Introduction to Program Reasoning

19CSE205 : PROGRAM REASONING

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Jul - Dec 2020

Contents

What is Program Reasoning?

The task of reasoning about the correctness of a program, for a given specification, either through manual or automated means.

- The goal is to identify the presence of errors or prove their absence.

- Static approaches ⇒ Based on source code
  - Code inspection
  - Peer review
  - Static analysis
  - Formal verification

- Dynamic approaches ⇒ Based on program execution
  - Testing
  - Debugging
  - Tracing
  - Instrumentation

Code inspection & Peer review

A formal review carried out by self, peer and/or group to evaluate the quality of code. Usually a manual activity. Errors are categorized based on the severity of their impact.

- Static approaches
  - Code inspection
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Good quality code is

- Modular
- Readable
- Correct
- Adheres to standards
- ...

Execution of the program with various (preferably all possible) inputs and checking the output. Testing can be either manual or automated.

- Static approaches
  - Code inspection ✓
  - Peer review ✓
  - Static analysis
  - Formal verification
- Dynamic approaches
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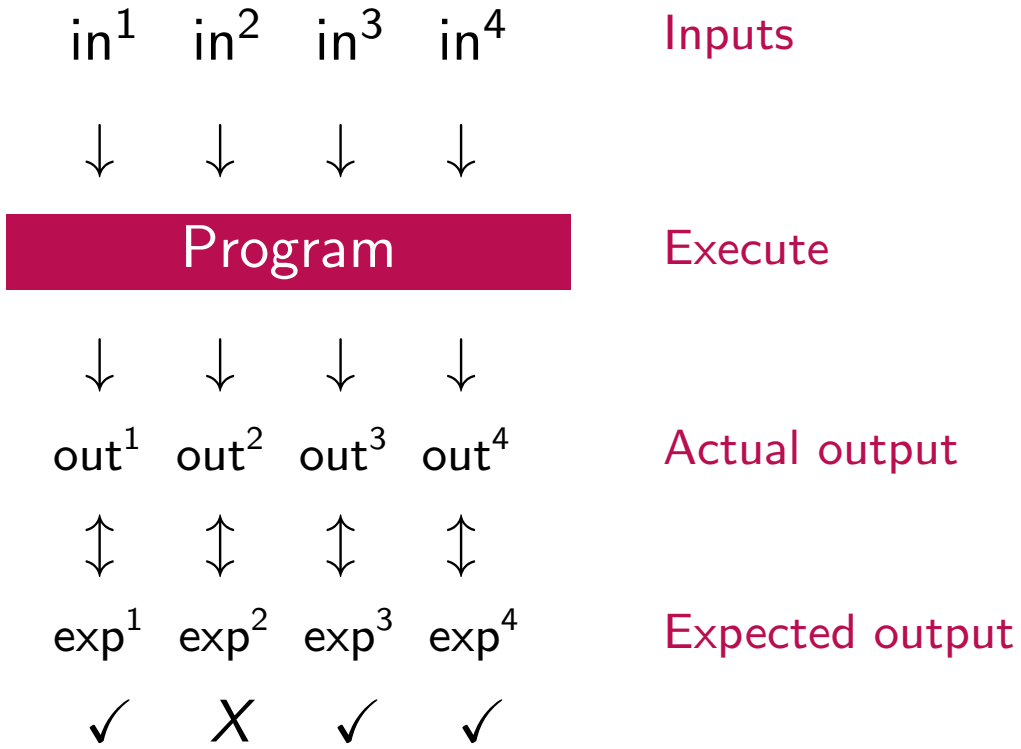

Debugging

The process of locating errors in the code and fix them. It is a manual activity. Debuggers are integral part of almost all IDEs.

- Static approaches
  - Code inspection ✓
  - Peer review ✓
  - Static analysis
  - Formal verification
- Dynamic approaches
  - Testing ✓
  - Debugging
  - Tracing
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Debuggers allow users to

- Pause execution by setting breakpoints
- Inspect program state and modify them
- Step into/out of/skip functions

Tracing

Tracing is the process of inserting print statements to the code to trace the program flow. It is usually a manual activity.

- Static approaches
  - Code inspection ✓
  - Peer review ✓
  - Static analysis
  - Formal verification
- Dynamic approaches
  - Testing ✓
  - Debugging ✓
  - Tracing
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Tracing a factorial program

```
int factorial(int n) {
    int fact = 1;
    printf("%d ",fact);
    for (int i=2; i<n; i++)
        fact = fact * i;
        printf("%d ",fact);
    return fact;
}
int main() {
    int result = factorial(6);
}
```

1 2 6 24 120

Instrumentation

Instrumentation is automatic injection of print statements to source or binary code.

