Java Bytecode Optimization

Variable folding optimization for Java bytecode

COMP2010 – Compilers

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1 Introduction

This report will explain how we implemented variable folding for Java bytecode. Performing folding at compile time can result in an extensive reduction of instructions in the bytecode and therefore in an improvement of the overall performance of a program.

The optimization is implemented into a given code framework. This framework contains both tests and a basic implementation so that we could concentrate solely on the optimization. Part of the given implementation is the `optimize` method which is called once for every `.class` file. It initiates the optimization process for every method in the given file.

In the following section 2, we will provide further explanation on how we classified the different bytecode instruction types. It is followed by a detailed description of our most important functions (section 3). The different instruction types in section 2 are all handled differently. Thus, the explanations of how they are handled are supported by flow chart diagrams. The optimization includes an extensive pattern matching phase. Thus, only the most important functions are described. There exists, however, an enumeration type (`OperationType`) as well as plenty help functions that make the pattern matching easier and more modular. Since they are self-explanatory and annotated with comments, we relinquish a detailed description and concentrate more on the algorithmic aspects. The report closes with an example showing the difference between unoptimized and unoptimized code (section 4).

2 Classification of instruction types

In order to distinguish between the different bytecode instructions, we classified the most important ones. Since the scope of this coursework only included arithmetic and logic operations, only the data types `int, long, float` and `double` are considered. We decided to have five different classes of instructions: Push, Conversion, Store, Arithmetic Operation and Comparison.

- **Push**: Instructions that push constants onto the local constant stack (`sipush, bipush, i/f/l/dload, ldc, ldc_w, ldc2_w, i/f/l/dconst`).
- **Conversion**: Instructions that convert the top most constant of the constant stack into a different type (`x2y` where $x, y \in \{i, l, d, f\}$ and $x \neq y$).
- **Store**: Instructions that pop a constant from the stack and store it in the local variable table (`i/f/l/dstore_x` where $x \in [0, 3]$)
- **Arithmetic Op.**: Operation that performs an arithmetic or logical calculation (`i/l/f/dadd/sub/mul/div/rem/neg, i/lshl, i/lshr, iushr, i/lor, i/land, i/lxor`).

- **Comparison**: Instructions that perform a comparison and either push the result on the stack or jump to a certain destination (`d/fcmpg, d/fcmpl, lcmp, ifne, ifle, iflt, ifge, ifgt, ifeq, if_icmpeq, if_icmpne, if_icmplt, if_icmpge, if_icmpgt, ic_icmple`).

3 Implementation description

3.1 `optimize()`

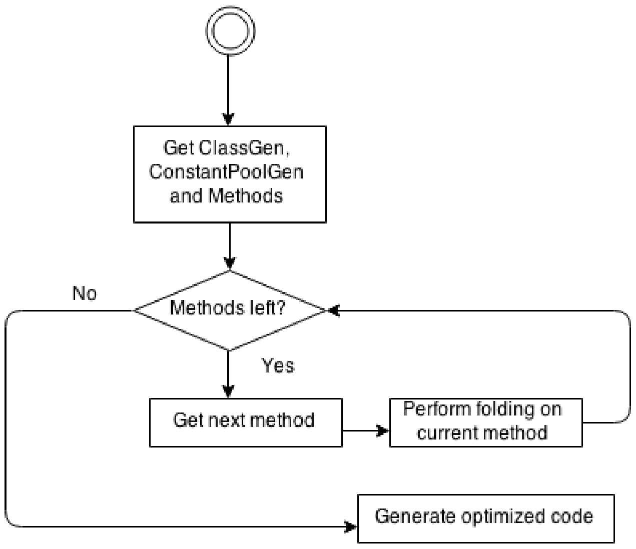

Get ClassGen, ConstantPoolGen and Methods
No
Methods left?
Yes
Get next method
Perform folding on current method
Generate optimized code

Figure 1: The control flow for `optimize`

Brief: Calls `performFolding` for every method.

First off, a new `ClassGen` object is created from which the `ConstantPool` and the unoptimized methods are retrieved. Then, a loop iterates over these methods and calls `performFolding` for each one, passing the current method, the `ConstantPoolGen` and the `ClassGen` object. Once there are no more methods remaining, the optimized code is generated.

