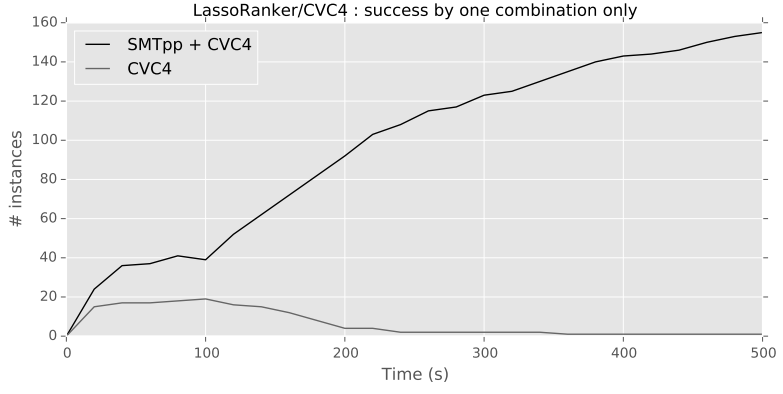
LA simplifications: experiments

Execution time on solved instances and count of uniquely solved instances



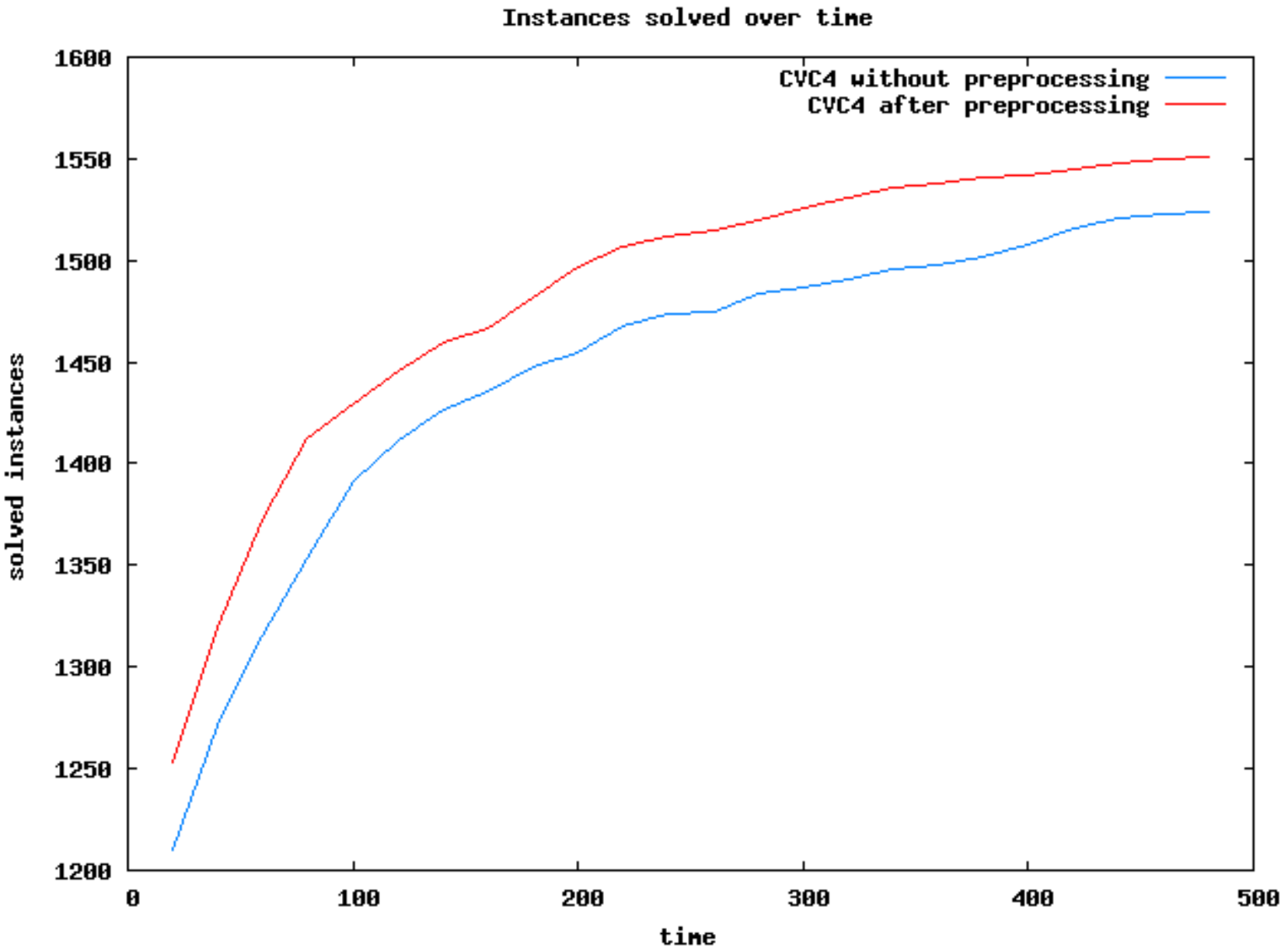






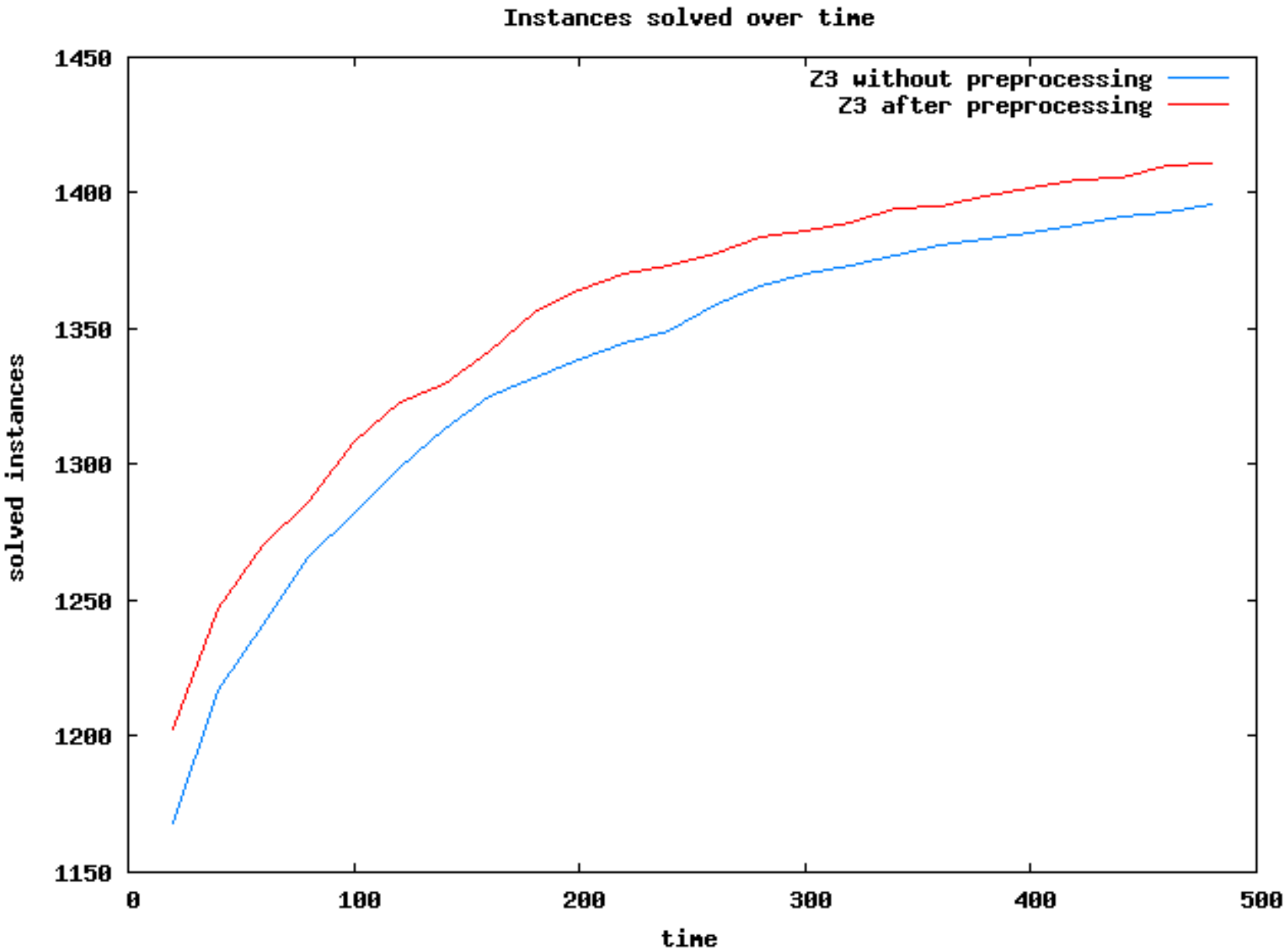
LA simplifications: experiments

Cumulated amount of solved instances: CVC4/smtpp+CVC4



LA simplifications: experiments

Cumulated amount of solved instances: Z3/smtpp+Z3



LA simplifications: user experience

- The implementer of this module was initially completely unfamiliar with OCaml.
  - 3-month experience with Scheme
- One day to get familiar with SMTpp code
  - core knowledge: AST API
- A prototype version of the module was implemented in two weeks
  - quick-and-dirty mode
  - more effort needed to make it stable

Conclusions

- SMTpp: already available
  - supports SMT-LIB 2.5
  - implemented several features useful to clients of SMT solvers
- preliminary results cross-checked with other tools
- usability:
  - permissive free software license
  - high-level programming language
- `https://github.com/ossanha/smtpp`

Future work

- type checking
- architectural challenges
  - processing of very-large benchmarks and memory usage (multiple-passes?)
  - integration with SMT-solvers (quantifier instantiation)
  - pluggable architecture: plug-ins *à la* Frama-C
  - tactic language: user-programmable combination of simplifications?
- handle requirements such as: traceability, proof production
- additional simplifications, rewriting:
  - symmetry detection and symmetry breaking
  - if-then-else simplifications
- extend to support delta-debugging, scrambling

Feedback

Questions?

`https://github.com/ossanha/smtpp`

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