# Interval Analysis

Course Project Tutorial

E0 227: Program Analysis and Verification 2021

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# Goal

- Given a Java program, implement a tool that performs Interval analysis.

- Phase 1:
    - Intraprocedural Interval Analysis (using Kildall's algo)

- Phase 2:
    - Interprocedural Interval Analysis. *(details will be specified later)*

# Phase1 - Input

- The analyser should work on programs written in Java programming language

- For Phase1, you may assume these restrictions.
    - Only integer variables.
    - No global variables.
    - Only static methods.
    - No Method Calls

- Input format: Input will be a java class file.

# Implementation requirements

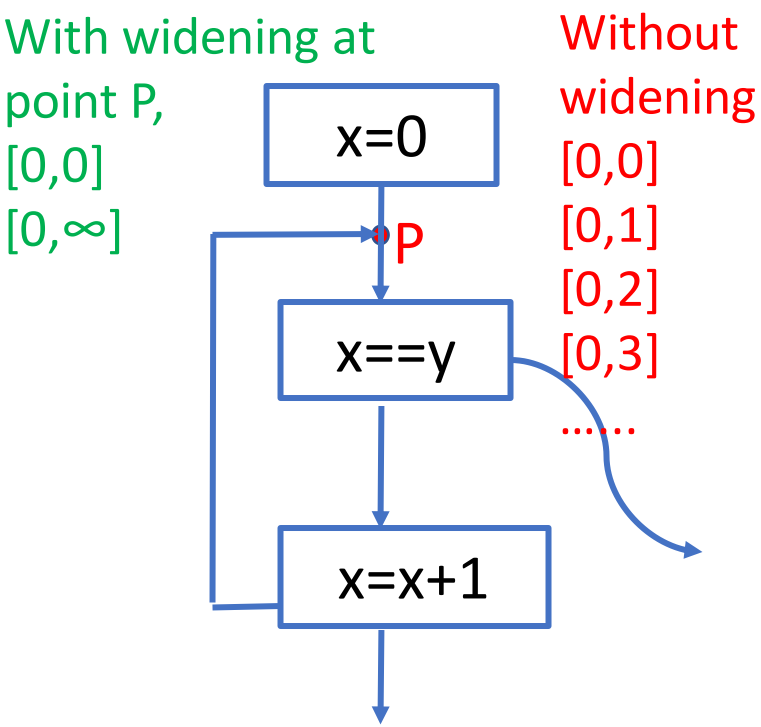
- The analysis must be implemented as a Java Program.
- It must use the *Soot* analysis framework.

# Implementation requirements

- Two parts:
  - Kildall's Algorithm implementation
    - Must be modular. (ie, Algorithm must be agnostic about the particular analysis details)
    - It should assume that transfer functions are of type LatticeElement -> LatticeElement
    - Where LatticeElement is an Interface and have these methods
      - equals, join_op, **widen_op**, tf_assignstmt, tf_condstmt
  - The Specific Analysis (Interval analysis)
    - It must be an implementation of the LatticeElement interface
- Note: The Kildall's Algo, should not directly refer to the IA implementation, instead should access it through the LatticeElement interface methods

# Widening Operator (Δ)

- Shorten an ascending infinite chain to a finite height.
- Execution of Kildall's algorithm on Interval Analysis example with infinite height lattice.
  - At P, intervals of **x** forms an infinite ascending chain.
  - Widening operator makes the chain into a finite one.




- Ref: Patrick Cousot and Radhia Cousot, Abstract interpretation: a unified lattice model for static analysis of programs by construction or approximation of fixpoints, In *POPL '77: Proceedings of the 4th ACM SIGACT-SIGPLAN symposium on Principles of programming languages*, pages 238--252, New York, NY, USA, 1977. ACM Press. - ***(Specifically, Section 9)***

# Widening Operator(contd.)

- Widening is done at any point with incoming Loopback edge(s). Other points use join as usual.
- [i,j] Δ [k,l] = [ if k<i then -∞ else i , if l>j then +∞ else j ]
- Note, Δ is not symmetric.
  - [i,j] above is the existing value at the point, [k,l] is the incoming value.
- Widening examples
  - [0,0] Δ [0,1] = [0,∞]
  - [0,1] Δ [0,0] = [0,1]
  - [0,0] Δ [-1,0] = [-∞,0]

# Analysis with Soot Framework

# Jimple Intermediate Representation

**java source**

```
class BasicTest2 {
    static int add_x(int flag)
    {
        int x = 0;
        int sum = 0;
        if (flag == 1) {
            x = x + 10;
        }
        sum = sum + x;
        sum = sum * 3;
        return sum;      }
}
```

