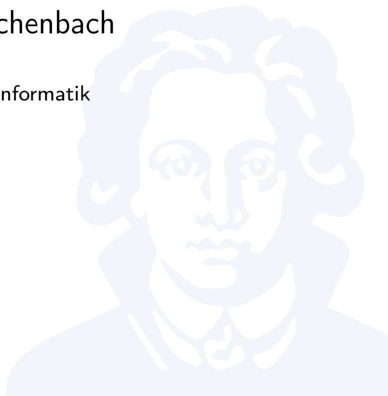
Software Engineering Tools 00

Prof. Dr. Christoph Reichenbach

Fachbereich 12 / Institut für Informatik

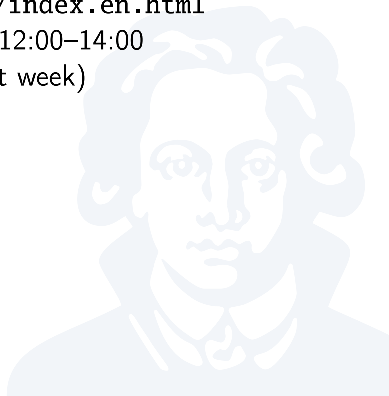
11. April 2014



Welcome to Software Engineering Tools!

Contact	`reichenb@cs.uni-frankfurt.de`
Class web page	`http://sepl.cs.uni-frankfurt.de/2014-ss/m-swe-pr/index.en.html`
Office hours	210a, RMS 10, Thu 12:00–14:00 (NOT this week/next week)

- Structure:
  - 3 lectures + today
  - project with individual meetings
  - final project presentation

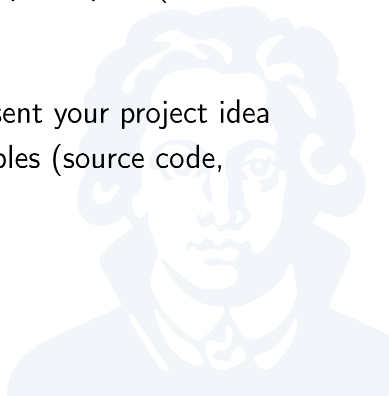


Expectations

- *Praktikum*: You have to implement/extend:
  - Software tool, or
  - Language extension
- Specifically:
  - Pick a project
  - Define project goals
  - Meet with me at least every 2-3 weeks to discuss project status
  - Give a 1h talk that demonstrates
    - Why the project matters
    - What it does
    - How you implemented it
    - What observations you made
  - Submit deliverables (source code, measurements, ...)

Important Dates

- TODAY: e-mail me if you want to participate (include Matrikelnummer)
- May 7th: Agree on a project idea
- July 23th/24th, 14:00–18:00: Present your project idea
- July 31st: Submit project deliverables (source code, write-up, as per project goals)



Overview

- Today:
  - Overview: software tools
  - Example: Java compiler & run-time
  - Preview
  - Project ideas
- Lecture 01: **Syntax & Semantics & Types**
- Lecture 02: **Static Program Analysis**
- Lecture 03: **Dynamic Program Analysis**

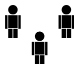
Literature

- "Compilers: Principles, Techniques, and Tools", by Aho, Lam, Sethi, & Ullman ("The Dragon Book")
  How to build compilers
- "Principles of Program Analysis", by Nielson, Nielson, & Hankin
  Static analysis from a formal perspective

How we develop software

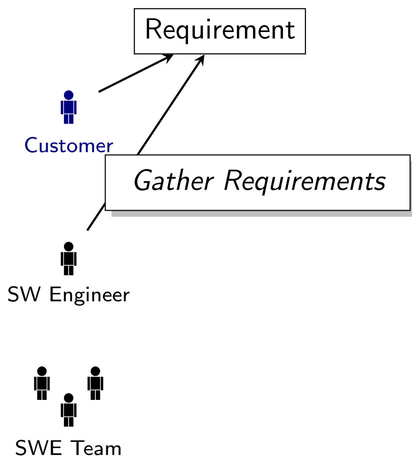
Customer

SW Engineer



SWE Team

How we develop software



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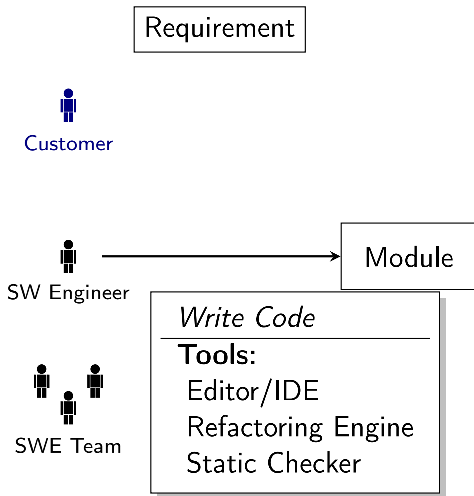

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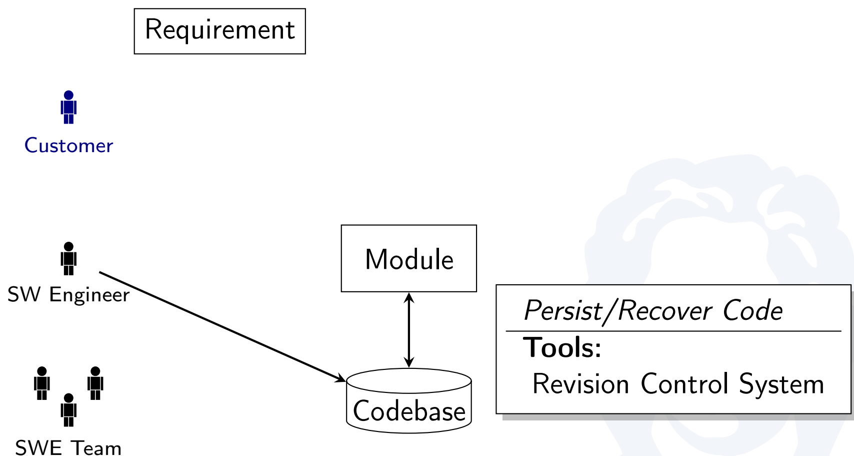

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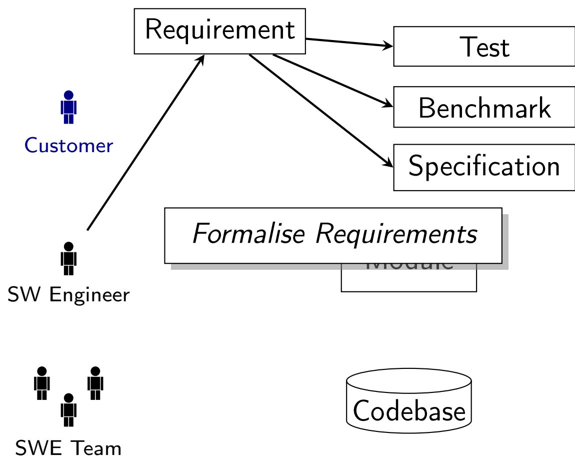

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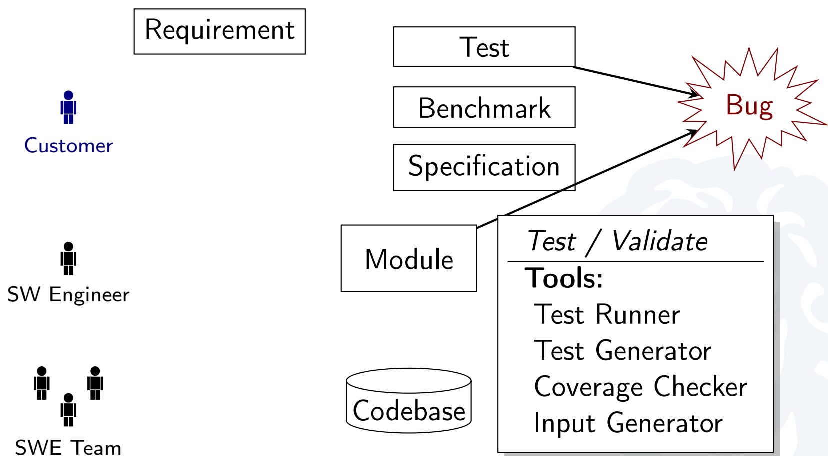

