Design and development of Svace static analyzers

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Agenda

- Static analysis and development lifecycle
- Haven’t we solved the problem yet?
- Design decisions and lessons learned*
  - Overall architecture
  - Supporting infrastructure
  - Analysis organization
  - Analysis algorithms
  - Warning review
- What lies ahead

* See also:
Al Bessey, Ken Block, Ben Chelf, Andy Chou, Bryan Fulton, Seth Hallem, Charles Henri-Gros, Asya Kamsky, Scott McPeak, and Dawson Engler. A few billion lines of code later: using static analysis to find bugs in the real world. Commun. ACM 53, 2 (February 2010), 66-75.

Static Analysis Requirements

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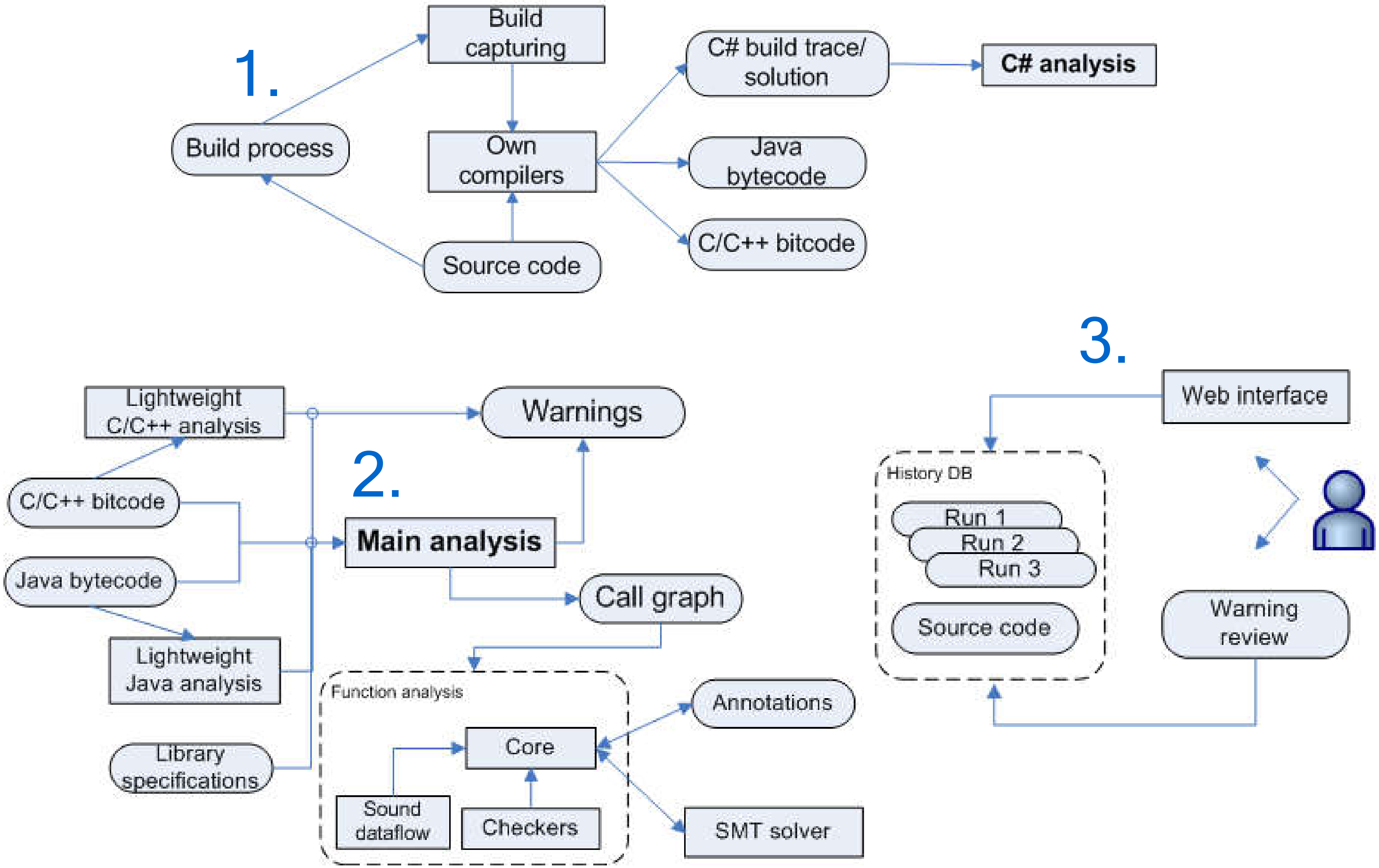
- Wide applicability: defect detection, program understanding, performance, ...
- Application for secure development lifecycle
  - CI integration, nightly builds, Q&A
- Requirements that follow:
  - Fully automatic analysis (no need to change the code)
  - Scalable to millions of LOC
  - Fair percent of true positives (*60+%*)
  - Sufficient *completeness**
  - Support of programming languages (C/C++/Java/C#), defect types (many), environments (Windows/Linux)
  - Extensibility with new checkers, flexibility (tailored config)

