Code Generation: Introduction

Example: gcc

test.c

```
#include <stdio.h>
int main() {
  int i = 0;
  int j = 0;
  while (i < 10) {
    printf("%d\n", j);
    i = i + 1;
    j = j + 2*i+1;
  }
}
```

gcc test.c -S

test.s

```
        jmp .L2
.L3:    movl -8(%ebp), %eax
        movl %eax, 4(%esp)
        movl $.LC0, (%esp)
        call printf
        addl $1, -12(%ebp)
        movl -12(%ebp), %eax
        addl %eax, %eax
        addl -8(%ebp), %eax
        addl $1, %eax
        movl %eax, -8(%ebp)
.L2:
        cmpl $9, -12(%ebp)
        jle .L3
```

What did (i<10) compile to?

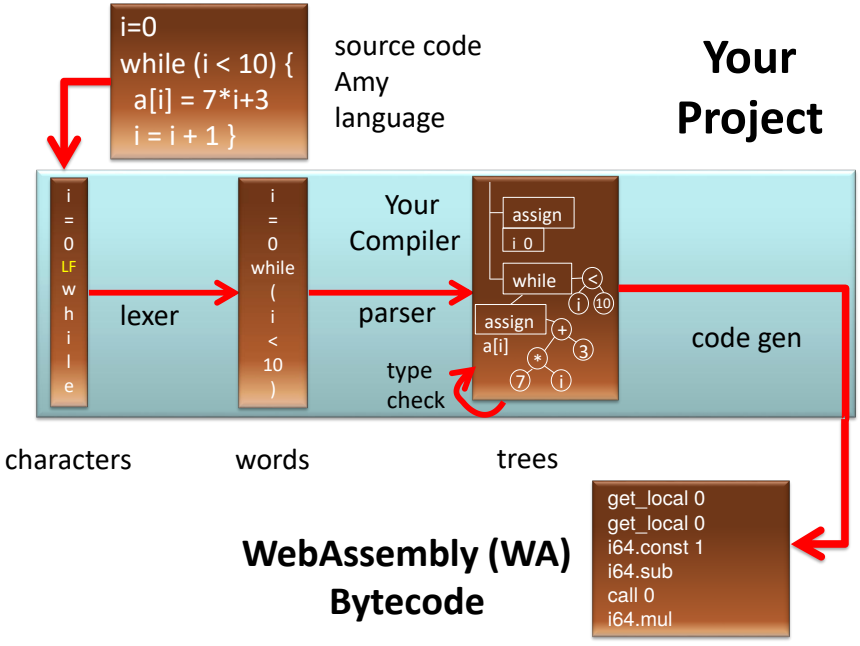
javac example

```
while (i < 10) {
  System.out.println(j);
  i = i + 1;
  j = j + 2*i+1;
}
```

javac Test.java
javap –c Test

```
4: iload_1
5: bipush 10
7: if_icmpge 32
10: getstatic #2; //System.out
13: iload_2
14: invokevirtual #3; //println
17: iload_1
18: iconst_1
19: iadd
20: istore_1
21: iload_2
22: iconst_2
23: iload_1
24: imul
25: iadd
26: iconst_1
27: iadd
28: istore_2
29: goto 4
32: return
```

Guess what each JVM instruction for the highlighted expression does.


i=0
while (i < 10) {
a[i] = 7*i+3
i = i + 1 }
source code
Amy
language
Your
Project
i = 0 LF w h i l e
lexer
i = 0 while (i < 10)
Your
Compiler
parser
assign
i 0
while
<
i
10
assign
a[i]
+
3
*
7
i
type
check
code gen
characters
words
trees
get_local 0
get_local 0
i64.const 1
i64.sub
call 0
i64.mul
WebAssembly (WA)
Bytecode

WebAssembly example

C++

```
int factorial(int n) {
  if (n == 0)
    return 1;
  else
    return n * factorial(n-1);
}
```

