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ESBMC-CHERI: Towards Verification of C/C++ Programs for CHERI Platforms with ESBMC

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Overview of this talk

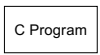
- Brief introduction to ESBMC
- Architectural changes necessary to support CHERI-C
- Challenges and solutions
- Conclusions and future work

Introduction to ESBMC

Efficient SMT-based Bounded Model Checker

- Open source logic-based automated reasoning for safety and security of C/C++ programs.
  - Apache License 2.0.
  - Used by industries: Intel, Nokia, ARM
  - Core concept: symbolic execution.
  - Concurrency support.
  - Frontends for different input languages.
- Input: Program, Output: verification success or failure + witness.
  - Witness is a trace of assignments leading to the violation.
- C/C++ frontends translate the Clang AST.

Architecture of ESBMC



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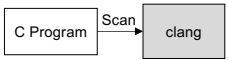

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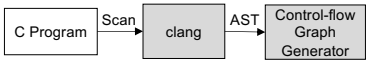

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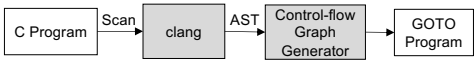

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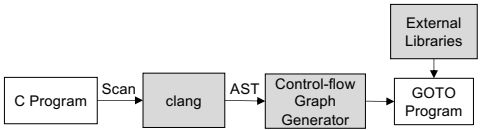

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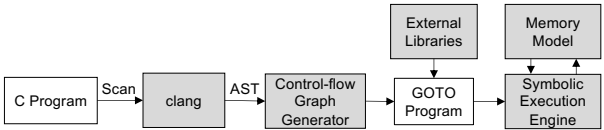

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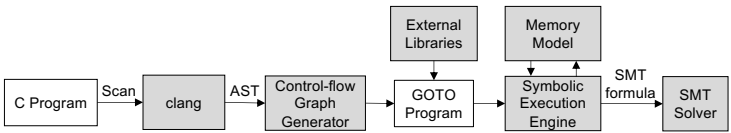

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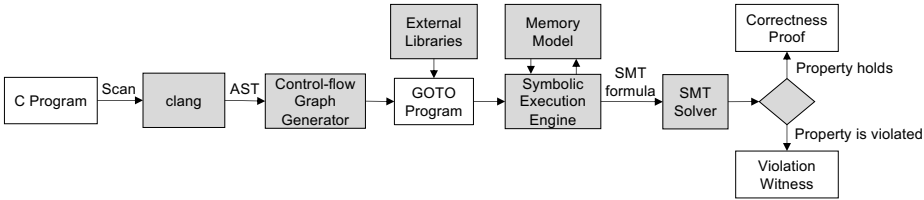

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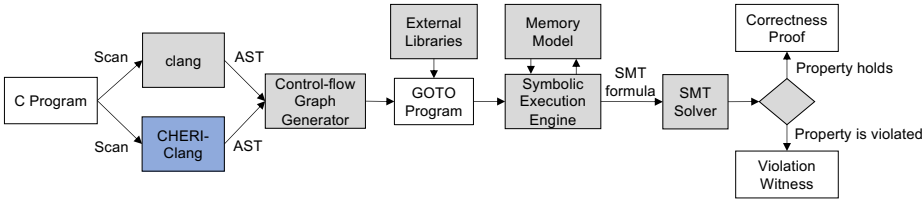

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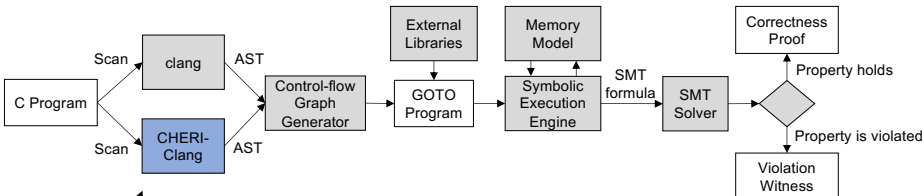
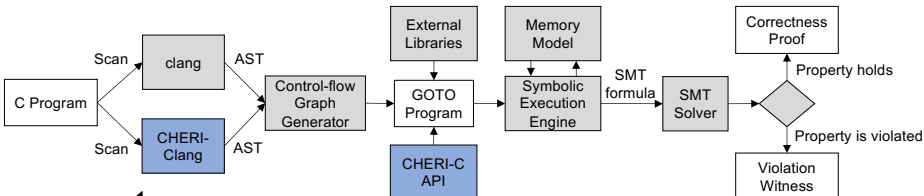