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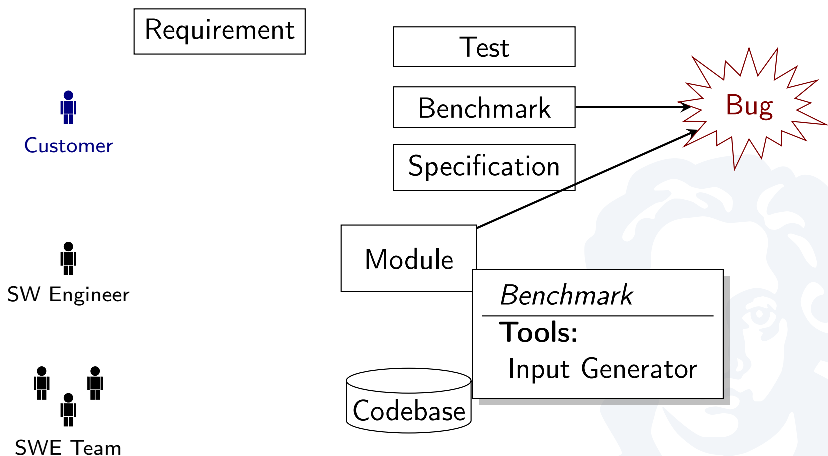

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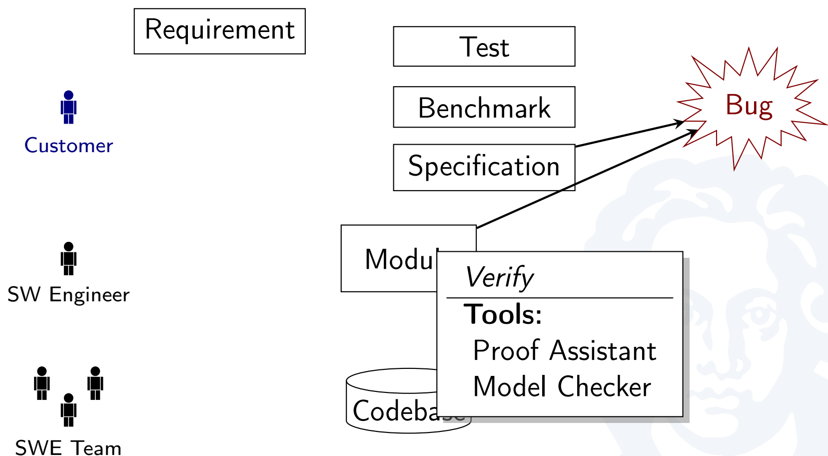

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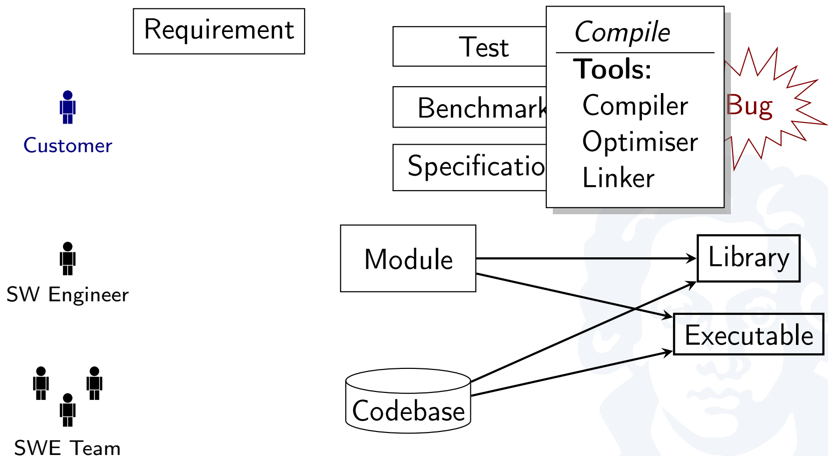

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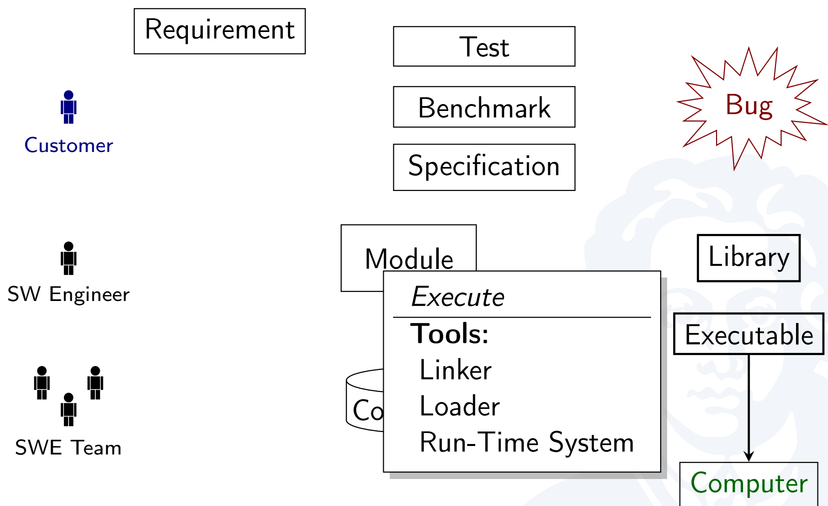


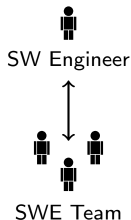
Software Tools: Examples

- Editor / IDE
- Refactoring Engine
- Static Code Checker
- Revision Control System
- Test Runner
- Test Generator
- Test Coverage Checker
- Input Generator
- Proof Assistant
- Model Checker
- Compiler
- Optimizer
- Linker
- Loader
- Run-Time System
- ...

Software Engineering Tools

- Include all Software Tools
- Also, tools for handling processes:
  - Issue Tracking
  - Scheduling / Planning
  - Document Management

  ...



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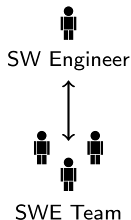

We focus on *Software Tools*

The purposes of Software Tools

- Human vs. artefact
  - Creation
  - Manipulation
  - Measurement
  - Visualisation
- Artefact vs. artefact
  - Translation
  - Generation
  - Validation
- Artefact vs. hardware
  - Execution

Incomplete list!

Usage Modes

- Activation
  - Automatic
  - Interactive

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- Activity cycle
  - Static: at or before compile time
    - Can see whole program
    - Can see all possibilities
  - Dynamic: during program execution
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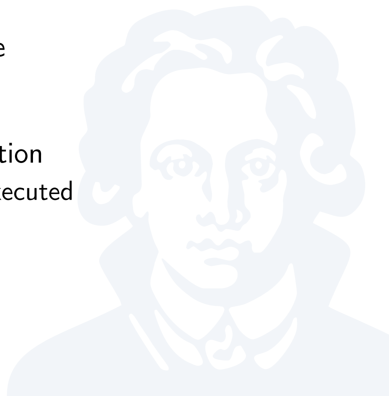
    - Can observe execution time



Usage Modes

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  - Automatic
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- Activity cycle
  - Static: at or before compile time
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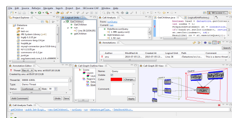
Modern approaches increasingly hybrid

Components of Software Tools



```
for (int i = 0; i < 10; i++) {
  z += i;
  if (z > 42) {
    System.out.println(z);
    z /= 10;
} }
```

```
E8 03 CD 10 c5 01 45 39 e5
38 83 eb 04 4c 39 ff 0f 84
01 45 84 f6 48 89 44 24 38
af 84 d2 79 ab 89 d0 83 e0
74 24 38 31 d2 4c 89 44 24
48 89 7c 24 38 e8 66 92 01
```

User Interface

Source Code

Binary Code

tokenise

parse

unparse

load

emit

run

Program Representation

Transformation

Analysis

Traces

Java lexing

```
int i;
if (2 > 0) {
  i = "One";
}
return i;
```

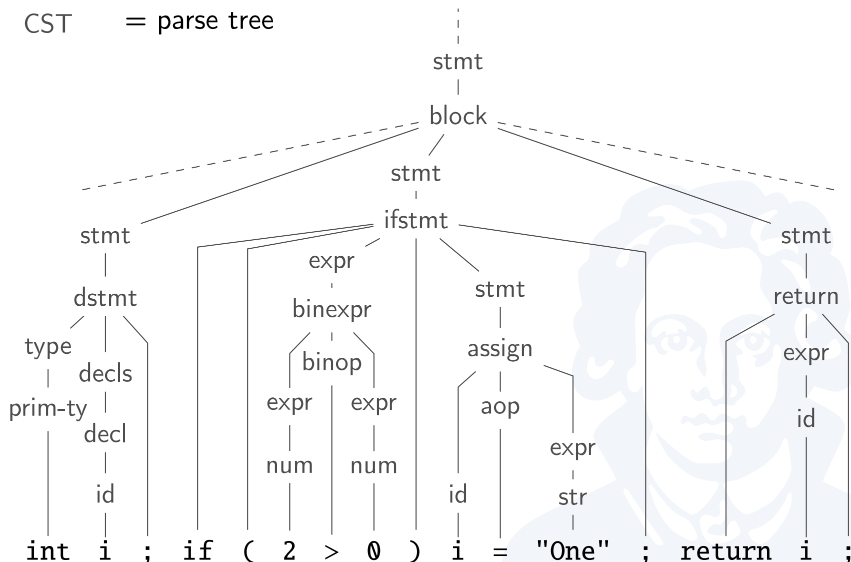
Java lexing

```
int i;
if (2 > 0) {
  i = "One";
}
return i;
```

