C⚙mpiler
C⚙nstruction

L2

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Outline

- L2

- The L2 compiler

Introduction to L2

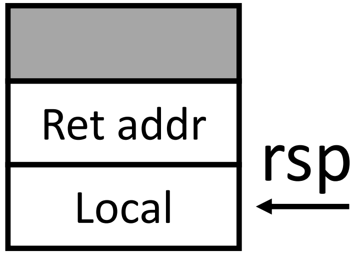
Variable is a powerful abstraction
Compilers have to deal with the complexity
of implementing that abstraction

- Like L1, but we have variables in L2!

- Example of L1 programs

```
(@go
  (@go 0 1
    mem rsp 0 <- 5
    //code
    rdi <- mem rsp 0
    rdi <<= 1
    mem rsp 0 <- rdi
    return
  )
)
```

To store a value on the stack



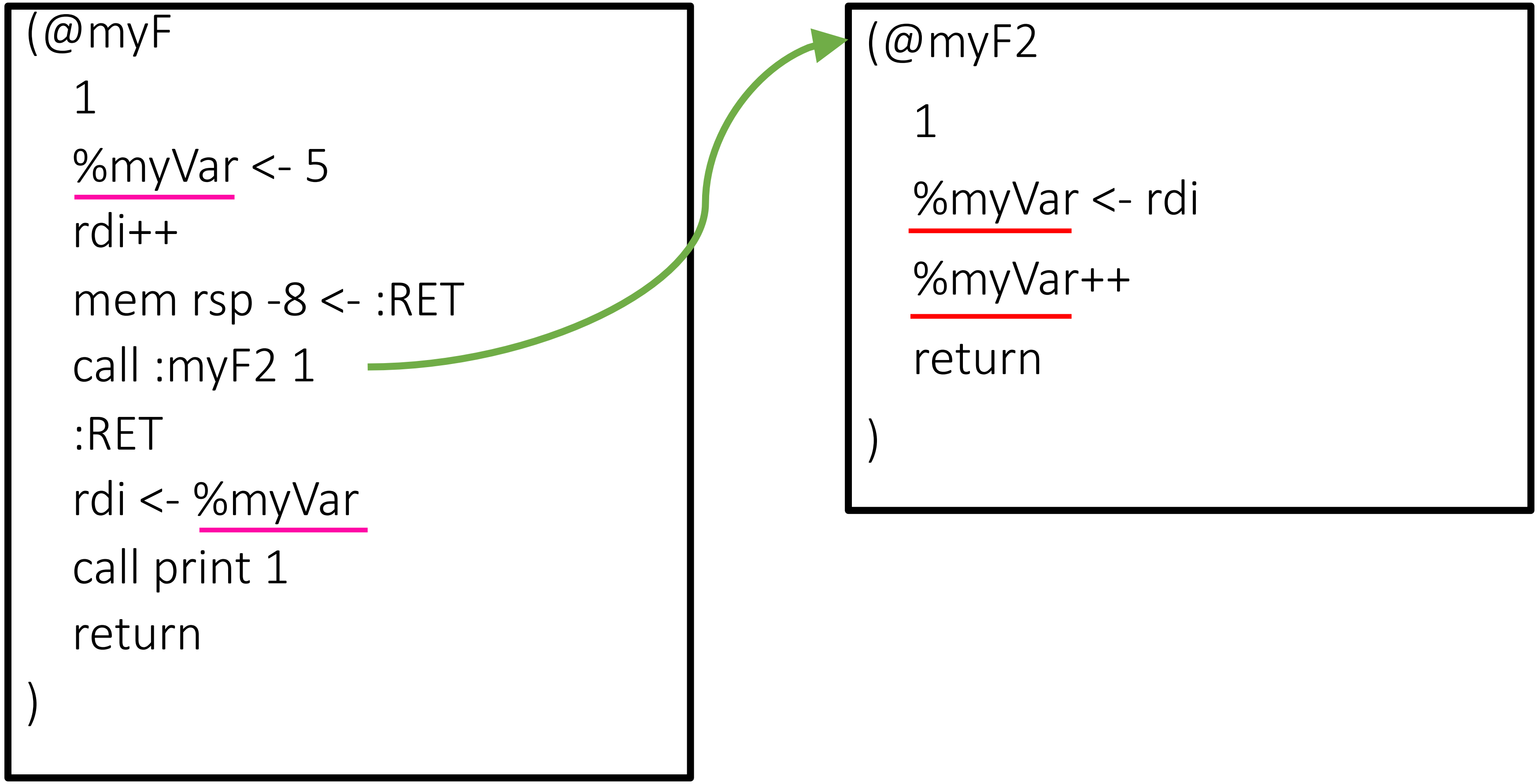
L2 programs

```
(@go
  (@go 0
    %myVar1 <- 5
    //code
    %myVar1 <<= 1
    return
  )
)
```

```
(@go
  (@go 0
    %myVar1 <- 5
    rdi <- %myVar1
    call print 1
    return
  )
)
```