**jimple IR**

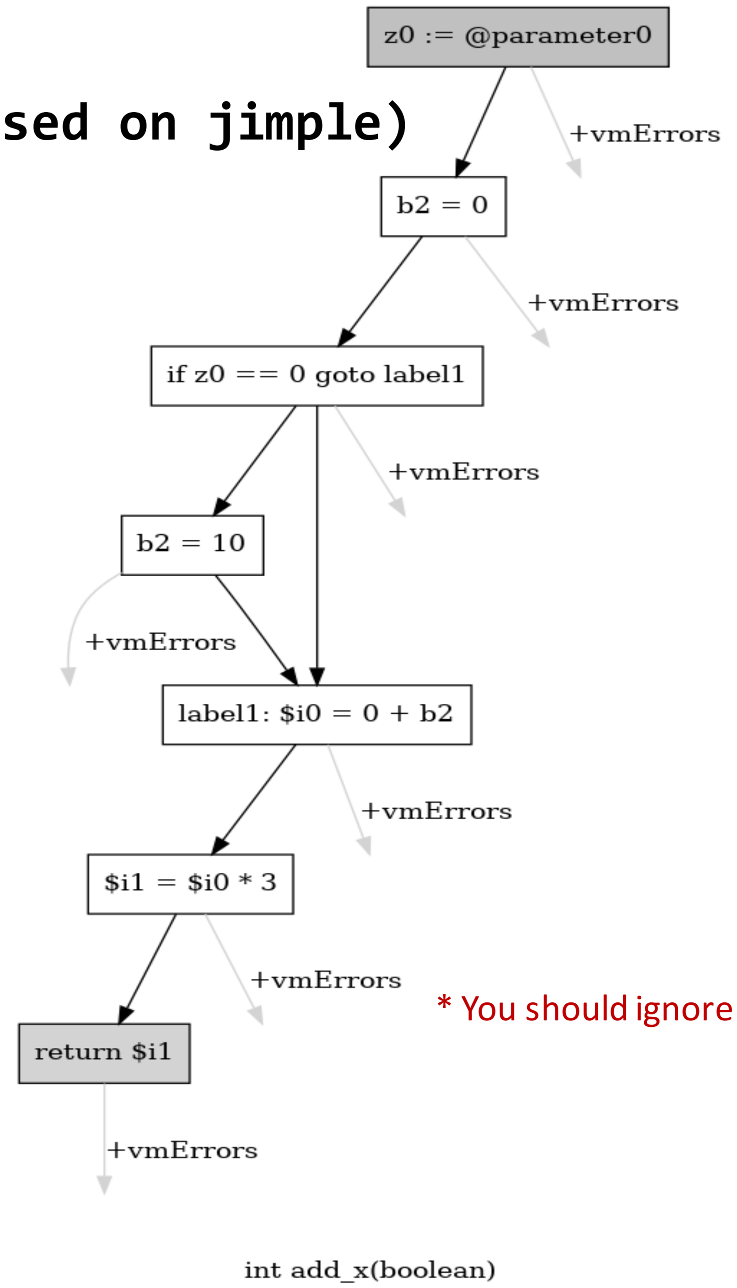
```
<BasicTest2: int add_x(int)>
        z0 := @parameter0: int
        b2 = 0
        if z0 == 0 goto label1
        b2 = 10
label1: $i0 = 0 + b2
        $i1 = $i0 * 3
        return $i1
```