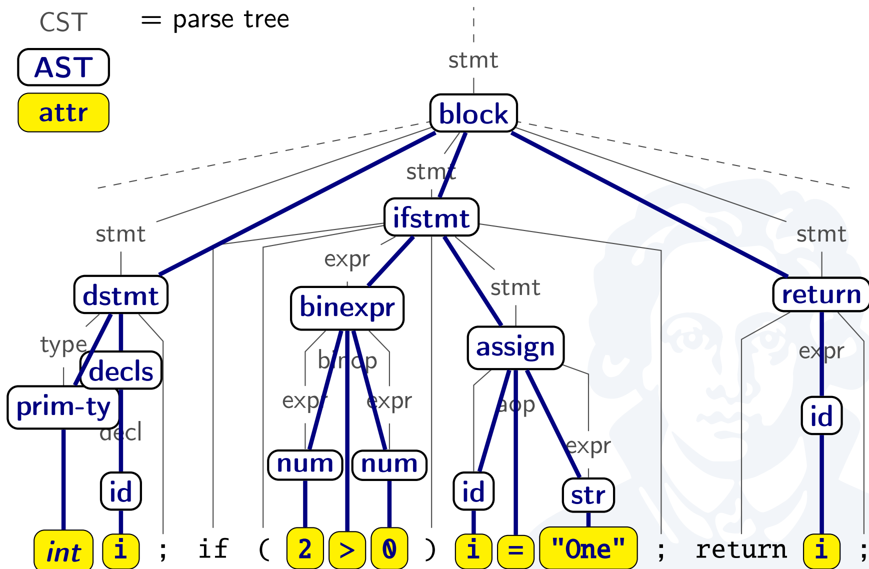
Lexing / Tokenisation

```
int  i  ;  if  (  2  >  0  )  i  =  "One"  ;  return  i  ;
```

Java parsing



Java parsing



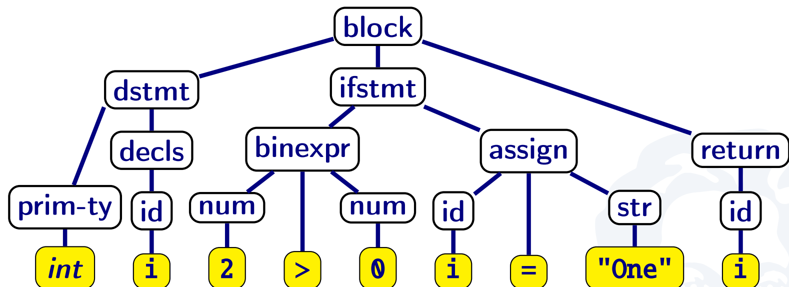
Parsing in general

Translate text files into ***meaningful*** *in-memory structures*

- CST = Concrete Syntax Tree
  - Full "parse", cf. language BNF grammar
  - Not usually materialised in memory
- AST = Abstract Syntax Tree
  - Standard in-memory representation
  - Avoids syntactic sugar from CST, preserves important nonterminals as **AST nodes**
  - Converts useful tokens into attributes

Program analysis starts on the AST

In-Memory Representation



Typical in-memory representations for this AST:

- Algebraic values (functional)
- Records (imperative)

In-Memory Representation

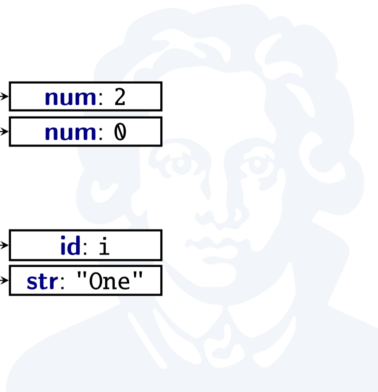
dstmt
type: → **prim-ty**: *int*
decls-list: → **id** : i

ifstmt
cond: → **binexpr**: >
- *lhs:* → **num**: 2
- *rhs:* → **num**: 0

true: → **assign**: =
- *lhs:* → **id**: i
- *rhs:* → **str**: "One"

false: → ◇

return → **id** : i

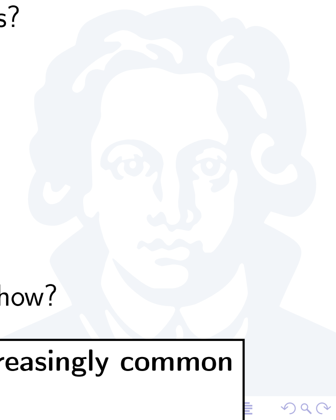


Program Analysis

We run numerous code analyses on the AST:

- *Name Analysis*:
  - Which name *use* binds to which *declaration*?
- *Type Analysis*:
  - What are the types of all expressions?
- *Static Correctness Checks*:
  - Are there type errors?
  - Is a variable unused?
  - Are we initialising all variables?

    ...
- *Optimisations*:
  - Can we speed up the program somehow?



Advanced static correctness checks increasingly common in compilers

Name Analysis

dstmt
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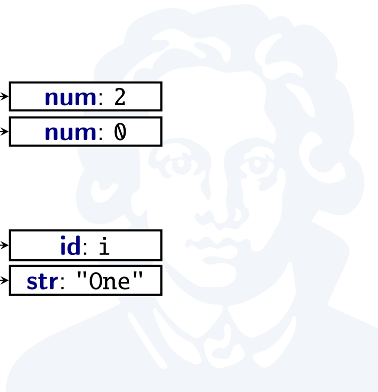
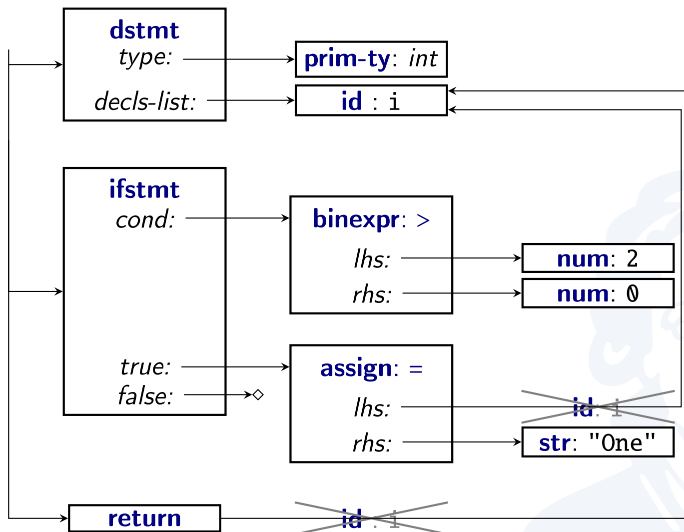
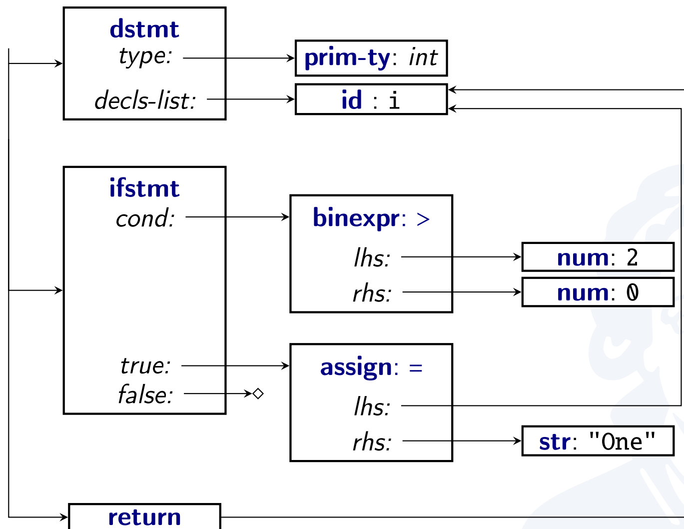


