RemGen: Remanufacturing A Random Program Generator for Compiler Testing

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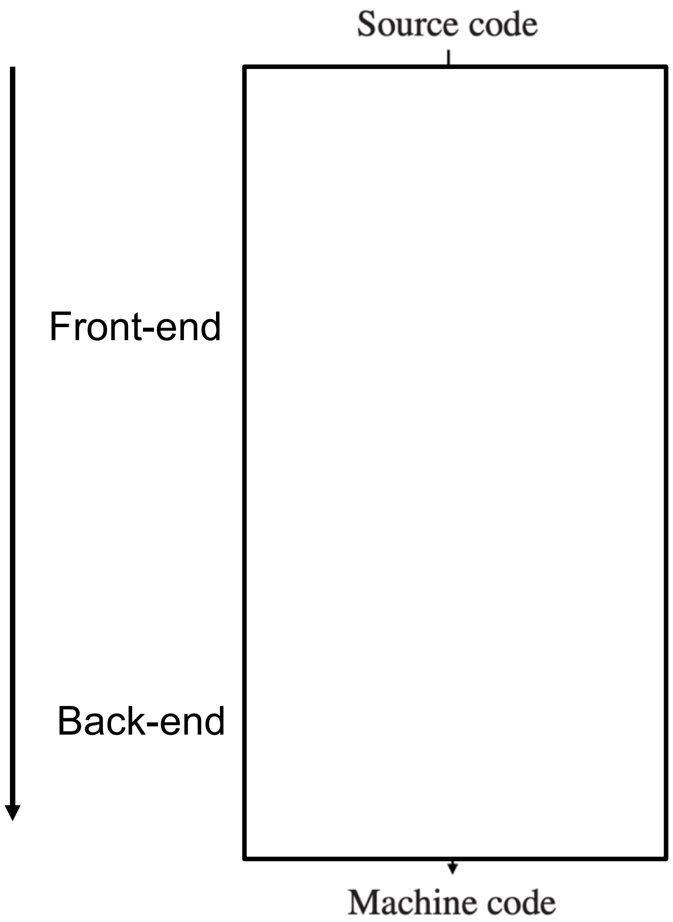
Outlines

- ❑ Background
- ❑ Motivation
- ❑ Approach
  - RemGen
- ❑ Evaluation
- ❑ Conclusion

Part 1: Background

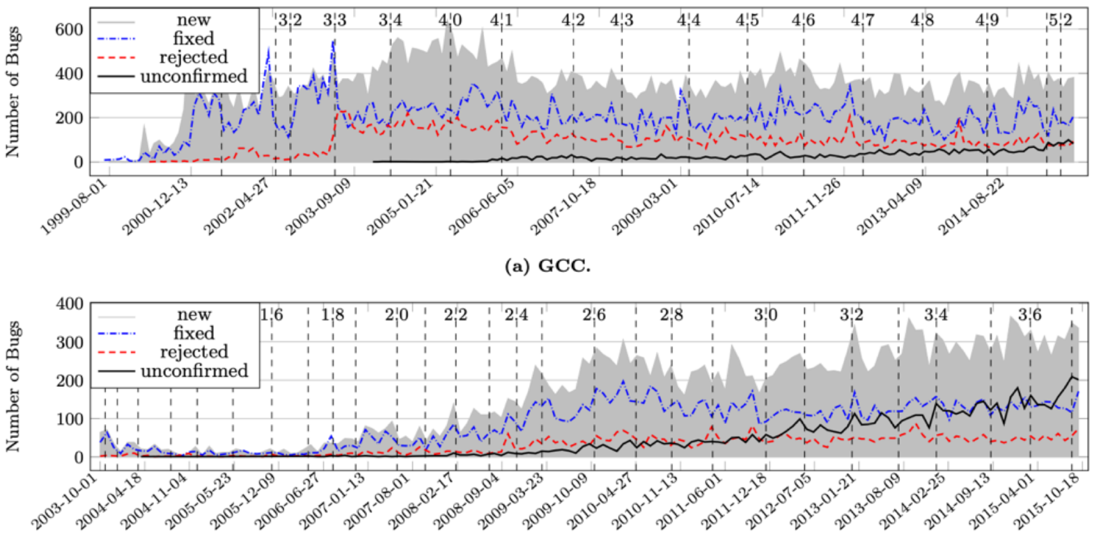
What is a compiler ?



