Viper

A Verification Infrastructure for Permission-Based Reasoning

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(and many students)

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Verification via Automatic Provers

- Last 10 years: rapid progress in automatic tools for first-order logics (SMT solvers, provers)
- Intermediate Verification Languages: e.g. Boogie and Why
- Provide common infrastructures for building program verifiers
- Many success stories and tools
  - Microsoft Hypervisor (VCC)
  - Device-drivers (Corral)
  - .. and many more, e.g., Why3, GPUVerify, Spec#, Dafny, Vericool, Krakatoa, etc....
Permission-Based Reasoning

- Separation Logic (and others): custom logics for heap reasoning
- control of ownership/sharing of \textit{partial heaps} (heap fragments)
- First-order prover technology \textit{difficult} to directly exploit
  - Custom verification engines (usually symbolic execution)
  - Lots of work to implement
  - Hard to reuse for new work
  - ... fewer tools available 😞
The Viper Project

- We have designed **Silver**: a new intermediate verification language
  - Reusable *native support* for permission-based heap reasoning
  - Few, expressive constructs
- The tool infrastructure is called **Viper**
  - Includes back-ends (**two verifiers**)
- Some front-end tools also available:
  - Proof-of-concept translators for
    - *Chalice, Scala* (fragment), etc..
    - used for various other projects
Basic Assertion Language

• Based on *Implicit Dynamic Frames* [Smans et al. ’09]

• Permission assertions: *accessibility predicates* \(\text{acc}(e.f)\)
  • exclusive: similar to \(e.f \mapsto _-\) in separation logics

• Expressions \(e\) may depend directly on the heap
  • e.g. \(\text{acc}(x.f) \&\& x.f > 0\)

• *Fractional permissions* [Boyland’03], e.g. \(\text{acc}(x.f, \frac{1}{2})\)
  • allow reading (and framing), not writing

• Conjunction \(\&\&\) is multiplicative for permissions
  • e.g. \(\text{acc}(x.f, \frac{1}{2}) \&\& \text{acc}(x.f, \frac{1}{2}) \equiv \text{acc}(x.f, 1)\)
Silver primitives: Inhale and Exhale

- A statement **inhale A** means:
  - all permissions required by are **A** gained
  - all logical constraints (e.g. $x.f > 0$) are *assumed*
- A statement **exhale A** means:
  - check, and remove all permissions required by **A**
  - all logical constraints (e.g. $x.f > 0$) are *asserted*
  - any locations to which all permissions is lost are implicitly *havoced* (their values are no-longer known)
- Can be seen as the *permission-aware analogues* of assume/assert statements used in first-order verification
  - used to model ownership transfer of partial states
  - cf. “produce” and “consume” in symbolic execution
Example : Encoding Locks (CSL-style)

class C {
    int[ ] data; int count = 0;

    monitor invariant this.data↦_ * this.count↦_
        
    void Foo( ) {
        acquire this;
        int i = data.length;
        while( 0 < i )
            invariant this.data↦_ * this.count↦_
            invariant holds( this );
            { ... ; i = i - 1; }
        count = count + 1; release this;
    }
}

Example : Encoding Locks (CSL-style)
A few powerful Viper features....

- **Paired assertions** \([A, B]\)
  - \(A\) used when inhaled, \(B\) used when exhaled
  - mismatches: external justification / proof obligations
- **Quantification over local state** \(\text{forallrefs}[f] \ x ::\)
  - non-standard for separation logics (but handy)
Example : Two-state invariants

class C {
    int[ ] data; int count = 0;

    monitor invariant this.data→_ * this.count→_
        && this.count > old(this.count)

    void Foo( ) {
        acquire this;
        int i = data.length;
        while( 0 < i )
            invariant this.data→_ * this.count→_
            invariant holds( this );
            { ... ; i = i - 1; }
        count = count + 1; release this;
    }
}

A few powerful Viper features....

- **Paired assertions** $[A,B]$
  - $A$ used when inhaled, $B$ used when exhaled
  - mismatches: external justification / proof obligations
- **Quantification over local state** $\forall \text{refs} [f] \ x ::$
  - non-standard for separation logics
- **State snapshots, labelled “old” expressions**
- **Custom predicates, heap-dependent functions** [ECOOP’13]
  - fold/unfold for predicates, functions mostly automatic
- **Constrainable permissions** [VMCAI’13, FTfJP’14]
  - Alternative to fractional permissions (angelic amounts)
- **“Magic wand” support** [ECOOP’15]
  - Powerful connective from separation logic
- **Custom domains, sets and sequences, quantifiers**
Verification of Silver Code (back-ends)

Silver code

verified by

verified by

Carbon

Boogie
(Microsoft)

encodes in

queries

queries

Silicon

Z3
(Microsoft)

queries

Verification Condition Generation

Symbolic Execution
Verification of Silver Code (back-ends)

Query prover once with full information (encode heap)

Program read by Verifier calculates WPs given to Prover

Program read by Verifier maintains Symbolic State $\sigma$

$\sigma_1 \sigma_2 \sigma_3 \sigma_4 \sigma_5$

Query prover often with limited information (no heap)
Tool Availability and Future Work

- Core tools released (open-source) in September 2014: http://www.pm.inf.ethz.ch/research/viper.html
  https://bitbucket.org/viperproject
- We have (public!) issue trackers for known problems
- Some advanced features are in the pipeline (but ask)

- Building / supporting new tools by translations into Silver
  - SL, dynamic frames, invariants, rely-guarantee, types
  - More-advanced program logics? Weak memory? ...
  - Also interested in work we cannot encode (yet ...)

- Make tools to implement your cool research with Viper 😊
  - Coalesces much formal and practical past research
  - Users can focus on the aspects relevant to their work
Silicon
Carbon
Boogie (Microsoft)

Z3 (Microsoft)

Chalice2Silver
Scala2Silver

Java (UTwente) (VerCors project - Marieke Huisman)
OpenCL (UTwente)

Any questions?

front-ends

Chalice2Silver

back-ends

verified by

infer additional specifications

generate

encodes in

queries

queries

Sample