Name Analysis



Type Analysis



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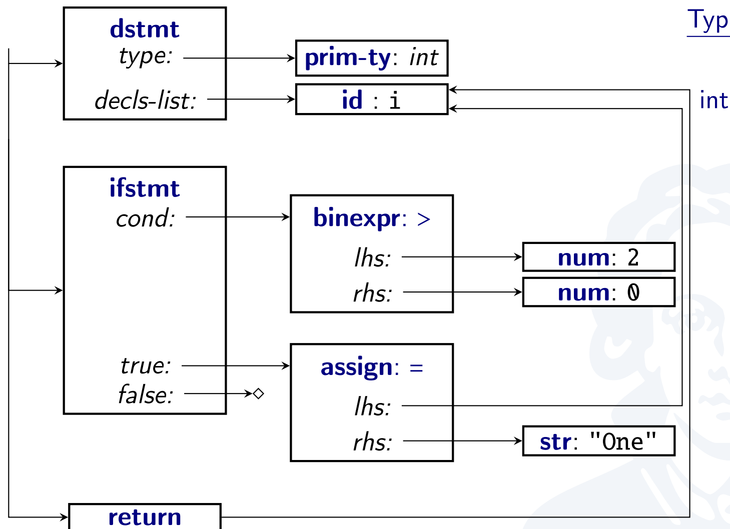
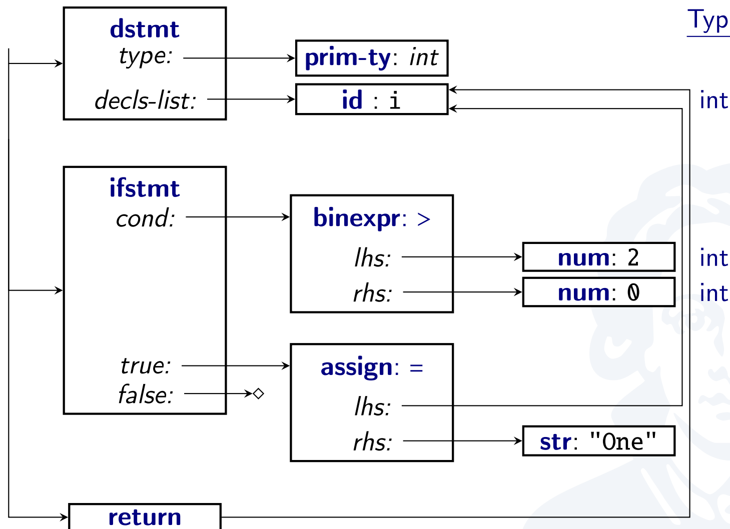


Type

int

Type Analysis



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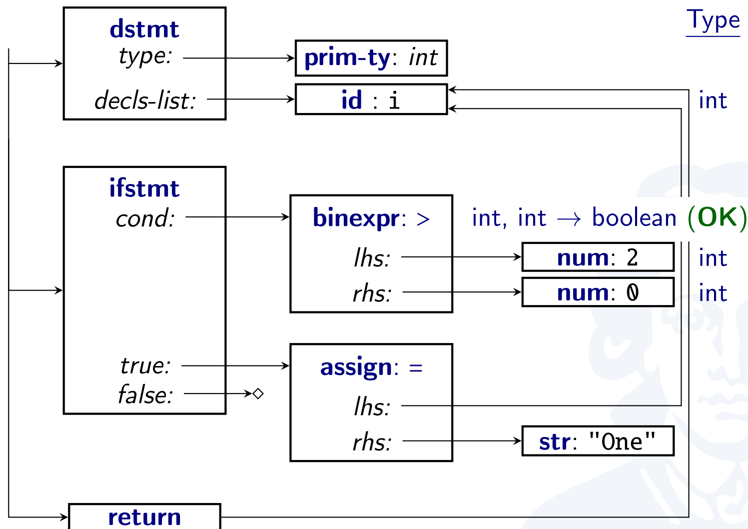

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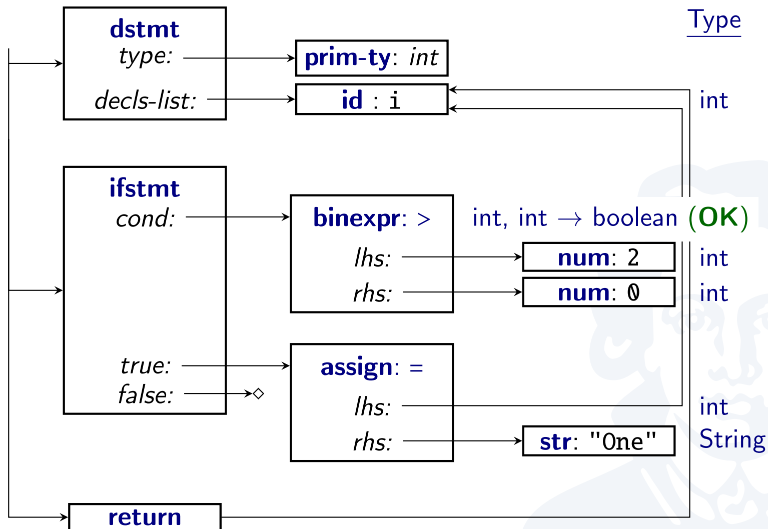

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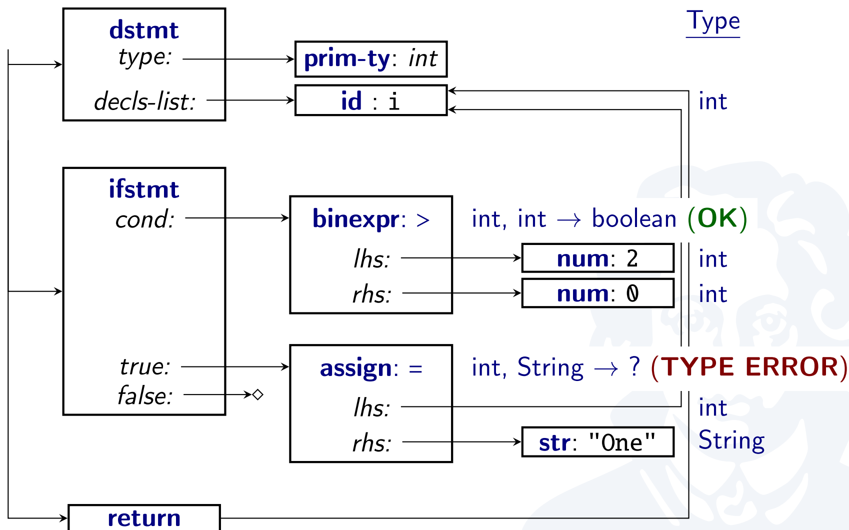

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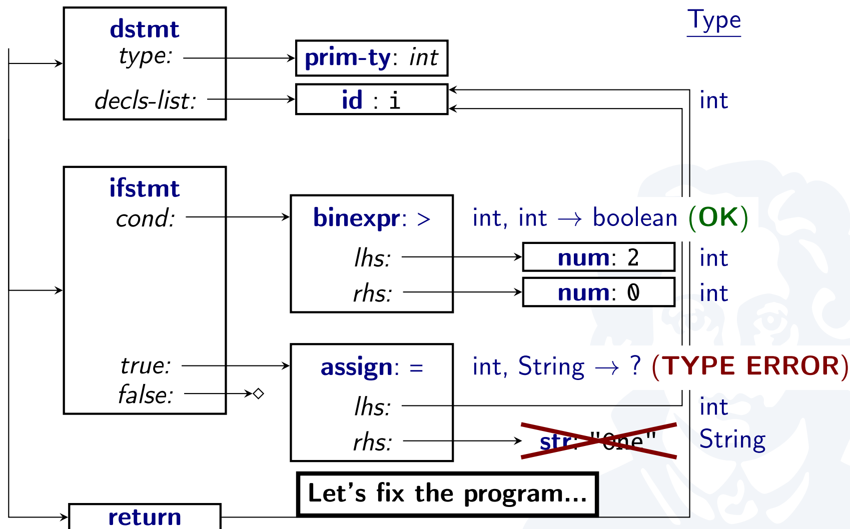

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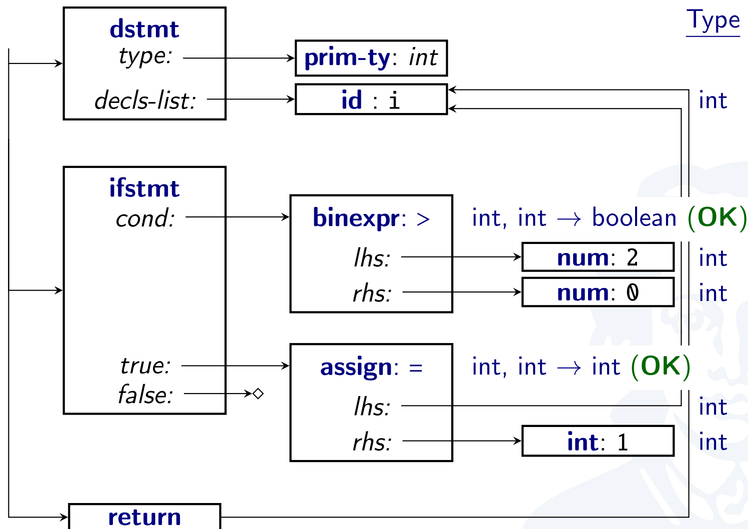
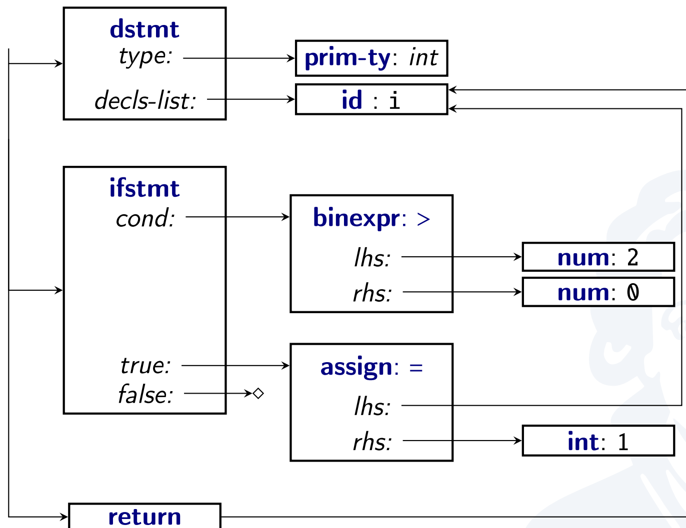


