Compilers and computer architecture

Code-generation (2): register-machines

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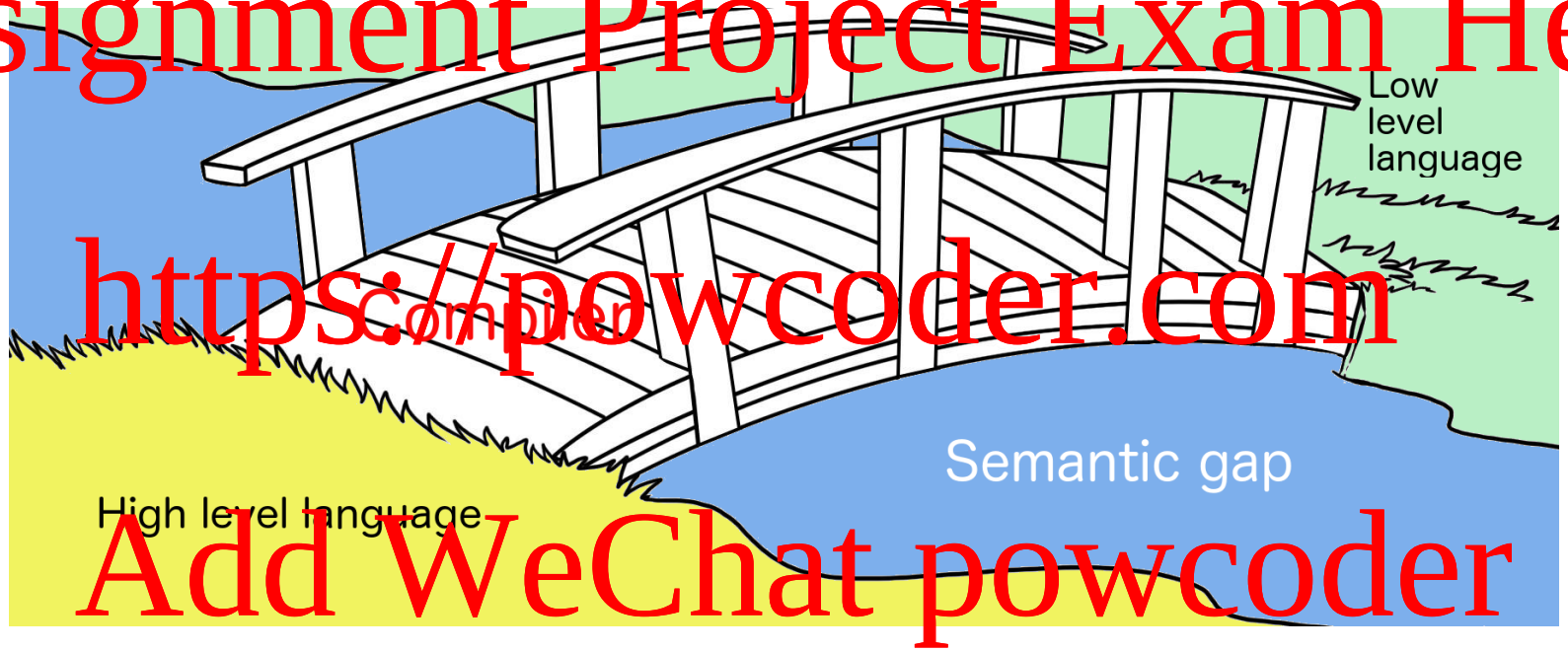
November 2017

