Introduction to Program Analysis

CSE 6049

Basic Information

- Instructor: Woosuk Lee
- Position: Assistant professor, Hanyang University
- Expertise: Software Analysis, Programming Languages
- Office: Rm 403, 3rd Engineering Building
- Email: woosuk@hanyang.ac.kr
- Office Hours: 10:00am–12:00pm Mondays and Wednesdays (by appointment)

Basic Information

- Course Website
  - http://psl.hanyang.ac.kr/courses/cse6049/
  - Course materials will be available here.
- Grading
  - Homework: 70%
  - Student presentation: 20%
  - Attendance: 10%

Student Presentation

- Every student is expected to give a talk about reading materials in the course website.
- Within 30 minutes
- Please sign up and close all the slots; here's the schedule link:
  - https://docs.google.com/spreadsheets/d/16FGO0ddBHbgN0ftSlu2FBJtyfueRbAfr-g-JnAqELPY/edit?usp=sharing

Student Presentation

- Evaluation criteria
  - **Content**: comprehensible even for outsiders, adequate level of detail
  - **Coherence**: The transitions are smooth. The presentation is succinct and not choppy.
  - **Timeliness**: Within the 30 minute goal
  - **Question responsiveness**: address all major questions.

Lab Assignments

- 4~5 labs to complement the lessons and impart hands-on experience
- Each lab is using a software analysis tool based on a technique covered in lectures, reporting your findings, and answering conceptual questions.
- A VM image compatible with both Virtualbox and VMWare is provided for relevant assignments.

Why Take This Course?

- Learn methods to improve software quality
  - reliability, security, performance, etc.
- Become a better software developer/tester
- Build specialized tools for software diagnosis and testing

The Ariane Rocket Disaster (1996)

Post Mortem

- Caused due to numeric overflow error
  - Attempt to fit 64-bit format data in 16-bit space
- Cost
  - $100M's for loss of mission
  - Multi-year setback to the Ariane program
- Read more at http://www.around.com/ariane.html

Security Vulnerabilities

- Exploits of errors in programs
- Widespread problem
  - Stuxnet Worm
  - Heartbleed
  - Meltdown and Spectre
- Getting worse …

What is Program Analysis?

- Body of work to discover useful facts about programs

- Broadly classified into three kinds:
  - Dynamic (execution-time)
  - Static (compile-time)
  - Hybrid (combines dynamic and static)

Dynamic Program Analysis

- Infer facts of program by monitoring its runs
- Examples:

Array bound checking
Purify

Datarace detection
Eraser

Memory leak detection
Valgrind

Finding likely invariants
Daikon

Static Analysis

- Infer facts of the program by inspecting its source (or binary) code

- Examples:

Suspicious error patterns
Lint, FindBugs, Coverity

Memory leak detection
Facebook Infer

Checking API usage rules
Microsoft SLAM

Verifying invariants
ESC/Java

QUIZ: Program Invariants

An invariant at the end of the program is (z == c) for some constant c. What is c?

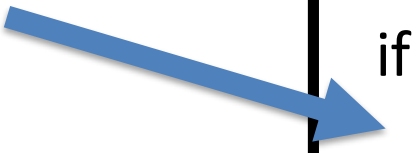
```
int p(int x) { return x * x; }

void main() {
    int z;
    if  (getc() == 'a')
        z = p(6) + 6;
    else
        z = p(-7) – 7;

}
```

z = ?

QUIZ: Program Invariants

An invariant at the end of the program is (z == c) for some constant c. What is c?

