Optimizing String manipulation performance

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Section 1

Motivation

Example

The "normal" way

```java
String result = "";

for (int i = 0; i < line.length(); i += 2) {
  result += line.substring(i, i + 1);
}

return result;
```

Example

The optimized way

```
SubstringString lineOpt = new SubstringString(line);

StringListBuilder builder = new StringListBuilder();

for (int i = 0; i < line.length(); i+=2) {
  builder.append(lineOpt.substring(i, i + 1));
}

return builder.toString();
```

What is the difference?

- Java strings are immutable → manipulation causes `char[]` copy
- '+' operator is compiled to a `StringBuilder`, **but** the loop is not recognized
- `StringBuilder` also array-based
- optimized types avoid this behavior

What is the difference?

- optimized types avoid this behavior
- SubstringString returns only a new object pointing to the new boundaries
- StringListBuilder is a linked list

Measurement

Wouldn't it be nice to have the performance of the optimized one with the readability of the normal one?

Requirements

Given a method optimization definition, the system should . . .

- . . . be applicable to to already compiled programs
- . . . identify method calls in the Java bytecode
- . . . replace these method calls by the optimized ones

Section 2

Bytecode

Bytecode

- What the JVM actual executes (platform independence)
- Assembly language like
- Stack-based and imperative

Bytecode

Java:

```
String x = "Hallo Welt";
String y = x.substring(5);
```

Bytecode:

```
LDC "Hallo World!"
ASTORE 1
ALOAD 1
ICONST 5
INVOKEVIRTUAL java/lang/String.substring(I)Ljava/lang/
    String;
ASTORE 2
```

WALA

- T.J. Watson Library of Analysis (IBM)
- static analysis for Java bytecode and Javascript
- open sourced at `http://github.com/wala/WALA` since 2006

Features

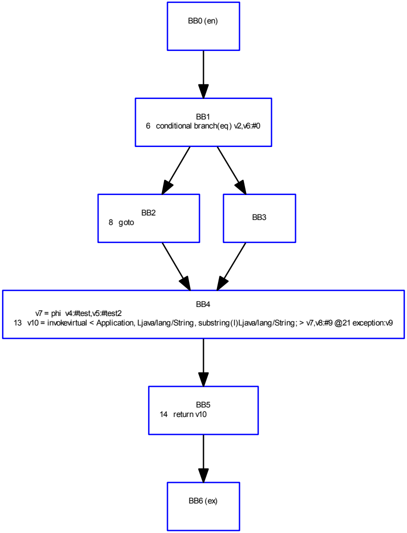
- Java type system and class hierarchy analysis
- supports frontends for Java and JavaScript
- SSA-based Intermediate Representation
- bytecode manipulation

Intermediate Representation

- central data structure that represents the analyzed method
- abstracts the actual bytecode
- is in static single assignment form
- consists of a control-flow graph
- ϕ-nodes represent a merge of variables

```
String a = "test";
String b = "test2";
String c = ((is) ? a:b);

return c.substring(9);
```



BB0 (en)

BB1
6 conditional branch(eq) v2,v6:#0

BB2
8 goto

BB3

BB4
v7 = phi v4:#test,v5:#test2
13 v10 = invokevirtual < Application, Ljava/lang/String, substring(I)Ljava/lang/String; > v7,v8:#9 @21 exception:v9

BB5
14 return v10

BB6 (ex)

Section 4

Analysis

Naming

value number

a variable in the IR

local

a local variable in the bytecode

label

a definition how certain method calls are identified and can be replaced

Basic idea

- Create a dataflow graph of the value numbers in the IR
- determine a bubble in that graph by
    - label all affected method call instructions
    - inherit the labels to all connected value numbers and instructions, if possible