# Jimple IR and CFG

## jimple IR

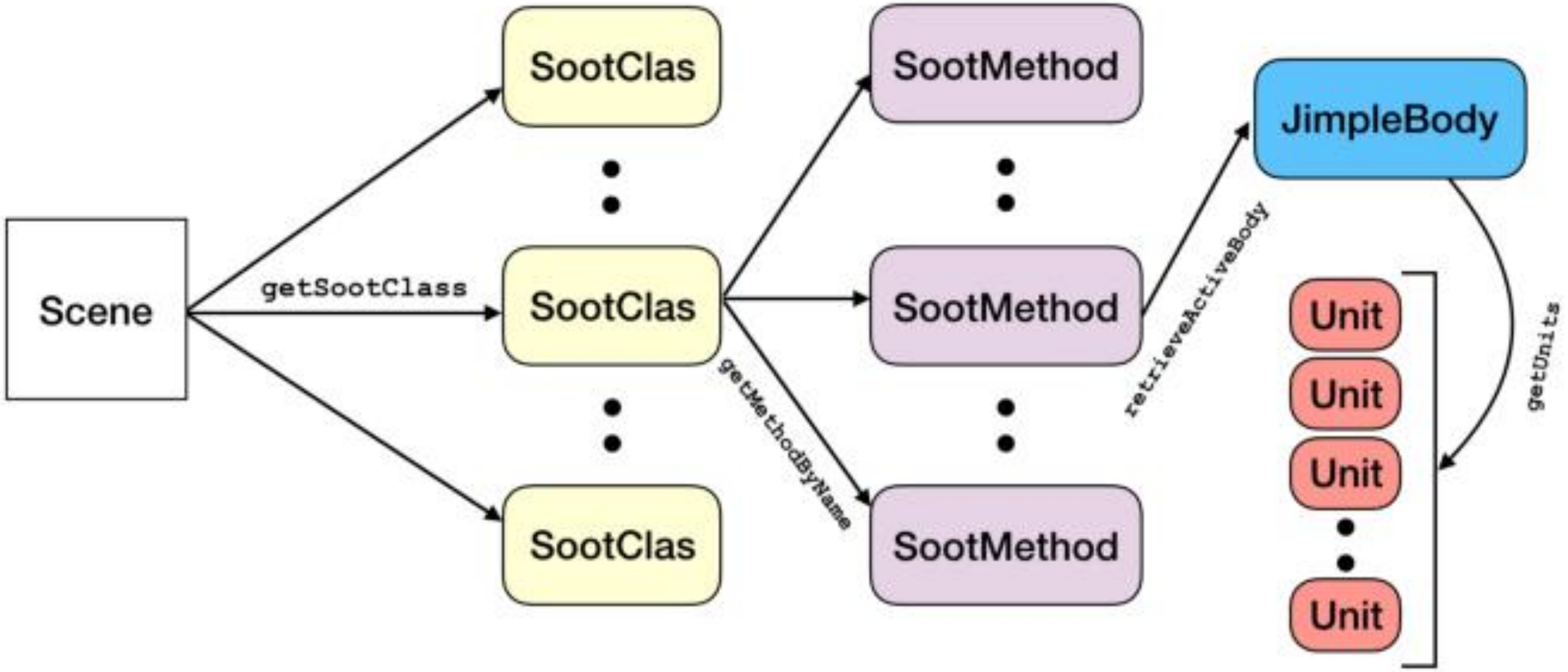
```
<BasicTest2: int add_x(int)>
        z0 := @parameter0: int
        b2 = 0
        if z0 == 0 goto label1
        b2 = 10
label1: $i0 = 0 + b2
        $i1 = $i0 * 3
        return $i1
```

## CFG (based on jimple)




* You should ignore exception edges

# Soot Analysis Framework




https://noidsirius.medium.com/a-beginners-guide-to-static-program-analysis-using-soot-5aee14a878d

# Soot Analysis Framework(Contd.)

- Units (Stmt, StoreInst, AssignStmt, ...)
- Values (Immediate, FieldRef, AddExpr, ...)
- Boxes (UnitBox, ValueBox, ExprBox, StmtBox, ImmediateBox, VariableBox, ExprBox, ...)

https://www.sable.mcgill.ca/soot/doc/soot/Unit.html

# Units, Values & Boxes

- Unit
  - A code fragment (eg Stmt or Inst), used within Body classes. Intermediate representations must use an implementation of Unit for their code. In general, a unit denotes some sort of unit for execution.
- Value
  - Data used as, for instance, arguments to instructions; typical implementations are constants or expressions. Values are typed, clonable and must declare which other Values they use (contain).
- Boxes
  - References in Soot are called boxes. There are two types – Unitboxes, ValueBoxes.

# UnitGraph

- UnitGraph
  - Represents a CFG where the nodes are Unit instances and edges represent unexceptional and (possibly) exceptional control flow between Units.

# Analysis Workflow

# Soot Driver Program

- A base soot driver program is provided. `(Analysis.java)`
  - It can be extended for your implementation.
- Input (Program Arguments)
  - args[0]: *path to target directory/jar* of classes, where the analysis class resides.
  - args[1] : fully qualified name of the main class (entry point of the soot analysis).
  - args[2] : fully qualified name of the class containing the method to be analysed.
  - args[3] : method name, for which the analysis is to be done.
  - Eg:(1) ~/project/target1 AddNumFun AddNumFun mySum
  - (2) ~/project/antlr.jar Main ErrorTest findError