Recall the function of compilers



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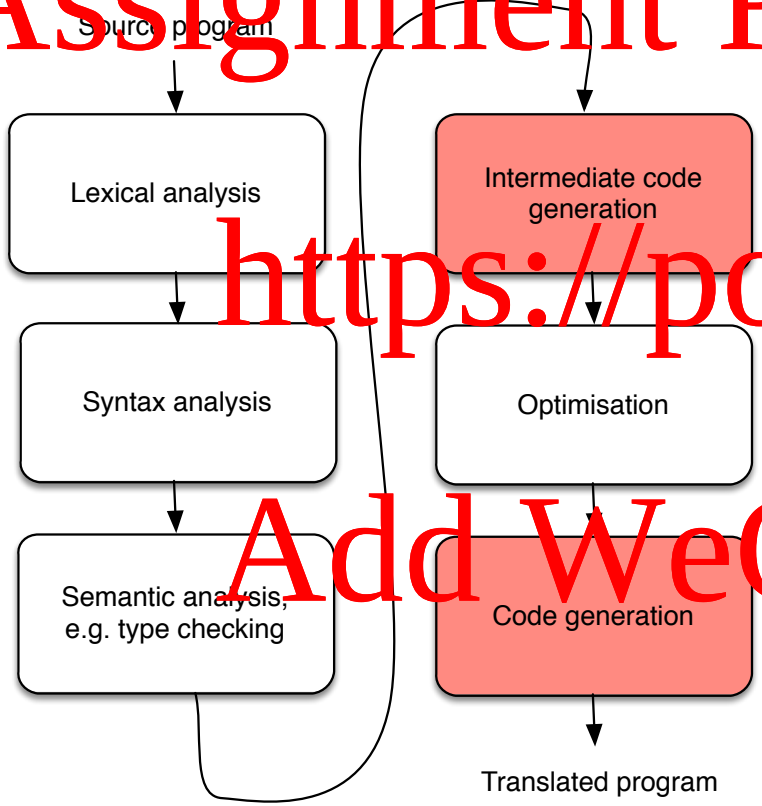

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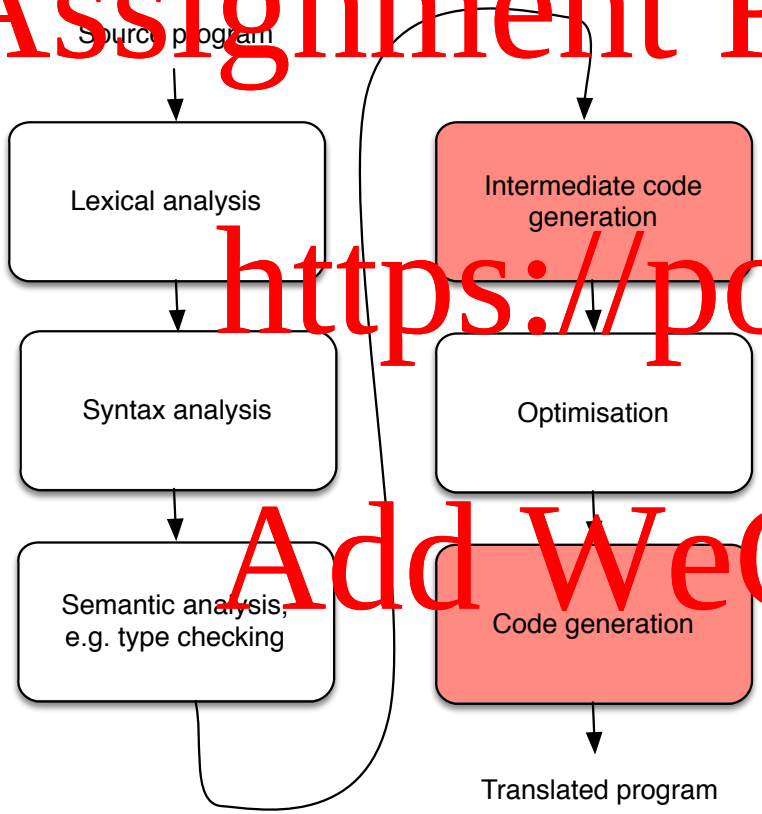

In the previous section we introduced the stack machine architecture, and then investigated a simple syntax-directed code-generator for this architecture.

This week we continue looking at code generation, but for register machines, a faster CPU architecture. If time permits, we'll also look at accumulator machines.

