# FastKLEE: Faster Symbolic Execution via Reducing Redundant Bound Checking of Type-Safe Pointers

***ESEC/FSE 2022 Tool Demonstration***

**Haoxin Tu**, Lingxiao Jiang, Xuhua Ding (Singapore Management University)
He Jiang (Dalian University of Technology)

# Outlines

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- **Background**
- **Motivation**
- **Solution**
  - FastKLEE
- **Preliminary Evaluation**
- **Conclusion**

# Background

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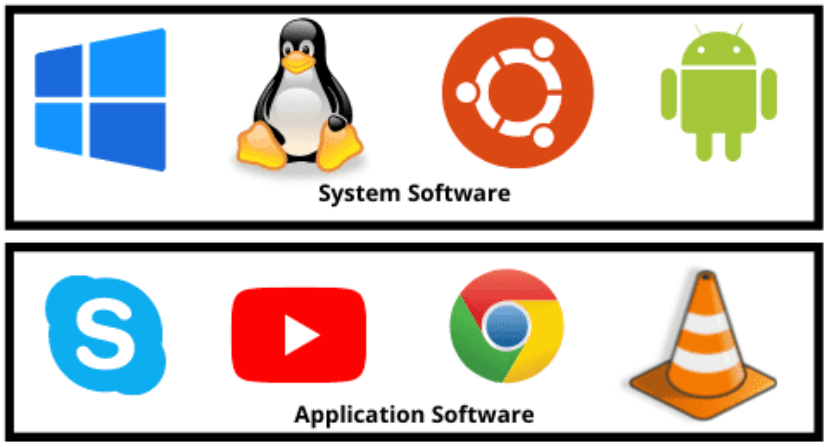
# Background



***Examples of System & Application Software***



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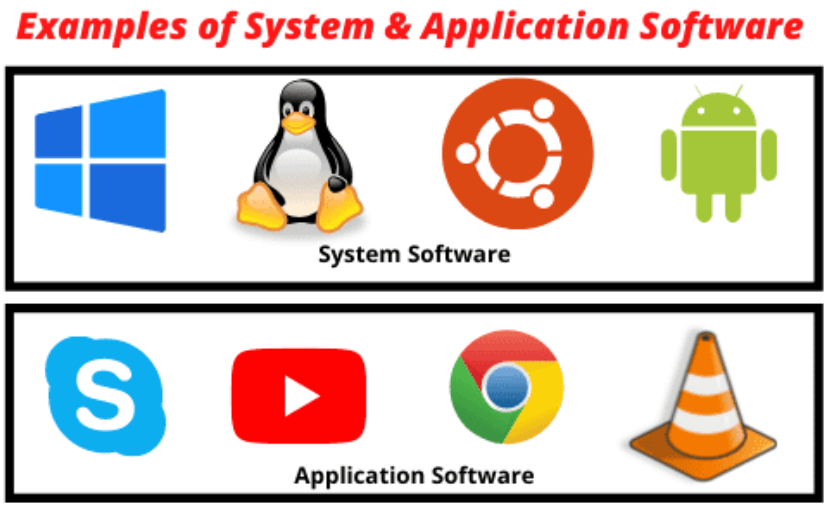


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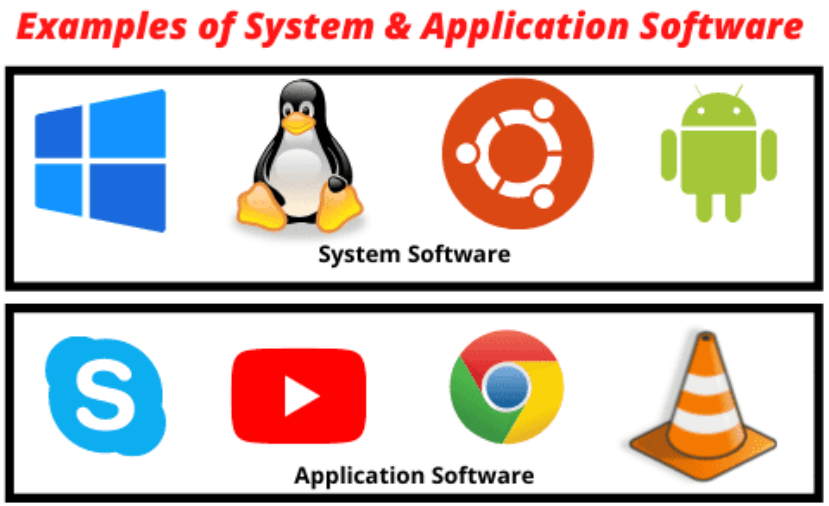


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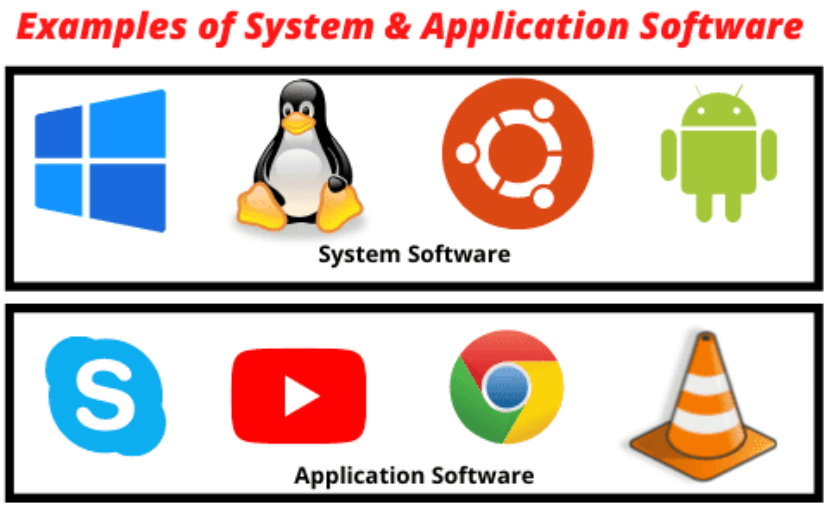


