Register Allocation, i

Overview & spilling

L1

```
      p ::= ((i ...) (label i ...) ...)
      i ::= (x <- s)
          | (x <- (mem x n4))
          | ((mem x n4) <- s)
          | (x aop= t)
          | (x sop= sx)
          | (x sop= num)
          | (cx <- t cmp t)
          | label
          | (goto label)
          | (cjump t cmp t label label)
          | (call u)
          | (tail-call u)
          | (return)
          | (eax <- (print t))
          | (eax <- (allocate t t))
          | (eax <- (array-error t t))
   aop= ::= += | -= | *= | &=
    sop ::= <<= | >>=
    cmp ::= < | <= | =
      s ::= x | num | label
      t ::= x | num
      u ::= x | label
   x, y ::= cx | esi | edi | ebp | esp
     cx ::= eax | ecx | edx | ebx
     sx ::= ecx
```

L2

```
p ::= ((i ...) (label i ...) ...)
i ::= (x <- s)
    | (x <- (mem x n4))
    | ((mem x n4) <- s)
    | (x aop= t)
    | (x sop= sx)
    | (x sop= num)
    | (cx <- t cmp t)
    | label
    | (goto label)
    | (cjump t cmp t label label)
    | (call u)
    | (tail-call u)
    | (return)
    | (eax <- (print t))
    | (eax <- (allocate t t))
    | (eax <- (array-error t t))
aop= ::= += | -= | *= | &=
 sop ::= <<= | >>=
 cmp ::= < | <= | =
   s ::= x | num | label
   t ::= x | num
   u ::= x | label
x, y ::= cx | esi | edi | ebp | esp
  cx ::= eax | ecx | edx | ebx | var
  sx ::= ecx | var
 var ::= variable matching regexp ^[a-zA-Z_][a-zA-Z_0-9-]*$,
         except registers and keywords (e.g., print, call, cjump, ...)
```

L2 semantics: variables

L2 behaves just like L1, except that non-reg variables are function local, e.g.,

```
(define (f x)        ⇒   ((; :main
  (+ (g x) 1))              (eax <- 10)
                            (call :f))
(define (g x)              (:f (temp <- 1)
  (+ x 2))                     (call :g)
                               (eax += temp)
(f 10)                         (return))
                           (:g (temp <- 2)
                               (eax += temp)
                               (return)))
```

The assignment to **`temp`** in **`g`** does not break **`f`**, but if **`temp`** were a register, it would.

L2 semantics: esp & ebp

L2 programs must use neither **`esp`** nor **`ebp`**. They are in L2 to facilitate register allocation only, *not* for the L3 → L2 compiler's use.

From L2 to L1

Register allocation, in three parts; for each function body we do:

- **Liveness analysis** ⇒ interference graph (nodes are variables; edges indicate "cannot be in the same register")
- **Graph coloring** ⇒ register assignments
- **Spilling:** coping with too few registers
- Bonus part, **coalescing** eliminating redundant `(x <- y)` instructions

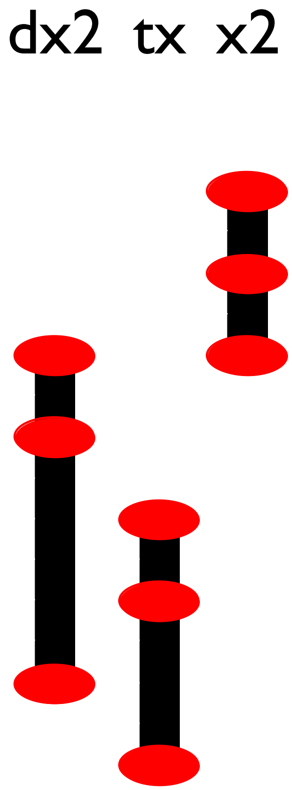
Example Function

int f(int x) = $2x^2 + 3x + 4$

```
:f
(x2 <- eax)
(x2 *= x2)
(dx2 <- x2)
(dx2 *= 2)
(tx <- eax)
(tx *= 3)
(eax <- dx2)
(eax += tx)
(eax += 4)
(return)
```