3.2 `performFolding(ClassGen gen, ConstantPoolGen cpgen, Method method)`

Brief: Performs simple, constant and dynamic folding on method `m`, invoking itself recursively until no further optimization is possible.

3.2.1 Data Structures

It uses five major data structures to always keep track of the algorithm's and method code's state:

- `constantStack`: Simulates the constant stack and contains only the most recent values.
- `instructionStack`: Contains the actual processed instructions and all those that will be removed at the end.
- `pushInstrIndexStack`: Contains indices of all push instructions of the current optimisation step in the order they appeared in the bytecode.
- `instructionMap`: Instead of completely removing the store operation, it is saved in this data structure in case it is needed at a later point in the code.
- `constantMap`: When a store instruction is read, the topmost constant is popped from the `constantStack` and stored in a local variable table. This `constantMap` simulates that table, so that we always have access to the most recent value of a variable.

3.2.2 Other Variables and Data Structures

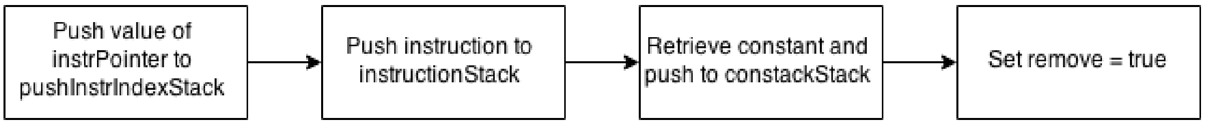
- `methodCode`: Code of the method, containing a header and the `instList`.
- `instList`: List consisting of references to all instructions (`InstructionHandles`) in the method's code
- `remove`: Flag that indicates if an instruction can be removed, i.e. an interaction with the `instructionStack` is necessary.
- `changed`: Flag that indicates whether the instructions have been optimized (i.e. the original code has changed)
- `instrPointer`: Indicates the number of instructions on the `instructionStack`. Incremented only when an instruction is added and decremented when instructions are popped from the stack.

3.2.3 Code Description

The `performFolding` method does all three types of folding: simple, constant, and dynamic. It first retrieves the method's code from the method object and then receives all instructions as a list (`instList`). Then it iterates over the instruction list using the instruction `handle` (pointer to specific instruction in `instList`). Each handle is checked to see if it is a valid instruction - if it is not, then the instruction is ignored and the next handle is addressed. The algorithm determines an instruction's type by making use of Java's `instanceof` operator.

When the loop is finished or has been interrupted by an optimization, the `changed` flag is checked. If `changed` is `true`, the actual reduction step is performed (`performReduction`, subsection 3.3), followed by a clean up (`cleanUpInstructionList`, subsection 3.4) of the `instList`. The latter is necessary to get rid of store-related instructions that do not have an appropriate load and are therefore useless. After the clean up, a new method is created which replaces the current one, and `performFolding` is invoked with this new method (i.e. the optimized code of the original method) as actual parameter.

As explained before, it checks whether each instruction is of type Push (direct/indirect), Conversion, Store, Arithmetic Operation or Comparison (see section 2 for further explanation).



Push value of instrPointer to pushInstrIndexStack
Push instruction to instructionStack
Retrieve constant and push to constackStack
Set remove = true

Figure 2: Control flow for push instructions

Push instructions. First, the instruction is pushed to the `instructionStack`, and the loaded constant is pushed to the `constantStack`. The flag `remove` is also set to `true` which indicates that all following instructions must be taken into account. In the next iteration, if `remove` is set to `true`, it checks the next instruction. If the instruction is not of type Push, it executes specific code according to the instruction type.

It is worth mentioning, that we distinguish between *direct* and *indirect* push operations. Direct push instructions immediately push constants to the stack. Indirect push instructions first load the constant from the local variable table and then push it to the constant stack. The only indirect push instructions are those of type `load`.