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(Symbolic Execution)

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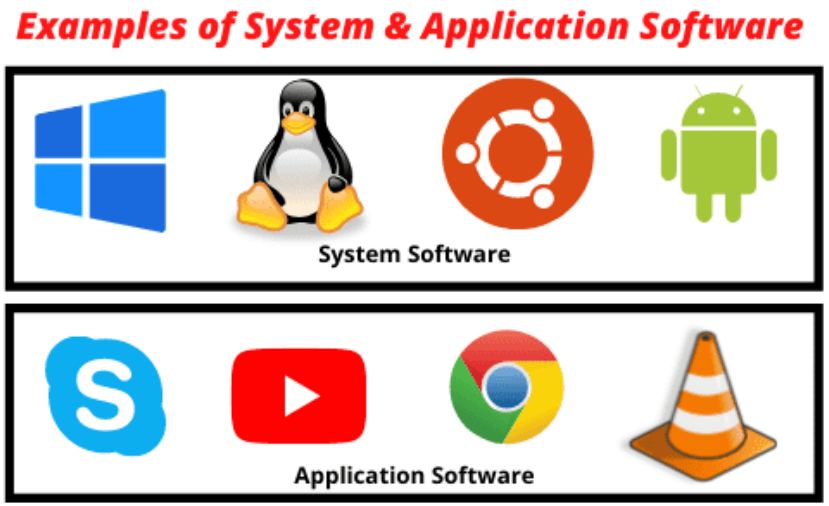


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A General Workflow of Symbolic Execution (SE)

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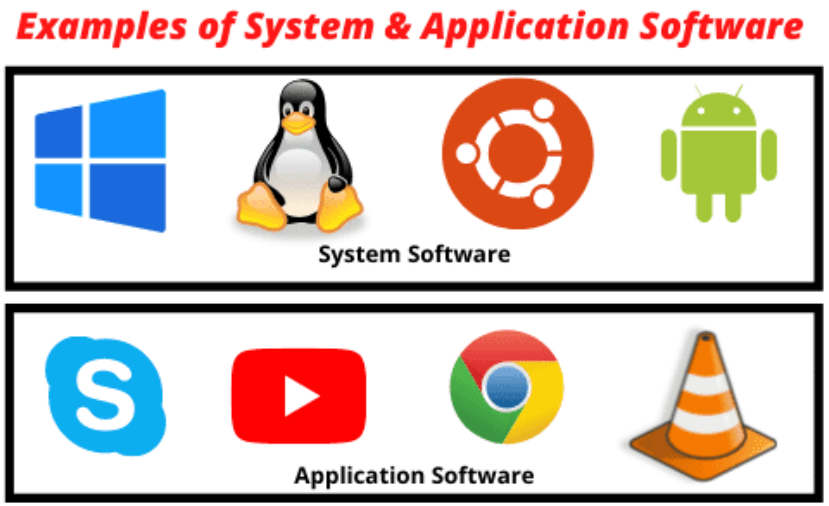


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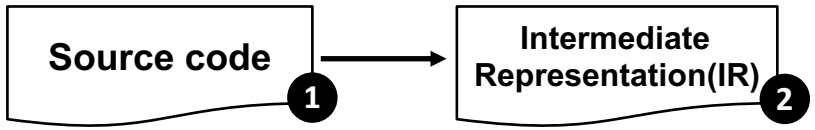


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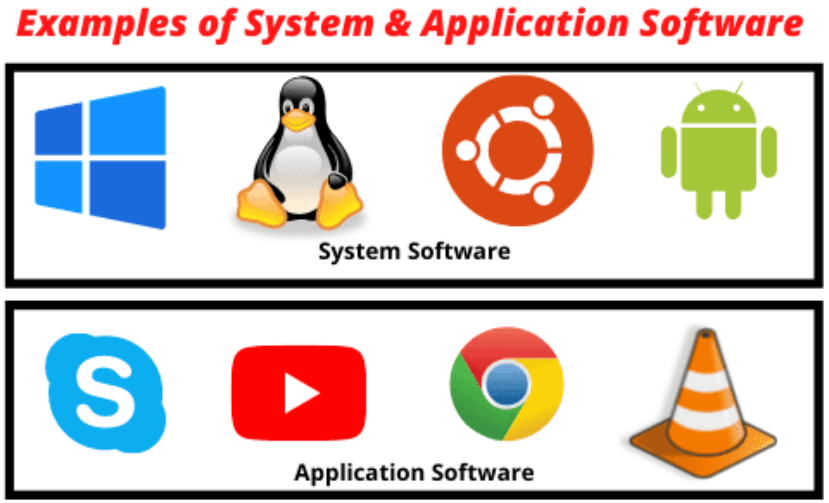


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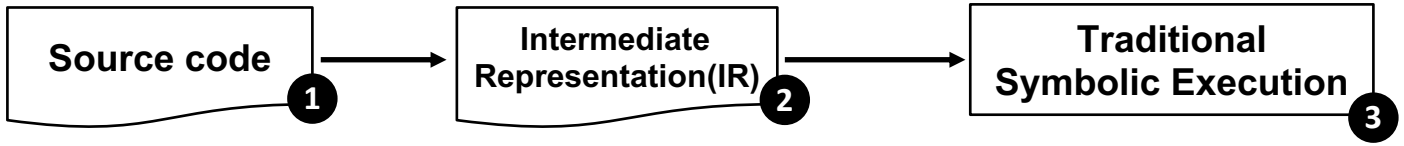