Variables in L2

- Variables (on top of registers)
- L2 variables are function local



```
(@myF
   1
   %myVar <- 5
   rdi++
   mem rsp -8 <- :RET
   call :myF2 1
   :RET
   rdi <- %myVar
   call print 1
   return
)
```

```
(@myF2
   1
   %myVar <- rdi
   %myVar++
   return
)
```

L1

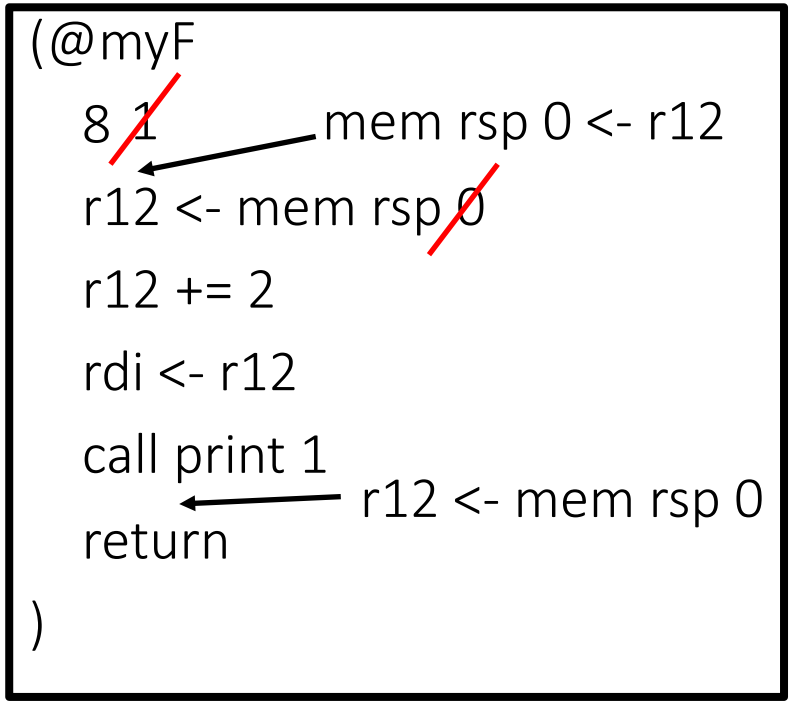
p ::= (l f^+)
f ::= (l N N i^+)
i ::= w <- s | w <- mem x M | mem x M <- s |
w aop t | w sop sx | w sop N | mem x M += t | mem x M -= t | w += mem x M | w -= mem x M |
w <- t cmp t | cjump t cmp t label | label | goto label |
return | call u N | call print 1 | call input 0 | call allocate 2 | call tensor-error F |
w ++ | w -- | w @ w w E
w ::= a | rax | rbx | rbp | r10 | r11 | r12 | r13 | r14 | r15
a ::= rdi | rsi | rdx | sx | r8 | r9
sx ::= rcx
s ::= t | label | l
t ::= x | N
u ::= w | l
x ::= w | rsp
aop ::= += | -= | *= | &=
sop ::= <<= | >>=
cmp ::= < | <= | =
E ::= 1 | 2 | 4 | 8
F ::= 1 | 3 | 4
M ::= *multiplicative of 8 constant (e.g., 0, 8, 16)*
N ::= (+|-)? [1-9][0-9]* | 0
l ::= @name
label ::= :name
name ::= sequence of chars matching [a-zA-Z_][a-zA-Z_0-9]*

L2

```
p     ::= (l f+)
f     ::= (l N i+)
i     ::= w <- s | w <- mem x M | mem x M <- s | w <- stack-arg M |
          w aop t | w sop sx | w sop N | mem x M += t | mem x M -= t | w += mem x M | w -= mem x M |
          w <- t cmp t | cjump t cmp t label | label | goto label |
          return | call u N | call print 1 | call input 0 |  call allocate 2 | call tensor-error F |
          w ++ | w -- | w @ w w E
w     ::= a | rax
a     ::= rdi | rsi | rdx | sx | r8 | r9
sx    ::= rcx | var
s     ::= t | label | l
t     ::= x | N
u     ::= w | l
x     ::= w | rsp
aop   ::= += | -= | *= | &=
sop   ::= <<= | >>=
cmp   ::= < | <= | =
E     ::= 1 | 2 | 4 | 8
F     ::= 1 | 3 | 4
M     ::= multiplicative of 8 constant (e.g., 0, 8, 16)
N     ::= (+|-)? [1-9][0-9]* | 0
l     ::= @name
label ::= :name
name ::= sequence of chars matching [a-zA-Z_][a-zA-Z_0-9]*
var   ::= %name
```

A problem for L1 developers

- We want to print the last argument of @myF plus 1
- Is there any bug in our L1 program?
- We need to save r12
- Is there any bug in our L1 program?