Definite Assignment Analysis



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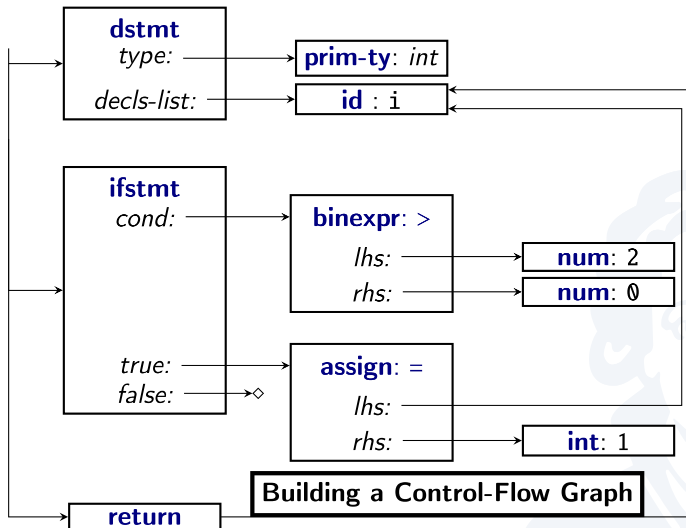

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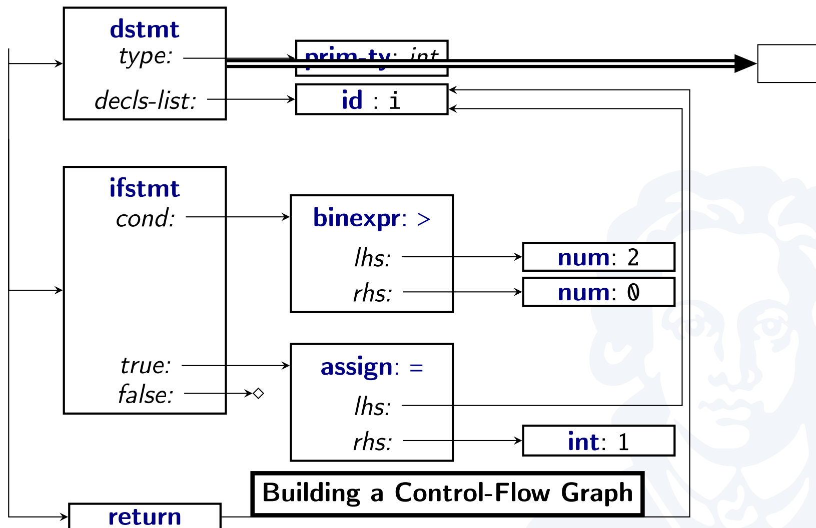

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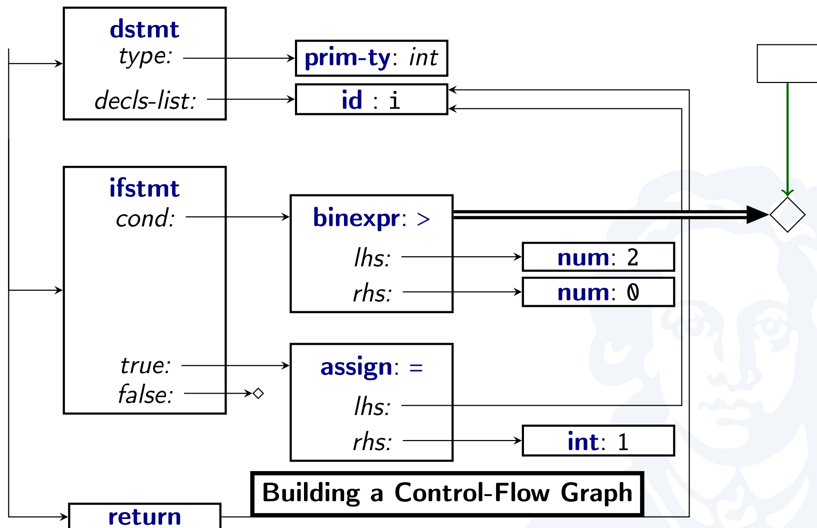

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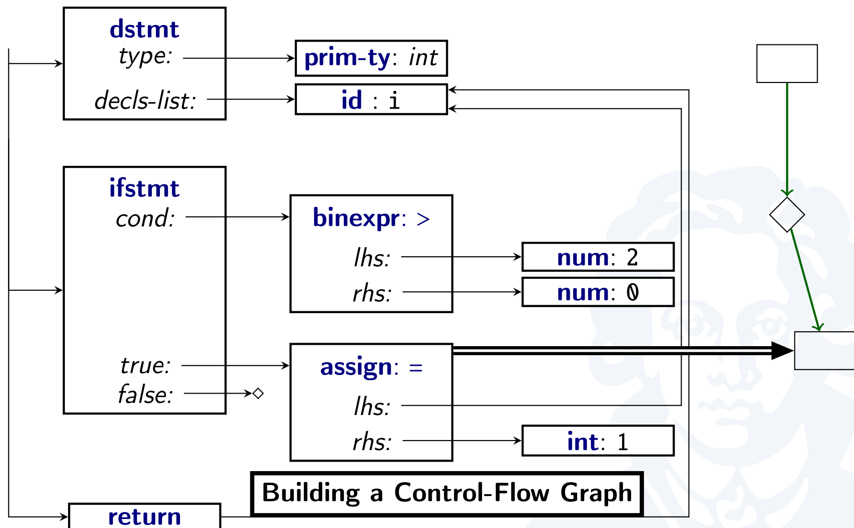

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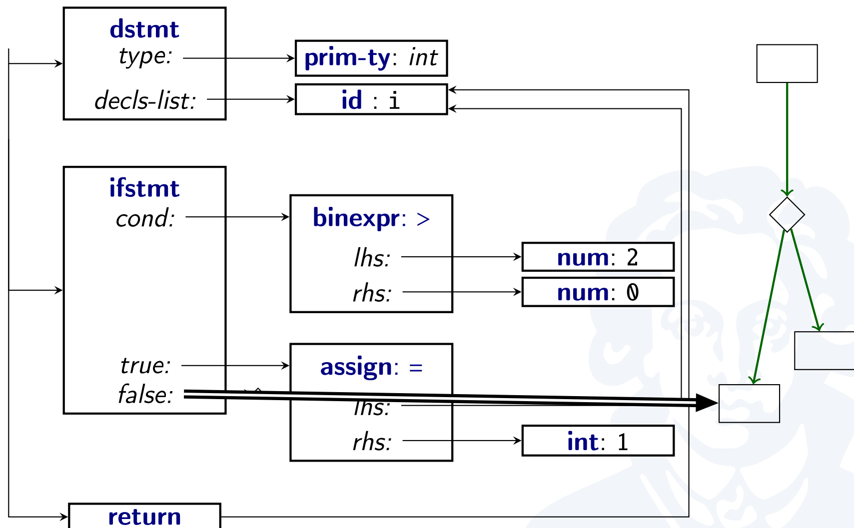

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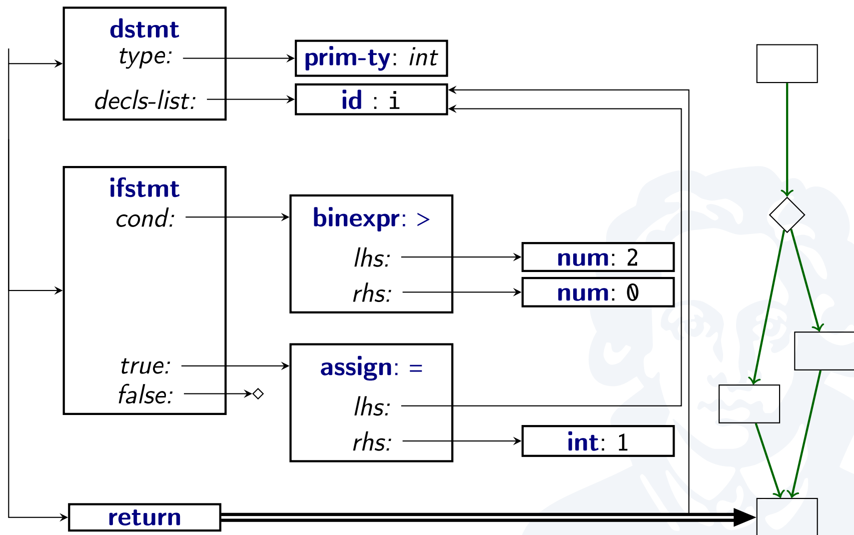

