UBFuzz:
Finding Bugs in Sanitizer Implementations

Steve Gustaman

Original paper by Shaohua Li and Zhendong Su
ASPLOS 2024

Motivation

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  - Buffer overflow
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security issue!

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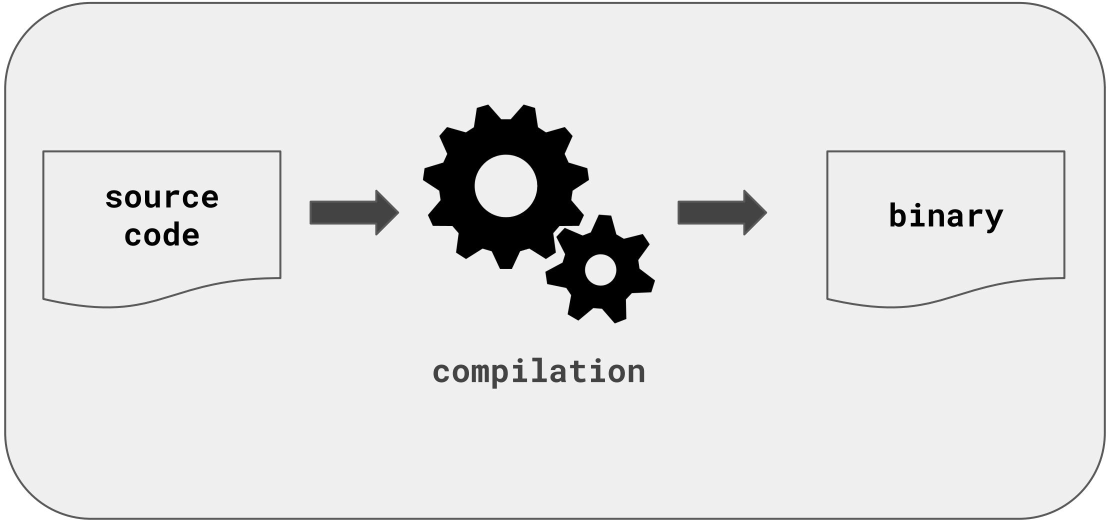

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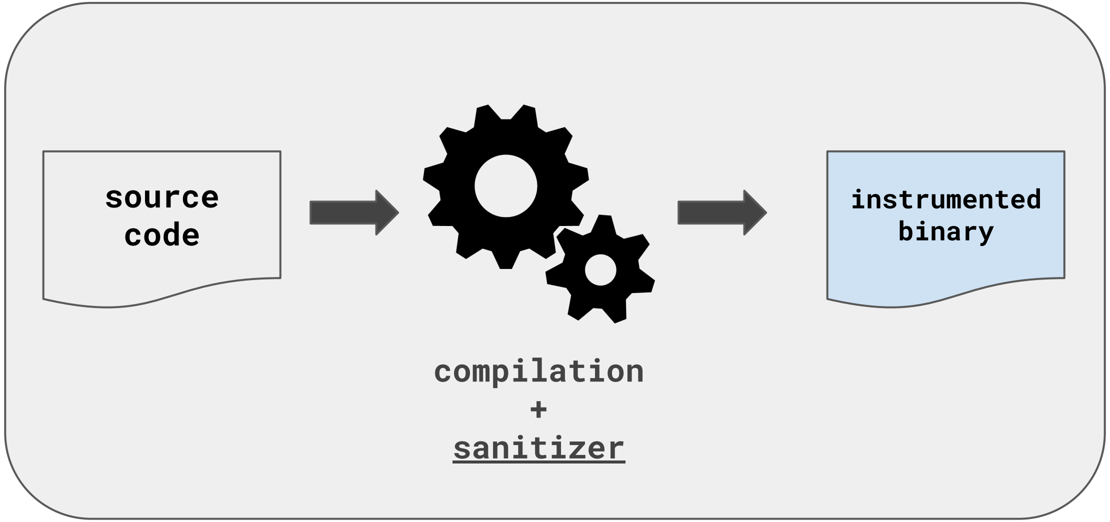

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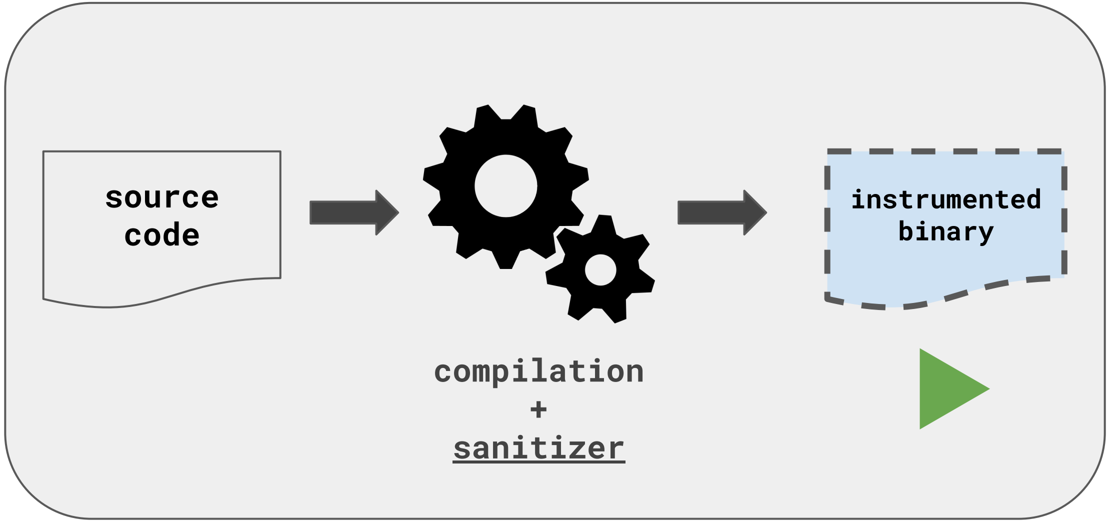