(@myF

8 ~~1~~

mem rsp 0 <- r12

r12 <- mem rsp ~~0~~

r12 += 2

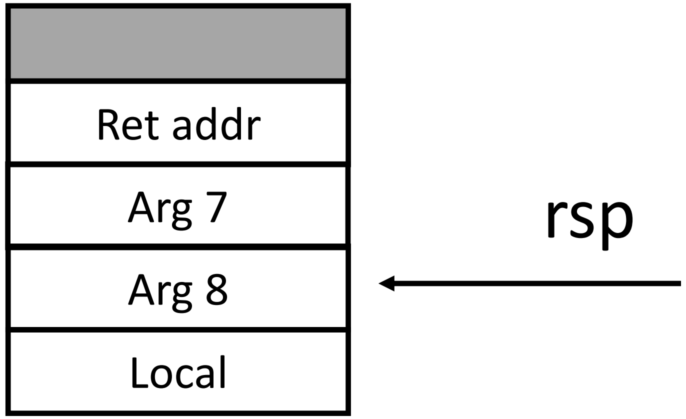
rdi <- r12

call print 1

r12 <- mem rsp 0

return

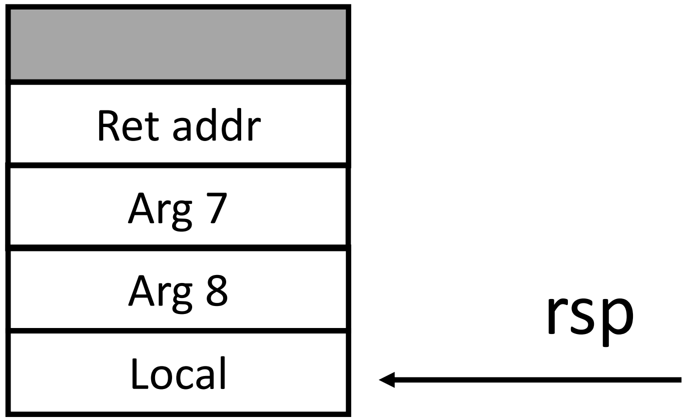
)



A problem for L1 developers

- We want to print the last argument of @myF plus 1
- Is there any bug in our L1 program?
- We need to save r12
- Is there any bug in our L1 program?

```
(@myF
   8 1              mem rsp 0 <- r12
   r12 <- mem rsp 8
   r12 += 2
   rdi <- r12
   call print 1
                      r12 <- mem rsp 0
   return
)
```



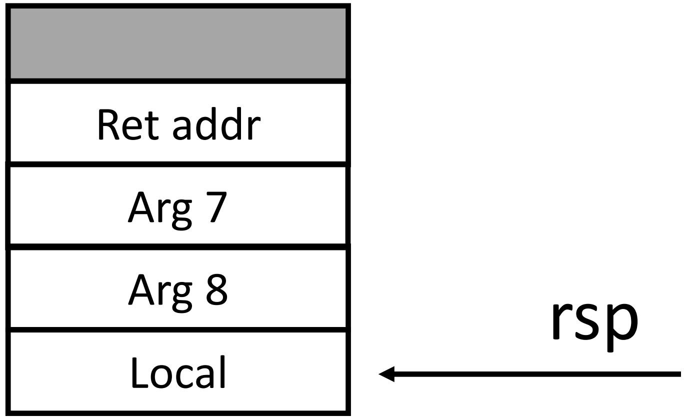
The new L2 instruction

- It accesses stack-based arguments

  w <- stack-arg M

```
(@myF
   8
   r12 <- ~~stack-arg 0~~
   r12 += 2
   rdi <- r12
   call print 1
   return
)
```

- stack-arg 0 is always the last stack argument
- stack-arg 8 is always the second to last argument



Stack locations for L2 programs

- No locals
- Stack locations can be used only
  - To store stack arguments at the caller site
  - To store the returning label

```
mem rsp -8 <- :MYL
mem rsp -16 <- 5
call @F 7
:MYL
```