Disaster averted!



```
int p(int x) { return x * x; }

void main() {
    int z;
    if  (getc() == 'a')
        z = p(6) + 6;
    else
        z = p(-7) – 7;

  if (z != 42)
     disaster();
}
```

z = 42

Discovering Invariants By Dynamic Analysis

(z == 42) *might be* an invariant

```
int p(int x) { return x * x; }

void main() {
    int z;
    if  (getc() == 'a')
        z = p(6) + 6;
    else
        z = p(-7) – 7;

  if (z != 42)
      disaster();
}
```

z = 42

Discovering Invariants By Static Analysis

is definitely

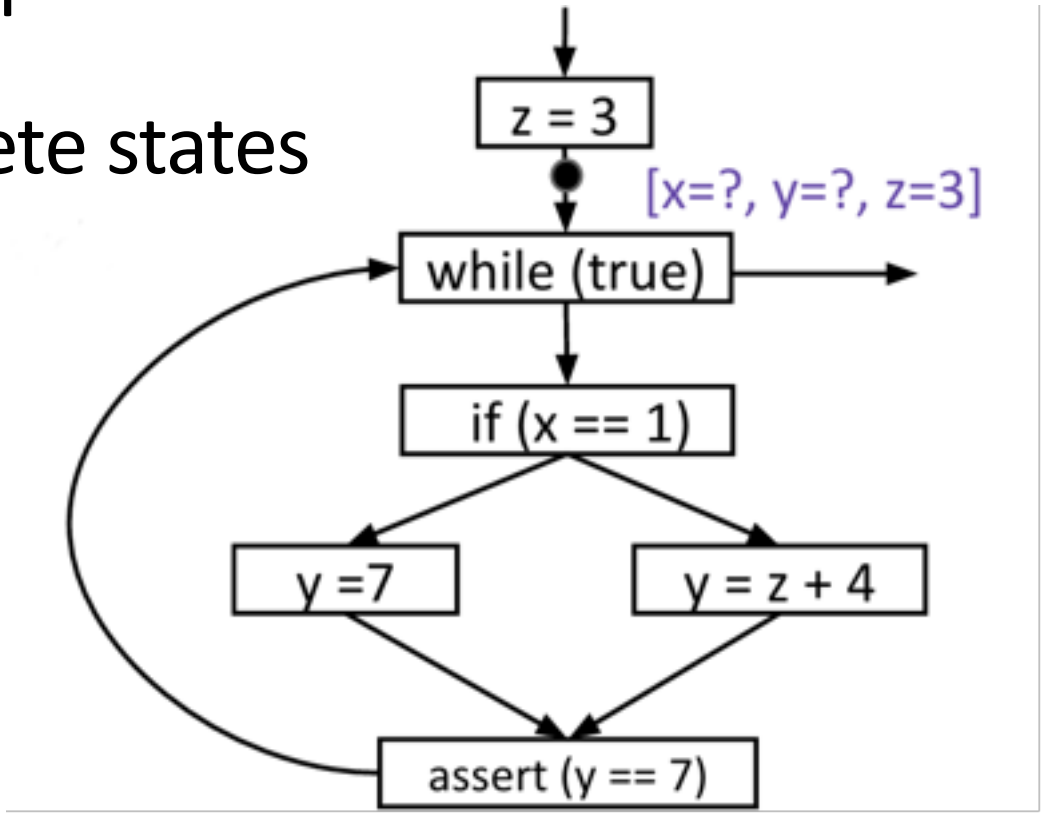
(z == 42) ~~*might be*~~ an invariant

```
int p(int x) { return x * x; }

void main() {
    int z;
    if  (getc() == 'a')
        z = p(6) + 6;
    else
        z = p(-7) – 7;

  if (z != 42)
      disaster();
}
```

z = 42

Terminology

- Control-flow graph
- Abstract vs. concrete states
- Termination
- Completeness
- Soundness