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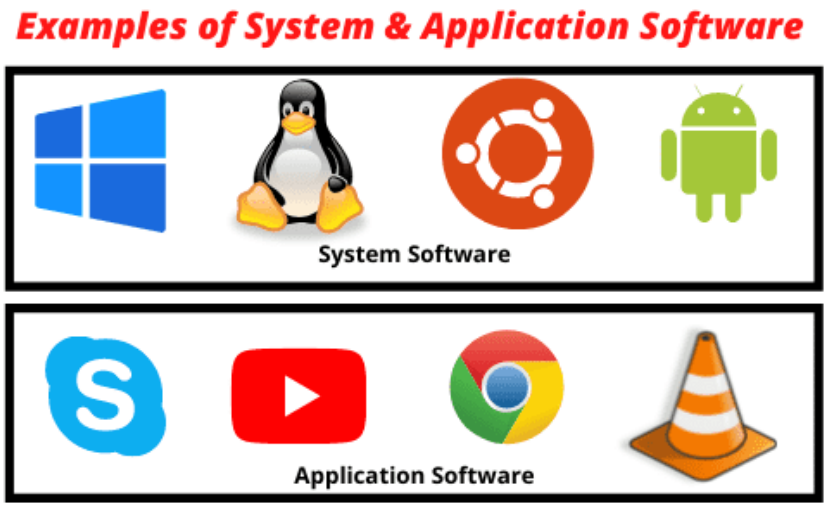


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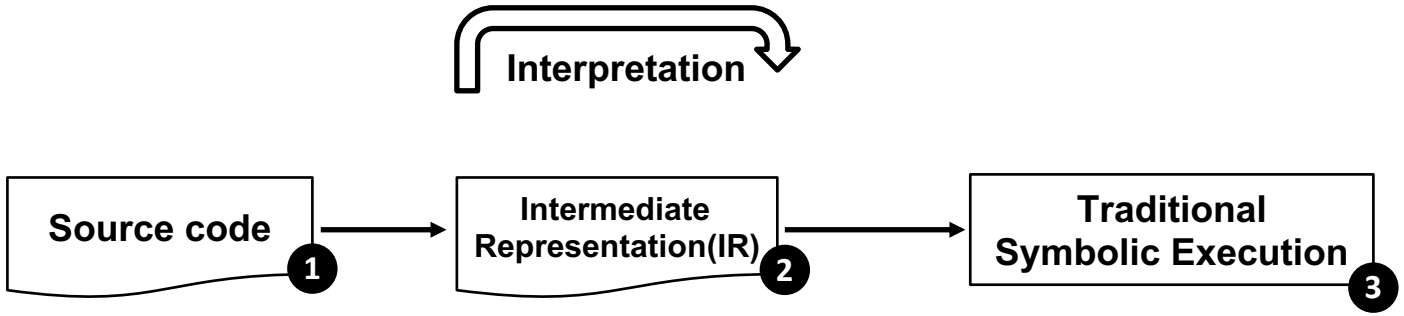


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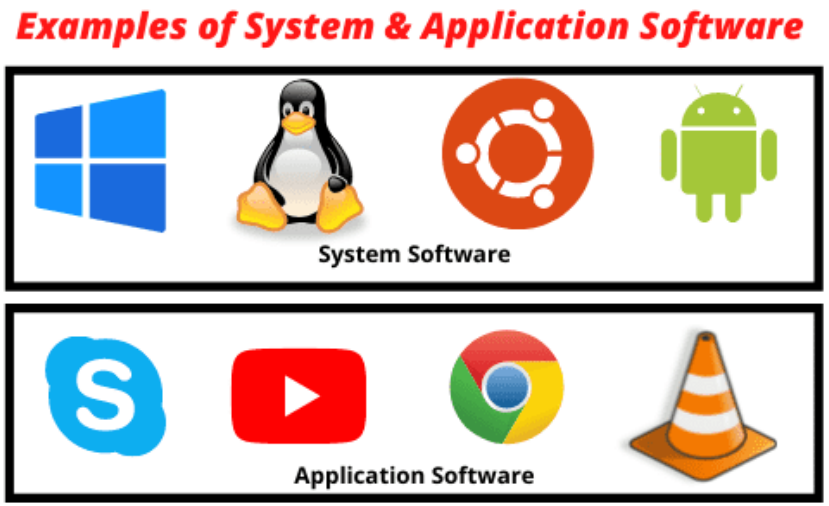


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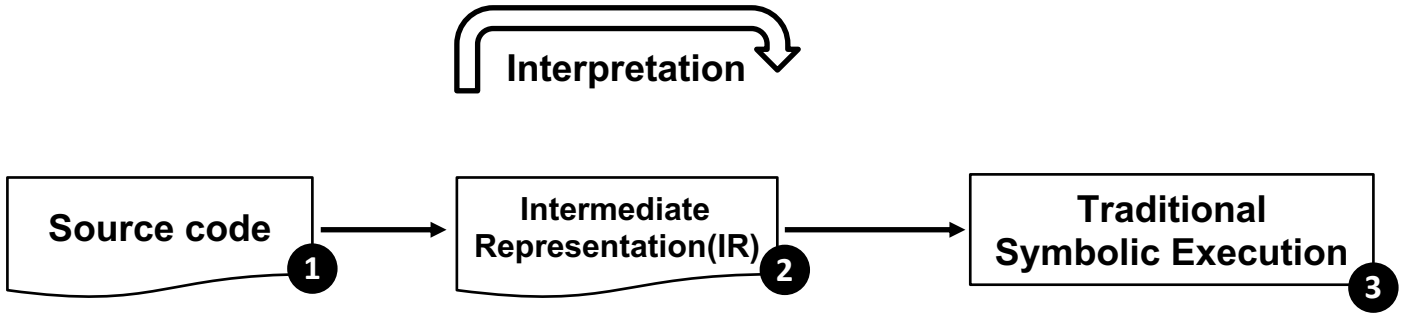