WebAssembly

```
get_local 0        // n
i64.const 0        // 0
i64.eq             // n==0 ?
if i64
    i64.const 1    // 1
else
    get_local 0    //  n
    get_local 0    //  n
    i64.const 1    //  1
    i64.sub        // n-1
    call 0         // f(n-1)
    i64.mul        // n*f(n-1)
end
```

More at: https://mbebenita.github.io/WasmExplorer/

Stack Machine: High-Level Machine Code

stack

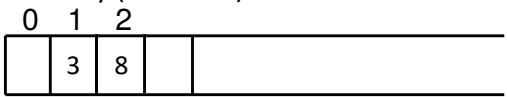
top of stack

instruction sequence:

program counter

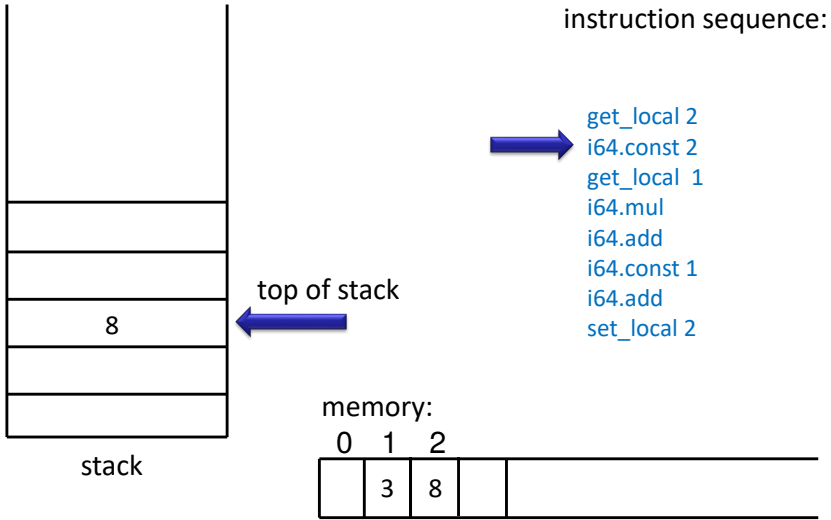
```
get_local 2
i64.const 2
get_local  1
i64.mul
i64.add
i64.const 1
i64.add
set_local 2
```

Memory (for locals):

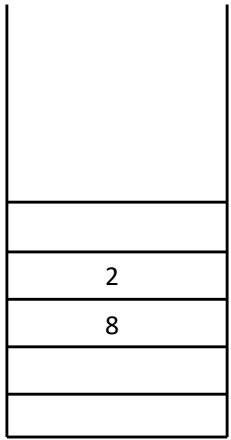


Let us step through

Operands are consumed from stack and put back onto stack



Operands are consumed from stack and put back onto stack

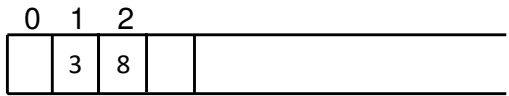


top of stack

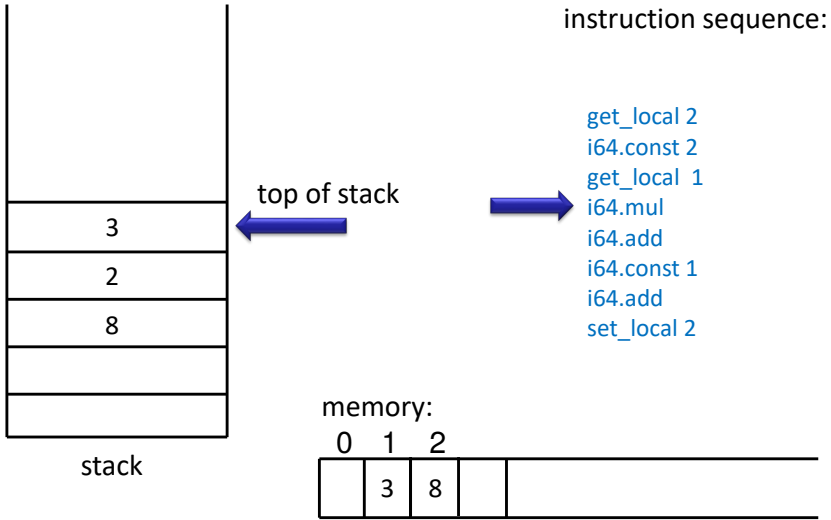
instruction sequence:

```
get_local 2
i64.const 2
get_local  1
i64.mul
i64.add
i64.const 1
i64.add
set_local 2
```