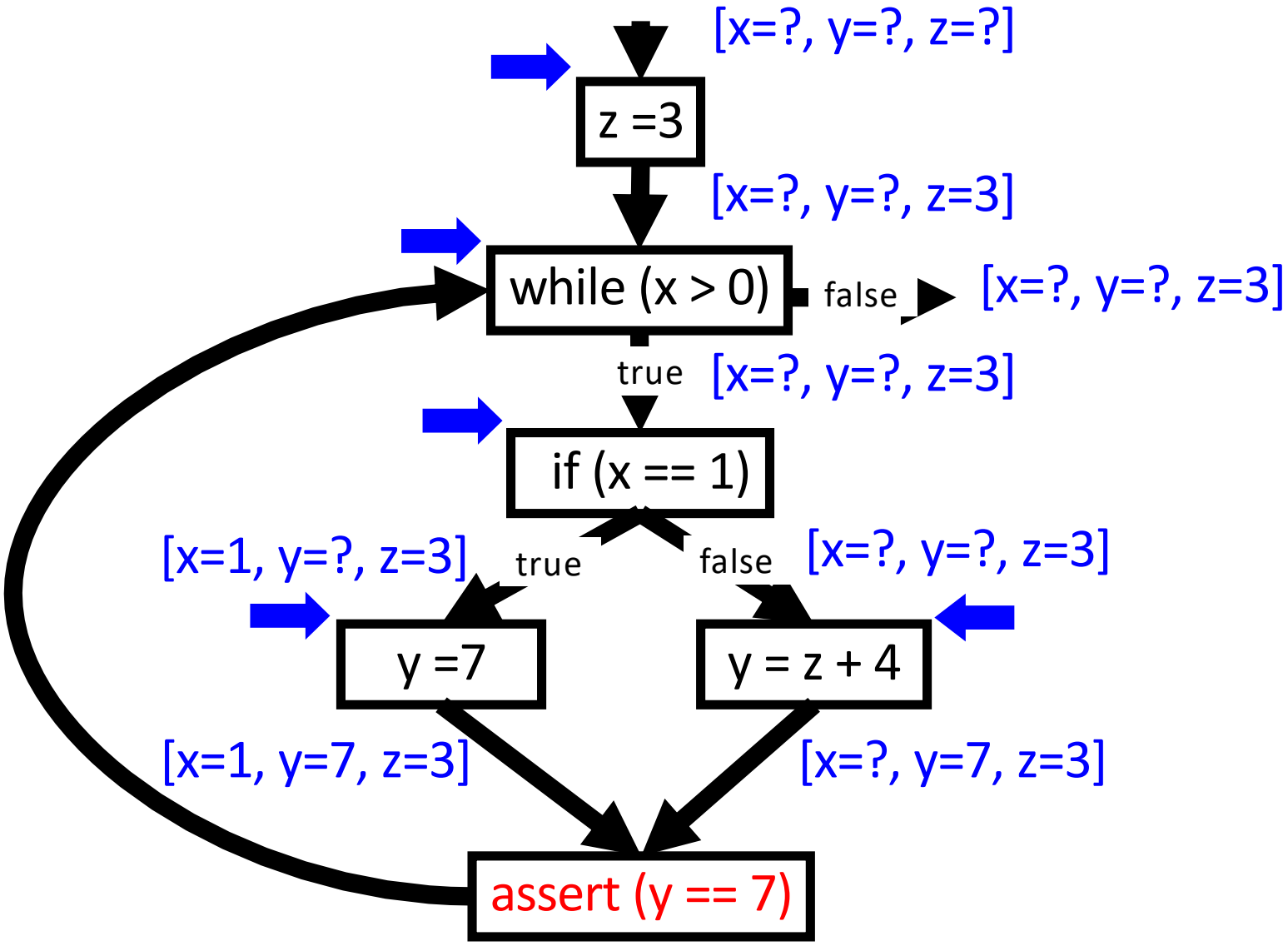


Example Static Analysis Problem

- Find variables that have a constant value at a given program point

```
void main() {
    z = 3;
    while (true) {
        if (x == 1)
            y = 7;
        else
            y = z + 4;
        assert (y == 7);
    }
}
```