- **Hence:** mem rsp X

It must be negative

Final notes on L2

As for L1:

- The scope of labels is the program
- Values are encoded following the same rules of L1
- Same calling convention of L1
- Same rules for memory heap allocation
- Same undefined behaviors

Tests for homework 1

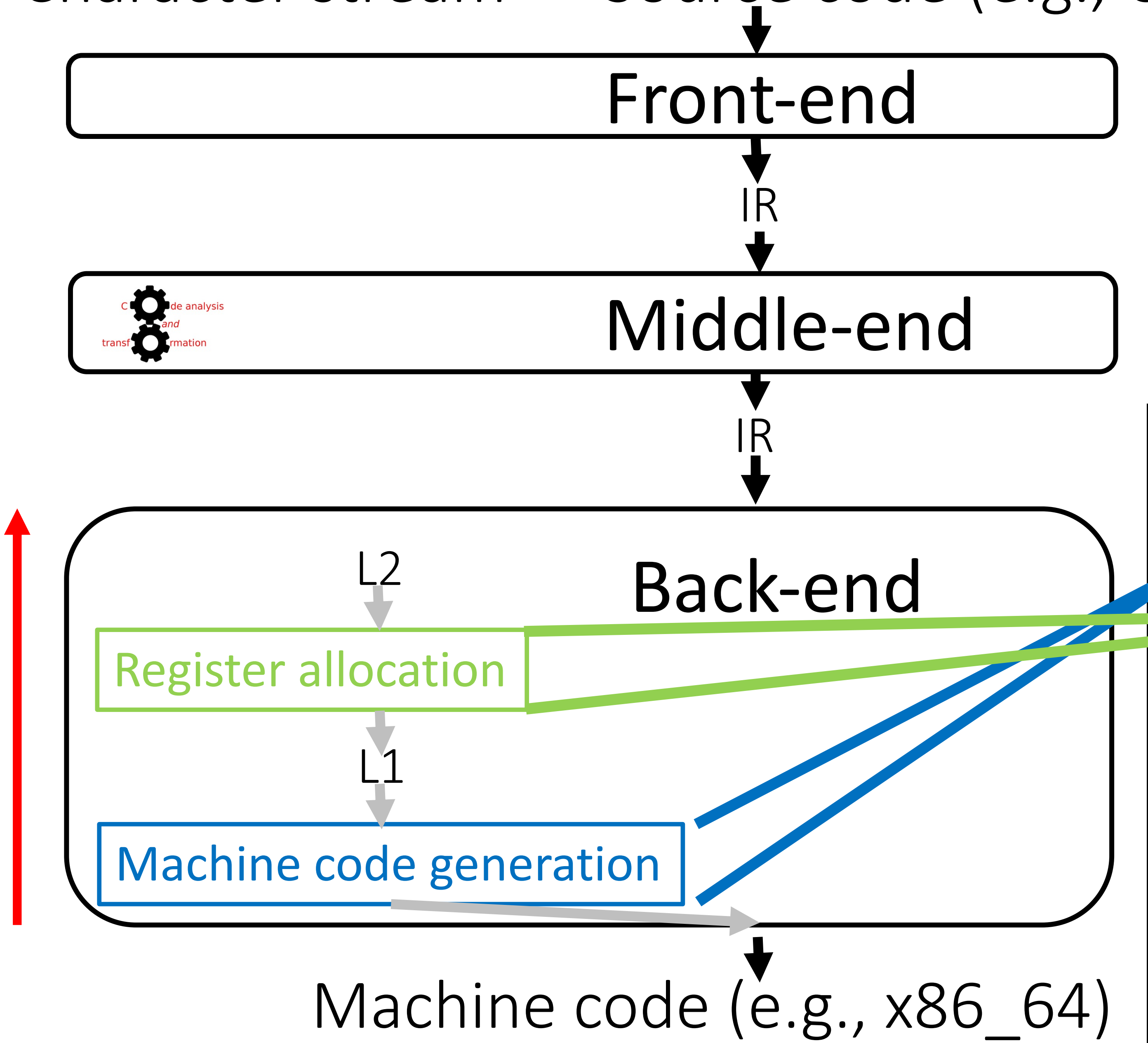
- Rewrite your L1 program using the L2 language
    - To compile an L2 program:
        - Use the original framework, which is still available on Canvas
            - Not the one you have modified to implement your L1 compiler
        - cd L2
        - Interpreter:
            - ./L2i L2_program.L2
        - Compiler:
            - ./L2c L2_PROGRAM.L2 ; ./a.out
- Write another L2 program that implements any algorithm that you want that generates an output from an input
    - Upload the input (.L2.in), the expected output (.L2.out), and the L2 program (.L2)
- Deadline: check Canvas