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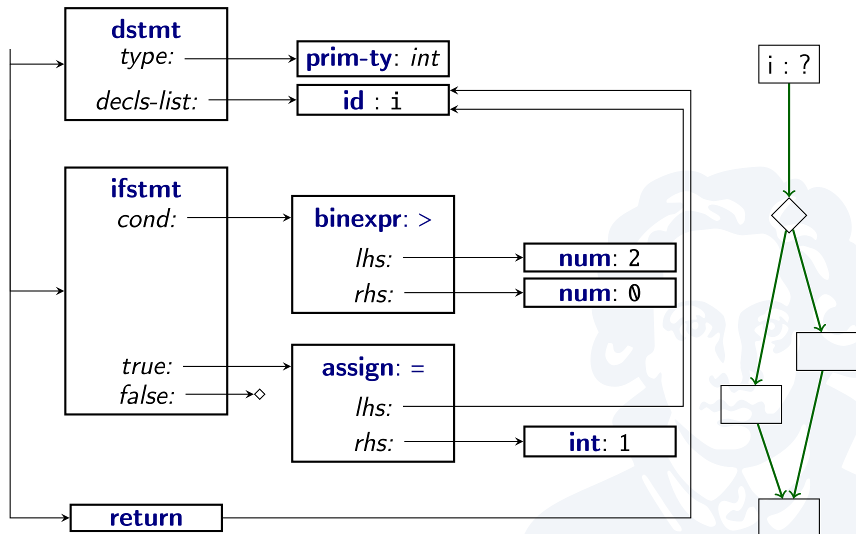

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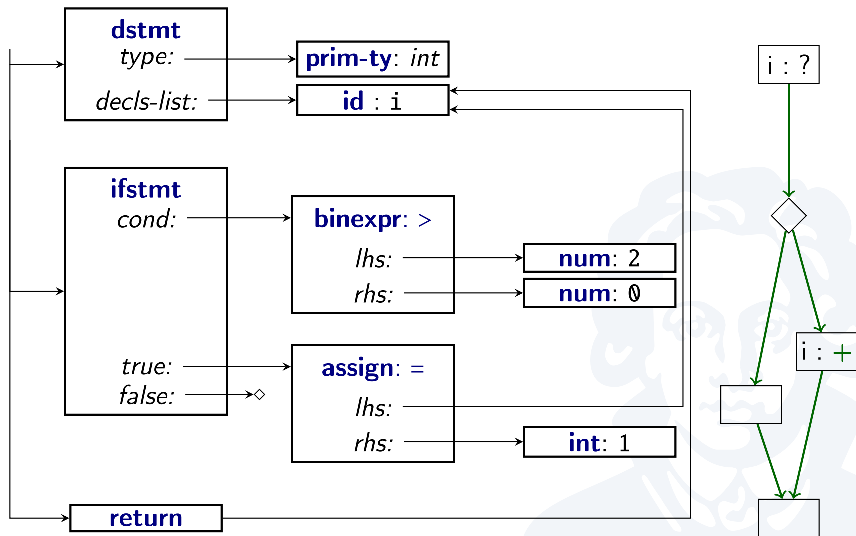

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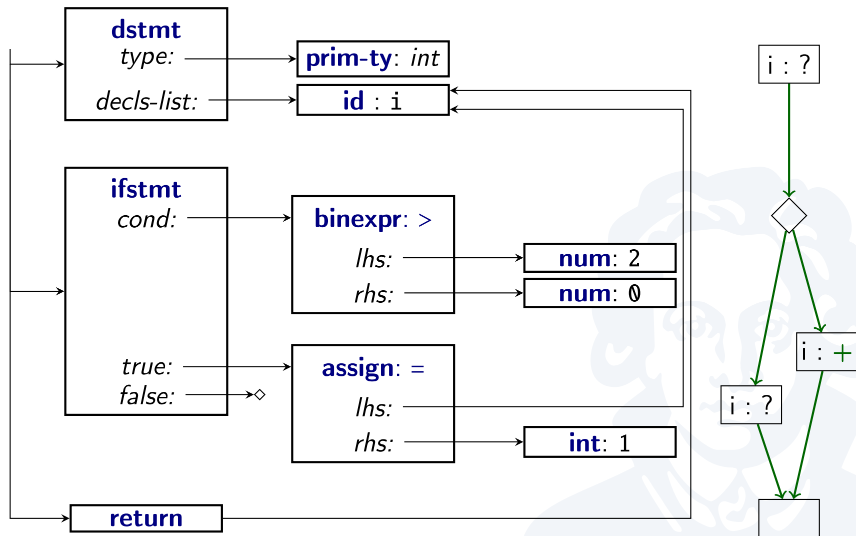

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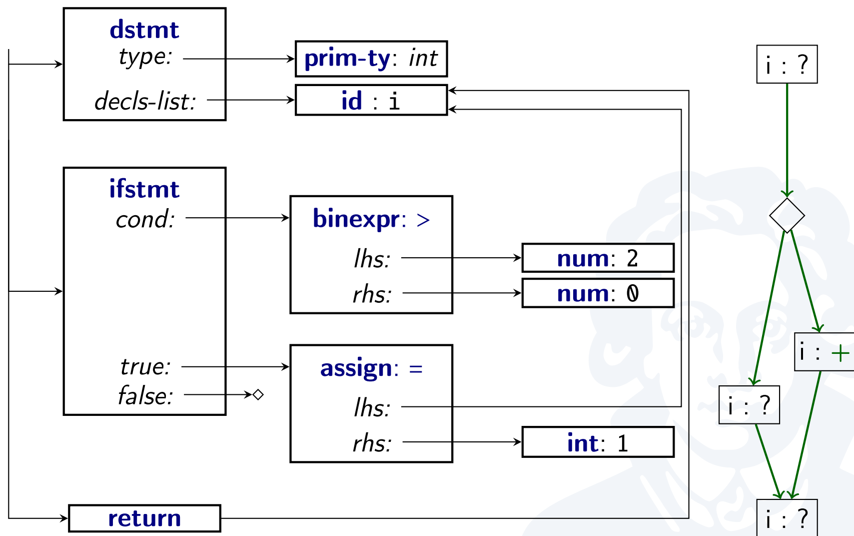

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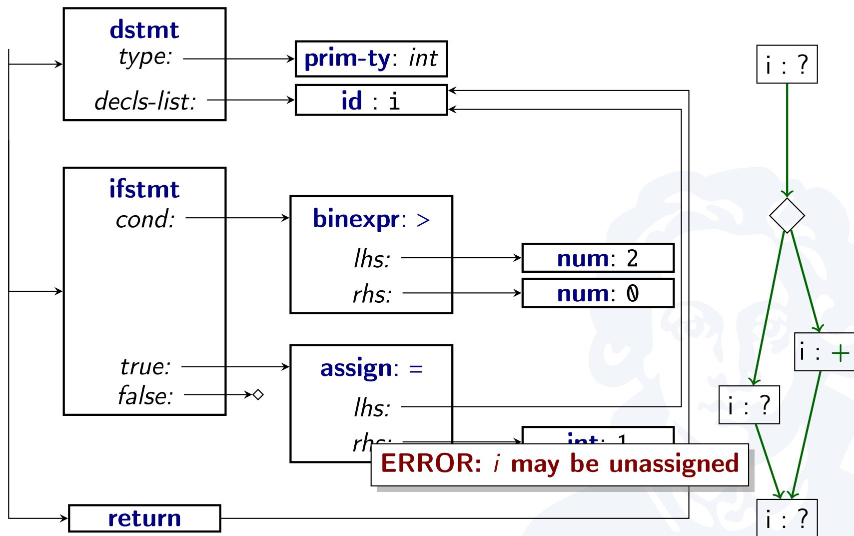


Definite Assignment Analysis

Definite Assignment Analysis:

- Ensures that any variable is assigned prior to use
- Is example of a *data-flow analysis*:

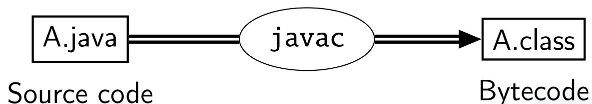
Let's fix the program *again*:

```
int i;
if (2 > 0) {
  i = 1;
} else {
  i = 0;
}
return i;
```

Emitting code

The compiler backend emits bytecode from the AST structure:

- Involves additional steps




```
...
int i;
if (2 > 0) {
  i = 1;
} else {
  i = 0;
}
return i;
...
```

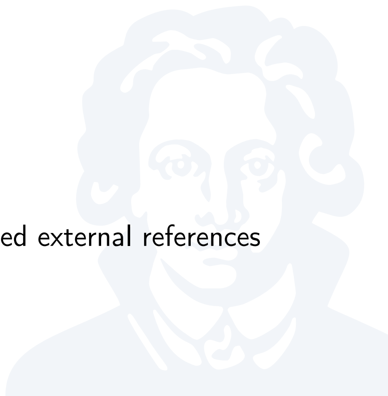
```
...
0:    iconst_2
1:    ifle 9
4:    iconst_1
5:    istore_1
6:    goto 11
9:    iconst_0
10:   istore_1
11:   iload_1
12:   ireturn
...
```

Would typically optimise this bytecode, too. . .

