CS 241, Lecture 20: Code Generation for Procedures

1 Procedures

1.1 Differences between generic procedures and wain:

- We don't need imports
- Need to update `$29`
- Save registers
- Restore registers and stack and `jr $31` at the end

1.2 Saving and Restoring Registers, Arguments

- Our convention is that the caller saves `$31`, and the callee will save registers that it will modify and restore in the end.
- The caller also saves register `$29`,
- We now need to store the arguments to pass to a function.
- We can't store this on registers, we need to store this on the stack.
- We get the following code for a `factor` → `ID(expr1, \dots , exprn)`:

```
code(factor) = push(s29)
               + push(s31)
               + code(expr1)
               + push(s3)
               + code(expr2)
               + push(s3)
               + ...
               + code(exprn)
               + push(s3)
               + lis s5
               + .word ID
               + jalr s5
               + pop n times
               + pop(s31)
               + pop(s29)
```

- For `procedures` → **`int`** `ID(params) dcls statements RETURN expr;`, we have:

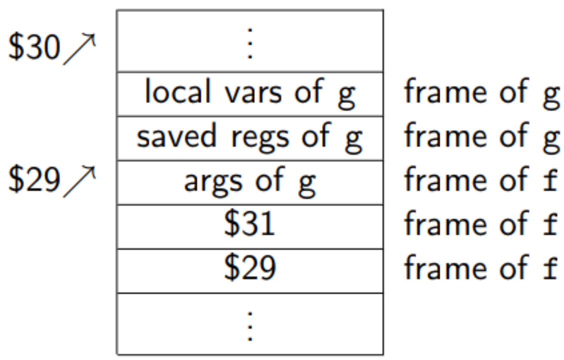
```
code(procedure) = sub s29, s30, s4
                  ;save registers we are going to use:
                  + push regs
                  + code(dcls) ;local vars
                  + code(stmts)
                  + code(expr)
                  + pop regs ;restore saved regs
                  + add s30, s29, s4
                  + jr s31
```

. . . except nope, this isn't going to be that easy! We have some problems!

1.3 Stack

- Basically, the issue with our previous approach is that our parameter offsets will be below register \$29. . . which isn't good! This also causes problems with local variables since the saved registers come before local variables.

- Essentially, the issue is that our saved registers of our function would come before our local vars. . . like so:



- We rewrite our procedure code:

```
code(procedure) = sub s29, s30, s4
                  + push dcls ;local vars
                  + push regs ;save used regs
                  + code(stmts)
                  + code(expr)
                  + pop regs ;restore saved regs
                  + add s30, s29, s4
                  + jr s31
```

  where `push dcls` means to run `code(dcls)` and push them all to the stack.

- Now our stack looks like this:

\$30 ↗	⋮	
	saved regs of g	frame of g
	local vars of g	frame of g
\$29 ↗	args of g	frame of f
	\$31	frame of f
	\$29	frame of f
	⋮	

- In summary:
  - Parameters should have positive offsets
  - Local variables should have non-positive offsets
  - Symbol tables should have added 4 $\times$ #params to each entry in the table

1.4 Labels

- What if we have a function called `print` in our WLP4 code? We would have duplicate labels with our reserved label for printing!
- This is also a problem with `new, init, delete`. We could just ban these keywords... but that seems a bit much.
- Luckily there's an easy and simple solulution — just append an `F` in front of our labels for functions! So our code for factors into function calls would now be:

```
code(factor) = push(s29)
               + push(s31)
               + code(expr1)
               + push(s3)
               + code(expr2)
               + push(s3)
               + ...
               + code(exprn)
               + push(s3)
               + lis s5
               + .word FID ;append F in front of the ID
               + jalr s5
               + pop n times
               + pop(s31)
               + pop(s29)
```

1.5 Optimization

- **Constant folding:** if we are constantly using the same constant repeatedly, we can just load it *once* instead of multiple times!
- If you aren't going to ever use a local variable, you could remove the stack entry part, saving more space.
- **Common subexpression elimination:** If you see the same value being computed twice, you can instead compute that value ONCE and call it on itself. For example, $(a-b)*(a-b)$ can be resolved by solving $(a-b)$ once then calling `mult` on itself.
- **Dead code elimination:** Remove code that will never execute!
- **Register allocation:**
  - Accessing variables on RAM is expensive... and we have unused registers \$14 to \$28... so let's use them!
  - But *what* should we store here? Most used? Recently used?
  - We try to do it such that variables are in registers when in a live range, and remove them when outside of this range.
  - For example, given this code:

    ```
    int wain(int a, int b) {
        int x = 0; int y = 0; int z = 0;
        x = 3;
        y = 10;
        println(x);
        z = 7;
        y = y - x;
        y = y - z;
        println(z);
        return z;
    }
    ```

    the live ranges are `x`: lines 3 to 7, `y`: lines 4-8, and `z`: lines 6 to 10.
  - Note that in this example, we could easily just stick all three variables into registers.
- **Strength reduction:** Use addition instead of multiplication if possible.
- **Inlining procedures:** Consider the following:

  ```
  int f (int a, int b) {
      return a + b;
  }

  int wain(int a, int b) {
      return f(a, b);
  }
  ```

This is equal to:

```
int wain(int a, int b) {
    return a + b;
}
```

This eliminates the overhead of a function call. Note this isn't *always* shorter, but it is if `f`'s body is shorter than the code to call it, and/or if we are calling it only a few times.

- **Tail recursion:**
  - Given code where the last operation in a function is returning a value when recursing, we can reuse the current stack frame to save operations... but we can't do this in WLP4 as we don't allow for return statements in if statements!
  - But if we could... then all we need to do is in our `factor` code, reset stack pointer and `jr` to the function label versus popping args, saving $31 or $29.
- Okay but... how do we do these optimizations? What we often do is first, rewrite our code *in our current language* - this is called **intermediate code**. So in our case, rewrite our stuff to work better *in* WLP4, THEN we run this through our compiler!