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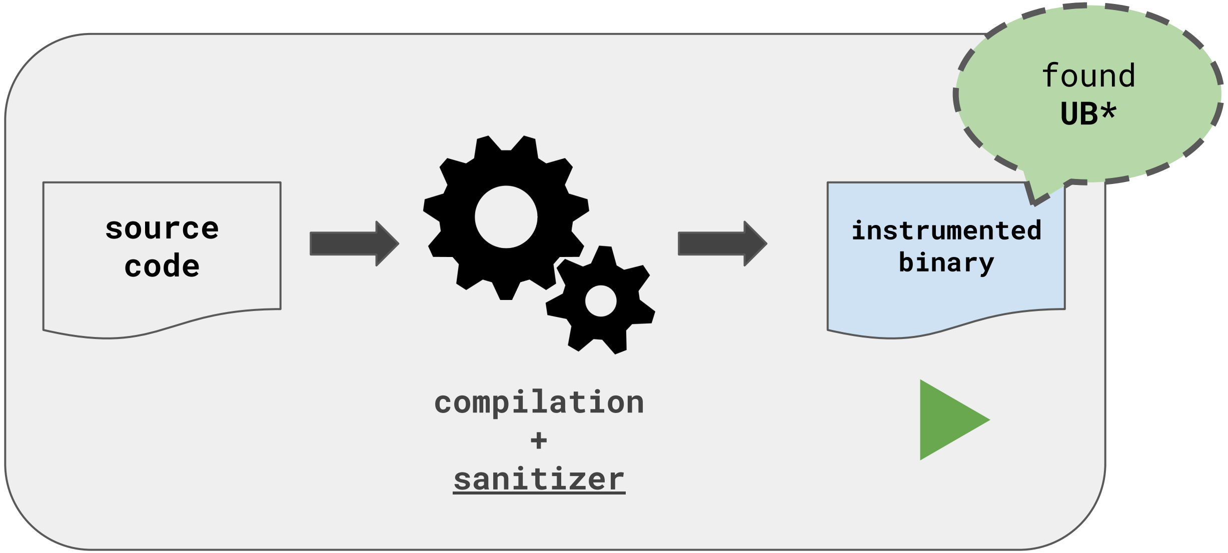

*during runtime

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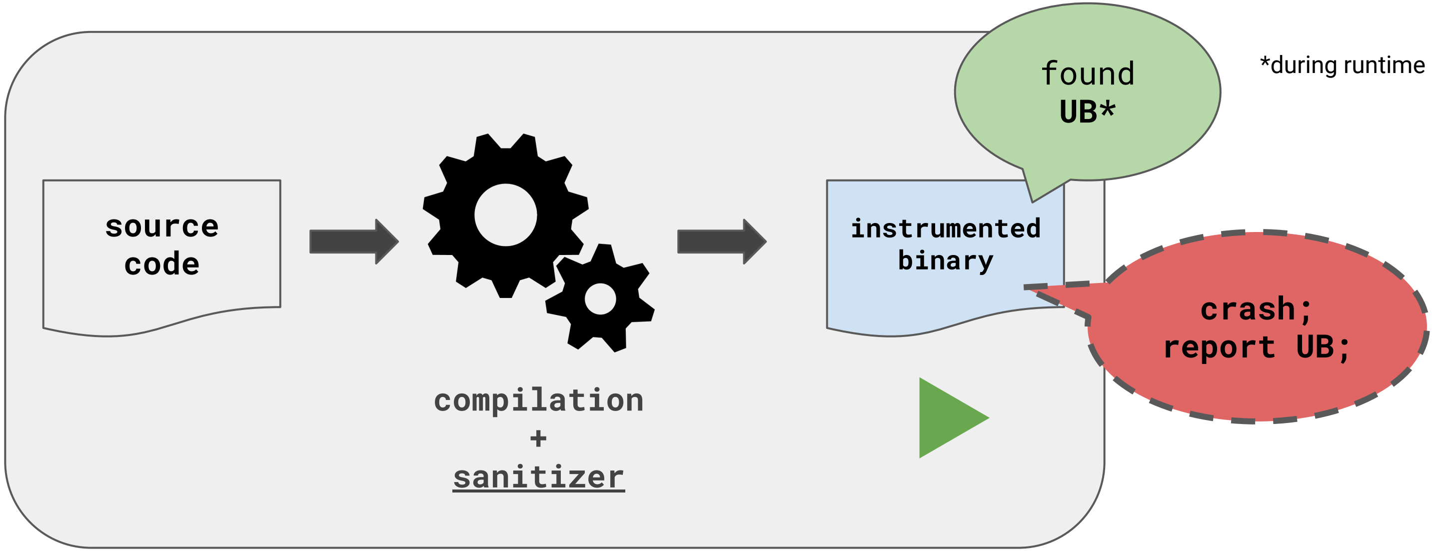

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Google OSS-Fuzz reported >20K UBs

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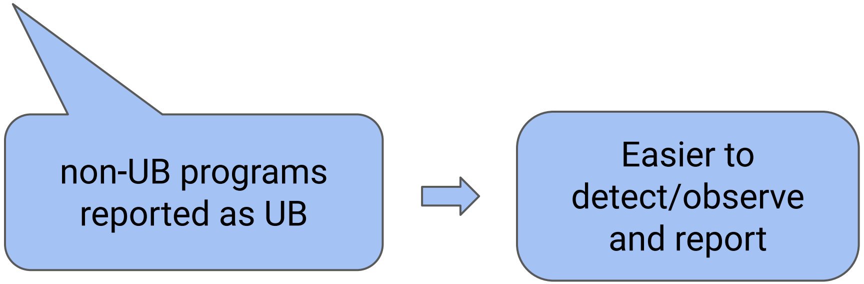

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possibly much more **hidden FN errors**

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Sanitizer: **many FNs = ineffective**

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- Sanitizers are widely used to detect UB
- Robustnes
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but how to effectively find **FN bugs** in sanitizers?

UBFuzz:

Finding Bugs in Sanitizer Implementations

with shadow statement insertion based program generation
and crash-site mapping oracle

UBFuzz Key Idea

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- UB-free program generation: **CSmith**

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- Idea: Introduce UB to generated UB-free program