A General Workflow of Symbolic Execution (SE)

One of the major concerns: Performance

# Motivation

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  - Compiler optimization-based
    - Existing compiler optimization for accelerating symbolic execution [6,7]
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- **Summary**
  - Performance issues still remain in existing interpreting-based SE engines
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**How can we reduce interpretation overheads for fast symbolic execution?**

# Solution – FastKLEE (1/2)

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- **Two key insights**

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# Solution – FastKLEE (1/2)

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- **Two key insights**
  - **Insight 1:** The number of interpreted instructions tends to be stupendous
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Elapsed: 01:00:04
KLEE: done: explored paths = 125017
KLEE: done: avg. constructs per query = 74
KLEE: done: total queries = 8859
KLEE: done: valid queries = 6226
KLEE: done: invalid queries = 2633
KLEE: done: query cex = 8859

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- **Two key insights**
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    - Inspired by ***Type Inference*** system

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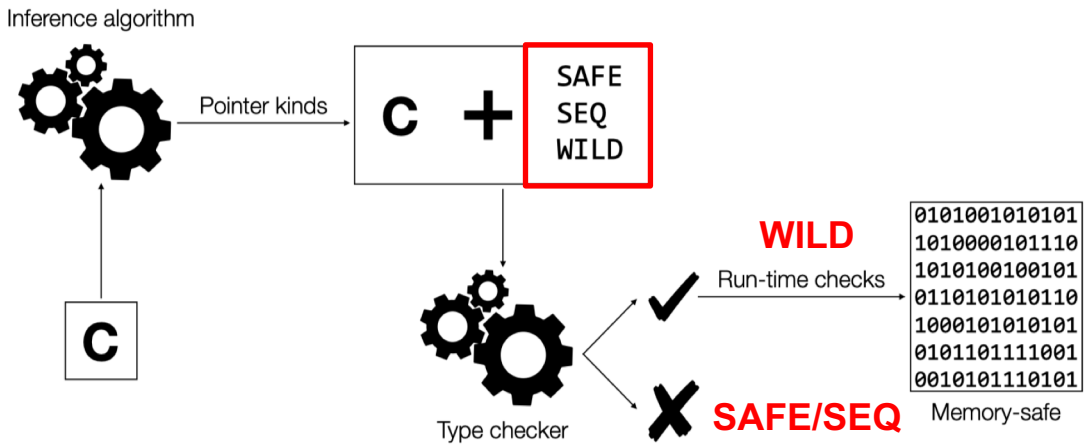

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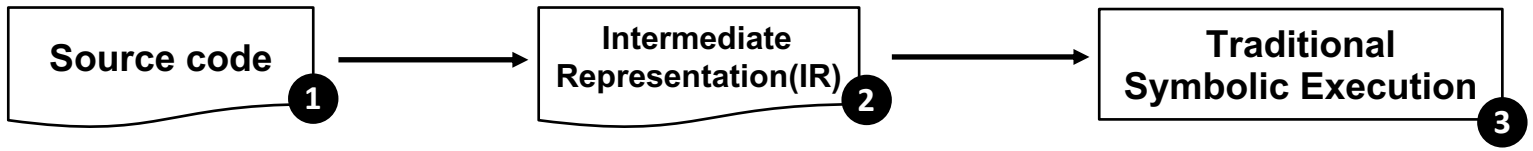

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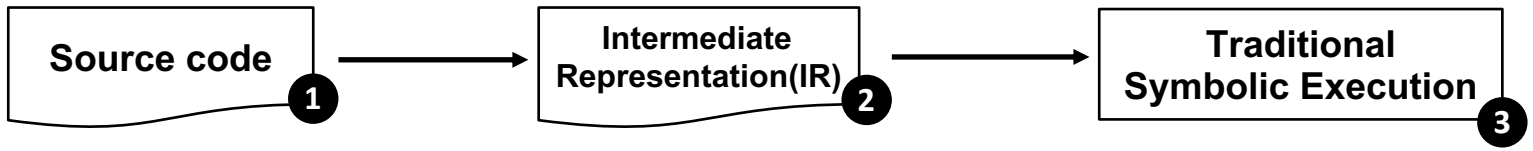


**Phase I** **Phase II**

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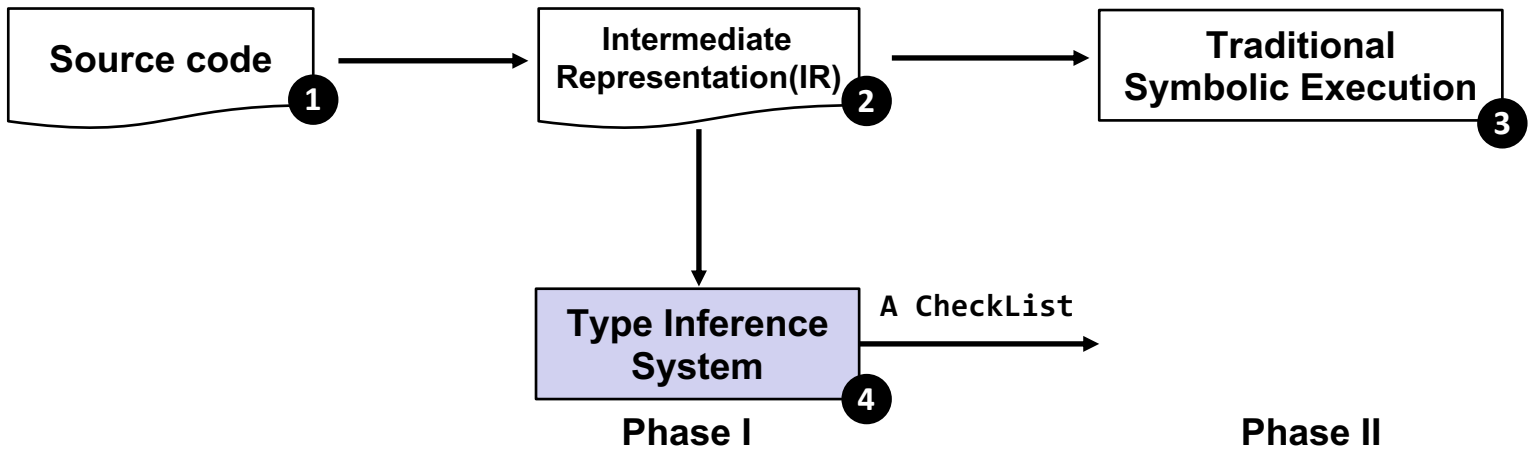