Store instruction. Firstly, the instruction's `handle` is added to the `instructionStack` and a temporary handle list (`instructionHandles`) is defined. Then, a variable called `lastPush` is created and initialized with the index of the last push operation, i.e. the topmost element of the `pushInstrIndexStack`. Then a while loop iterates over the `instructionStack` and in each iteration pops the topmost instruction and adds it to `instructionHandles`. Finally, `instrPointer` is decreased. This repeats until all handles that have been added since the last push operation are popped from the `instructionStack`. In this way, the algorithm can even consider conversion instructions which are placed between the last push and the current store instruction. Hence, it pops all handles that are necessary for this store instruction [1]. Once the loop has

[1]This might not even be necessary. However, due to lack of time, we kept it in our implementation, because it works fine.

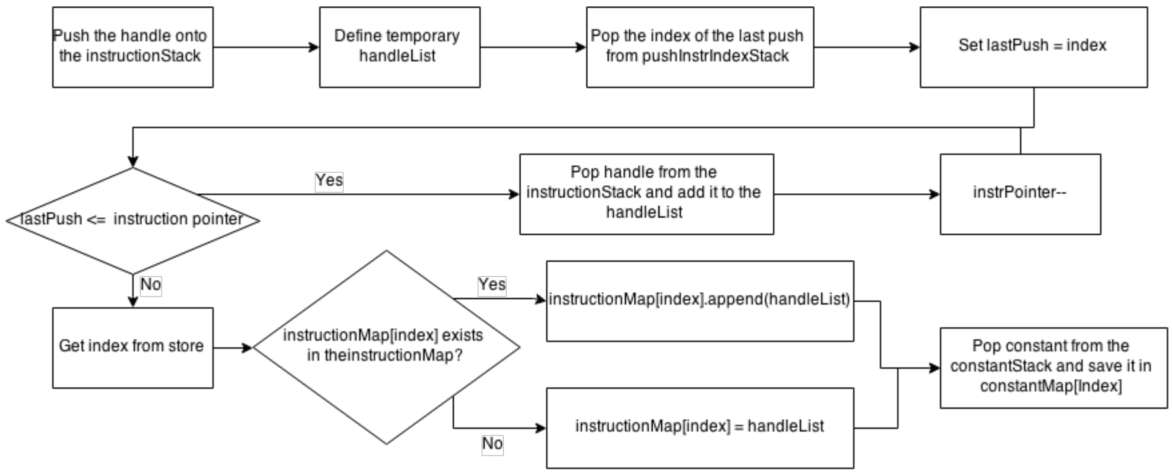

Push the handle onto the instructionStack
Define temporary handleList
Pop the index of the last push from pushInstrIndexStack
Set lastPush = index
lastPush <= instruction pointer
Yes
Pop handle from the instructionStack and add it to the handleList
instrPointer--
No
Get index from store
instructionMap[index] exists in theinstructionMap?
Yes
instructionMap[index].append(handleList)
No
instructionMap[index] = handleList
Pop constant from the constantStack and save it in constantMap[Index]

Figure 3: Control flow for store instructions

ended, it stores the value in the `constantMap`, where the key is the `store` instruction's reference index. It also saves the `handleList` in the `instructionMap`, again using the reference index as key. In case of dynamic folding, the `handleList` is added to the existing one in `instructionMap`. In case anything goes wrong, the containers will be cleared and remove is set to false, meaning that the pattern matching process will start from new in the next iteration.

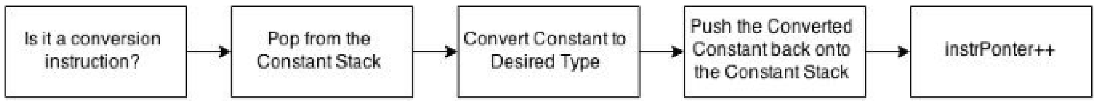

Is it a conversion instruction?
Pop from the Constant Stack
Convert Constant to Desired Type
Push the Converted Constant back onto the Constant Stack
instrPonter++

Figure 4: Control flow for conversion instructions

Conversion instructions. The topmost constant on the `constantStack` is popped and converted to the desired type. It is then pushed back to the `constantStack` and the particular instruction handle is pushed to the `instructionStack`. Finally, the `instrPointer` is incremented.

