EECS 483: Compiler Construction

Lecture 8:
Non-tail Function Calls, Calling Conventions

February 9
Winter Semester 2026

Reminders

- Assignment 2 due Friday

- Assignment 3 released next Monday, extends Assignment 2 with full support for functions (non-tail calls)

Learning Objectives

Implementation of true (non-tail) function calls

What is a **calling convention** and why do we need them?

x86 instructions for implementing (call) stacks

Two strategies for managing **stack-local variables** used in practice.

Details of the AMD System V 64 calling convention

Difference between volatile and non-volatile registers

State of the Snake Language

Adder: Straightline Code

Boa: Conditionals + Tail-called functions = arbitrary "local" control flow.

Good for implementing the "bodies" of functions, but missing key features:

1. Interaction with the Operating System (stdin/stdout, file I/O, random number generation)

2. Reusable sub-procedures (functions with non-tail calls)

Add these in **Cobra**

Extending the Snake Language

When we implement a compiler (to assembly) we need to address the following questions:

1. What is the syntax of the language we are compiling?
2. What is the semantics of the language we are compiling?
3. How can we implement that semantics in assembly code?
4. How should we adapt our intermediate representation to new features?
5. How can we generate assembly code from the IR?

Extending the Snake Language

Want the ability to interact with the operating system

So far: add new primitives one at a time

More flexible: allow importing "extern" functions from our Rust stub.rs file

Extending the Snake Language

```
extern read()
extern print(x)

def main(x):
  def loop(sum):
    let _ = print(sum) in
    loop(sum + read())
  in
  loop(0)
```

Implement read, print in stub.rs

SSA Changes

Add extern declarations to top-level SSA program

Add call as a new operation in SSA (not a terminator!)

```
x = call f(x1,...)
```

Change to lowering:

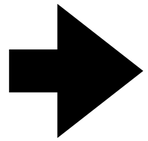
if a call to an **internal** function is a tail call, compile it as before as a branch with arguments

if a call to an **external** function is a tail call, compile it as a call and then return the result

SSA Changes

```
extern print(x)


def main(x):
  let y = x + 10
  print(y)
```



```
extern print(x)


main(x):
  y = x + 10
  res = call print(y)
  ret res
```

Code Generation

Each extern declaration becomes an x86 extern declaration

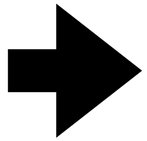
Function calls are compiled using the System V AMD64 Calling convention

Linking will fail unless the extern functions are implemented in stub.rs

SSA Changes

```
extern print(x)


main(x):
  y = x + 10
  res = call print(y)
  ret res
```



```
section .text
global entry
extern print

entry:
  ...
```

Non-tail Procedure Calls

When a function is called it needs to know **where** to return to, i.e., what its **continuation** is.

To implement this, procedure calls pass a **return address**. Think of this as an "extra argument" that is implicit in the original program.

When a function is called, it needs to know which registers and which regions of memory it is free to use