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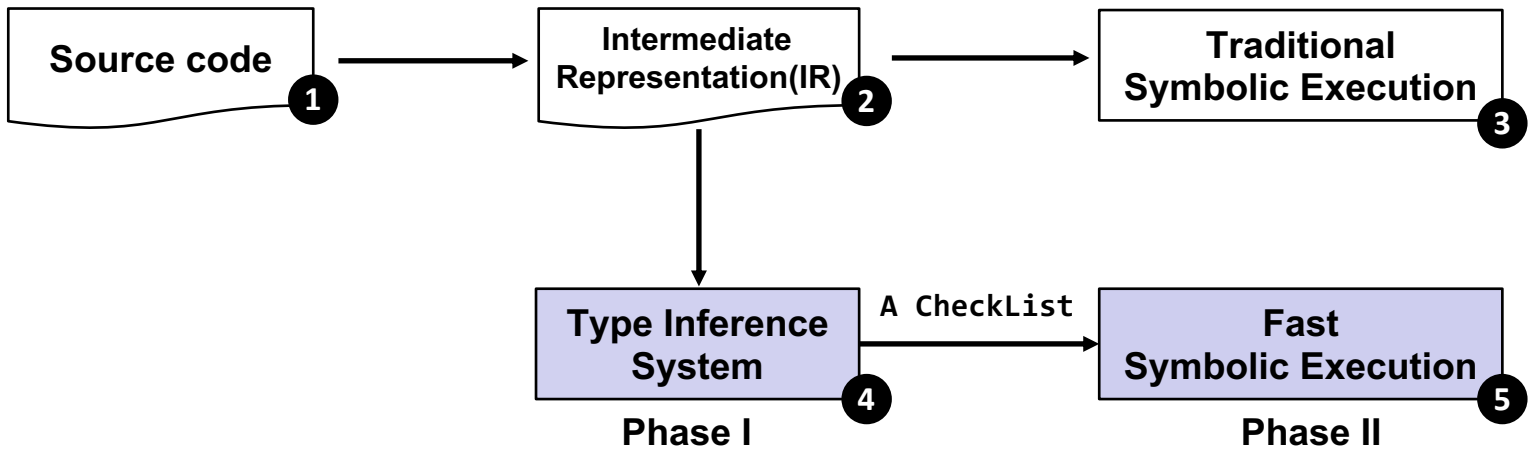


❹ • **Phase I**: Introduce a **Type Inference System** to classify instruction types
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❺ • **Phase II**: Conduct **Customized Instruction Operation** in Fast SE
  – Only perform checking for ***Unsafe*** instructions during interpretation

# Preliminary Evaluation

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- **Impementation**
  - KLEE [1] and Ccured [4]
- **Benchmark**
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  - ***Speedups***: the **time** spent on exploring the same number of instructions

$$Speedups: \frac{T_{baseline} - T_{our}}{T_{baseline}} \times 100$$

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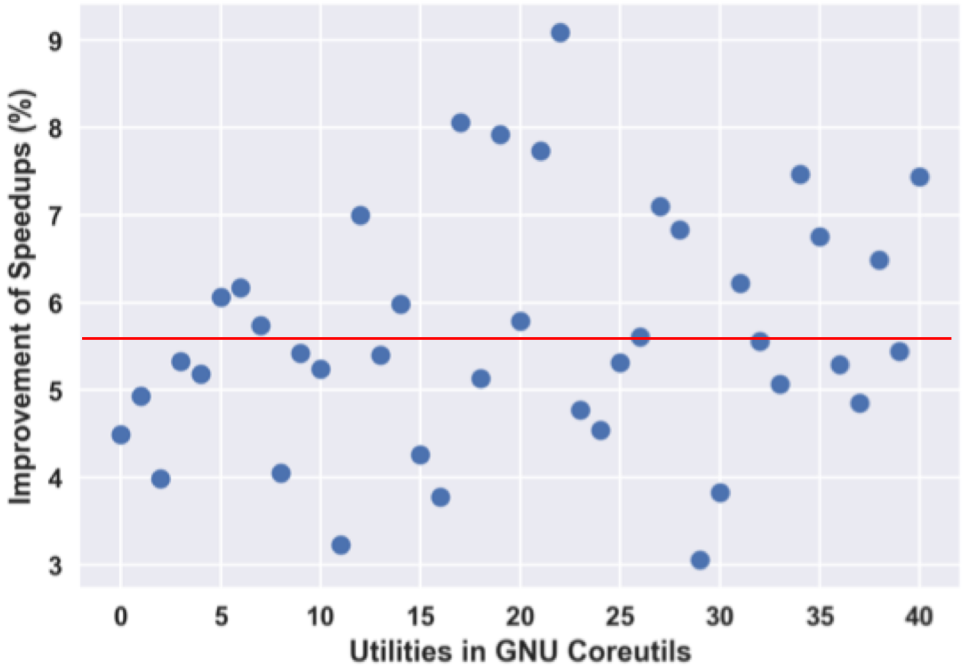