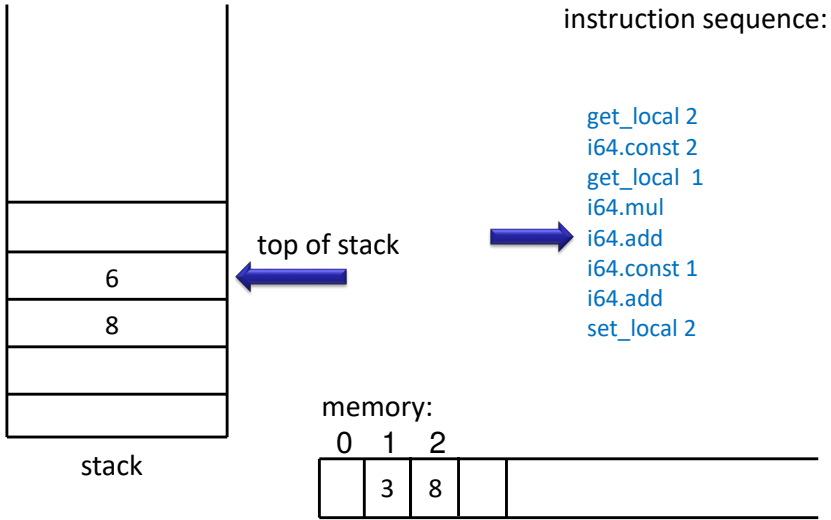
memory:



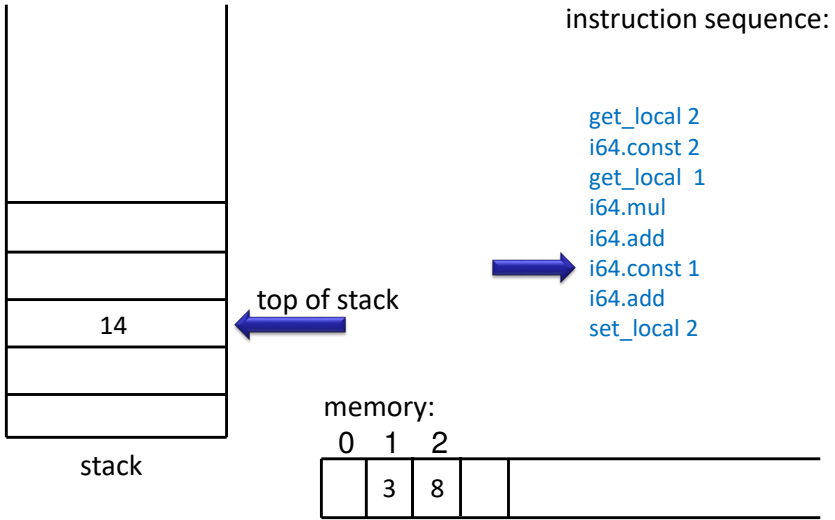
Operands are consumed from stack and put back onto stack