Example Function: live ranges

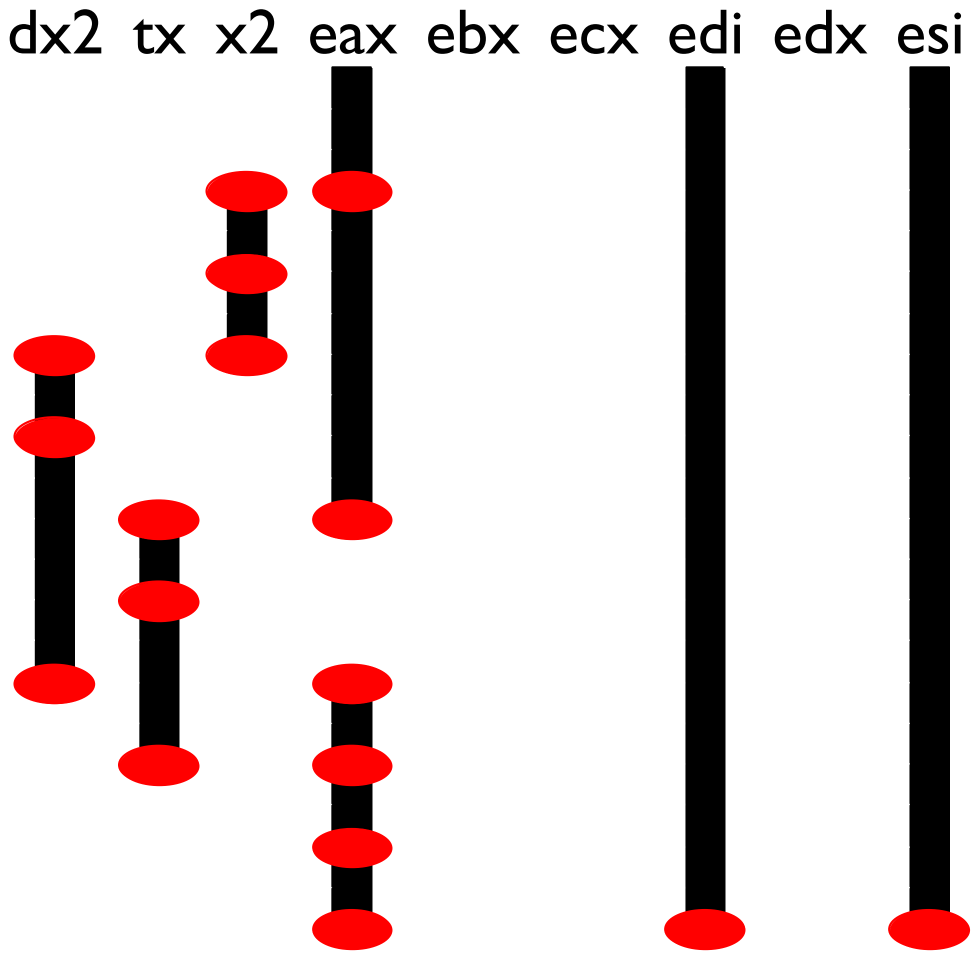
int f(int x) = $2x^2 + 3x + 4$




```
:f
(x2 <- eax)
(x2 *= x2)
(dx2 <- x2)
(dx2 *= 2)
(tx <- eax)
(tx *= 3)
(eax <- dx2)
(eax += tx)
(eax += 4)
(return)
```

Example Function: live ranges

int f(int x) = $2x^2 + 3x + 4$

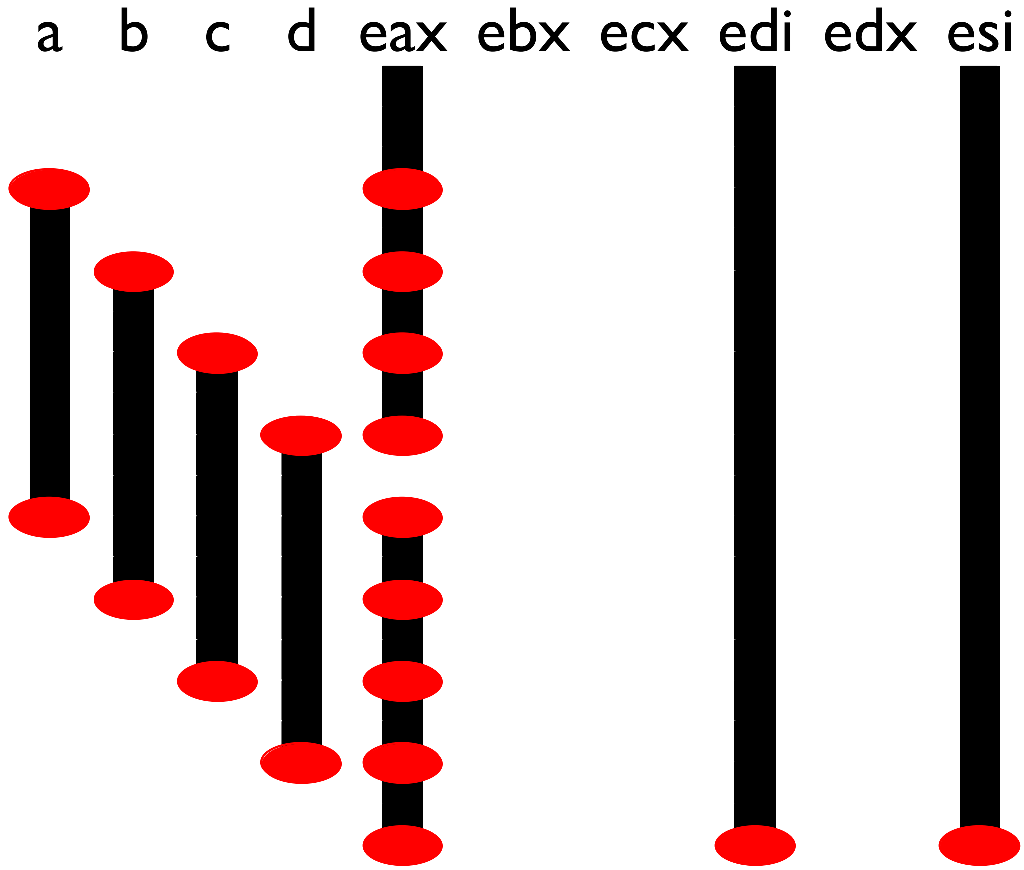



```
:f
(x2 <- eax)
(x2 *= x2)
(dx2 <- x2)
(dx2 *= 2)
(tx <- eax)
(tx *= 3)
(eax <- dx2)
(eax += tx)
(eax += 4)
(return)
```