- Two mainstream compilers
  - GCC (created by 1987)
    - ~ 5,000,000 lines of code
  - LLVM (created by 2003)
    - ~ 1,600,000 lines of code

- Implementation of compilers is complex
  - they can be unreliable and buggy

Compilers are important but unreliable



(a) GCC.

(b) LLVM

- Cited from [1]

XcodeGhost Bug: affect 3418 apps

CVE-2009-1897: Kernel crash to Dos attack

Improving the reliability of compilers is still a hot topic.

Constructing test programs for compiler testing

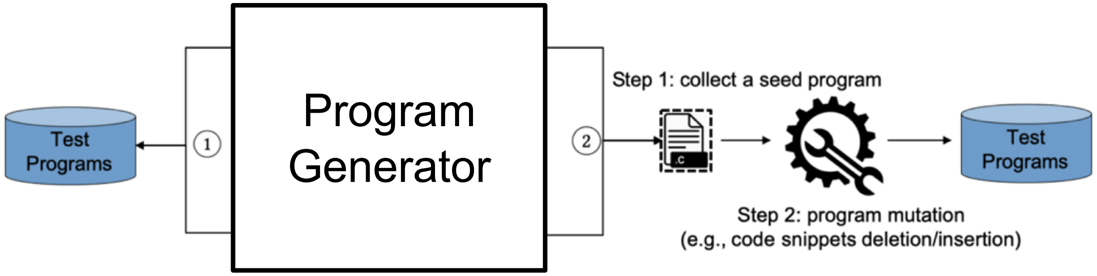
Program Generator
(e.g., Csmith)

- **Two primary approaches**
  - **1. Generation-based**
    - CCG [3], Csmith [4], and Yarpgen [5]
  - **2. Mutation-based**
    - Orion [6], Athena [7], and Hermes [8]

- **Observation: existing construction approaches all start from a random program generator!**

Part 2: Motivation

Motivation



- **Complaints from compiler testing studies or compiler expertise**
  - Csmith has found bugs before, but current production compilers are already **resilient** to it (from [5,6])
  - *Compilers have now caught up with CCG (since it's been pretty **hard to spot crashes** last time I tried.* (from CCG [1])
  - *I hadn't run Csmith for a while and it turns out LLVM is now amazingly **resistant** to it, ran a million tests overnight without finding a crash or miscompilation.* (from John Regehr [9])
  - ***Same** with YARPGen.* (from Dmitry Babokin [10])

Research question: Is it possible to make those generators effective again?

Remanufacturing

- **Definition [2]**
  - A process of bringing **a used product** to **a “like new” product**, which is being regarded as a sustainable mode of manufacturing
- Applications
  - Automobile, heavy-duty equipment, aerospace, machinery, medical devices, photocopiers, IT products [2]

❶ Preparation for remanufacturing

↓

❷ Remanufacturing

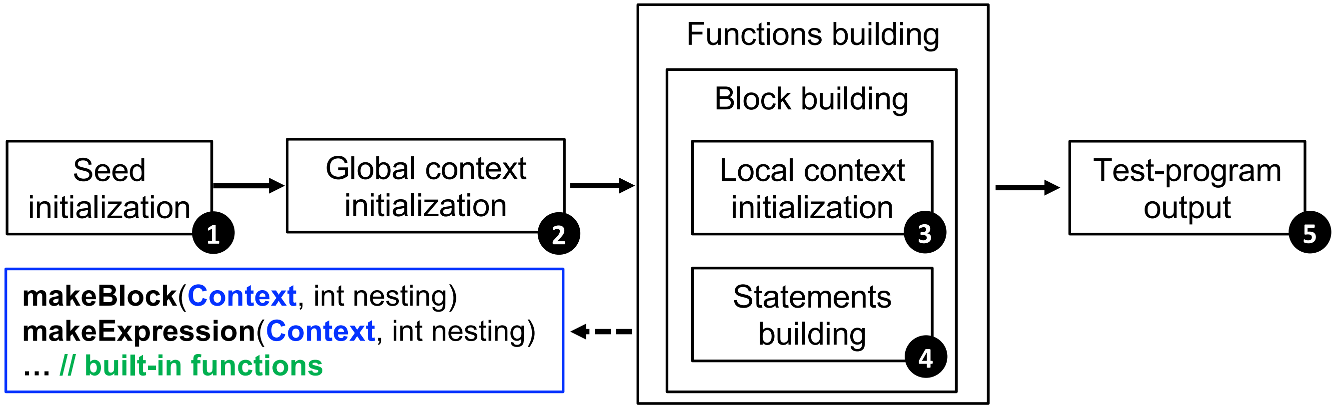
↓

❸ Testing the remanufactured product

Any chance to conduct remanufacturing on a program generator?