Arithmetic instructions. If it is an arithmetic instruction, the two topmost constants are popped from the `constantStack`. In case of a negation, only the one topmost constant is popped. The desired calculation is then performed and the result is pushed to the `constantStack` and, if necessary, added to the general constant pool. Next, a new push instruction is inserted within the instruction list directly before the current handle. The type of this instruction depends on the size of the variable. In that way, the algorithm does not add constants to the constant pool when they can be also pushed directly (using `sipush, bipush, i/l/d/fconst`).
If the instruction is not a negation, the topmost push instruction index is popped from

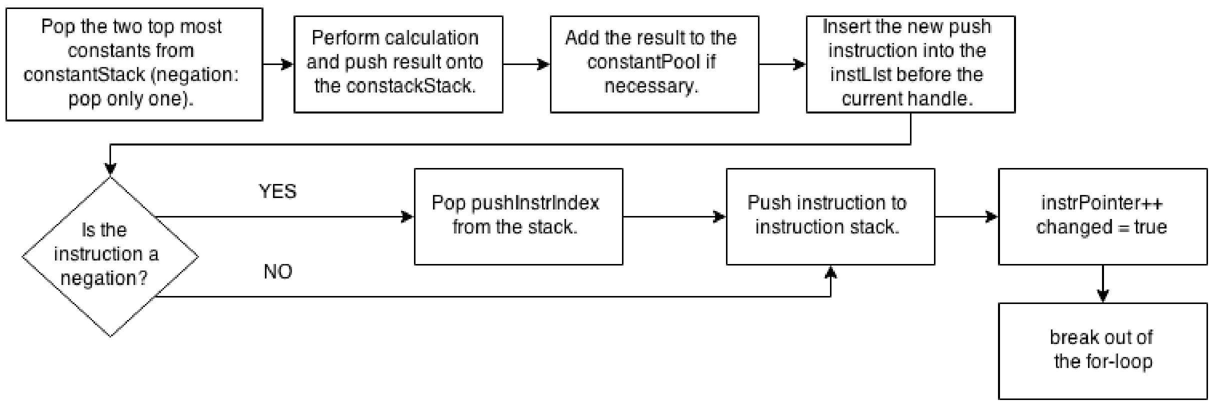

Pop the two top most constants from constantStack (negation: pop only one).
Perform calculation and push result onto the constackStack.
Add the result to the constantPool if necessary.
Insert the new push instruction into the instLIst before the current handle.
Is the instruction a negation?
YES
NO
Pop pushInstrIndex from the stack.
Push instruction to instruction stack.
instrPointer++ changed = true
break out of the for-loop

Figure 5: Control flow for arithmetic operations

pushInstrIndexStack. This is because two push operations are involved in the arithmetic operation and therefore the removal should not stop when reaching the last, but when reaching the second last push instruction on the pushInstrIndexStack. After that, the instruction is pushed to the instructionStack and the instrPointer is incremented by one. Also, the changed flag is set to true. Finally, the function breaks out of the loop, since the algorithm only performs one optimization at a time.