**Figure 2: Scatter plot of the improvement in speedups**

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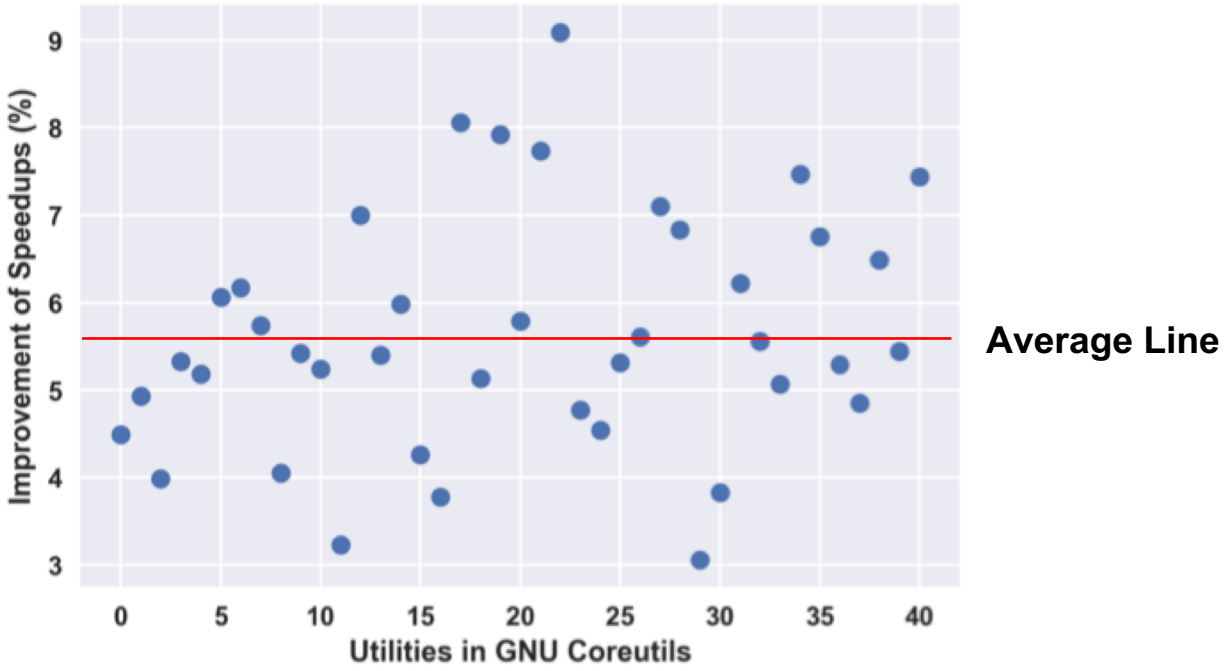
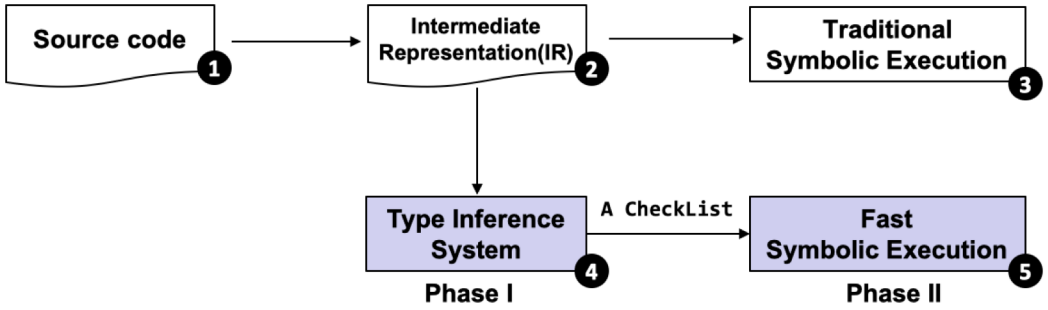



**Figure 2: Scatter plot of the improvement in speedups**

  - FastKLEE is able to reduce by up to **9.1% (5.6% on average)** time as the state-of-the-art approach

# Conclusion

- **Contribution**
  - We present **FastKLEE**, which aims to reduce the interpretation overheads for fast symbolic execution



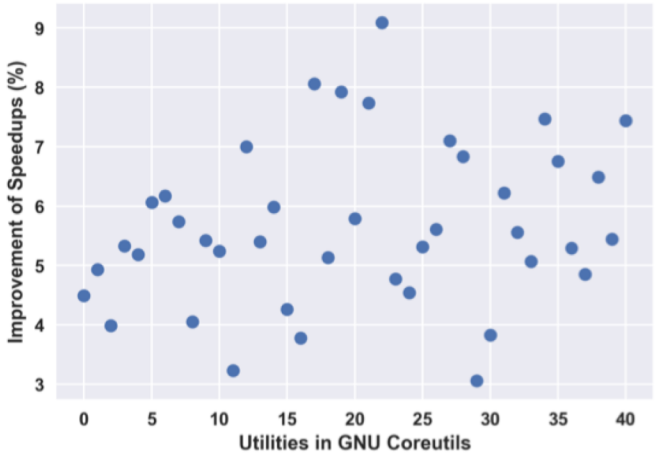




Figure 2: Scatter plot of the improvement in speedups

- **Future work**
  - Use FastKLEE to explore more **valuable** execution paths in software systems
    - valuable: vulnerable and exploitable

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

# References


[1] Cristian Cadar, Daniel Dunbar, and Dawson Engler. 2008. **KLEE: unassisted and automatic generation of high-coverage tests for complex systems programs.** In Proceedings of the 8th USENIX conference on Operating systems design and implementation (OSDI'08). USENIX Association, USA, 209–224.