Leverage capabilities in program generators

- **General workflow of a generator**



- **Key capabilities**
  - (1) they support various built-in functions to generate different new valuable code snippets
  - (2) the context (i.e., one of the parameters used in the built-in functions) used in generating code snippets can be reserved and then reused in a lightweight manner

Motivation

- **An example**

```
int a, b, c, d;
void e() {
    ... // code snippets generated by CCG
    a = 7;
    for (; a <= 78; a++) {
        d = 3;
        for (; d <= 73; d++) {
            // code produced by makeBlock() highlighted in gray
            int f = 0;
            b += c;
            if (b) {
                int g = 0;
                for (f = 5; f; g);
            }
        }
    }
} /* Grammar Coverage : G={0,0,0,2,0,0,0,0,0,0,0} */
```

- **Limitation of existing approaches**
  - Generation-based approaches: randomness
  - Mutation-based approaches: (1) limited synthesize template to produce code snippets and (2) costly
- **Our approach**
  - Leverage the unexplored capabilities in generators to synthesize new code snippets

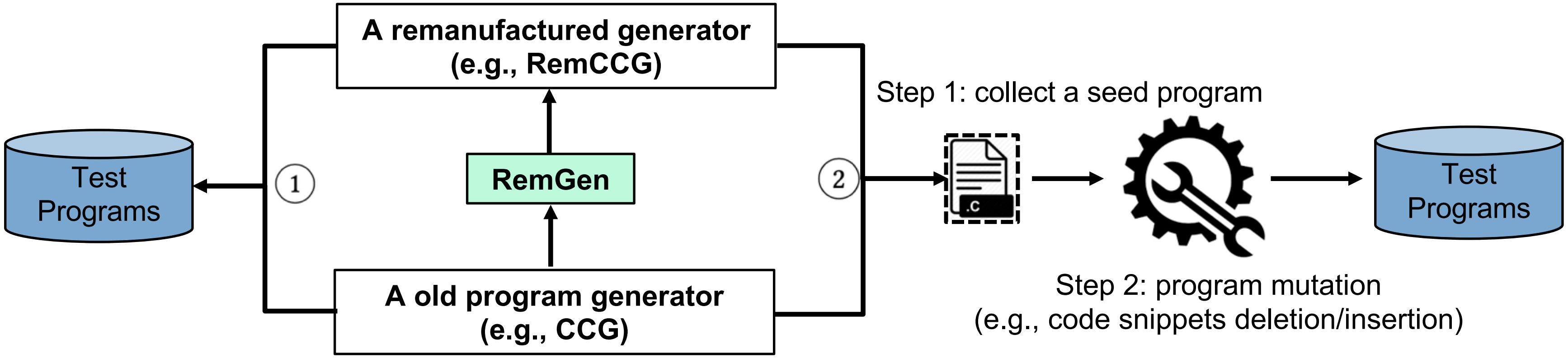
Challenges

- **1. The synthesis of diverse code snippets with low effort**
  - We do not know what the trigger for a compiler bug looks like [4].
  - Efforts in synthesizing code snippets should be lightweight
- **2. The selection of the bug-revealing code snippet for constructing test programs**
  - Not all **code snippets** are equal and only few can trigger bugs [12]
  - limited computing or human resource