# Analysis Workflow – Soot Driver Program

```java
public class Analysis extends PAVBase {
    private DotGraph dot = new DotGraph("callgraph");
    private static HashMap<String, Boolean> visited = new
        HashMap<String, Boolean>();

    public Analysis() {

    }

    public static void main(String[] args) {

        //String targetDirectory="./targe
        //String mClass="AddNumFun";
        //String tClass="AddNumFun";
        //String tMethod="expr"

        String targetDirectory=args[0];
        String mClass=args[1];
        String tClass=args[2];
        String tMethod=args[3];
        boolean methodFound=false;


        List<String> procDir = new ArrayList<String>();
        procDir.add(targetDirectory);

        // Set Soot options
        soot.G.reset();
        Options.v().set_process_dir(procDir);
        // Options.v().set_prepend_classpath(true);
        Options.v().set_src_prec(Options.src_prec_only_class);
        Options.v().set_whole_program(true);
        Options.v().set_allow_phantom_refs(true);
        Options.v().set_output_format(Options.output_format_none);
        Options.v().set_keep_line_number(true);
        Options.v().setPhaseOption("cg.spark", "verbose:false");

        Scene.v().loadNecessaryClasses();

        SootClass entryClass = Scene.v().getSootClassUnsafe(mClass);
        SootMethod entryMethod = entryClass.getMethodByNameUnsafe("main");
        SootClass targetClass = Scene.v().getSootClassUnsafe(tClass);
        SootMethod targetMethod = entryClass.getMethodByNameUnsafe(tMethod);

        Options.v().set_main_class(mClass);
        Scene.v().setEntryPoints(Collections.singletonList(entryMethod));
```

Get the specified inputs

Set necessary soot options and get the Jimple code

Perform Analysis & Print Output

# LatticeElement Interface

- Kildall implementation should not directly refer to IA implementation and should access the dataflow data only via LatticeElement interface.
- Receiver object of the LatticeElement methods should be the existing dataflow fact at a program point. The incoming dataflow fact is passed as a parameter for widen/join operator.
- No implementation of methods in this interface should modify the receiver object.
    - Fresh object should be returned.

# IDE

- You are free to use any IDE for development. (Eg: Eclipse, IntelliJ)
- Arguments to Analysis.java can be given in the Run Configuration.
- During the demo, your code should work by calling Analysis.java with command line arguments from terminal.

# Expected Output

- You should generate two files.
  - **File1** – should contain the *final output* of Analysis.
    - Format the output as shown in the *next slide*.
    - Filename format: class.method.output.txt

      Eg: `BasicTest1.myIncrement.output.txt`

  - **File2** – should contain the *full output* (including intermediate outputs).
    - In this file, you should show the updated dataflow fact, at the affected program points, after each step of the Kildall's Algorithm.
    - You can use the same format for output, as shown in the next slide.
    - Filename format: class.method.fulloutput.txt

      Eg: `BasicTest1.myIncrement.fulloutput.txt`

Note: Create these files in the same directory as the input .class file.

# Expected Output for File 1

**tc01-myIncrement()**

```
BasicTest1.myIncrement: in00: $i1: [-inf, +inf]
BasicTest1.myIncrement: in00: @parameter0: [-inf, +inf]
BasicTest1.myIncrement: in00: i0: [-inf, +inf]
BasicTest1.myIncrement: in01: $i1: [-inf, +inf]
BasicTest1.myIncrement: in01: @parameter0: [-inf, +inf]
BasicTest1.myIncrement: in01: i0: [-inf, +inf]
BasicTest1.myIncrement: in02: $i1: [-inf, +inf]
BasicTest1.myIncrement: in02: @parameter0: [-inf, +inf]
```

# Expected Output for File 1

**tc01-mySum()**

```
BasicTest1.mySum: in00: i0: [-inf, +inf]
BasicTest1.mySum: in00: i1: [-inf, +inf]
BasicTest1.mySum: in01: i0: [0, 0]
BasicTest1.mySum: in01: i1: [-inf, +inf]
BasicTest1.mySum: in02: i0: [0, +inf]
BasicTest1.mySum: in02: i1: [0, +inf]
BasicTest1.mySum: in03: i0: [0, +inf]
BasicTest1.mySum: in03: i1: [0, 10]
BasicTest1.mySum: in04: i0: [0, +inf]
BasicTest1.mySum: in04: i1: [0, 10]
BasicTest1.mySum: in05: i0: [0, +inf]
BasicTest1.mySum: in05: i1: [1, 11]
BasicTest1.mySum: in06: i0: [0, +inf]
BasicTest1.mySum: in06: i1: [11, +inf]
```

# Expected Output Format of File 1

- Each row in the output should be of format:

```
class.method: programpoint: var: [lower, upper]
```

- Format for the Result corresponding to interval [lower, upper]
  - "-inf" if lower is -∞, else lower.toString()
  - "+inf" if upper is +∞, else upper.toString()

- The lines in the file are in string sorted order (as shown in the examples).
- If dataflow fact at a particular point is \bot, then no output lines should appear at that point.