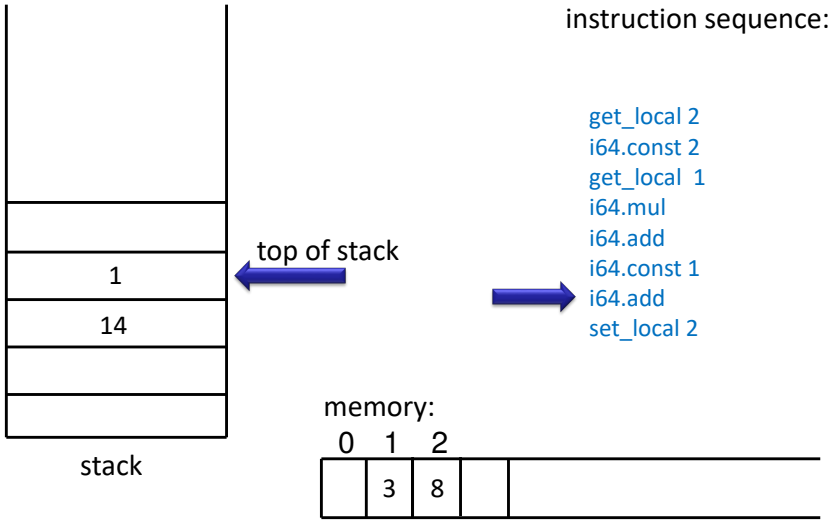
Operands are consumed from stack and put back onto stack



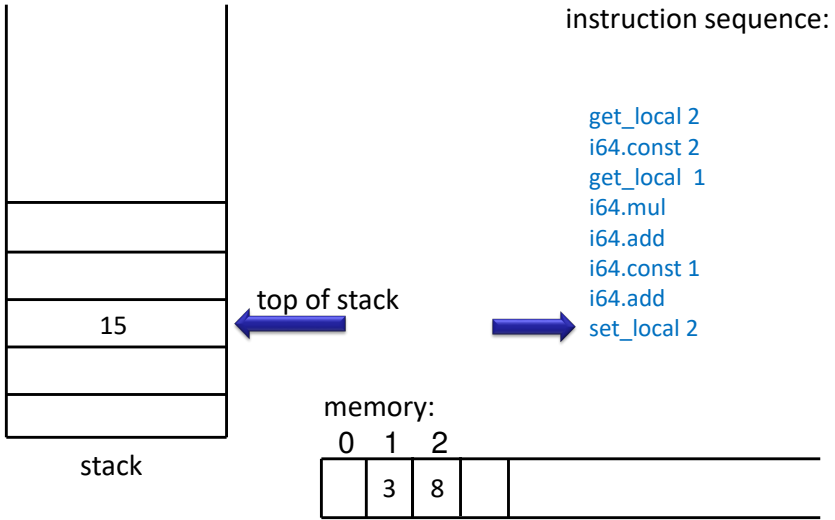
Operands are consumed from stack and put back onto stack



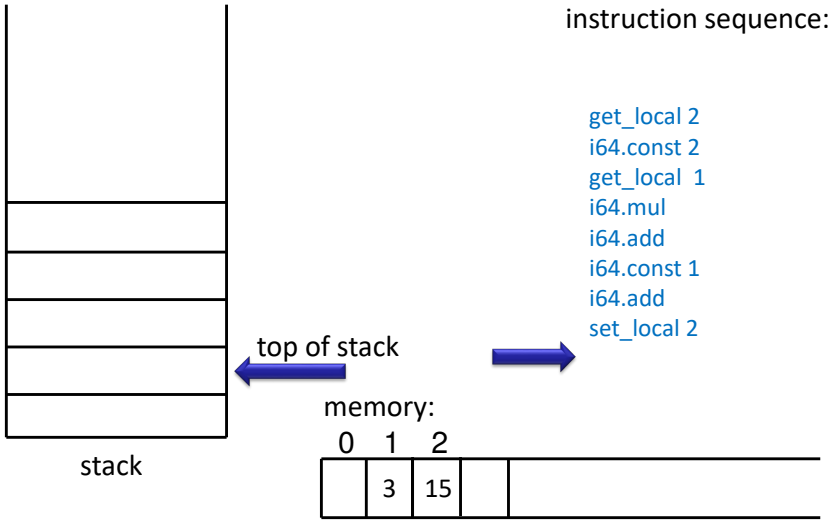
Operands are consumed from stack and put back onto stack