Recall: stack machine architecture

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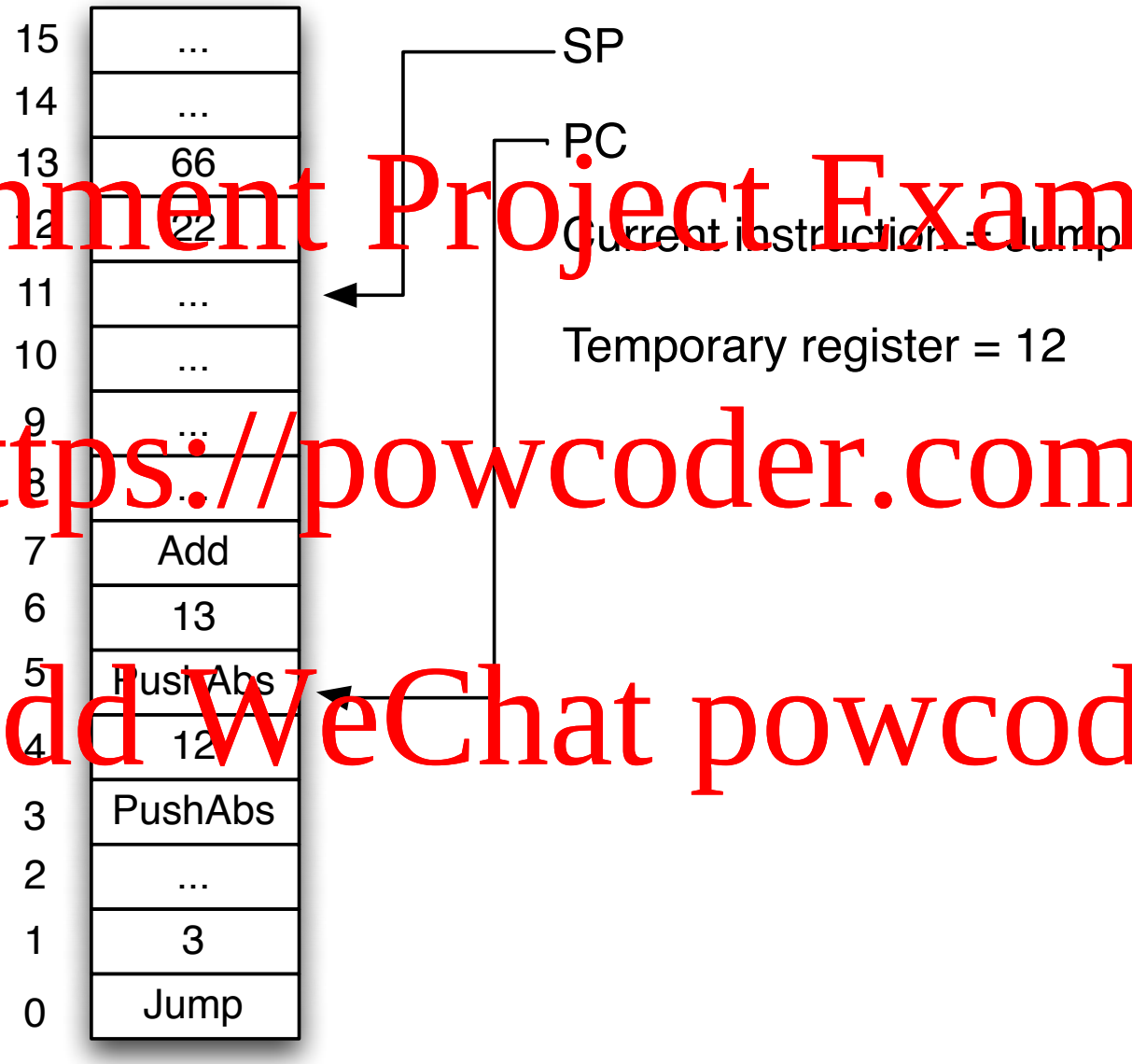

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PushAbs x	PushImm n
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Important: arguments (e.g. to Plus) are always on top of the stack, and are ’removed’ (by rearranging the stack pointer (SP)). The result of the command is placed on the top of the stack.

Register machines

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But compilation for register machines is more complicated than compilation for stack machines. Can you guess why?