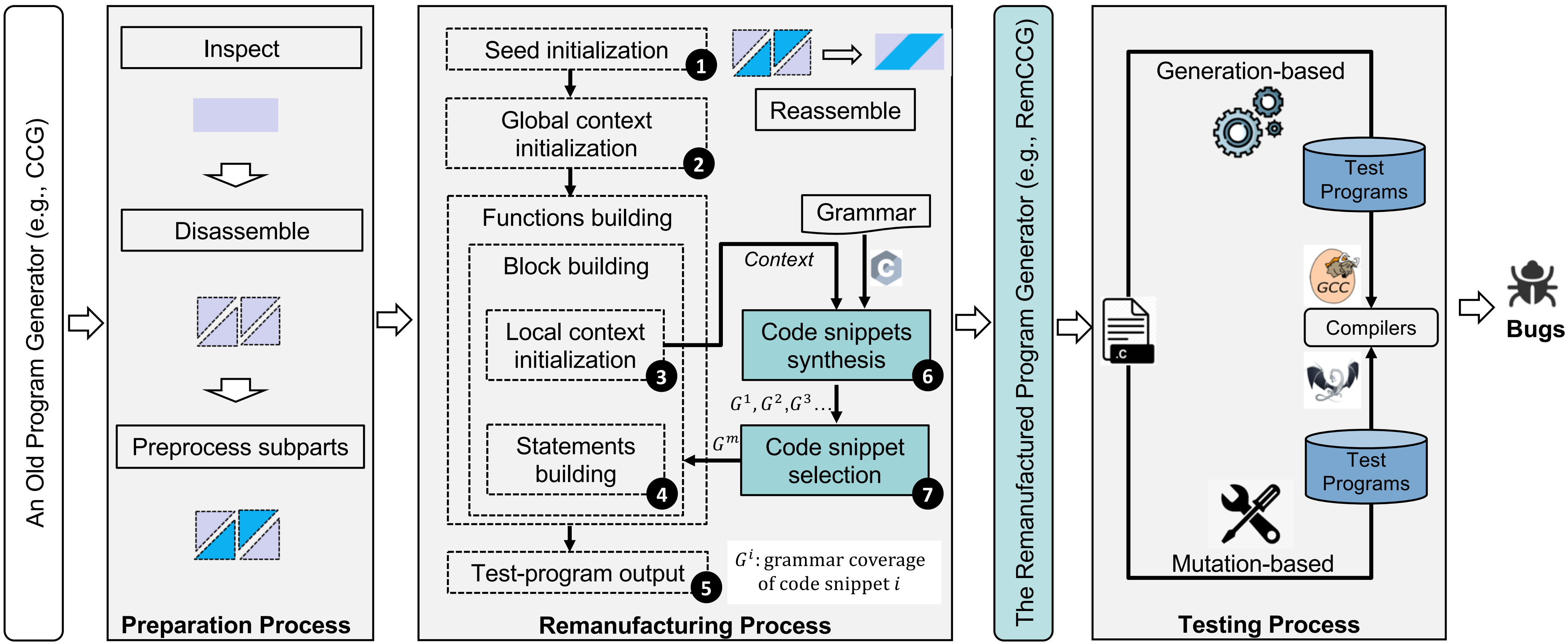
Part 3: Approach

Our approach: RemGen

- **Highlight**

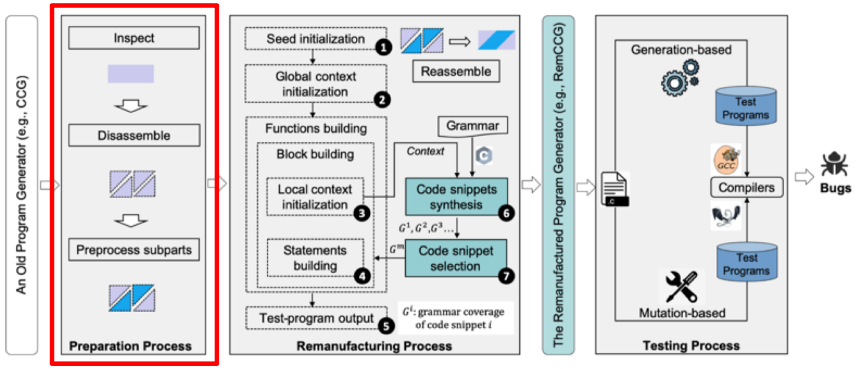


RemGen: Overview



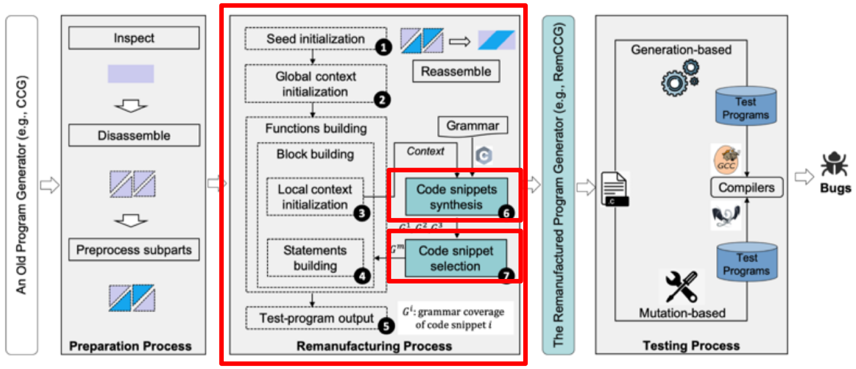
Preparation for remanufacturing ⇨ Remanufacturing ⇨ Testing the remanufactured product