[2] V. Chipounov, V. Kuznetsov, and G. Candea, **S2E: a platform for in-vivo multi-path analysis of software systems**, in Proceedings of the sixteenth international conference on Architectural support for programming languages and operating systems, New York, NY, USA, Mar. 2011, pp. 265–278.

[3] Y. Shoshitaishvili et al., **SOK: (State of) The Art of War: Offensive Techniques in Binary Analysis**, in 2016 IEEE Symposium on Security and Privacy (SP), May 2016, pp. 138–157.

[4] Ccured: George C. Necula, Jeremy Condit, Matthew Harren, Scott McPeak, and Westley Weimer. 2005. **CCured: type-safe retrofitting of legacy software**. ACM Trans. Program. Lang. Syst. 27, 3 (May 2005), 477–526.

[5] S. Poeplau and A. Francillon, **Symbolic execution with SymCC: Don't interpret, compile!,** in 29th USENIX Security Symposium, 2020, pp. 181–198.

[6] Dong, Shiyu, Oswaldo Olivo, Lingming Zhang, and Sarfraz Khurshid. **Studying the influence of standard compiler optimizations on symbolic execution**, In 2015 IEEE 26th International Symposium on Software Reliability Engineering (ISSRE). IEEE, 2015.

[7] Chen, Junjie, Wenxiang Hu, Lingming Zhang, Dan Hao, Sarfraz Khurshid, and Lu Zhang. **Learning to accelerate symbolic execution via code transformation**, In 32nd European Conference on Object-Oriented Programming (ECOOP 2018).

[8] Wagner, Jonas, Volodymyr Kuznetsov, and George Candea. **{-OVERIFY}: Optimizing Programs for Fast {Verification},** In 14th Workshop on Hot Topics in Operating Systems (HotOS XIV). 2013.

# Thanks you!

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Code: https://github.com/haoxintu/FastKLEE
Email: haoxintu.2020@phdcs.smu.edu.sg
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# Backup: other evaluations

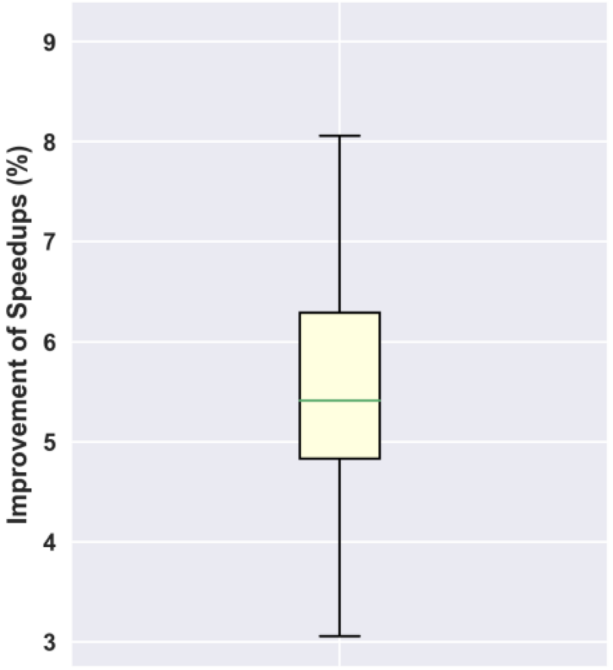



**Figure 4: Box plot of the improvement in speedups**

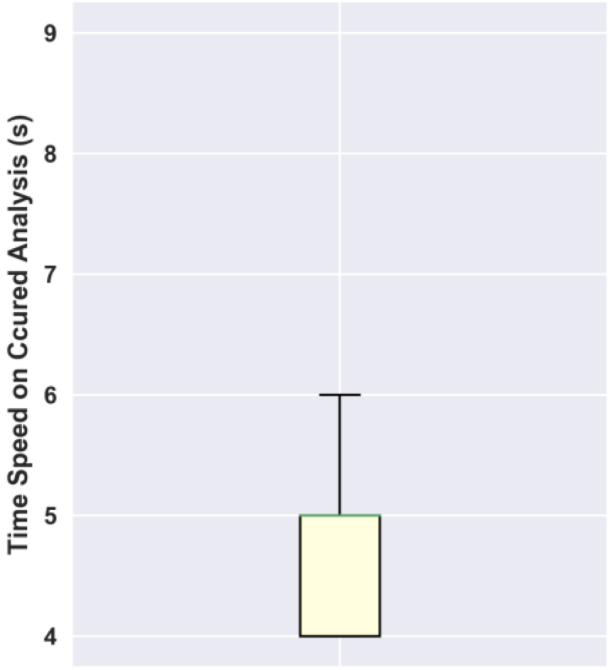
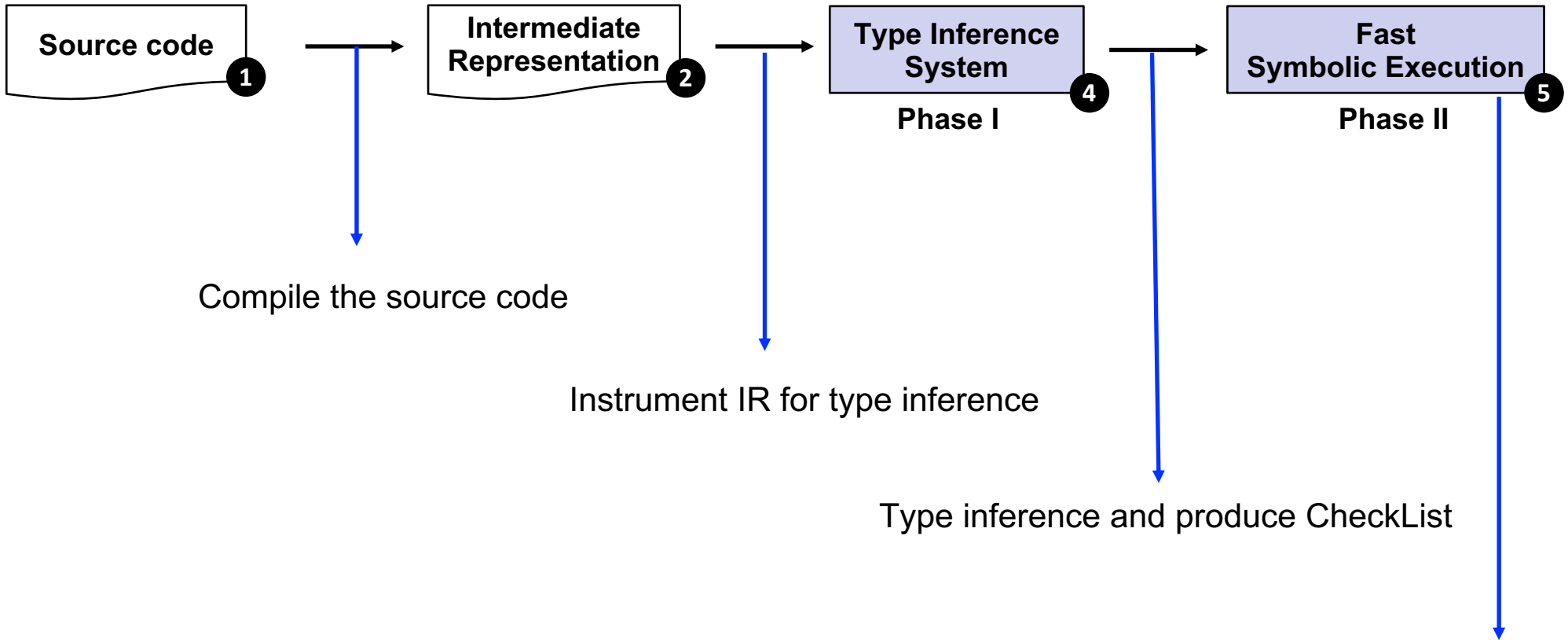