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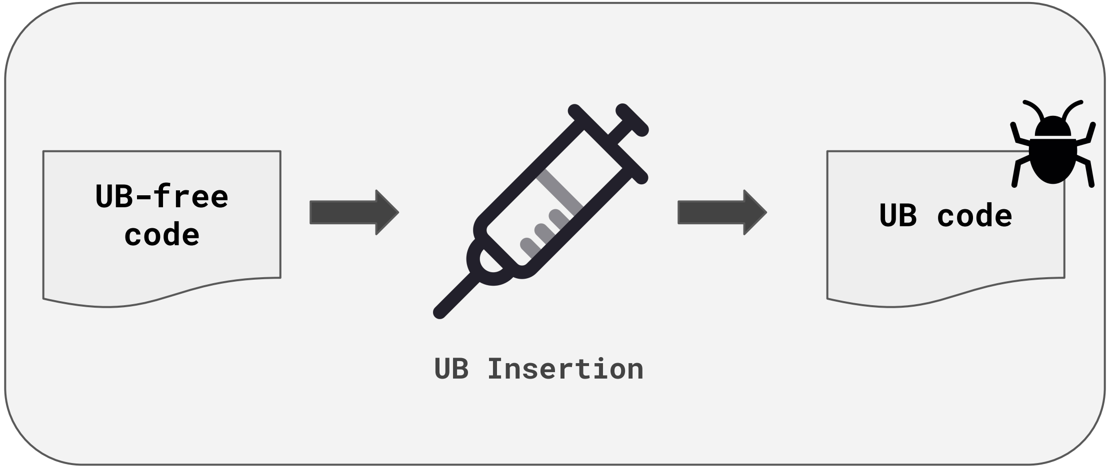

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shadow statement insertion

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- Approach is general
- Applied to 9 UB types in UBFuzz

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    - Cannot detect → **sanitizer FN bug**

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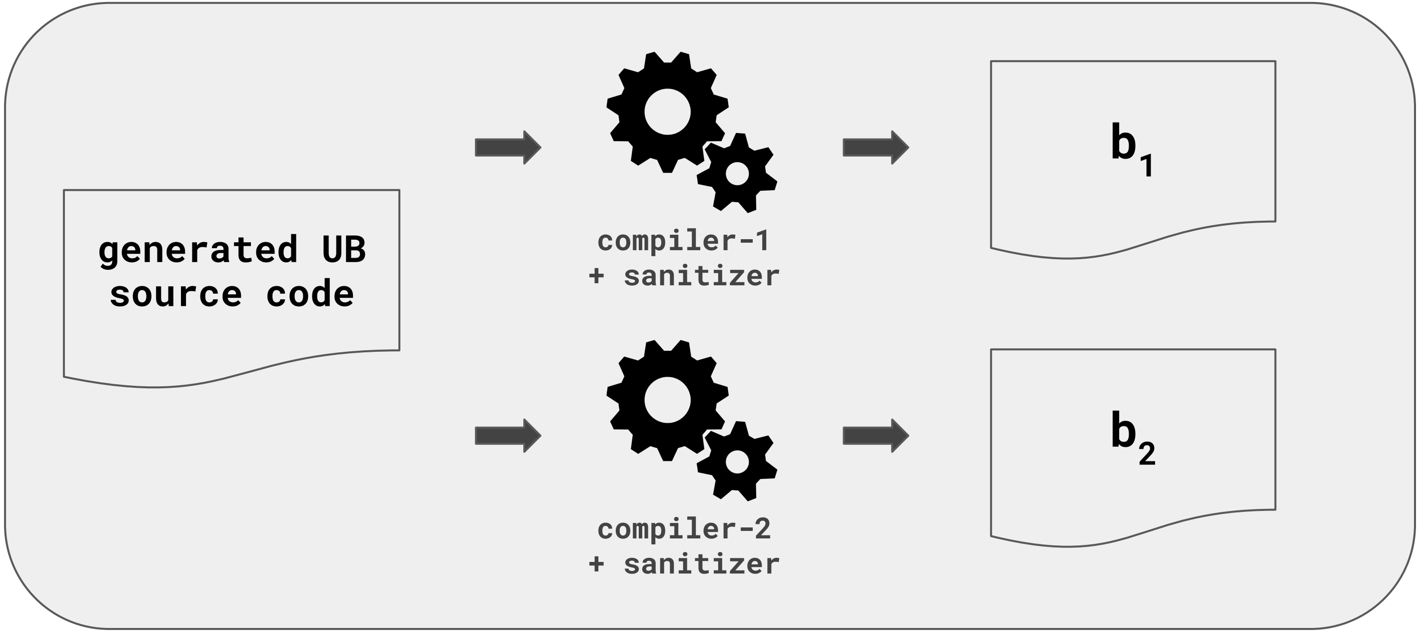

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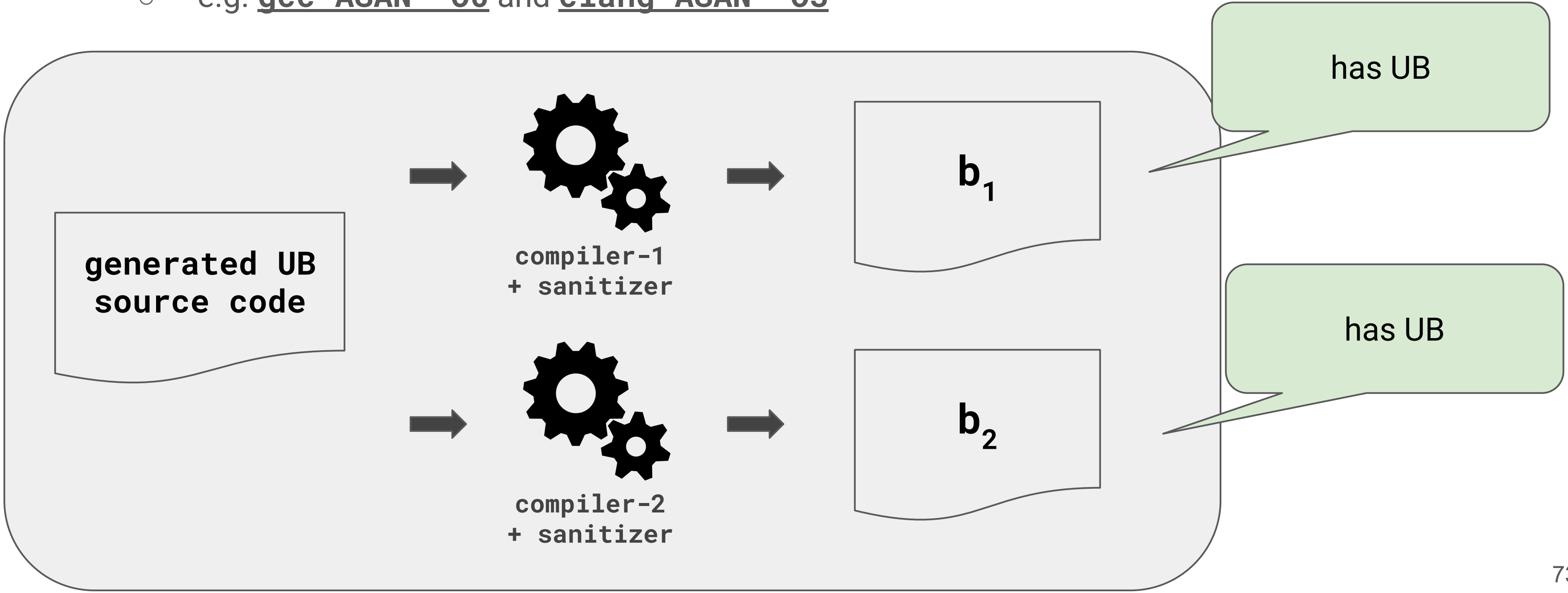