Iterative Approximation

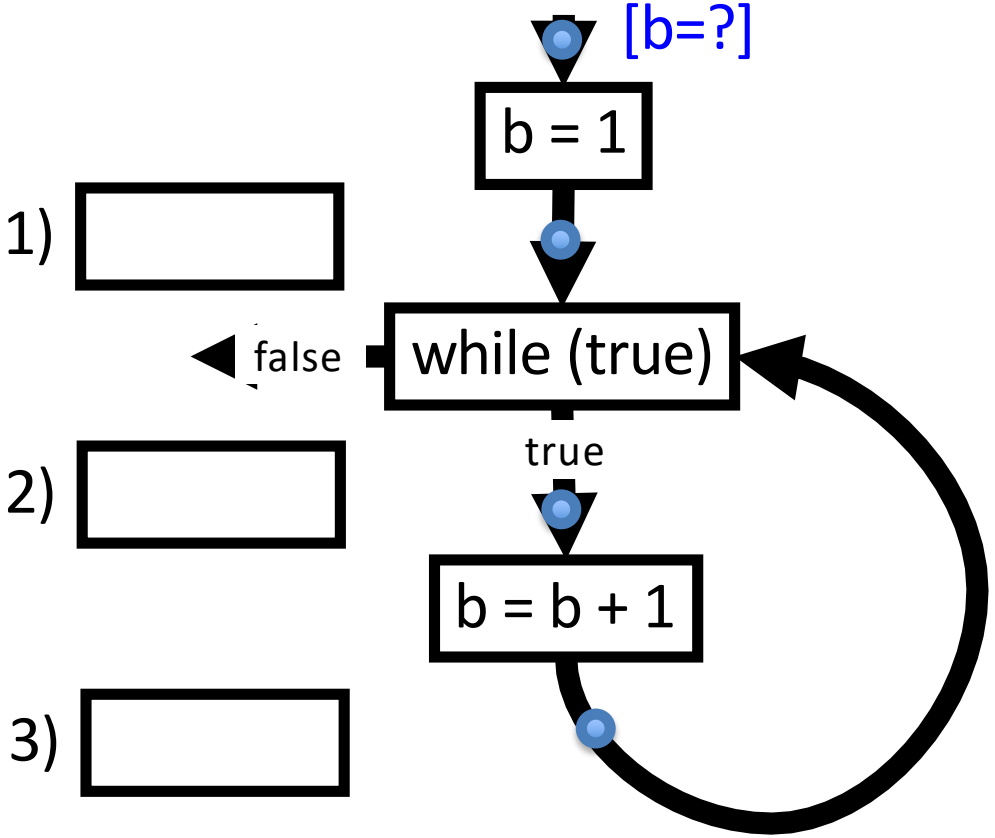


QUIZ: Iterative Approximation

Fill in the value of variable b that the analysis infers at:

1) the loop header
2) entry of loop body
3) exit of loop body

Enter "?" if a definite value cannot be inferred.



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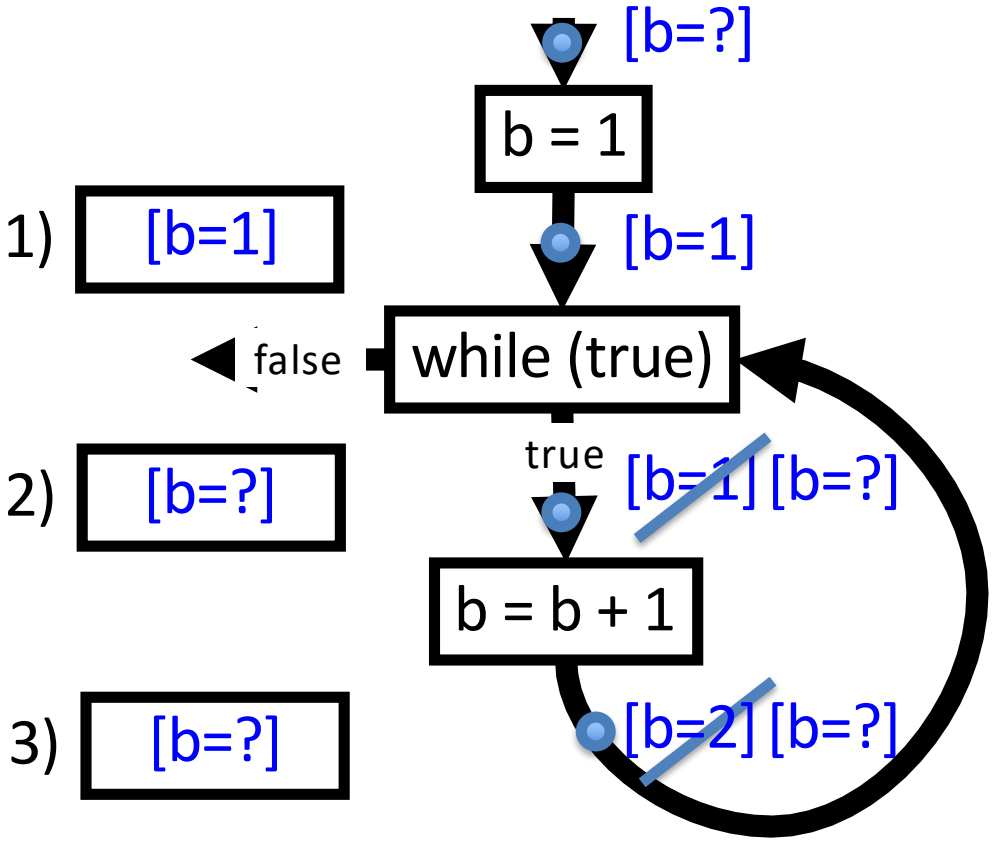