**Figure 5: Box plot of the time spent on type inference**

# Backup: Tool Usage

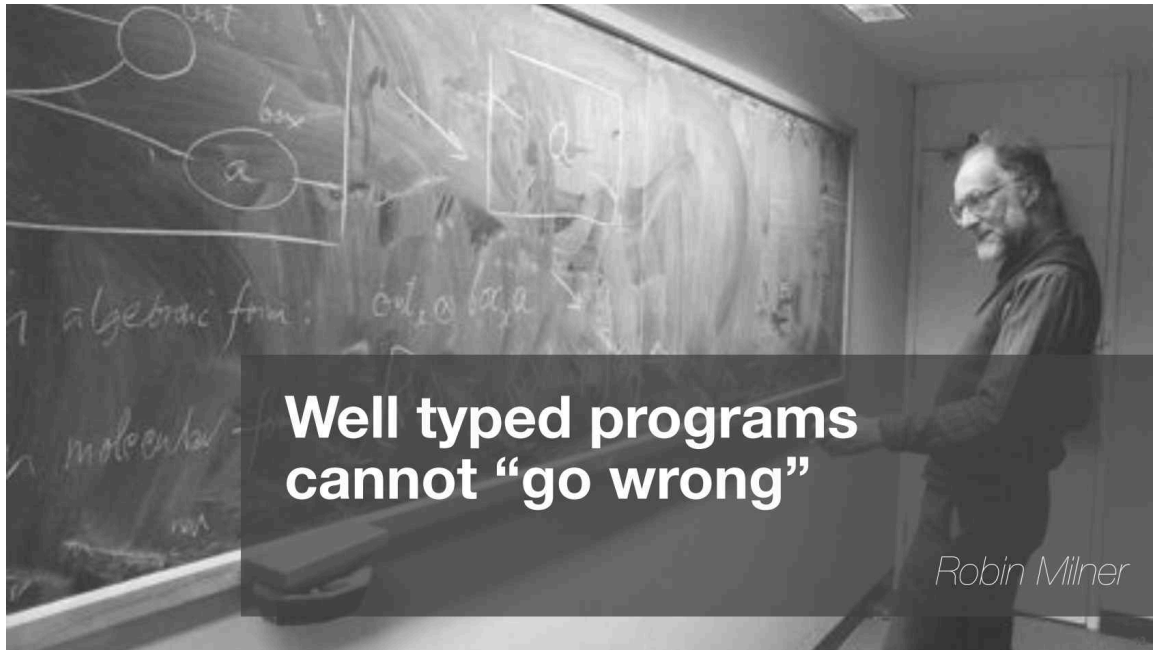



Installation of FastKLEE

Code: https://github.com/haoxintu/FastKLEE
(Please feel free to pull requests and raise any questions if you have!)

# Background: type safety (1)

- What is type safety?
  - Type safety means that the compiler will validate types while compiling, and throw an error if assign the wrong type to a variable.




Source: What is Type-safety?

Java

```
int x = 100;
String y = "hello";
int z = x + y;
```

**Error: incompatible types:**
**String cannot be converted to int**

Type ***safe*** programming language

```
int x = 100;
char* y = "hello";
int z = x + y;
```

**No errors**

Type ***unsafe*** programming language

**Note: type safety was intentionally sacrificed for flexibility/performance in C**

# Backup: type inference (2)

- **Type inference**
  - General Definition: automatic detection of the type of an expression in a programming language
  - Type inference in C
    - Try to keep type safety (specifically for pointer types)

- **Ccured** [4]
  - CCured transforms C programs to achieve memory safety guarantees
    - A large portion of pointers can be statically verified to be safe, and only small need run-time check