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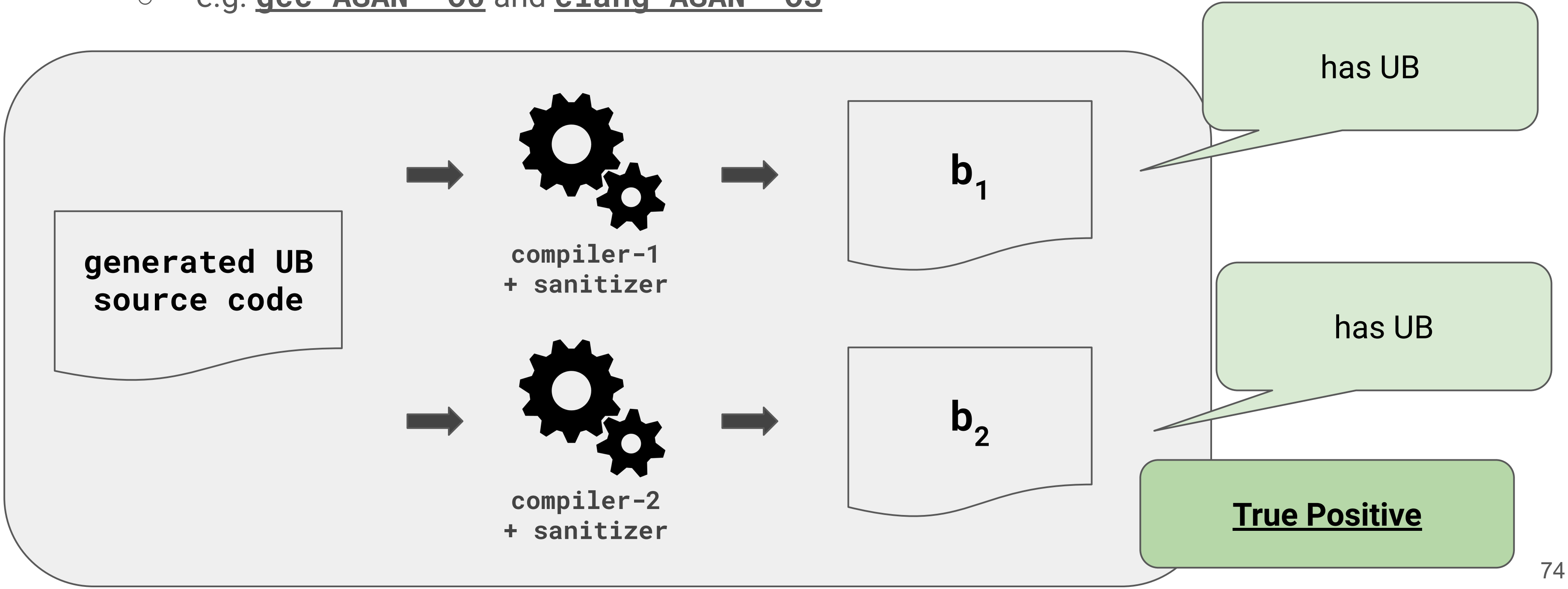

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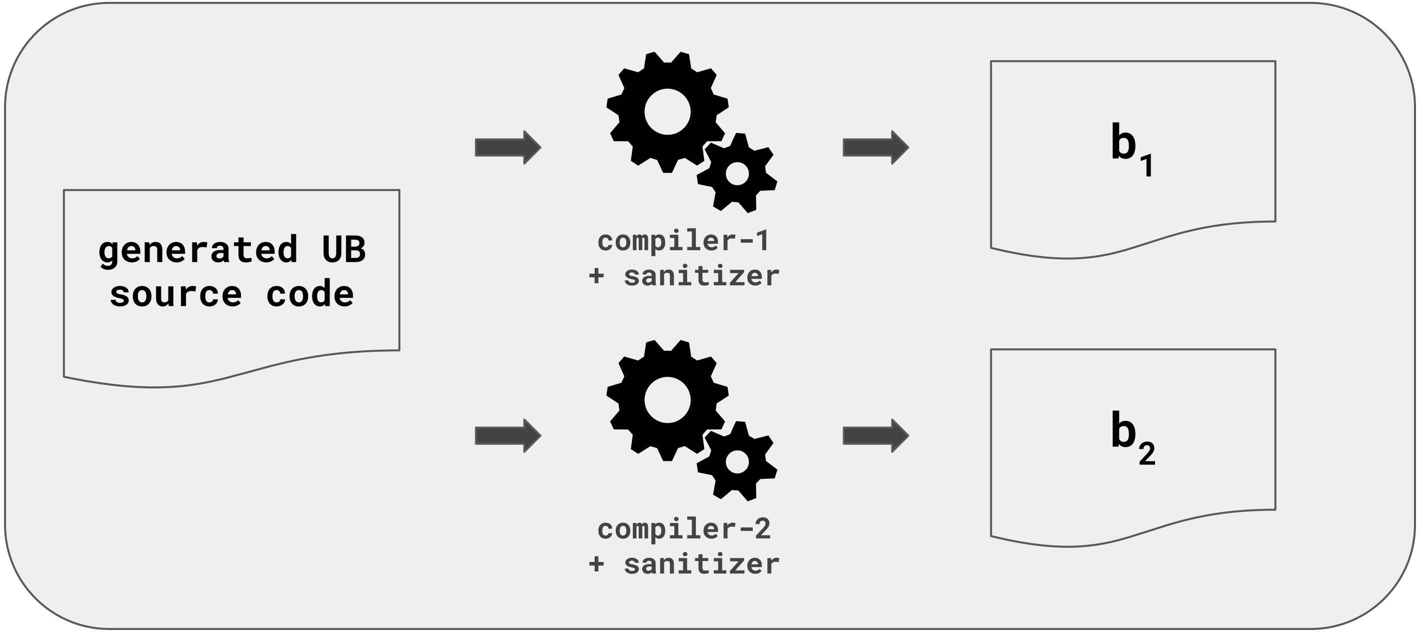