Example Function 2

`int f(int x) = x+x+x+x` (in a stupid compiler)

```
:f
(a <- eax)
(b <- eax)
(c <- eax)
(d <- eax)
(eax <- a)
(eax += b)
(eax += c)
(eax += d)
(return)
```



No way to get all of **`a`**, **`b`**, **`c`**, and **`d`** into their own registers; so we need to *spill* one of them.

Spilling

Spilling is a program rewrite to make it easier to allocate registers

- Pick a variable and a location on the stack for it
- Replace all writes to the variable with writes to the stack
- Replace all reads from the variable with reads from the stack

Sometimes that means introducing new temporaries

Spilling Example

Say we want to spill `a` to the location `(mem ebp -4)`.

Two easy cases:

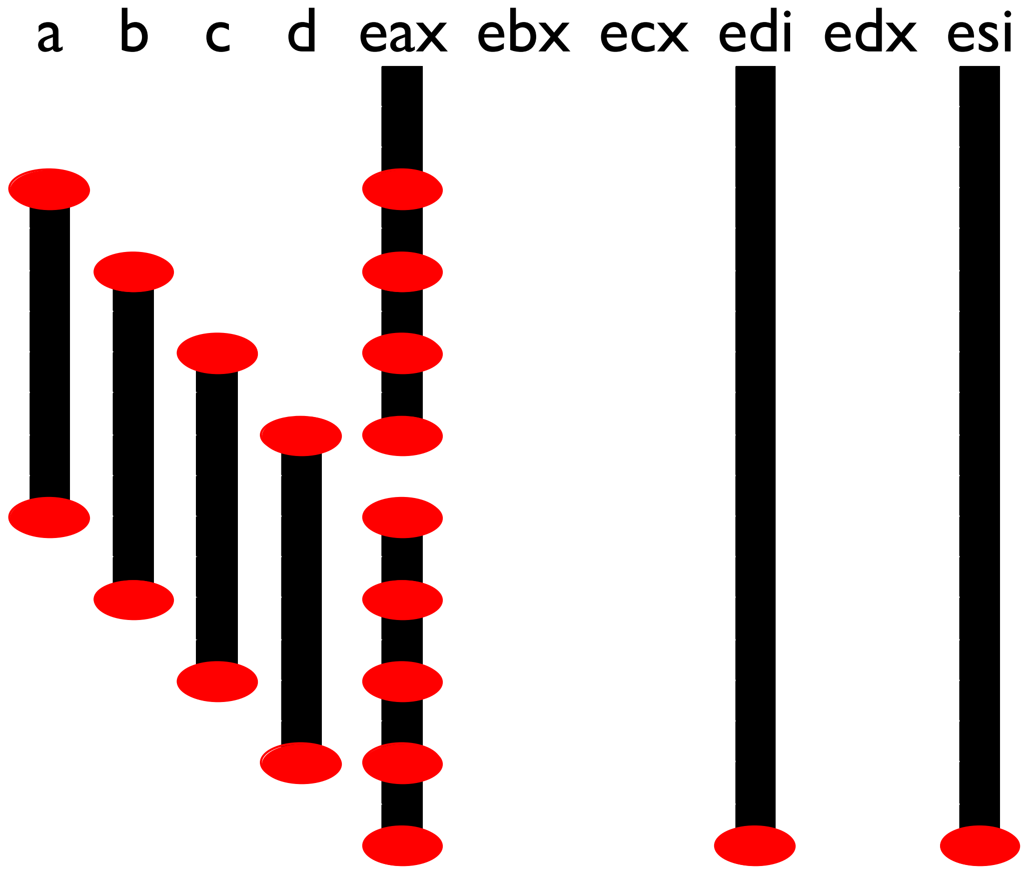
```
(a <- 1)  ⇒  ((mem ebp -4) <- 1)

(x <- a)  ⇒  (x <- (mem ebp -4))
```