Outline

- L2

- The L2 compiler

A compiler



Character stream --- Source code (e.g., C)

Front-end

IR

Middle-end

Code analysis and transformation

IR

Back-end

L2

Register allocation

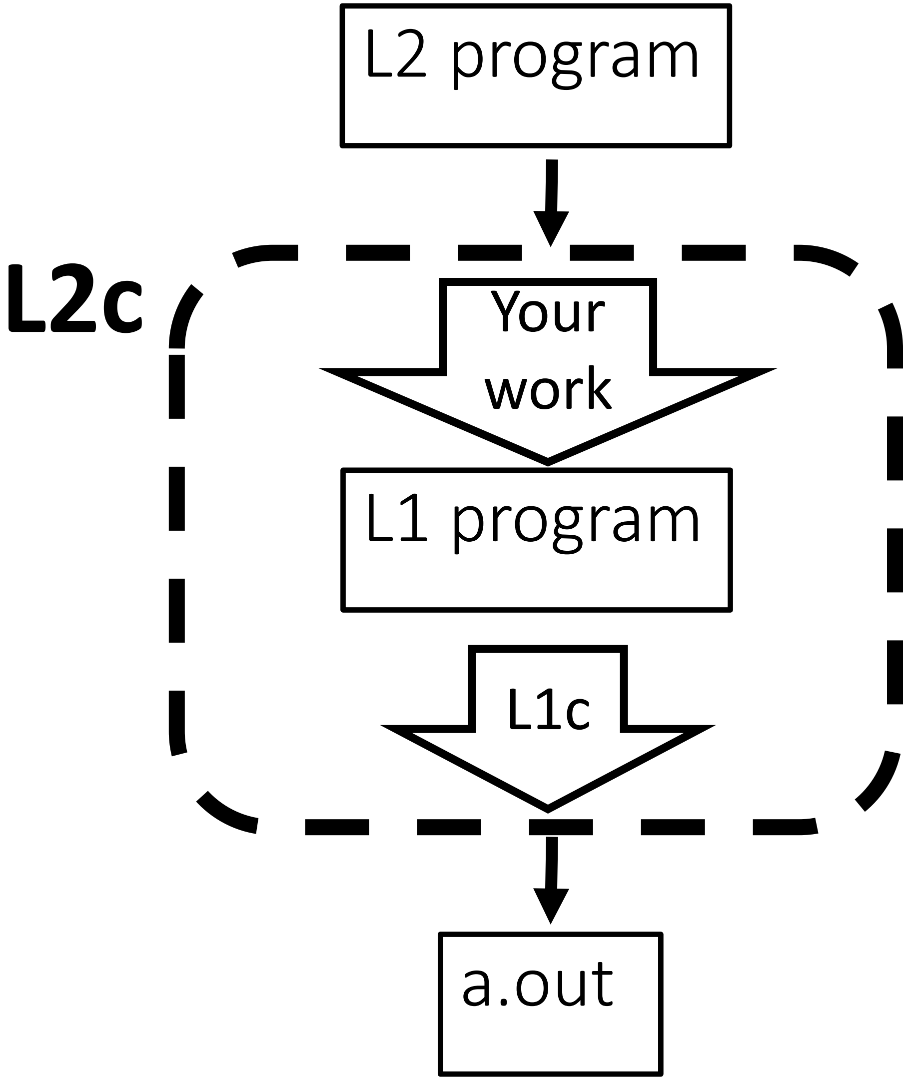
L1

Machine code generation

Machine code (e.g., x86_64)

```
bin
C
IR
L1
L2
L3
LA
LB
LC
LD
lib
Makefile
scripts
```

The L2 compiler (L2c)



- To build L2c:
  translate an L2 program
  to an equivalent L1
- We need to map L2 variables to registers
  - Register allocation
- We need to translate the L2 instruction
  w <- stack-arg M

Debugging Suggestion: testing your L1 compiler with my L2 compiler

- If your L2c does not pass a test, then the bug can be either
  - in your L1 compiler or
  - In your L2 compiler

- To understand where is the bug, you can mix your and mine compilers

- To compile an L2 program:
  - Compile your own L1 compiler: L1/bin/L1
  - Make sure you have my L2 compiler: L2/bin/L2
  - cd L2
  - ./L2c L2_PROGRAM.L2
  - ./a.out

Register allocation task

- Intra-procedural approach (most used)