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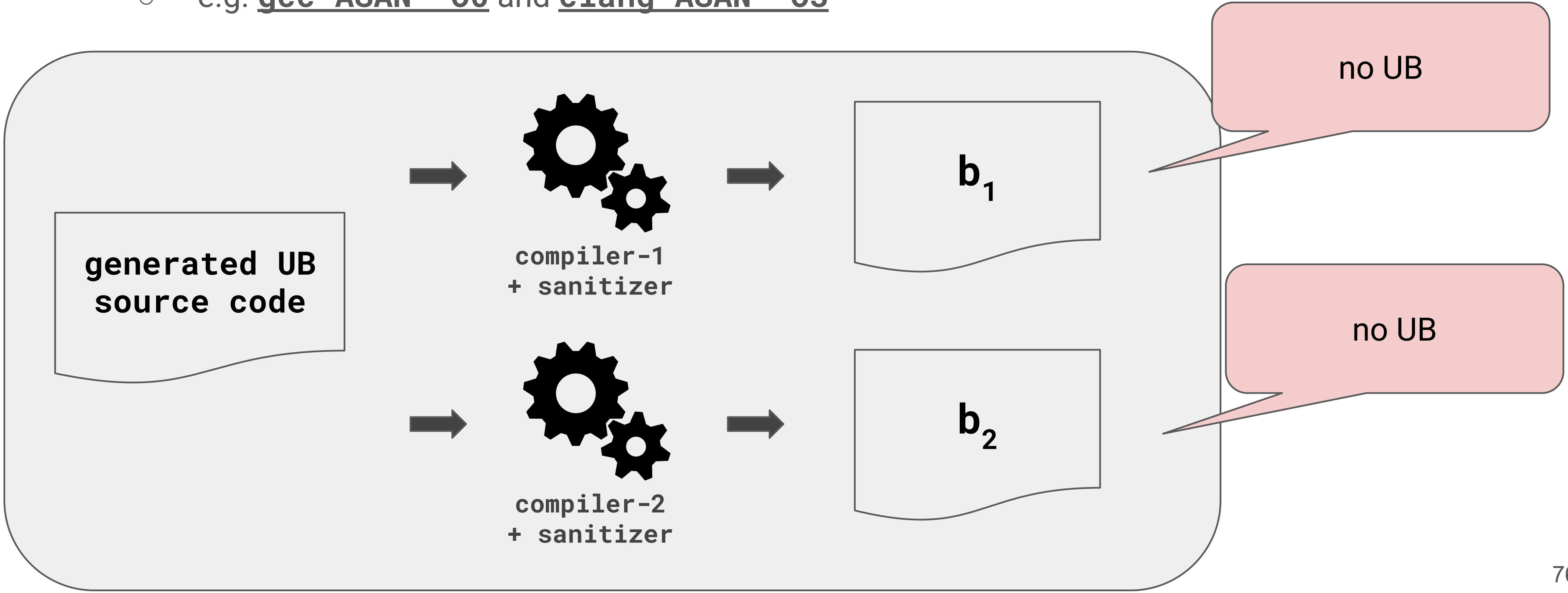

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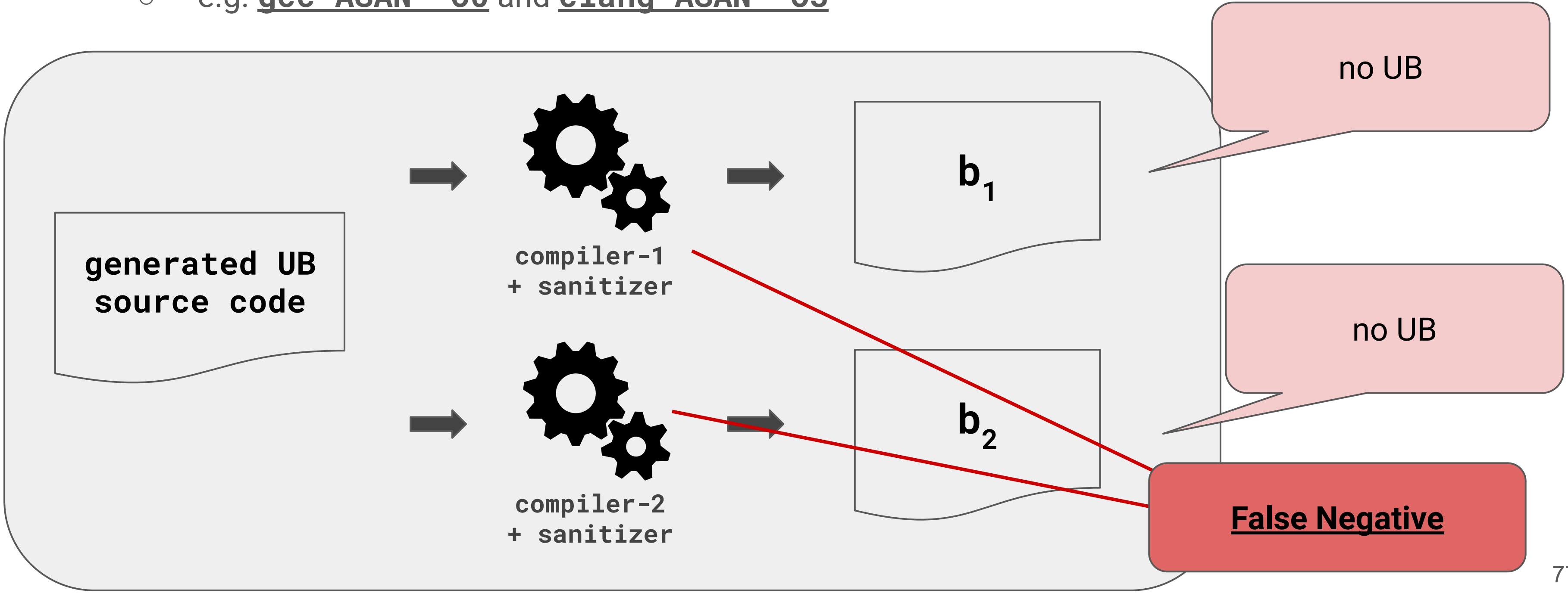