Example Function 2, need to spill

`int f(int x) = x+x+x+x` (in a stupid compiler)

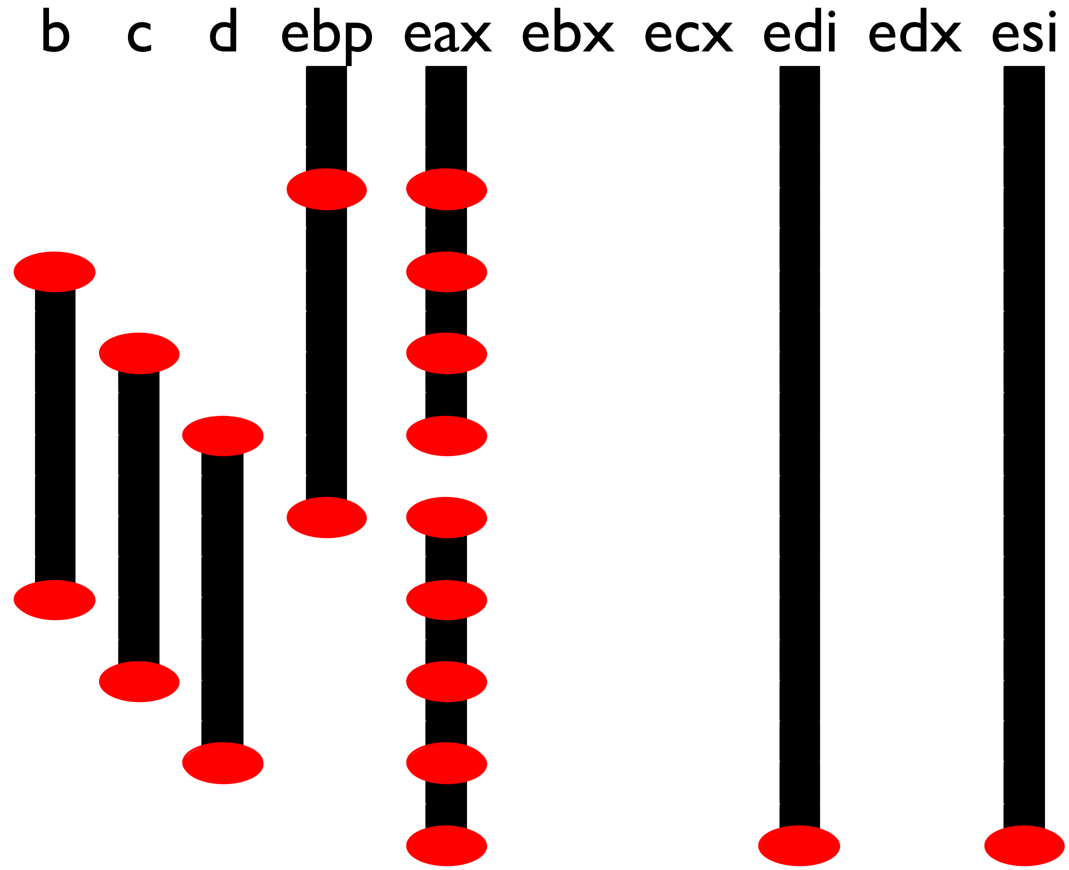
```
:f
(a <- eax)
(b <- eax)
(c <- eax)
(d <- eax)
(eax <- a)
(eax += b)
(eax += c)
(eax += d)
(return)
```



Example Function 2, spilling a

`int f(int x) = x+x+x+x` (in a stupid compiler)

```
:f
((mem ebp -4) <- eax)
(b <- eax)
(c <- eax)
(d <- eax)
(eax <- (mem ebp -4))
(eax += b)
(eax += c)
(eax += d)
(return)
```