RemGen: Preparation process



- **Inspect**
  - Checking the functionality from the input generator's "appearances"
- **Disassemble**
  - Decomposing the test program generation components to be modularized
- **Preprocess subparts**
  - Reconstructing required components (e.g., built-in functions) to be easily integrated with other components

RemGen: Remanufacturing process

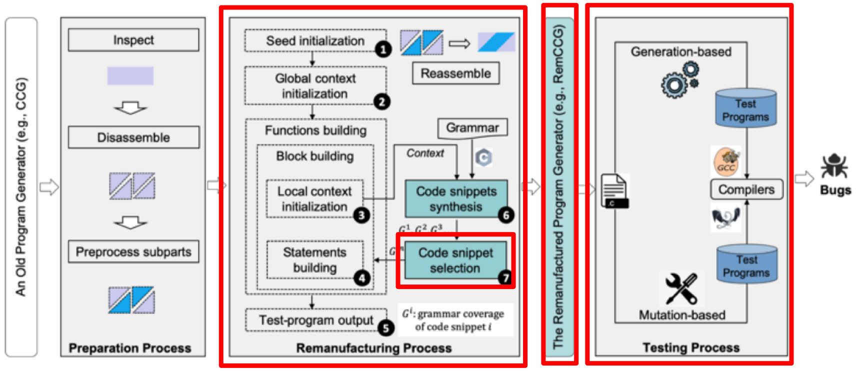


- **Remanufacturing: two new components**
  - Code snippets synthesis
  - Code snippet selection

❻ **Diverse code snippets synthesis (grammar-aided)**

- Collect the required context (i.e., global and local)
  - Low effort
- Invoke the built-in functions to generate new code snippets
- utilize our new “diversity”: *grammar coverage*
  - the number of grammar rules (e.g., *if* or *for* statements) invoked during the synthesis

RemGen: Remanufacturing process



❼ **Bug-revealing code snippet selection**

- Leverage grammar coverage in the prior component
- Order produced code snippets
  - Calculate the sum of the square of each grammar coverage
- Integrate the selected code snippet to construct bug-revealing test program

- **Reassemble**

- **Testing process**
  - More details in evaluation part

Part 3: Evaluation

Experimental Setup

- **We remanufactured an old program generator CCG into RemCCG under RemGen**

- **Research questions**
  - RQ1: Can RemCCG boost both generation-based and mutation-based approaches for compiler testing?
  - RQ2: Can RemCCG find new compiler bugs in practice?

- **Test settings**
  - For ***RQ1***, we run over the same compiler versions used in [15] (GCC-4.4.3, LLVM-2.6)
    - Running 90 hours 10 times, count the average number of bugs detected
  - For ***RQ2***, we run over current development versions of two compilers
    - Run RemCCG over the latest version of compilers

Evaluation (1/2)

- **RQ1:** Can RemGen boost generation-based approaches for compiler testing?
  - Compare with generation-based approach: CCG [1] (baseline)
  - Compare with mutation-based approach: Hermes [8]
    - Use CCG/RemCCG to generate seed programs

TABLE I: Results of Boosting in Generation-based Approach

Subject	Tools	Average Statistics			
		Cra.	*Perf.*	*Sum.*	*Imp.*
GCC	CCG [3]	2.9	0.3	3.2	16%
	REMCCG	3.1	0.6	3.7	-
LLVM	CCG [3]	9.2	2.7	11.9	11%
	REMCCG	9.7	3.5	13.2	-

TABLE II: Results of Boosting in Mutation-based Approach

Subject	Tools	Average Statistics			
		Cra.	*Perf.*	*Sum.*	*Imp.*
GCC	Hermes(CCG)	3.0	0.5	3.5	14%
	Hermes(REMCCG)	3.2	0.8	4.0	-
LLVM	Hermes(CCG)	9.8	3.6	13.4	11%
	Hermes(REMCCG)	10.6	4.3	14.9	-

Evaluation (2/2)

- **RQ2:** Can RemCCG find new compiler bugs in practice?