(Scalable to millions of LOC, fair percent of true positives, sufficient completeness: Quality tradeoff)

Haven't we solved it yet?

- A few production tools – can't they just evolve?
- Some non-trivial issues come to mind:
  - Difficult to compare with competitors: their licenses won't allow
  - Difficult to choose the evolution directions
    - memory modeling (separation logic etc.)
    - conventional analyses become demand-driven
    - SMT solvers become more powerful and change the way analyzers build queries for errors detection
  - The goal of saving developer time is taken further
    - *Tightly* integrate with developer's workflow (CI)
    - Prioritize analyzer's output so that true warnings are seen first
    - Suggest and make *semi*-automatic code fixes

Svace Architecture



Build Interception

- Detect process launch
  - LD_PRELOAD to dynamically linked executables
  - Debugging API (`ptrace`, WinAPI)
  - Wrappers (e.g. MS-DOS machine within Windows)
  - Java: agent injection for compilation APIs interception
  - C#: msbuild DLL injection (similar to Java)
- Parse cmdline/environment
  - Trace “interesting” launches
  - Decide on action (usually – run own compiler)
  - Transform cmdline (options/envvars) for our compiler, not loosing significant options, include paths, ...
- Launch our compiler for generating IR (or other needed tools)

Constructing An Analyzer Compiler

- Harsh requirements
  - Need to be as failproof as possible
  - Need to understand C/C++ dialects of dozens of desktop/embedded compilers
  - Need to understand modern language standards
- Has to base on production open source (C/C++ → GCC/LLVM) or buy EDG
  - Add some “fuzzy parsing” mechanism (ie not stop on error, but recover as much as possible)
  - Fixup for dialects (or “morph” user source to get rid of them)
  - Inject additional data if needed by the analyzer
  - >1000 patches wrt vanilla Clang
- Java/C# is no problem (one compiler)
  - Though Google invented (and deprecated) Jack compiler...

Analysis Engine

- Extensibility
  - Need to support many warning types / checkers
  - Ways to reuse code and calculated data for checkers (effectively the data that is always required becomes “core”)
- Multiple language support
  - Lower level common IR
  - Ensure that analysis assumptions are honored when making IR
- Call graph reconstruction
  - C/C++: requires gathering linkage information
  - C++/Java/C#: requires (some) devirtualization
- Parallel analysis
  - Analyze in parallel independent call graph parts
  - Take into account function locality w.r.t. modules
  - Speed / memory consumption tradeoff