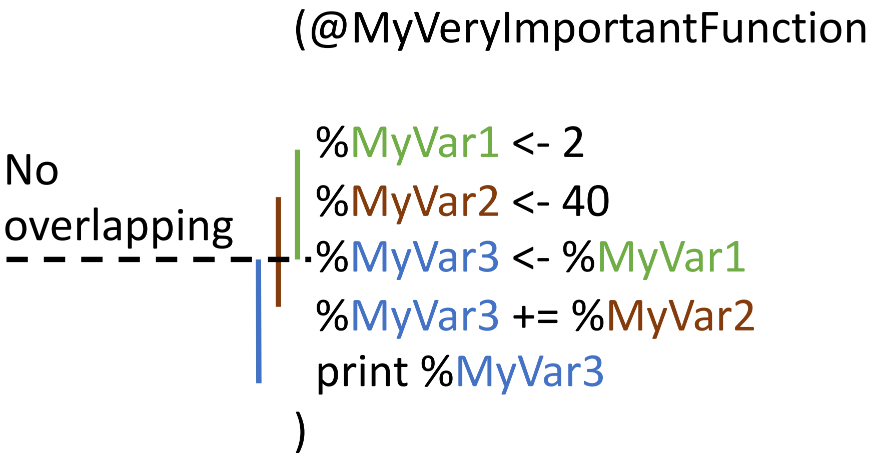
  For each function f

    Map each variable of f to either a register or to a stack location (within locals in the L1 stack)

- Inter-procedural approach

  Map variables of functions in registers exploiting their caller-callee links

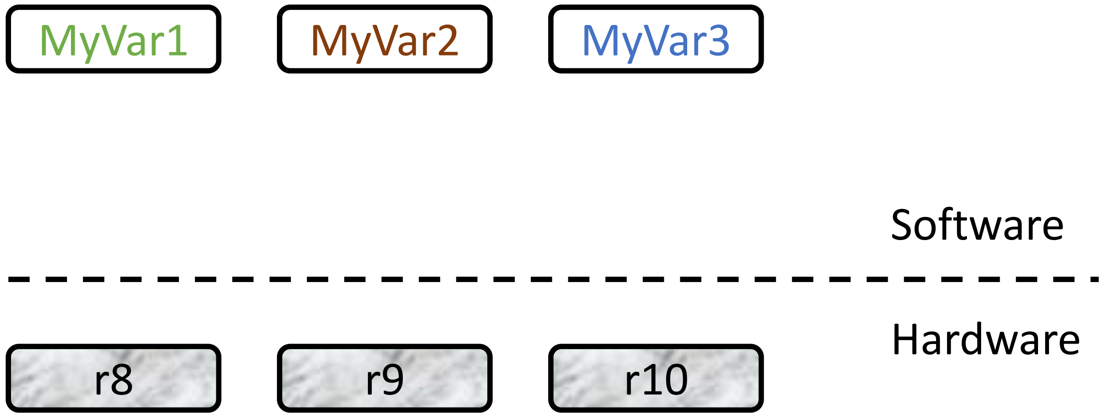
Task: From Variables to Registers



No overlapping

```
(@MyVeryImportantFunction

 %MyVar1 <- 2
 %MyVar2 <- 40
 %MyVar3 <- %MyVar1
 %MyVar3 += %MyVar2
 print %MyVar3
)
```