TABLE III: Results of All the Reported Bugs

Bug Status	GCC	LLVM	Total
Fixed	8	29	37
WorksForMe	0	2	2
Duplicate	2	3	5
Pending	0	12	15
Total	10	46	56

TABLE IV: Results of Bug Types of Fixed Bugs

But Types	GCC	LLVM	Total
Crash	6	16	22
Performance	2	13	15
Total	8	29	37

TABLE V: Details of Fixed Bugs

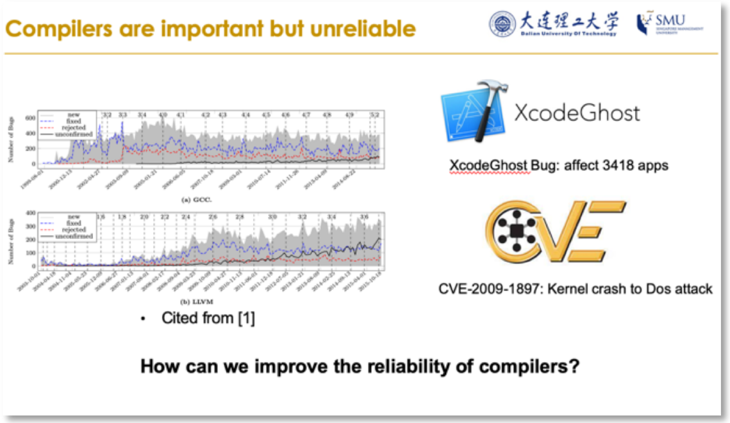
	Compiler-ID	Priority	Type	Affected. Opt.	Affected Versions
1	GCC-99694	P2	*Perf.*	-O1,2,3	**9.3-11.0 (trunk)**
2	GCC-99880	P2	*Crash*	-O3	10.2-11.0 (trunk)
3	GCC-99947	P1	*Crash*	-O3	11.0 (trunk)
4	GCC-100349	P2	*Crash*	-O2,3,s	11.0-12.0 (trunk)
5	GCC-100512	P3	*Crash*	-O2,3,s	12.0 (trunk)
6	GCC-100626	P2	*Crash*	-O1,2,3,s	11.0-12.0 (trunk)
7	GCC-102057	P3	*Crash*	-O1,2,3,s	12.0 (trunk)
8	GCC-102356	P3	*Perf.*	-O3	11.0-12.0 (trunk)
9	LLVM-49171	P3	*Perf.*	-O3	13.0 (trunk)
10	LLVM-49205	P3	*Perf.*	-O1,2,3,s	11.0-13.0 (trunk)
11	LLVM-49218	P3	*Crash*	-O1	12.0-13.0 (trunk)
12	LLVM-49396	P3	*Crash*	-O2,3,s	12.0-13.0 (trunk)
13	LLVM-49451	P3	*Crash*	-Os	13.0 (trunk)
14	LLVM-49466	P3	*Crash*	-O2	13.0 (trunk)
15	LLVM-49475	P3	*Perf.*	-O1	12.0-13.0 (trunk)
16	LLVM-49541	P3	*Perf.*	-O2,s	**7.0-13.0 (trunk)**
17	LLVM-49697	P3	*Crash*	-O3	**7.0-13.0 (trunk)**
18	LLVM-49785	P3	*Perf.*	-O3	13.0 (trunk)
19	LLVM-49786	P3	*Perf.*	-O2	13.0 (trunk)
20	LLVM-49993	P3	*Crash*	-O3	13.0 (trunk)
21	LLVM-50009	P3	*Crash*	-Os	12.0-13.0 (trunk)
22	LLVM-50050	P3	*Crash*	-O2,3,s	13.0 (trunk)
23	LLVM-50191	P3	*Crash*	-O2	13.0 (trunk)
24	LLVM-50238	P3	*Crash*	-O1,2,3,s	13.0 (trunk)
25	LLVM-50254	P3	*Perf.*	-O2,3	13.0 (trunk)
26	LLVM-50279	P3	*Perf.*	-O3	13.0 (trunk)
27	LLVM-50302	P3	*Perf.*	-O3	13.0 (trunk)
28	LLVM-50307	P3	*Crash*	-Os	13.0 (trunk)
29	LLVM-50308	P3	*Perf.*	-O1,2,3,s	12.0-13.0 (trunk)
30	LLVM-51553	P3	*Crash*	-O3	14.0 (trunk)
31	LLVM-51584	P3	*Perf.*	-O1,2,3,s	14.0 (trunk)
32	LLVM-51612	P3	*Crash*	-O2,3	14.0 (trunk)
33	LLVM-51656	P3	*Crash*	-O2,3	14.0 (trunk)
34	LLVM-51657	P3	*Perf.*	-O2,3,s	12.0-14.0 (trunk)
35	LLVM-51762	P3	*Perf.*	-O1	14.0 (trunk)
36	LLVM-52018	P3	*Crash*	-O3	14.0 (trunk)
37	LLVM-52024	P3	*Crash*	-O2	14.0 (trunk)