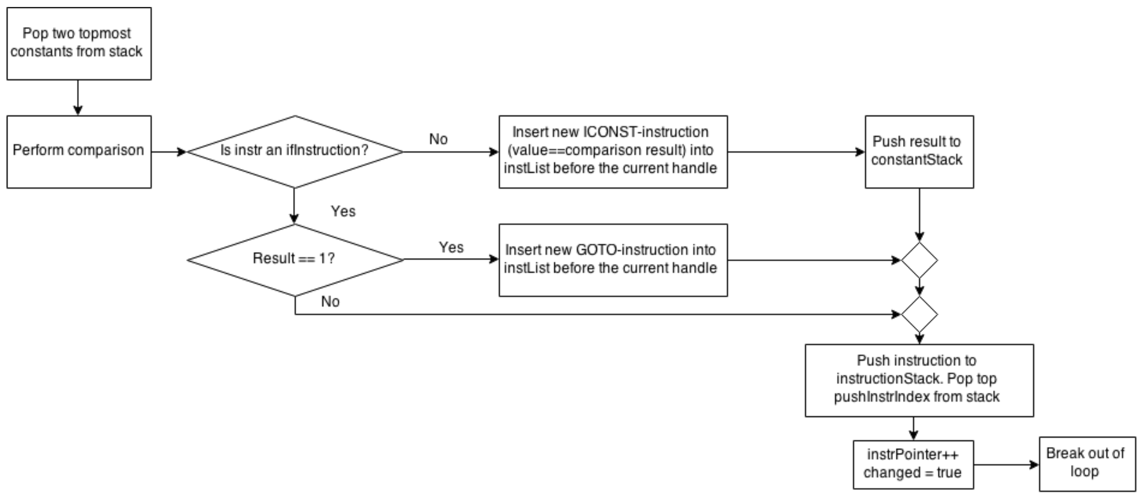

Pop two topmost constants from stack
Perform comparison
Is instr an ifInstruction?
No
Insert new ICONST-instruction (value==comparison result) into instList before the current handle
Push result to constantStack
Yes
Result == 1?
Yes
Insert new GOTO-instruction into instList before the current handle
No
Push instruction to instructionStack. Pop top pushInstrIndex from stack
instrPointer++ changed = true
Break out of loop

Figure 6: Control flow for comparison operations

Comparison instructions. If the instruction's type is a comparison, the two topmost constants are popped from the stack before the comparison is performed. Since particularly if-instructions imply a jump if the comparison evaluates to true, in that particular case the algorithm checks if the result is equal to 1, i.e. true. If this is the case, a new goto instruction is inserted into the instList before the current handle and the instruction is pushed to the instructionStack. This means nothing more than: the current instruction is replaced by a goto instruction. If the result is equal to 0, no

new instruction is added and the current one will simply be removed.
If the instruction is not an if-instruction, the current `handle` is replaced by an `iconst` instruction. Afterwards, the `instrPointer` is incremented and the `changed` flag is set to `true`. Finally, the function breaks out of the loop, since the algorithm only performs one optimization at a time.

3.3 performReduction(

```
        Deque<InstructionHandle> instructionStack,
        InstructionList instList,
        Deque<Integer> pushInstrIndexStack,
        int instrPointer)
```

Brief: Removes all instructions that are not needed any more once the optimization was successful.

This method deletes all instructions in the `instList` that are on the `instructionStack` between the last push and the top. If one of the deleted handles is still targeted by branch instructions, their targets are set to the parameter `newHandle` and the `TargetLostException` therefore handled accordingly.

3.4 cleanUpInstructionList(

```
        Map<Integer,ArrayList<InstructionHandle> > map,
        InstructionList instList,
        InstructionHandle newHandle)
```

Brief: Removes all instructions that are not needed any more once the optimization was successful.

This deletes all unneeded instructions from the instruction list. This is necessary to get rid of store related instructions that do not have an appropriate load and are therefore not needed any more.
First, a list is defined which will store all the entries that will be removed (`removeEntries`). Then the algorithm iterates over all entries in the `instructionMap` and checks whether the current `instList` contains a load with the same reference as the current `entry`'s key. If not, the `entry` is stored in `removeEntries` for later removal.
If one of the deleted handles is still targeted by branch instructions, their targets are set to the parameter `newHandle` and the `TargetLostException` is therefore handled accordingly.

4 Dynamic folding example

The following example illustrates how well our optimization performs. It implies dynamic and constant folding.

Given the following Java code:

```
int a = 42;
int b = (a + 764) * 3;
a = 22;
return b + 1234 - a;
```

Our optimization algorithm is able to perform all calculations at compile time and replaces almost all of the instructions of the unoptimized code with a single push instruction:

```
0: bipush        42
2: istore_1
3: iload_1
4: sipush        764
7: iadd
8: iconst_3
9: imul
10: istore_2
11: bipush        22
13: istore_1
14: iload_2
15: sipush        1234
18: iadd
19: iload_1
20: isub
21: ireturn
```

(a) Unoptimized

```
0: sipush        3630
21: ireturn
```

(b) Optimized

Figure 7: Unoptimized and optimized Java bytecode