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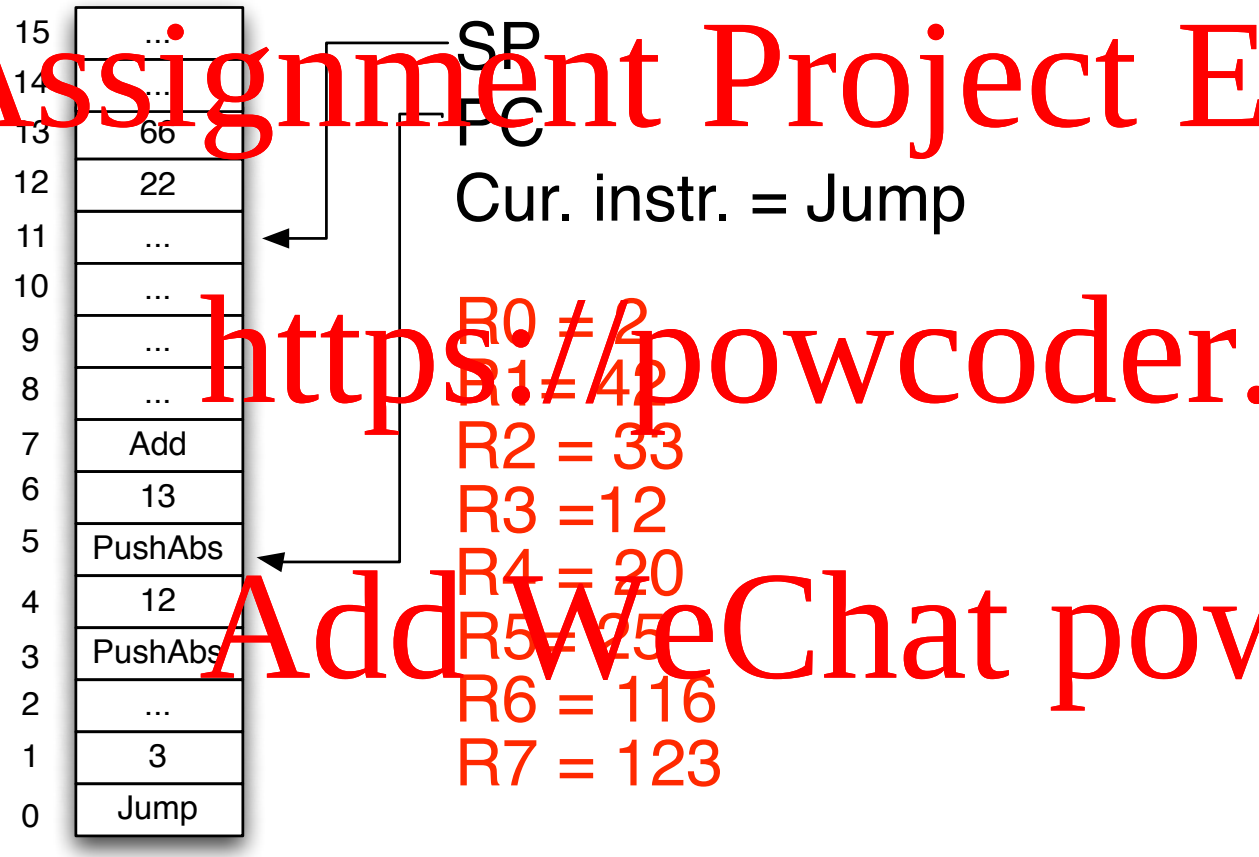

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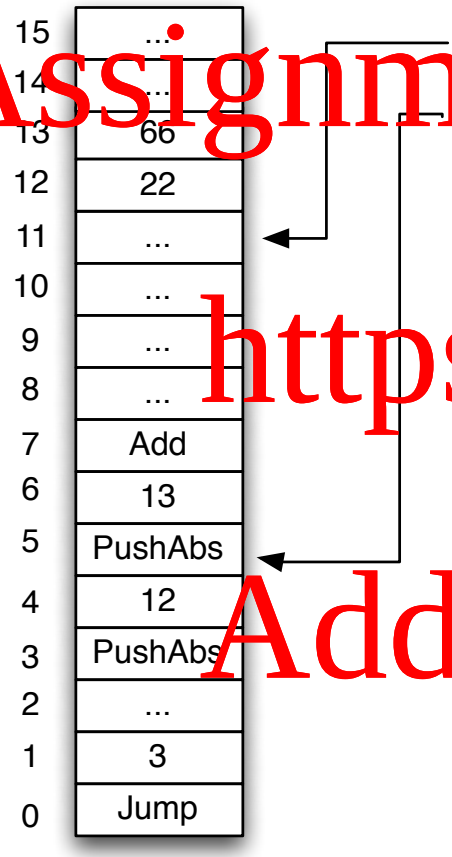

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PC

Cur. instr. = Jump

R0 = 0

R1 = 42

R2 = 33

R3 =12

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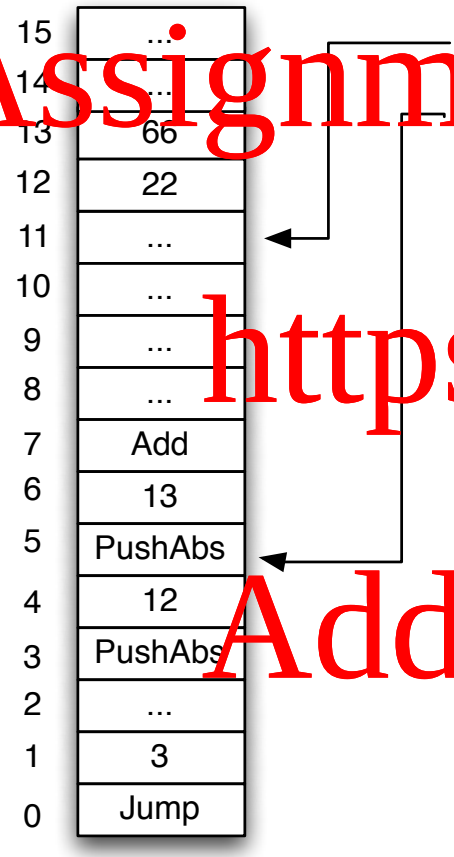

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How to generate code for register machines?