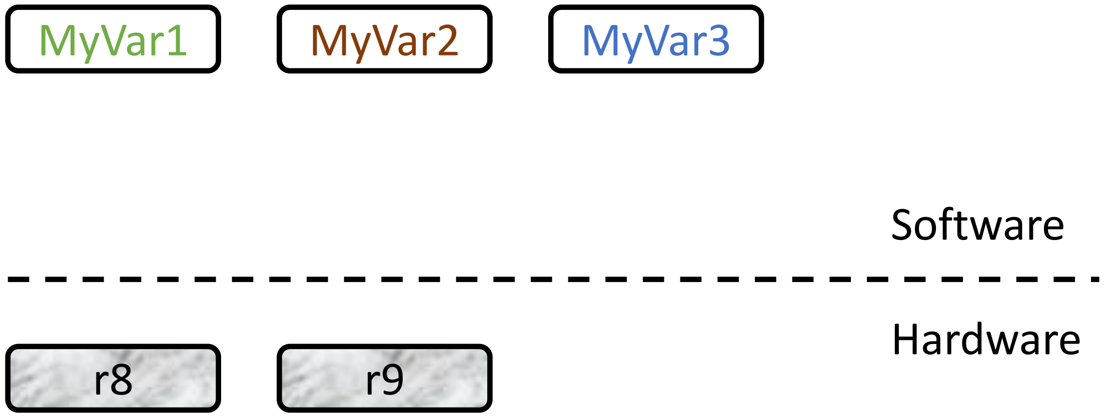


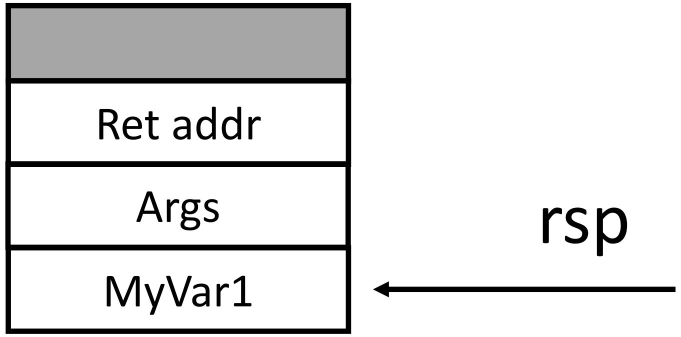
?

To register allocators: what are you doing?

```
(@MyVeryImportantFunction

 %MyVar1 <- 2
 %MyVar2 <- 40
 %MyVar3 <- 0
 %MyVar3 += %MyVar1
 %MyVar3 += %MyVar2
 print %MyVar3
)
```