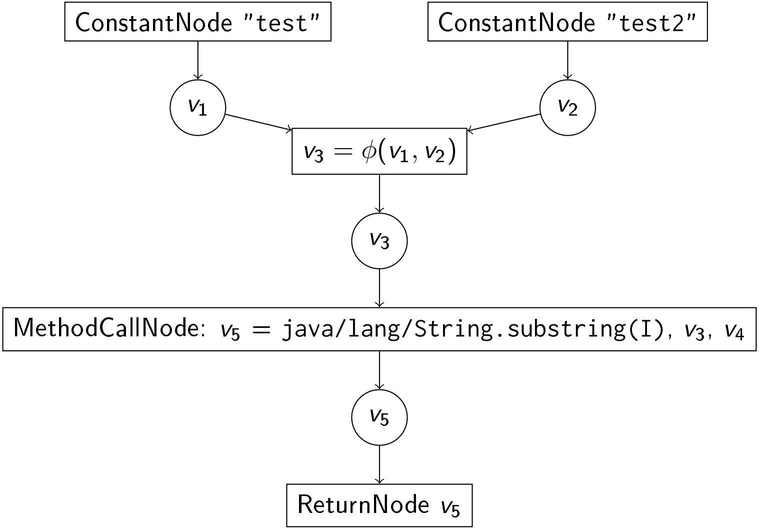
How does the dataflow graph look like?

- directed graph based on the IR
- is composed of 2 kinds of nodes
  - `Reference` merely the value number (R)
  - `InstructionNode` can be seen as a instruction (I)
- for $r \in R$, $i \in I$,
  - (i, r) is called the definition of r
  - (r, i) is called a use of r
- $\forall r \in R, in(r) = 1$, so every r has exactly 1 definition, but n uses (SSA)
- $\forall i \in I, out(i) \leq 1$, so every i can at most define one r

InstructionNodes

- ConstantNode a constant definition (e.g. "Hallo World")
- ParameterNode a parameter of the method
- MethodCallNode a method call (e.g. x.f(y))
- ReturnNode a return instruction of the method
- PhiNode a ϕ node in the IR

example graph



How to define a label?

From the interface TypeLabel:

```
boolean canBeUsedAsParamFor(MethodReference,int)
boolean canBeUsedAsReceiverFor(MethodReference)
boolean canBeDefinedAsResultOf(MethodReference)
boolean canReturnedValueBeLabeled(MethodReference)
boolean compatibleWith(TypeLabel)
ReceiverInfo getReceiverUseInfo(MethodReference)
```

How to deal with phis?

- ϕ-nodes just represent the merge of value numbers
- any label could be compatible with any ϕ instruction
- so they where labeled after the analysis has taken place
- the decision is made by the count of labeled references connected to the particular phi

Section 5

Transformation

What to do?

- Create conversation at the "bubbles" barriers
- replace the original method calls with the optimized ones
- to not overwrite the original values, create appropriate locals for the optimized ones

local matrix

maxlocals are 6 and there are 2 labels (l_1, l_2):

original	l_1	l_2
1	7	10
2	8	11
5	9	12

How to get the locals for a value number?

- IR is an abstraction of the actual bytecode
- simple stack simulation tries to find the position at which the object is pushed onto / popped of the stack
- additionally save the position of the relevant (if any) `store` / `load` instruction
- not possible for branches

Conversations

2 different scenarios:

1. *The value is stored to a local*: Double the value and store it to the optimized local
2. *The value is kept on the stack*: Convert the value on the stack

Method call replacement

- replace the load instruction to load the optimized type
- replace the method call itself to match the expected optimized type
- replace the store instruction to store the result to the optimized type

Section 6

Benchmarks

What are the results?

What did go wrong?

Section 7

Conclusion

Future Work

- loop sensitive `StringBuilder` optimization
- inter procedural optimization would boost performance
- a more offensive bubble growing strategy would cause a bigger bubble

Conclusion

- algorithm to determine the "bubble" is type independent
- transformation on bytecode level makes the system applicable to already compiled programs (libraries in the classpath)