P → Instrumenter → P'

Debug tracing: An alternate method to hook into program execution, which then spits out runtime events by pause-spit-resume mechanism.

- Static approaches
  - Code inspection ✓
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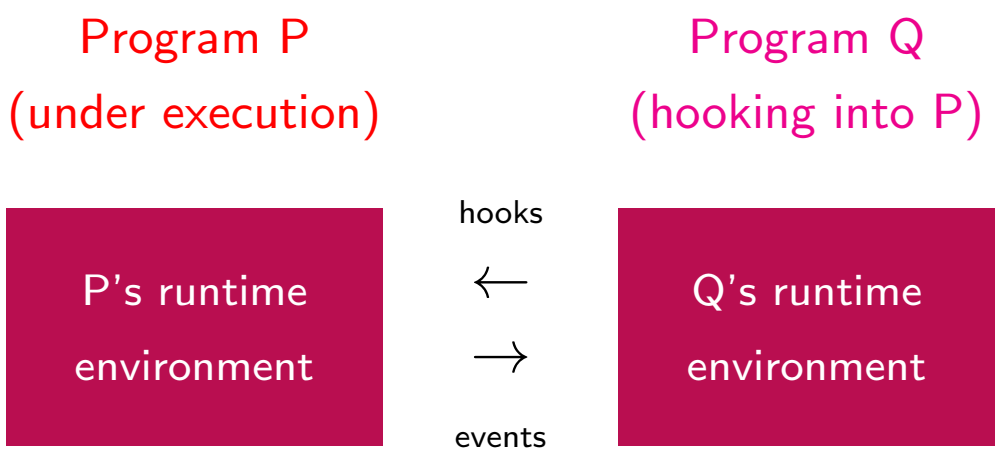


Static analysis

Static analysis is an automated way to analyze the source code. The source code is first converted to a tree or graph form and analysis is carried out by traversing through the structure.

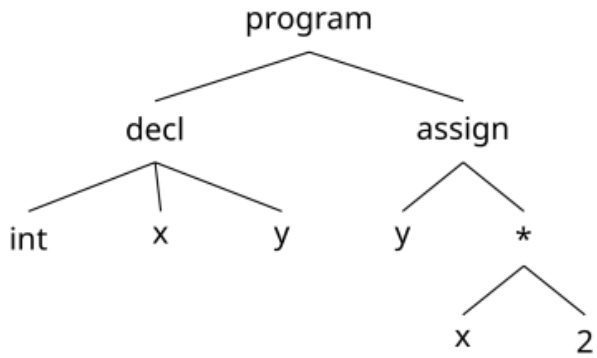
- Static approaches
  - Code inspection ✓
  - Peer review ✓
  - Static analysis
  - Formal verification
- Dynamic approaches
  - Testing ✓
  - Debugging ✓
  - Tracing ✓
  - Instrumentation ✓

Sample program

```
int x, y;
y = x * 2;
```

The initial value of x is not set

Abstract Syntax Tree



Symbol table

var	type	value
x	int	?
y	int	?

There are so many representations and several analysis techniques!

Formal Verification

The program is turned into logical formulae or a model. User states the correctness criteria. Theorem provers / SMT solvers / Model checkers are then used to prove that correctness specifications are met.

- Static approaches
  - Code inspection ✓
  - Peer review ✓
  - Static analysis ✓
  - Formal verification
- Dynamic approaches
  - Testing ✓
  - Debugging ✓
  - Tracing ✓
  - Instrumentation ✓

Verification in Frama-C

```
/*@ ensures \result >= a
          && \result >= b;
*/
int max(int a, int b) {
    if (a > b)
        return a;
    else
        return b;
}
```

Unlike other methods discussed earlier, which seek to identify errors, formal verification seeks to prove the absence of errors.

Terms and their meanings

- Static: Based on source (or executable) code
- Dynamic: Based on execution of the program
- Manual: Activity carried out by a human
- Automated: Activity performed by a program
- Semi-automated: Partly automated, human intervention necessary
- Code inspection: Examining source code to identify errors
- Peer review: A peer inspects the source code
- Static analyser: A program that analyzes the code and reports warnings and potential errors
- Program verifier: A program that takes source code and correctness criteria from user to ascertain if they will be met
- Testing: Execution of the program with different inputs and check if the actual output deviates from the expected
- Debugging: Interrupt the execution to examine the state in order to determine the cause of an error
- Tracing: Insert print statements in the program to trace errors
- Instrumentation: A program that inserts prints statements automatically during the execution