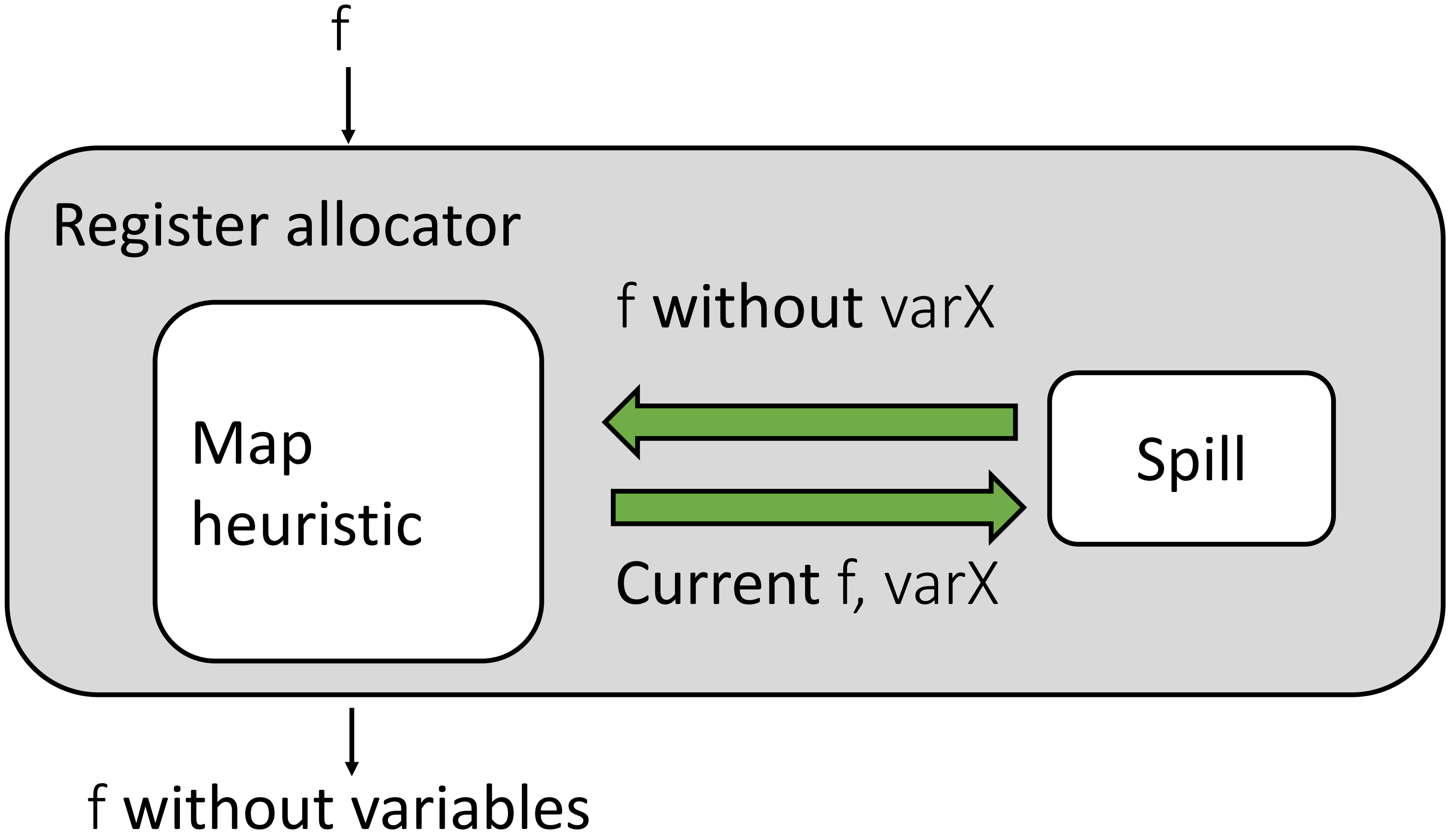


- MyVar1 -> stack (spilled)
- MyVar2 -> r8
- MyVar3 -> r9

Two naïve solutions for register allocation:

1. Spill all variables
2. Increase the #registers

A register allocator structure



f

Register allocator

Map heuristic

f **without** varX

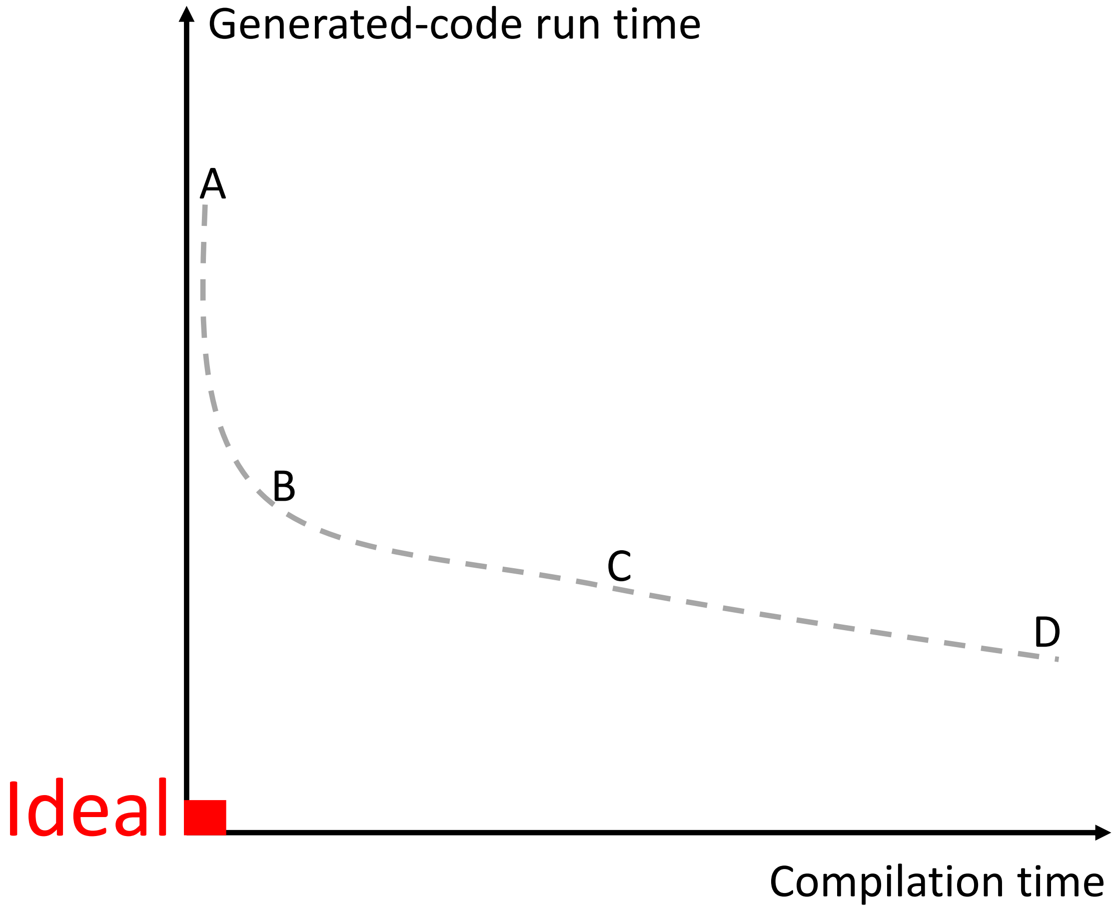
Current f, varX

Spill

f **without variables**

Register Allocation

A. Spill all variables
B. Linear scan
C. Graph coloring
D. Integer linear programming



Always have faith in your ability

Success will come your way eventually

Best of luck!