Java Runtime: Loading and Linking Bytecode

Scenario:

- During execution:
  Class `B` calls our code in class `A`
- The Java *Class loader*:
  - finds class `A` (e.g., on harddisk)
  - loads class into RAM
  - *validates* bytecode
  - registers class
  - asks *Linker* to resolve any required external references (none here)



Java Runtime: Interpretation

Bytecode is now in memory and gets *interpreted*:

```
...
     0:   iconst_2
     1:   ifle 9
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     11:  iload_0
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...
```

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Java Runtime: Interpretation

Bytecode is now in memory and gets *interpreted*:

```
...
        0:   iconst_2     Load constant 2
        1:   ifle 9       2 <= 0? No, so continue
  =>    4:   iconst_1
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```

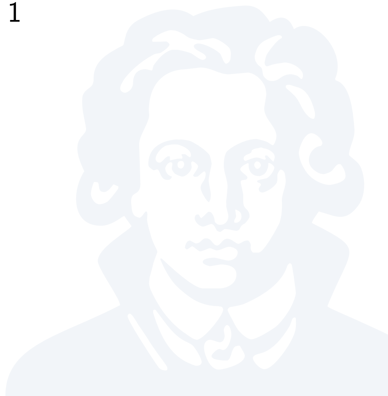
Java Runtime: Interpretation

Bytecode is now in memory and gets *interpreted*:

...

	0:	iconst_2	Load constant 2
	1:	ifle 9	2 <= 0? No, so continue
	4:	iconst_1	load the value 1
⇒	5:	istore_0	
	6:	goto 11	
	9:	iconst_0	
	10:	istore_0	
	11:	iload_0	
	12:	ireturn	

...



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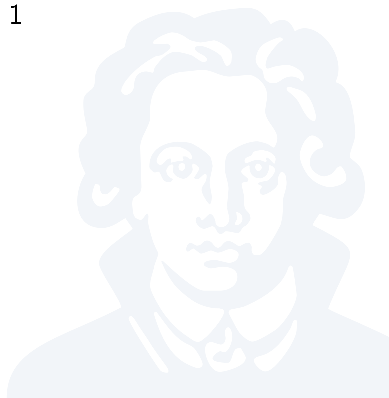
```
...
        0:   iconst_2     Load constant 2
        1:   ifle 9       2 <= 0? No, so continue
        4:   iconst_1     load the value 1
        5:   istore_0     i := 1
  ⇒     6:   goto 11
        9:   iconst_0
        10:  istore_0
        11:  iload_0
        12:  ireturn
...
```



Java Runtime: Interpretation

Bytecode is now in memory and gets *interpreted*:

```
...
        0:   iconst_2     Load constant 2
        1:   ifle 9       2 <= 0? No, so continue
        4:   iconst_1     load the value 1
        5:   istore_0     i := 1
        6:   goto 11      jump to label 11
        9:   iconst_0
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  ⇒     11:  iload_0
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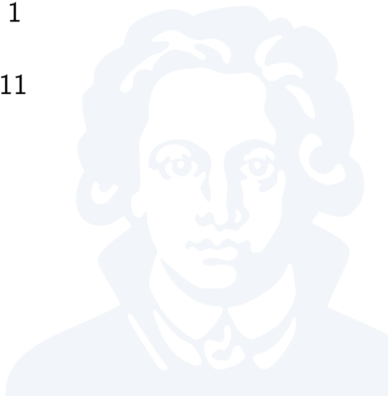
```



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	`5:`	`istore_0`	i := 1
	`6:`	`goto 11`	jump to label 11
	`9:`	`iconst_0`	
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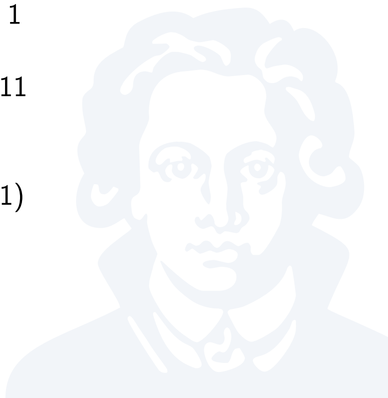
⇒	`12:`	`ireturn`	

...



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`10:`	`istore_0`	
`11:`	`iload_0`	Load *i* (value 1)
`12:`	`ireturn`	Return 1.

...

And the method returns.

Java Runtime: Just-in-time compilation

- Interpretation is fine if code only used once...
- ...very inefficient for important code.
- Option: Compile code in JVM
  - Great for important code
  - Wasteful for unimportant code: *compilation takes time, too!*

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- Option: Compile code in JVM
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    compilation takes time, too!

Let's measure how important the code is!

Java Runtime: Hotness Profiling

```
hotness[METHOD_ID]++
if (hotness[METHOD_ID] > 3) {
    m = compile(METHOD_ID);
    replace(METHOD_ID, m);
    return m();
} else {
            0:    iconst_2
            1:    ifle 9
            4:    iconst_1
            5:    istore_1
            6:    goto 11
            9:    iconst_0
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}
```

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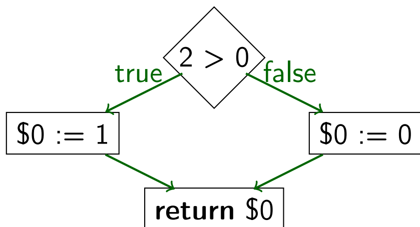
            12:   ireturn
}
```

The JVM only compiles ‘hot’ methods.

Java Runtime: Dynamic Compilation

- Just-in-time compiler translates bytecode into intermediate representation:



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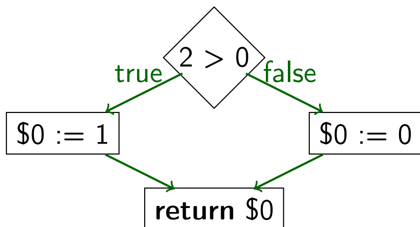
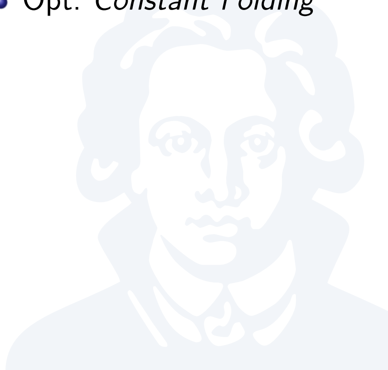


- Opt: *Constant Folding*



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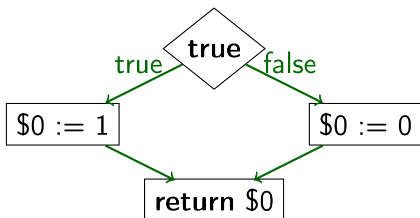

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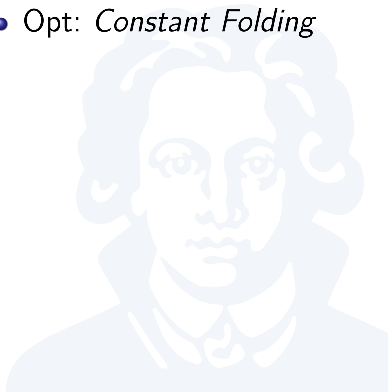

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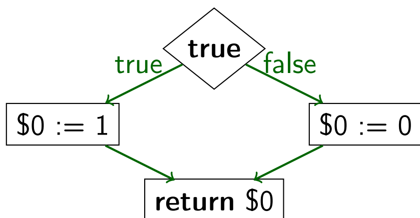

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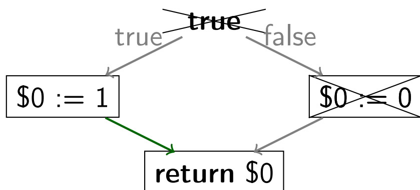

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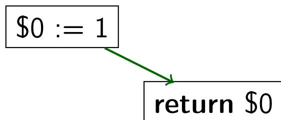

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- Opt: *Dead code elimination*
- Opt: *Constant Propagation*

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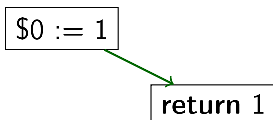

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Java Runtime: Dynamic Compilation