Spilling Example

A trickier case:

```
(a *= a)  ⇒  (a_new <- (mem ebp -4))
             (a_new *= a_new)
             ((mem ebp -4) <- a_new)
```

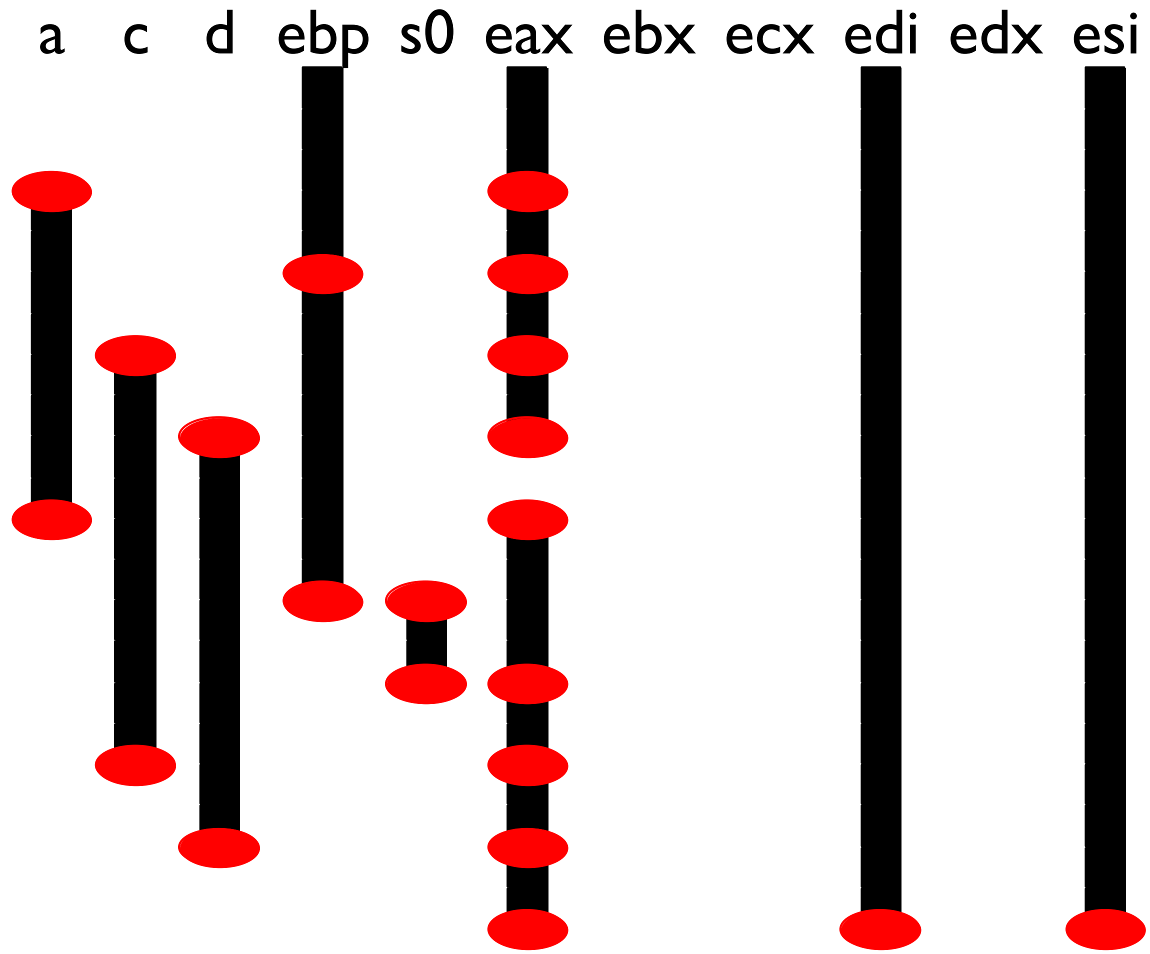
In general, make up a new temporary for each instruction that uses the variable to be spilled

This makes for very short live ranges.

Example Function 2, spilling b

`int f(int x) = x+x+x+x` (in a stupid compiler)

```
:f
(a <- eax)
((mem ebp -4) <- eax)
(c <- eax)
(d <- eax)
(eax <- a)
(s0 <- (mem ebp -4))
(eax += s0)
(eax += c)
(eax += d)
(return)
```



Example Function 2, spilling b

Even though we still have four temporaries, we can still allocate them to our three unused registers because the live ranges of `s0` and `a` don’t overlap and so they can go into the same register.

Your job

Implement:

```
spill : (i ...) ;; original function
        var     ;; to spill
        offset  ;; multiple of 4
        var     ;; prefix for temporaries
     -> (i ...) ;; spilled version
```