CHERI Clang/LLVM
compiler

Architecture of ESBMC



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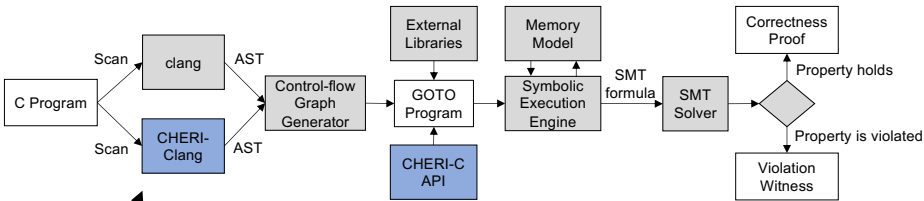
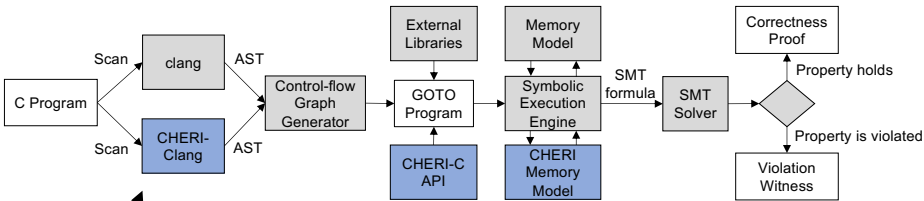


CHERI Clang/LLVM compiler

Implement computational model for CHERI-C API

Architecture of ESBMC



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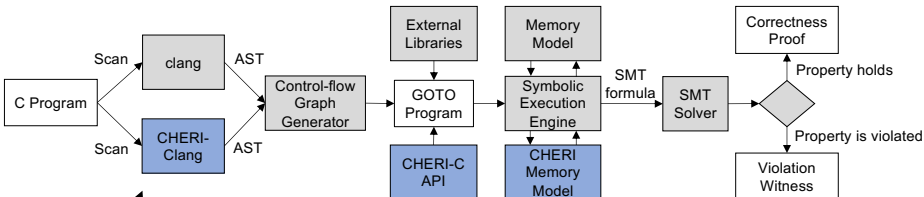

CHERI Clang/LLVM compiler

Implement computational model for CHERI-C API

- New capability types
- Tagged memory
- Capability dereferencing

ESBMC-CHERI

Goals:

- both uncompressed and concentrate capabilities modelled bit-precise
- reasoning in CHERI-BSD execution environment of capability hardware platforms RISC-V, ARM Morello, (MIPS)
- both, hybrid and purecap mode

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Challenges wrt. compression algorithms

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Challenges wrt. compression algorithms

Two directions for verification of CHERI-C programs:

- Proving absence of CHERI-exceptions
  - Bit-precise model of in-memory representation of capabilities
  - Base/bounds might differ from those ESBMC already maintains
  - Additional checks for permissions
- Assuming absence of CHERI-exceptions
  - Reasoning about unmodelled external C functions (libraries) via pointer provenance
  - Simplification of ESBMC's spatial memory safety checks
  - Optimisation of operational models of `libc` functions

Challenges for Pointer Provenance

Non-provenance in 'real world'

1. International Competition on Software Verification (SV-COMP[1]):

```
void *p = malloc(n);
intptr_t i = p;
free(p);
p = malloc(n);
assert(i != p);
```

Should fail verification.

2. ARM Realm Management Monitor project[2]:

```
char buffer[n];
intptr_t i = nondet(); /* user-input */
assume(buffer <= i && i < buffer + n);
char *q = buffer + ((char *)i - buffer);
*q;
```

Expected to work.

[1] https://sv-comp.sosy-lab.org

[2] Part of Arm Confidential Compute Architecture

Conclusions

- CHERI-Clang makes frontend changes easy.
- Tagged memory & CHERI-C API using existing functionality.
- Provenance not universally compatible with existing expectations.
- In-memory representation of capabilities and their permissions are difficult.
- On the other hand: assuming CHERI semantics reduces complexity of software verification.