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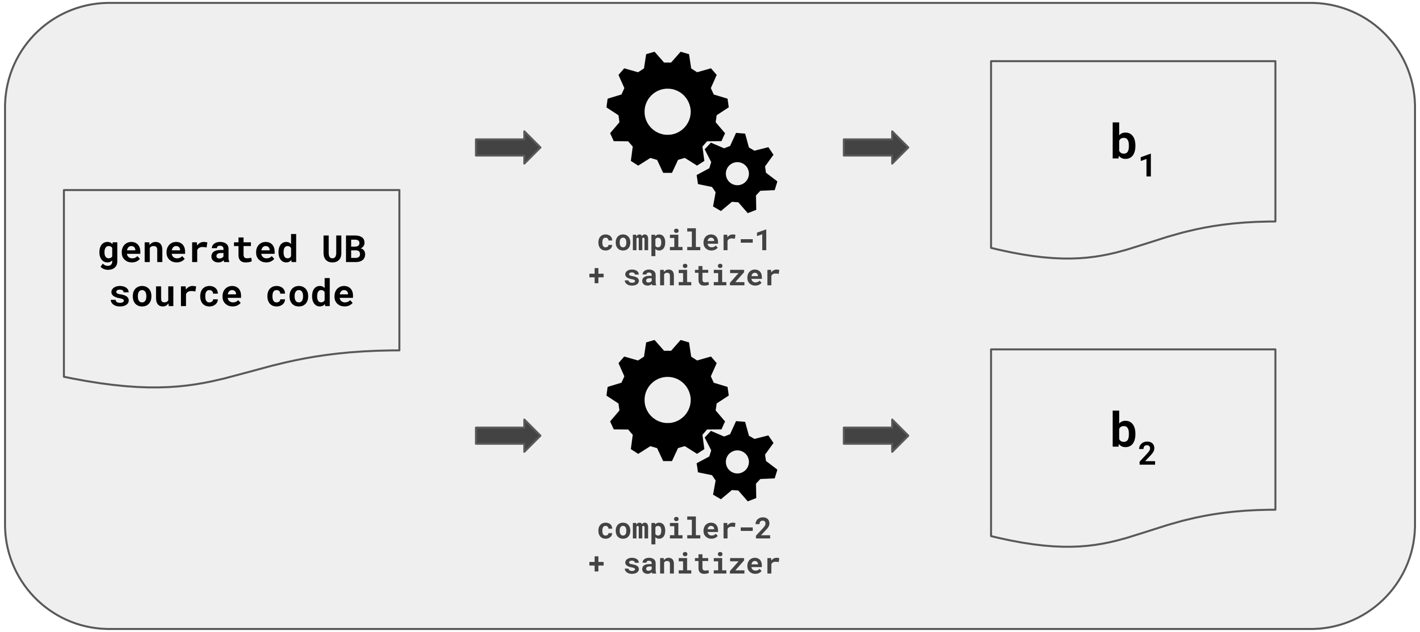

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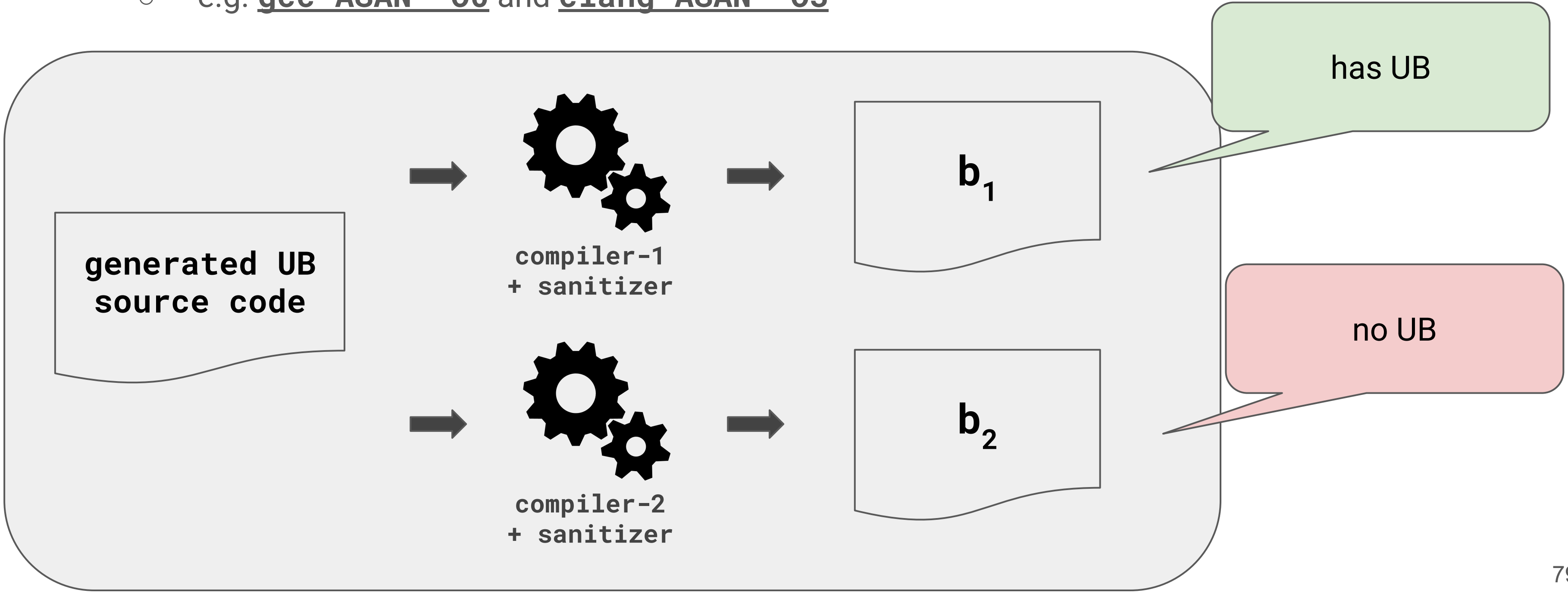