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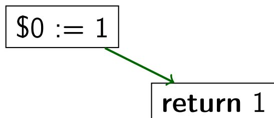


Might compile to e.g.:

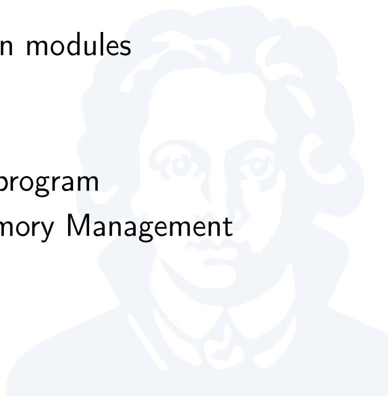
```
b8 01 00 00 00   mov eax,0x1
c3               ret
```

- Opt: *Constant Folding*
- Opt: *Dead code elimination*
- Opt: *Constant Propagation*

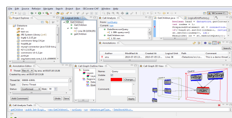
Java Runtime System

Many duties:

- *(Class) Loader*: Loads bytecode
- *Linker*: Resolves references between modules
- *Interpreter*: Slow execution
- *Profiler*: Find important code
- *(Just-in-time) Compiler*: Compile program
- *Garbage Collector*: Automatic Memory Management



Summary: Components of Software Tools



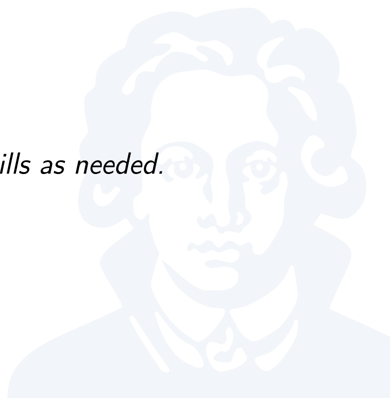
```
for (int i = 0; i < 10; i++) {
  z += i;
  if (z > 42) {
    System.out.println(z);
    z /= 10;
} }
```

```
E8 03 CD 10 c5 01 45 39 e5
38 83 eb 04 4c 39 ff 0f 84
01 45 84 f6 48 89 44 24 38
af 84 d2 79 ab 89 d0 83 e0
74 24 38 31 d2 4c 89 44 24
48 89 7c 24 38 e8 66 92 01
```

Preview: Lectures 01–03

- 01: Syntax, Semantics, Types
- 02: Static Program Analysis
- 03: Dynamic Program Analysis

You are expected to pick up additional skills as needed.

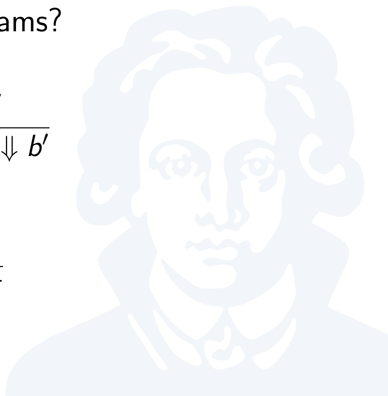


Preview: 01: Syntax, Semantics, Types

- How does meaning follow from structure?
- What is the purpose of types for meaning?
- What do types tell us about programs?

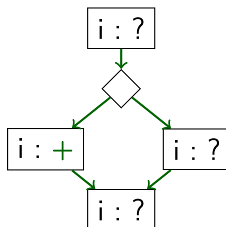
$$\frac{a \Downarrow \text{true} \quad b \Downarrow b'}{\textbf{if } a \textbf{ then } b \textbf{ else } c \Downarrow b'}$$

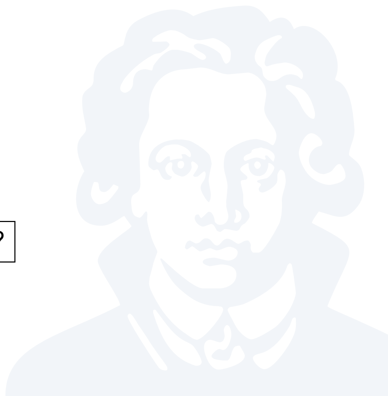
$$\frac{\Gamma, x : \tau \vdash e : \sigma}{\Gamma : \lambda x.e : \tau \to \sigma}$$



Preview: 02: Static Program Analysis

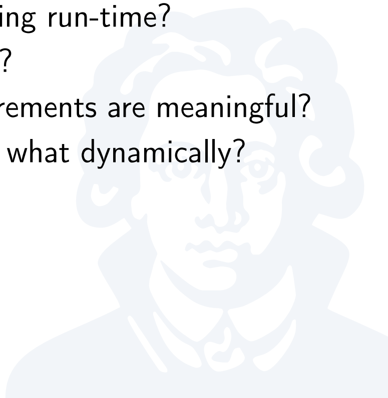
- How can we analyse programs?
  - Type / Effect analysis
  - Flow analysis
  - Constraint analysis
  - Abstract Interpretation





Preview: 03: Dynamic Program Analysis

- How can we analyse programs during run-time?
- What can we measure at run-time?
- How can we make sure our measurements are meaningful?
- What can/should we do statically, what dynamically?



Project proposals

- The following proposals are some possible ideas
- Details have to be worked out
- Proposals available first-come-first-serve
- *Other suggestions are very welcome!*

Contact me *before* May to start discussing options!

Project #1: Automatic (De)serialisation

Joint project with Prof. Dr. Koch, Bioinformatics

- *Serialisation*: information → byte stream
- Writing objects to disk, to the network, ...
- Java has built-in serialisation support
  - *However:* when classes change, loading fails

Goal:

- Design & build serialisation extension to Java
- Use Google Protocol Buffers
- Integrate into the Bioinformatics MonaLisa framework

Project #2: Fix-Up for Program Metamorphosis

Program Metamorphosis:

- Generalisation of *Refactoring*:
  - Source-to-source transformations
  - Individual transformations may alter behaviour
  - Sum of all transformations guaranteed to restore behaviour

Goal:

- Port existing Program Metamorphosis Eclipse plugin to latest Eclipse
- Extend plugin to allow adding elements
- Design & build automatic recovery mechanism

Project #3: Automatic Axiom Inference over Java

Axioms can be used to describe program behaviour:

- $\forall s, x.(s.\text{push}(x).state).\text{pop}().value = x$
- $\forall s, x.(s.\text{push}(x).state).\text{pop}().state = s$

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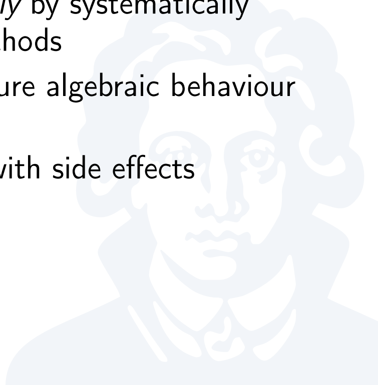
- These can be inferred *automatically* by systematically combining & calling Java API methods
- With enough axioms, we can capture algebraic behaviour of datatypes
- Doesn't scale well for operations with side effects



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- These can be inferred *automatically* by systematically combining & calling Java API methods
- With enough axioms, we can capture algebraic behaviour of datatypes
- Doesn't scale well for operations with side effects

Goal

- Extend existing tool for axiom inference:
  - Use bytecode analysis: what side effects are possible?
  - Expand axiom search to include side effects

Project #4: Probabilistic Modelling in Ren'Py

- Computer game design often involves randomness
- Large numbers of random factors can make it hard to balance the game

Goal:

- For a specially selected subset of the game framework Ren'Py:
- Use *Abstract Interpretation* to capture dependencies between
  - Randomly generated numbers
  - User selections
- Build statistical models
- Use formal reasoning or statistical sampling to answer questions about game balance

Project #5: Automatic Build File Generation

- Developers often experiment with various command-line tools
- Later go back, write their findings into scripts / build files

Goal:

- Automate this process:
- Use Linux `ptrace` mechanism to observe:
  - Which process creates which file?
  - With what command line?
  - From what input files?
- Collect observations
- Propose abstractions over collected data
- Write `Makefile` or similar specification that captures observations

Project #6: Infer Operational Semantics

- Assume as given:
  - A complete language syntax
  - An interpreter for the language
  - A means for obtaining the final last computed value, or 'timeout', or 'error'

Goal:

- Design systematic search that infers language semantics as rules
- Try to make 'reasonable' assumptions
- Can this be extended to handle side effects (e.g., via `ptrace`)?
- Try it out with an existing language (e.g., lua)

Project #7: PQL/C++

PQL/Java is a Java language extension that adds expressions such as:

```
Set<Integer> s = query(Set.contains(x)):
                    s1.contains(x)
                 && s2.contains(x)
                 && x > 10;
```

- Set intersection with value filter
- PQL can choose different implementation strategies for this query

Goal:

- Build a prototype for a similar system for C++

Next week:

Syntax, Semantics, Types