QUIZ: Dynamic vs. Static Analysis

Match each box with its corresponding feature.

	Dynamic	Static
Cost		
Effectiveness		

A. Unsound (may miss errors)

B. Proportional to program's execution time

C. Proportional to program's size

D. Incomplete (may report spurious errors)

QUIZ: Dynamic vs. Static Analysis

Match each box with its corresponding feature.

	Dynamic	Static
Cost	B. Proportional to program's execution time	C. Proportional to program's size
Effectiveness	A. Unsound (may miss errors)	D. Incomplete (may report spurious errors)

Undecidability of Program Properties

- Can program analysis be sound and complete?
  - Not if we want it to terminate!
- Questions like “is a program point reachable on some input?” are undecidable
- Designing a program analysis is an art
  - Tradeoffs dictated by consumer

Who Needs Program Analysis?

Three primary consumers of program analysis:

- Compilers
- Software Quality Tools
- Integrated Development Environments (IDEs)

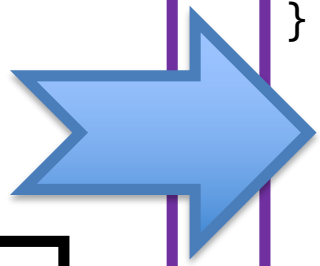
Compilers

- Bridge between high-level languages and architectures
- Use program analysis to generate efficient code

```
int p(int x) { return x * x; }
void main(int arg) {
   int z;
   if (arg != 0)
      z = p(6) + 6;
   else
      z = p(-7) - 7;

 print (z);
}
```

z = 42



```
int p(int x) { return x * x; }
void main() {
   print (42);
}
```

- Runs faster
- More energy-efficient
- Smaller in size

Software Quality Tools

- Primary focus of this course
- Tools for testing, debugging, and verification
- Use program analysis for:
  - Finding programming errors
  - Proving program invariants
  - Generating test cases
  - Localizing causes of errors
  - …

```
int p(int x) { return x * x; }

void main() {
    int z;
    if  (getc() == 'a')
        z = p(6) + 6;
    else
        z = p(-7) – 7;

  if (z != 42)
      disaster();
}
```

z = 42

Integrated Development Environments

- Examples: Eclipse and Microsoft Visual Studio
- Use program analysis to help programmers:
  - Understand programs
  - Refactor programs
    - Restructuring a program without changing its behavior
- Useful in dealing with large, complex programs

What Have We Learned?

- What is program analysis?
- Dynamic vs. static analysis: pros and cons
- Program invariants
- Iterative approximation method for static analysis
- Undecidability => program analysis cannot ensure
  termination + soundness + completeness
- Who needs program analysis?