# Expected Output Format of File 1

- Each Jimple statement (I.e., Unit) becomes a node in the CFG.
- The point just before each node (Unit) is to be treated as a program point. Hence, program points and nodes correspond one-to-one in this project (unlike in the theory).
- Program points are to be numbered in00, in01, in02, etc.
  - The numbering is in the order as returned by body.getUnits()
  - At each program point, ALL variables in the method under analysis, need to be shown.
- Initial data flow fact (at program entry) is `[-inf, +inf]` for all variables.

# Other Important Information

# Evaluation

- What we are looking for:
  - Your tool should not crash.
  - Your analysis should be sound.
  - Your analysis should be as precise as possible.
  - Should not ignore any valid Java constructs (modulo the assumptions stated earlier).

- Scoring:
  - Each error has an associated penalty
  - Your score: TOTAL SCORE – sum(PENALTIES)

# Evaluation (Contd.)

- Phase 1 Submission Deadline:
  - Date: October 29th, 2021.
  - Extended to: November 3rd, 2021 (11:59pm)
- Demo of Phase 1:
  - During demo: run your tool on predisclosed (public) as well undisclosed (private) testcases.
- You should add your own testcases, for increased test coverage.
- Credits will be divided between Phase I and Phase II.
- No changes to the score of Phase I shall be entertained after the demo of Phase I.

# Also,

- Your code will be carefully analyzed with plagiarism checkers.
  - Copying will be dealt with severely.
  - You can learn general Java programming idioms and patterns from other open-source applications, but *should not look up* Kildall implementation or Interval Analysis implementation from any source.
  - Don't use any Soot libraries other than the ones already used in Analysis.java given to you. Don't use any other libraries, either, other than Java utilities (such as collections).
- Both teammates need to participate. During the demo, we will be evaluating the responses of both members.
  - Ideally, we would like to see the commits of both members. Nevertheless, this is not strictly enforced.

# Suggestion for starting:

- Understand Soot framework basics, like Units, Values, Boxes.
- Pick one of the public test case targets.
- Traverse the CFG explicitly, and print out the *Units* and *useBoxes*, *defBoxes*, and *unitBoxes* corresponding to each Unit.

# References (Soot)

- A Survivors Guide to Soot
  - https://cs.au.dk/~amoeller/mis/soot.pdf

- Soot Tutorials
  - https://github.com/soot-oss/soot/wiki/Tutorials
  - https://github.com/noidsirius/SootTutorial/tree/master/docs/1
  - https://noidsirius.medium.com/a-beginners-guide-to-static-program-analysis-using-soot-5aee14a878d

# Project Logistics

- Base repo for the project (includes the soot driver)
  - [https://gitlab.com/alvg/pav-2021-project-base](https://gitlab.com/alvg/pav-2021-project-base)
  - `gitlab.com` will be our online repository hosting service.
- Create an account in gitlab.com
  - Each member of the team should have a gitlab account.
- Fork the base repo to your useraccount
  - Fork with repo name as "pav2021-teamXX" (eg: pav2021-team08)
    - Team number as assigned in the Excel sheet for forming project teams.
  - Create only one fork per team (either of the team member can do this.)
    - This will be your "team repo". (aka the "forked repo").
  - Add the other team members to the repo (as Maintainers)

- Add @alvg, @raseekc as Maintainers

# Project Logistics

- The "forked repo" (your "team repo") will be your common collaboration method
    - This will enable all team members to work simultaneously on the code.
- Clone the forked repo to your desktop/laptop
- Follow the instructions in the README
- Now you may start modifying your implementation

# Project Logistics

## Workflow Tips (not mandatory – but recommended)

- Start the day by doing a "git pull" to receive the changes made by other team members
  - "git pull" tries to automatically merge changes made by all team members
  - But if git cannot decide this automatically, a merge conflict will be reported.
  - In that case, you need to resolve it by deciding on how to merge the changes manually.
- "git commit" after making each logical set of changes
  - "Logical set" is arbitrary and can be as few as 1 line to 100+ lines of change.
  - Eg: After adding a new method/class to the code, or after fixing a bug.
- "git push" atleast once a day
  - This will enable other team members to see your changes, and will also reduce the chance of merge conflicts.

Thank You !