Analysis Engine – II

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- Incremental analysis
  - May be used for CI integration and for running on developer’s PC
  - Needs changes in all components (“merging” old and new data)
  - Need to understand whether to draw a line in analyzing the unchanged code with changes in context
- Determinism
  - Same/slightly changed results for same/slightly changed source
  - Varying input data (due to build issues)
  - Analysis results grouping
  - Dependence on the iteration order over input data (fixup the order or change the algorithm)
  - Function analysis timeouts (avoid “real” timeouts if possible)
  - Statistical checkers

Analysis Algorithms

- Memory model / aliasing
  - Field sensitivity, limited number of dereferences
  - Alias analysis, escaped memory analysis, strong/weak updates
- Sound / unsound
  - Most analysis is unsound (parameter aliases, loops, limitations on summary / derefs)
  - But need fully sound part (unreachable code, functions exiting program)
- Tracking values’ properties
  - Reason about properties of values, not of memory cells
  - Should be careful when there are multiple ways to reinterpret the value

Analysis Algorithms – II

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Parameterized summaries

- Scalability requires limiting the number of passes over a function
- Context sensitivity means varying analysis behavior for different calling contexts
- Using function summaries that parameterize analysis results on external memory means visiting every function only once
- Careful to put to the summary only the data describing “escaped” memory and to limit its size
- Checkers should decide what information is important to save

“Symbolic” external values

- When treating unknown values’ properties conservatively, intraprocedural analysis doesn’t yield anything useful
- Try saving any merges/*computations* with such values and resolve them upfront in the call graph with concrete values

Error Definitions

- Beliefs / inconsistencies
  - Known way to detect errors: find inconsistencies in the assumptions the code does about some dataflow facts
- Find a control flow "segment" where:
  - either there's always an error if we go there, or
  - the "segment" is unreachable / unfeasible
  - Both ways it makes sense to warn
  - Rely on *programmers* not writing unneeded code
- A segment may be a control flow edge or an execution path (for path sensitive analysis)
- Statistical checkers also find "inconsistencies" (*mostly* done this way → this way is "right")
- Language specific definitions are possible (C++, Java)

Path sensitivity via symbolic execution

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- ❑Core engine computes a path predicate
- ❑Symbolic states are tracked and merged
- ❑Checkers are free to attach conditions to the attributes they are tracking
  - ➢We are still reasoning about values, not memory
- ❑Just tracking values' changes (aka "symbolic state") is often not enough
  - ➢Taking a specific path is useful information (comparisons)
- ❑Condition simplification
  - ➢It is useful to apply a handful of trivial simplifications before passing a query to an SMT solver

Warning Review

- Convenient review interface
  - Web-based, but now better be integrated into CI or dev.env
  - “Dashboard” (bird’s eye view)
- Runs comparison
  - Never see anything once reviewed as a false positive
  - Need to support slightly changed code and repo branches
- Lots of data to store (except analysis results)
  - Source code to show it
  - Tokens/relations to do syntax coloring/navigation
  - Even more for e.g. incremental analysis
- Migration without loosing review
  - Match warnings between releases to avoid spurious new stuff
  - Avoid too much churn (cf. mentioned Coverity paper)

What Lies Ahead – Analyzer

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- More of aliasing
- Better loop handling
- C++/Java collections
  - No chance to infer their semantics through implementation, need to make their primitive operations “first class” in the IR
- Serving to different clients
  - Basic use case assumes warnings will be reviewed by humans
  - Need to configure “verboseness”
  - Need to adapt to the dynamic analysis toolchain use case
- Analysis API
  - Some checkers (e.g. simple source-sink ones) can be done by customers, and they wish to do so
  - External API will help but needs resources for support

What Lies Ahead – Around Analyzer

- Being input to further analyses
- Prioritization
  - Sort out warnings to make true ones stand out
- Code fixes
  - Suggest fixes to certain warnings and (optionally) apply them
- Improving review experience (ML)
  - Direct more attention to the changes that are potentially risky
- Code base wide refactorings
  - Making changes guided by static analysis results for the whole code base (think hundreds of git repos)

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Success is a team effort