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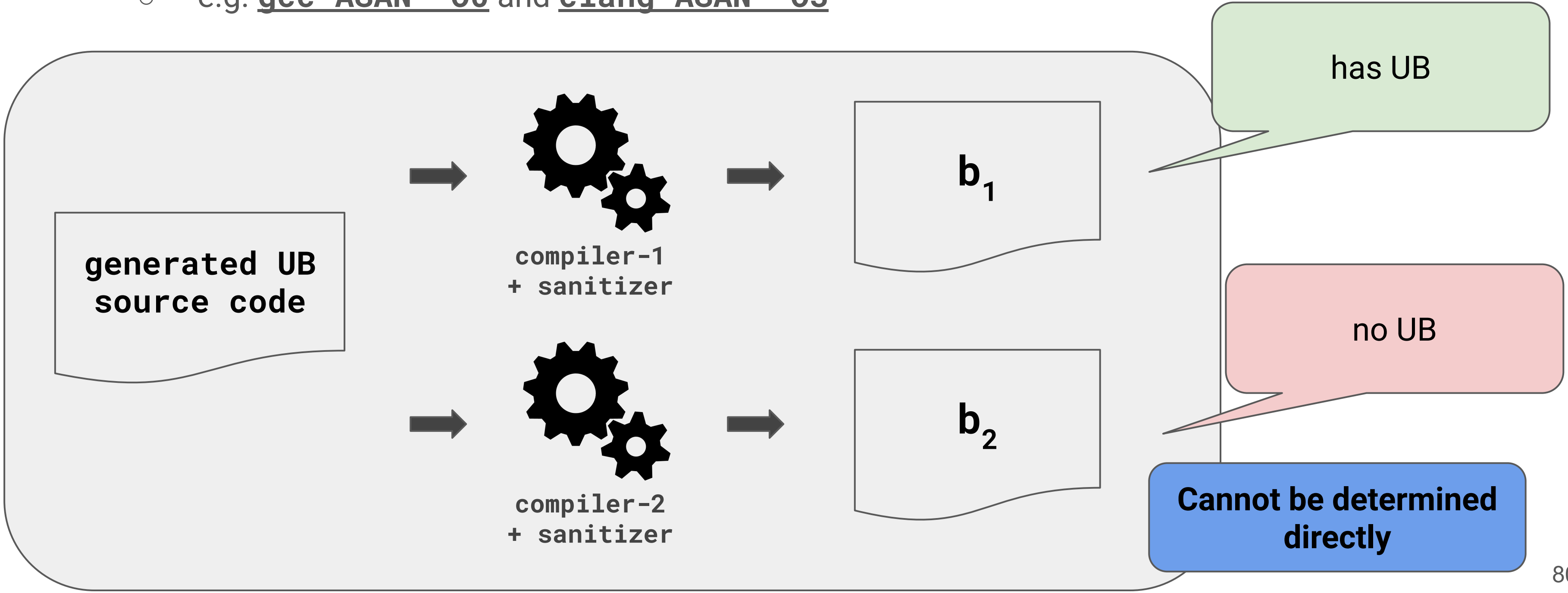
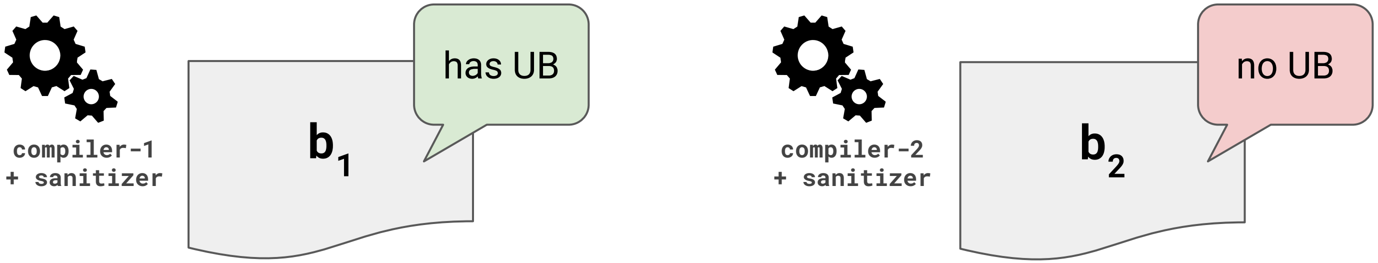


UB Test Oracle with Crash-site Mapping



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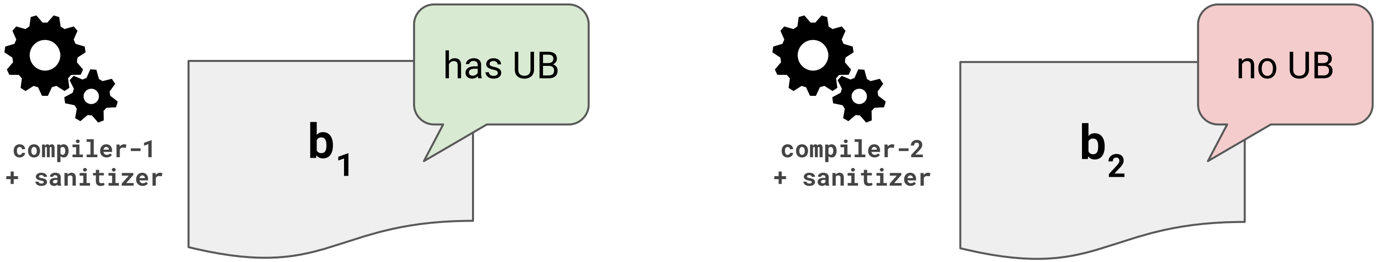

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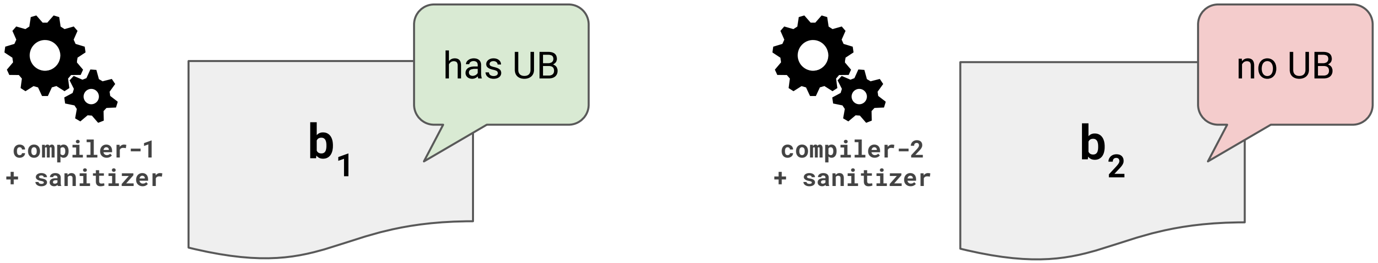