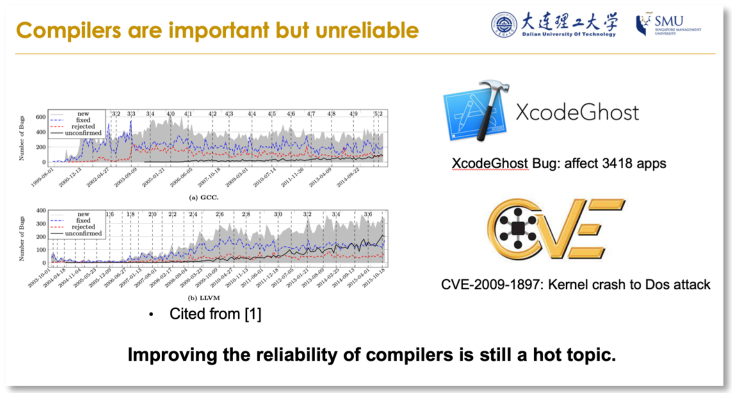
Discussion

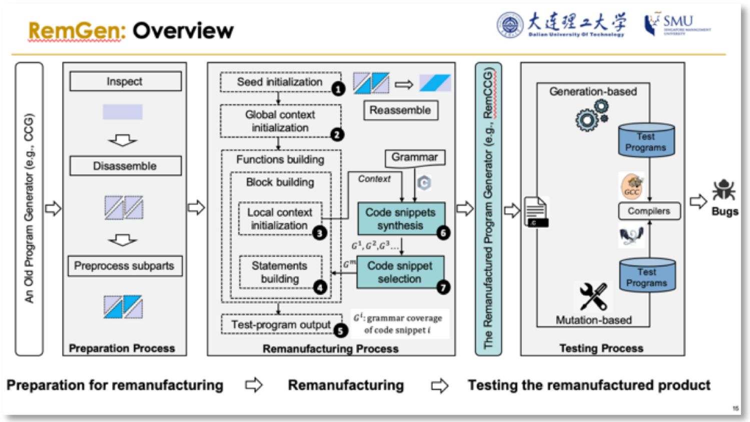
- Effectiveness of the two proposed components
  - we compare RemCCG with its variants
- Comparison with Csmith [4] and YARPGen [5]
  - Find 164%/363% and 120%/595% more bugs than Csmith and YARPGen, in GCC/LLVM, respectively
  - This is reasonable due to the different design goal between those tools
- Limitation of RemCCG
  - Inherits the limitation from CCG: can only find two kinds of (i.e., crash and performance) bugs

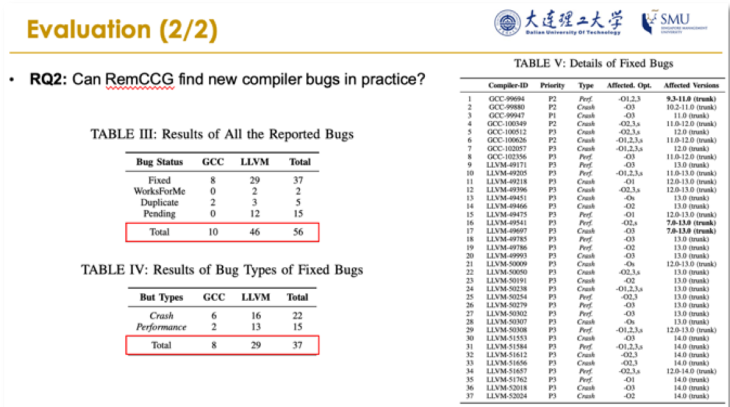
Part 5: Conclusion

Conclusion









Code: https://github.com/haoxintu/RemCCG
Email: haoxintu.2020@phdcs.smu.edu.sg
(Please feel free to pull requests or raise any questions if you have!)

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Thank you && Questions?

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