Operands are consumed from stack and put back onto stack

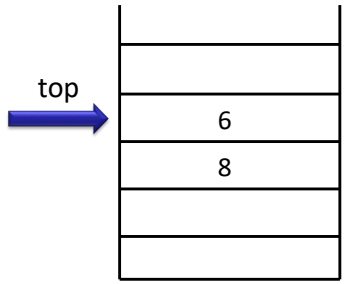


Operands are consumed from stack and put back onto stack



Stack Machine Simulator

```
var code : Array[Instruction]
var pc : Int   // program counter
var local : Array[Int]  // for local variables
var operand : Array[Int]  // operand stack
var top : Int
```




```
while (true) step

 def step = code(pc) match {
   case Iadd() =>
     operand(top - 1) = operand(top - 1) +   operand(top)
     top = top - 1  // two consumed, one produced
   case Imul() =>
     operand(top - 1) = operand(top - 1) * operand(top)
     top = top - 1  // two consumed, one produced
```

Stack Machine Simulator: Moving Data

```
case iconst(c) =>
  operand(top + 1) = c   // put given constant 'c' onto stack
  top = top + 1
case Igetlocal(n) =>
  operand(top + 1) = local(n)  // from memory onto stack
  top = top + 1
case Isetlocal(n) =>
  local(n) = operand(top)  // from stack into memory
  top = top - 1  // consumed
}
if (notJump(code(n)))
  pc = pc + 1   // by default go to next instructions
```

WebAssembly reference interpreter in ocaml:

https://github.com/WebAssembly/spec/tree/master/interpreter

Selected Instructions

Reading and writing locals (and parameters):

- **get_local**: read the current value of a local variable
- **set_local**: set the current value of a local variable
- **tee_local**: like set_local, but also returns the set value

Arithmetic operations (take args from stack, put result on stack):

i32.add: sign-agnostic addition

i32.sub: sign-agnostic subtraction

i32.mul: sign-agnostic multiplication (lower 32-bits)

i32.div_s: signed division (result is truncated toward zero)

i32.rem_s: signed remainder (result has the sign of the dividend x in x%y)

i32.and: sign-agnostic bitwise and

i32.or: sign-agnostic bitwise inclusive or

i32.xor: sign-agnostic bitwise exclusive or

Comparisons, stack, memory

i32.eq: sign-agnostic compare equal

i32.ne: sign-agnostic compare unequal

i32.lt_s: signed less than

i32.le_s: signed less than or equal

i32.gt_s: signed greater than

i32.ge_s: signed greater than or equal

i32.eqz: compare equal to zero (return 1 if operand is zero, 0 otherwise)

There are also: 64 bit integer operations i64._ and floating point f32._ , f64._

drop: drop top of the stack

i32.const C: put a given constant **C** on the stack

Access to memory (given as one big array):

i32.load: get memory index from stack, load 4 bytes (little endian), put on stack

i32.store: get memory address and value, store value in memory as 4 bytes

Can also load/store small numbers by reading/writing fewer bytes, see http://webassembly.org/docs/semantics/

Example: Area

```
int fact(int a, int b, int c) {
  return ((c+a)*b + c*a) * 2;
}
```

```
(module  (type $type0 (func (param i32 i32 i32)
                            (result i32)))
  (table 0 anyfunc)  (memory 1)
  (export "memory" memory)
  (export "fact" $func0)
  (func $func0 (param $var0 i32)
               (param $var1 i32)
               (param $var2 i32)    (result i32)
    get_local $var2
    get_local $var0
    i32.add
    get_local $var1
    i32.mul
    get_local $var2
    get_local $var0
    i32.mul
    i32.add
    i32.const 1
    i32.shl              // shift left, i.e.  *2
))
```