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Let's start by looking at register machines with an **unlimited** number of registers.

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Nop	Does nothing
Pop r	removes the top of the stack and stores it in register r
Push r	Pushes the content of the register r on stack
Load r x	Loads the content of memory location x into register r
LoadImm r n	Loads integer n into register r
Store r x	Stores the content of register r in memory location x
CompGreaterThan r r'	Compares the content of register r with the content of register r'. Stores 1 in r if former is bigger than latter, otherwise stores 0

Commands for register machines

CompEq r r’	Compares the content of register r with the content of register r. Stores 1 in r if both are equal, otherwise stores 0
Jump l	Jumps to l
JumpTrue r l	Jumps to address/label l if the content of register r is not 0
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Some commands have arguments (called operands). They take two (if the command has one operand) or three units of storage, the others only one. These operands need to be specified in the op-code, unlike with the stack machine. (Why?)

Commands for register machines

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Important for e.g. procedure/method invocation. We'll talk about that later.

Source language

Our source language is unchanged: a really simple imperative language.

$$M ::= M;M \mid \texttt{for}\ x = E\ \texttt{to}\ E\ \{M\} \mid x := E$$
$$E ::= n \mid x \mid E + E \mid E - E \mid E * E \mid E / E \mid -E$$

Everything that's difficult to compile, e.g. procedures, objects, is left out. We come to that later.

Code generation for register machines

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def codegen ( s : AST, target :  Register )
            : List [ Instruction ]

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Similar conventions for `codegen` for statements.

Code generation for constants


```
def codegenExpr ( exp : Expr, target : Register ) = {
    if exp is of shape
       ...
       Const ( n ) then
            List ( I_LoadImm ( target, n ) ) } }
```

Code generation for variables


```
def codegenExpr ( exp : Expr, target : Register ) = {
    if exp is of shape
        ...
    Ident ( x ) then
        List ( I_Load ( target, x ) )
```

Code generation for binary expressions

```
def codegenExpr ( exp : Expr, target : Register ) = {
    if exp is of shape
        Binop ( lhs, op, rhs ) then {
            codegenExpr ( rhs, target ) ++
            codegenExpr ( lhs, target+1 ) ++
            codegenBinop ( op, target, target+1 ) }
```

where

```
def codegenBinop ( op : Op, r1 : Register,
                                r2 : Register ) = {
    if op is of shape
        Plus then List ( I_Plus ( r1, r2 ) )
        Minus then List ( I_Minus ( r1, r2 ) )
        Times then List ( I_Times ( r1, r2 ) )
        Divide then List ( I_Divide ( r1, r2 ) ) } }
```

Code generation for binary expressions

Note that the call `codegenExpr(lhs, target+1)` in

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Please convince yourself that each clause of `codegenExpr` really implements this guarantee!

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Load r19 x
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How is this better?

Side by side

Compilation of (x*3)+4

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LoadImm r17 4
LoadImm r18 3
Load r19 x
Times r18 r19
Plus r17 r18
```

Compilation of 4+(x*3)

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LoadImm r17 3
Load r18 x
Times r17 r18
LoadImm r18 4
Plus r17 r18
```

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The translation on the left uses 3 registers, while the right only two. We are currently assuming an unbounded number of registers, so who cares...

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The translation on the left uses 3 registers, while the right only two. We are currently assuming an unbounded number of registers, so who cares... For realistic CPUs the number of registers is small, so smart translation strategies that save registers are better. More on this later!

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Then (x*3)+4 translates to

```
Load r17 x
TimesImm r17 3
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This is a different **address(ing) mode**. We may see more about this later.

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Now we do something more interesting.

Bounded register numbers

It's easy to compile to register machine code, when the number of registers is unlimited. Now we look at compilation to register machines with a fixed number of registers.

Let's go to the other extreme: just one register called **accumulator**. Operations take one of their arguments from the accumulator, and store the result in the accumulator. Additional arguments are taken from the top of the stack.

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The effect is that most expressions get the full benefit of registers, while unusually large expressions are handled correctly.