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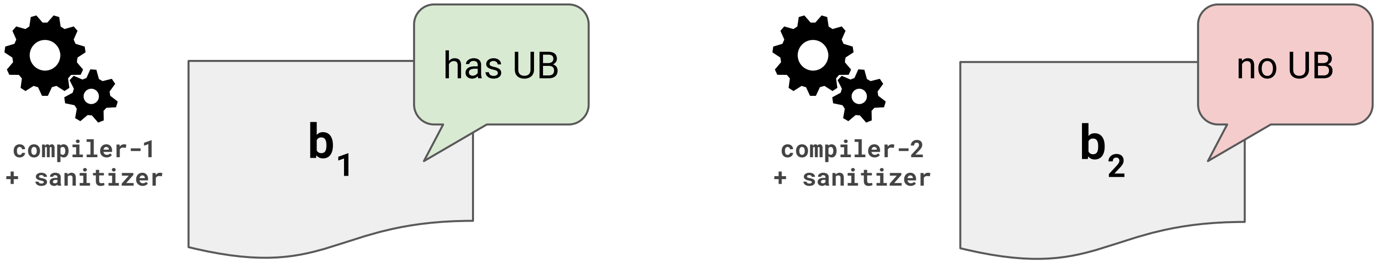

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- If $\mathbf{b_1}$ executes the same line
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- Otherwise
  - Compiler optimization removes UB-inducing code

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- **Goal**: Find FN bugs in sanitizer (undetected, but actual UB)
  - **Generate program with UB ✔**
  - Check if sanitizer is able to detect the UB
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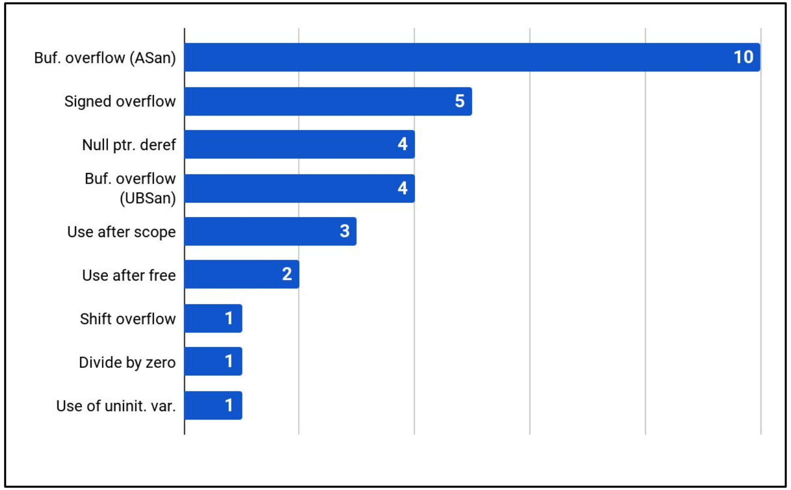

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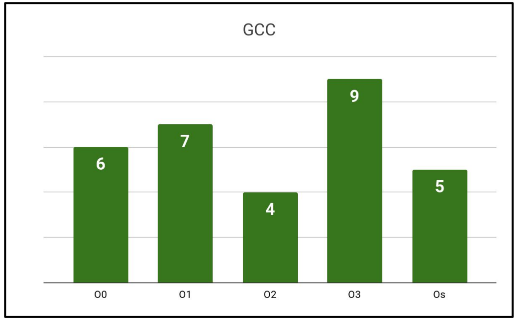

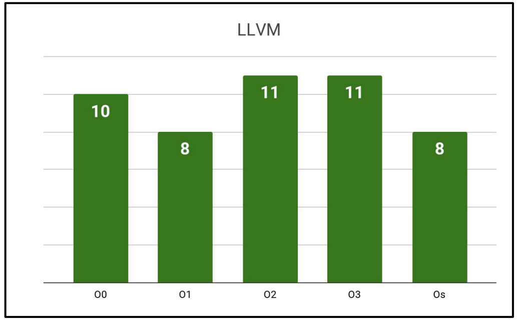

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only arithmetic UBs

Evaluation

- **How effective is our UB program generator in constructing interesting UB programs?**
  - Compare against
    - CSmith + MUSIC (random C code mutator)
    - CSmith-NoSafe (no safe checking in arithmetic logic generation)
  - Juliet Test Suite (collection of UB programs)
    - All 16K programs are detected as UB by sanitizers
    - Not effective to detect sanitizer FN bugs

Conclusion

- **UBFuzz**: novel framework for testing sanitizer implementations
- With **UB program generator** that **inserts shadow statement** from UB free seed programs
- Differential testing is done with **crash-site mapping** as **test oracle**
- UBfuzz has discovered **31 bugs** in ASan, UBSan, and MSan from both GCC and LLVM

Thank you

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```c
1 int g, *ptr = &g;
2 int **p_ptr = &ptr;
3 int main() {
4   int buf[3]={1,2,3};
5   *ptr = 1;
6   *p_ptr =&buf[3];
7   *ptr = 0xfff;
8 }
```

(a) GCC ASan at -O1 missed the buffer overflow access `*ptr` at line 7. [7]

```c
1 int a, c;
2 short b;
3 long d;
4 int main() {
5     a = (short)(d == c |
6         b > 9) / 0;
7     return a;
8 }
```

(b) GCC's UBSan at all levels missed the division-by-zero at line 5. [9]

```c
1 void b() {
2   int c[1];
3   c;
4 }
5 int main() {
6   int d[1]={1};
7   int *e = d;
8   a = 0;
9   for(;a<=5;++a){
10    int f[1]={};
11    e = f;
12    a||(b(), 1);
13  }
14  return *e;
15 }
```

(c) GCC's ASan missed the use after scope at line 14, where the pointer `e` points to an inner scope variable `f` defined at line 10. [8]

```c
1 volatile int a[5];
2 void b(int x) {
3     if(x)
4       a[5] = 7;
5 }
6 int main(){ b(1); }
```

(d) LLVM's ASan missed the buffer overflow at line 4. [19]

```c
1 int main() {
2     int *a = 0;
3     int b[3]={1, 1, 1};
4     ++b[2];
5     ++(*a);
6 }
```

(e) LLVM's UBSan missed the null pointer dereference at line 5. [20]

```c
1 int main() {
2     unsigned char a;
3     if (a-1)
4         __builtin_printf("boom!\n");
5     return 1;
6 }
```

(f) LLVM's MSan missed the use of uninitialized memory at line 3. [21]

Figure 12. Sample UB programs that trigger sanitizer FN bugs.