Use **rsp** as a pointer to denote which part of the stack is free space

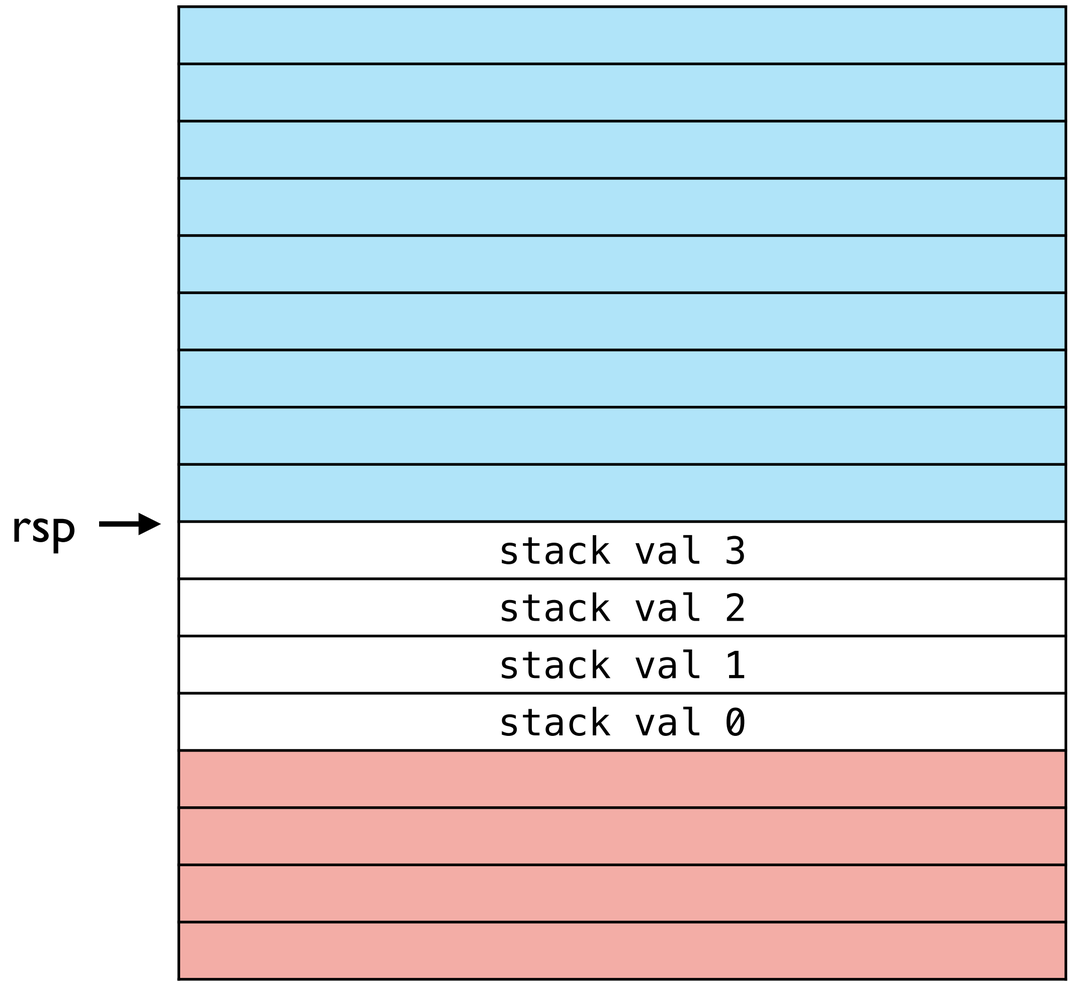
Designate which registers are **volatile** or **non-volatile**

When implementing calls within a programming language we can decide these conventions for ourselves. When implementing calls that work with external code need to pick a standard **calling convention**

x86 Abstract Machine: The Stack

So far we have used rsp as a base pointer into our stack frame

But several instructions treat it as a "stack pointer" pointing to the **top** of a stack of values (growing downwards in memory address space)



x86 Instructions: push

push arg

Semantics:

sub rsp, 8

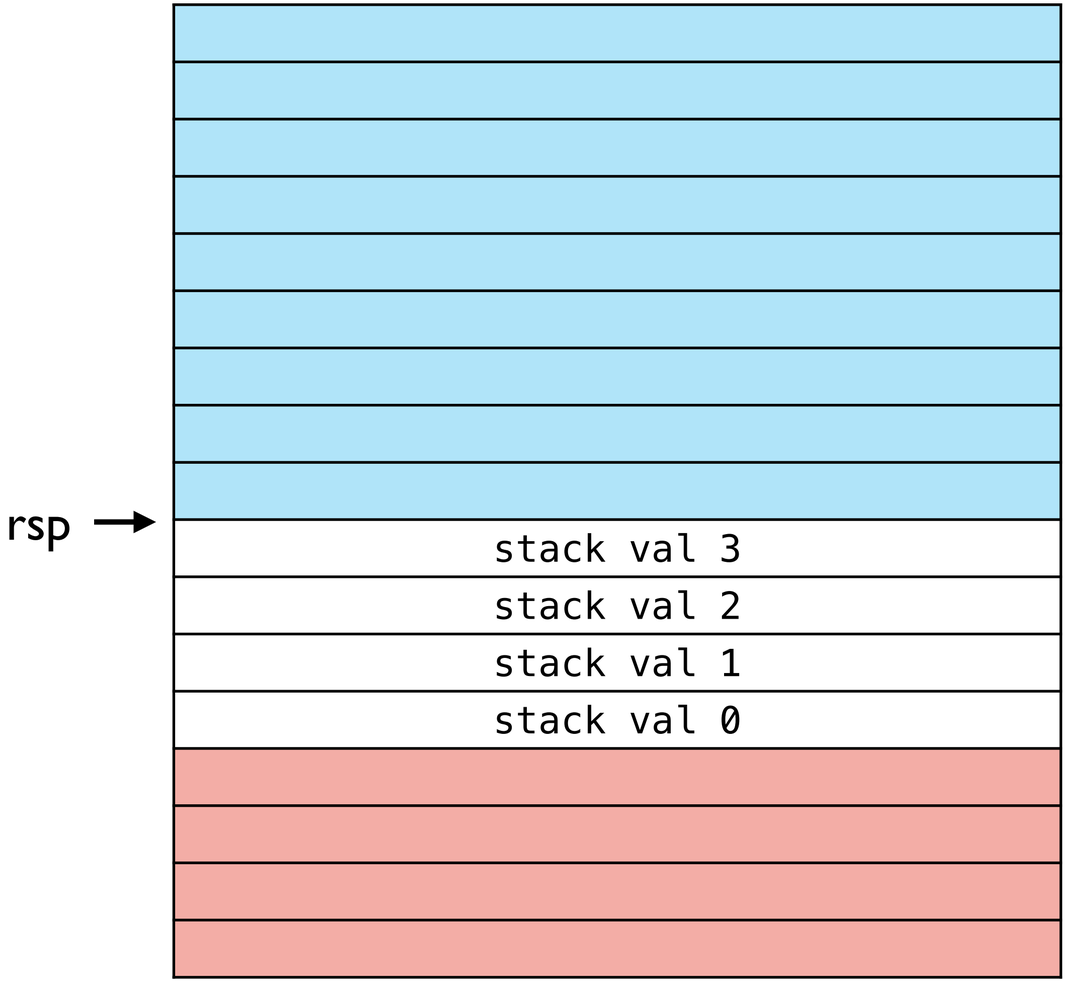
mov [rsp], arg

If rsp is the pointer to the "top" of the stack, this pushes a new value on top.

Example:

```
push 483

...
```



x86 Instructions: push

push arg

Semantics:

sub rsp, 8

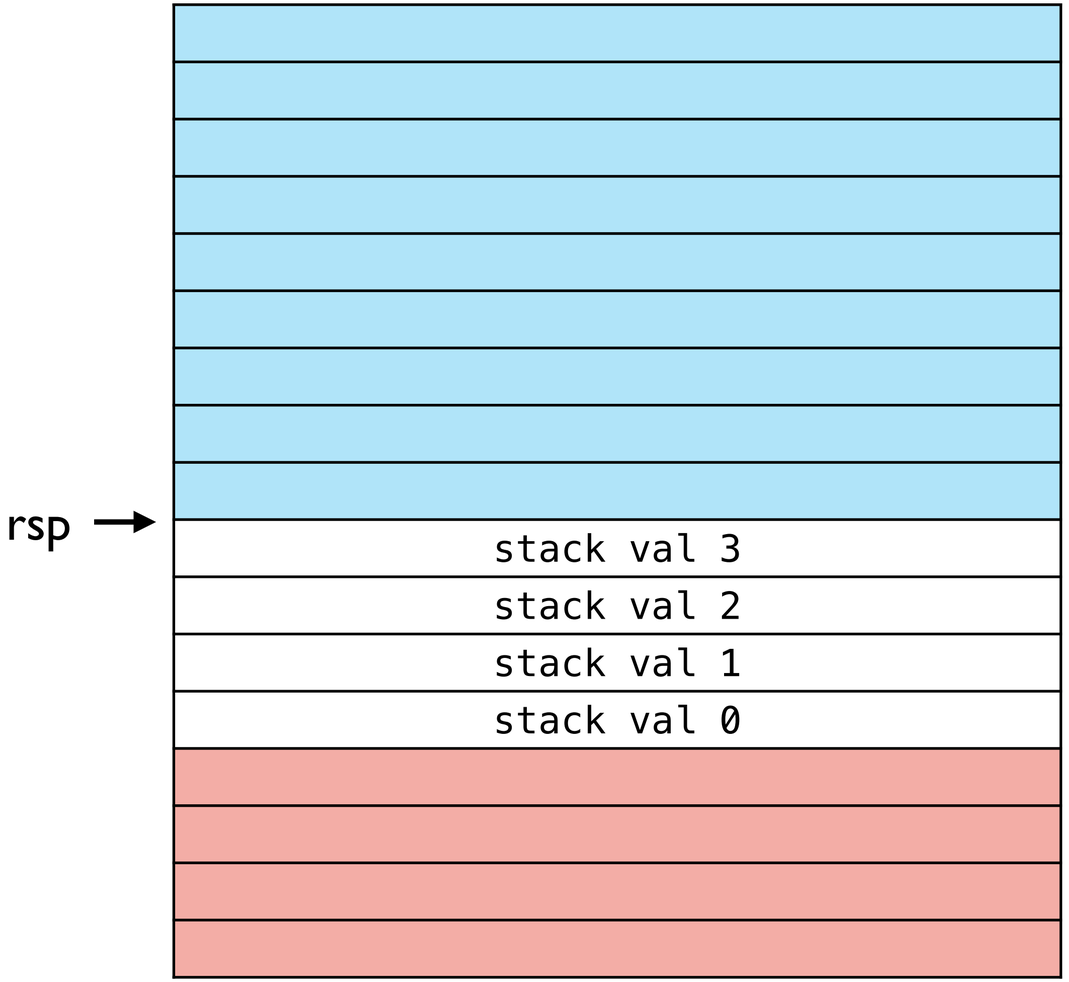
mov [rsp], arg

If rsp is the pointer to the "top" of the stack, this pushes a new value on top.

Example:

rip → `push 483`

`...`



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```
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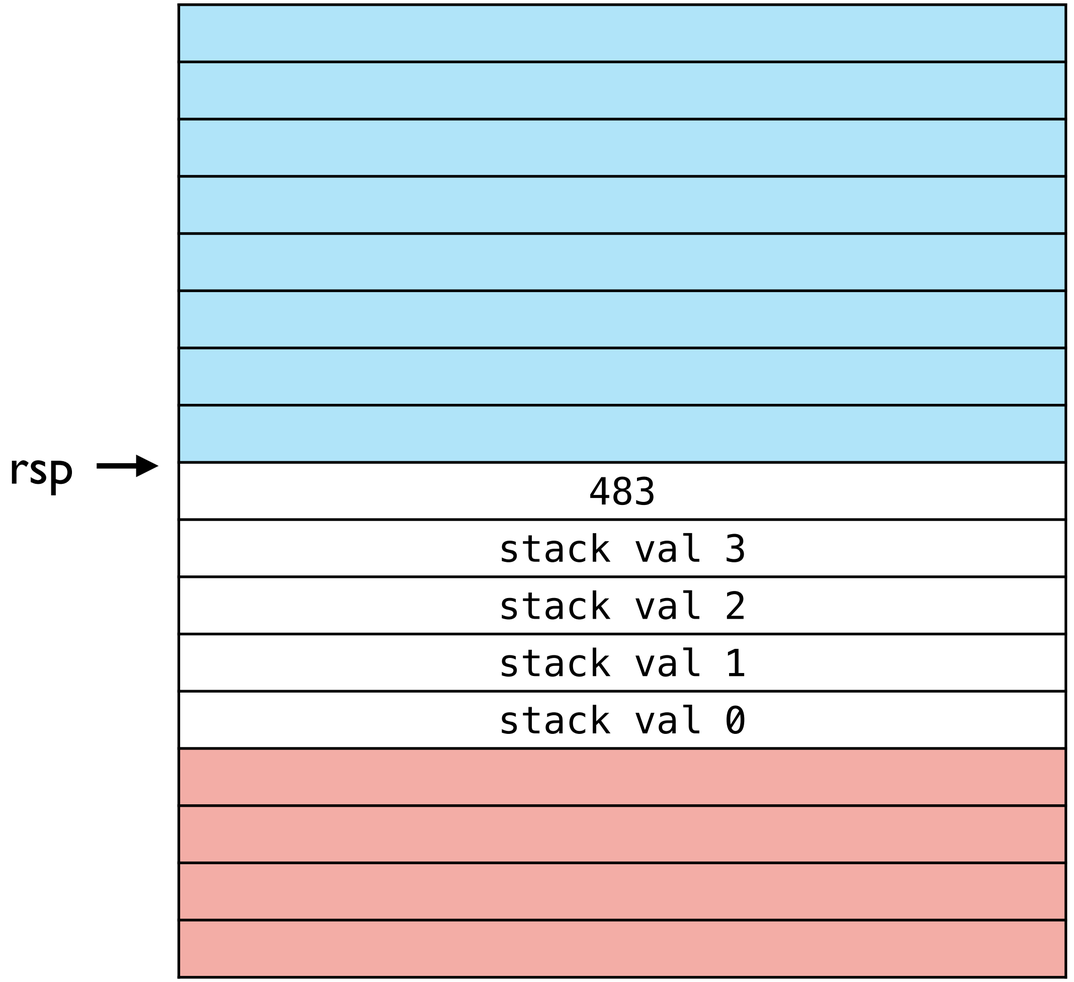
```

rip → . . .



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Semantics:

sub rsp, 8

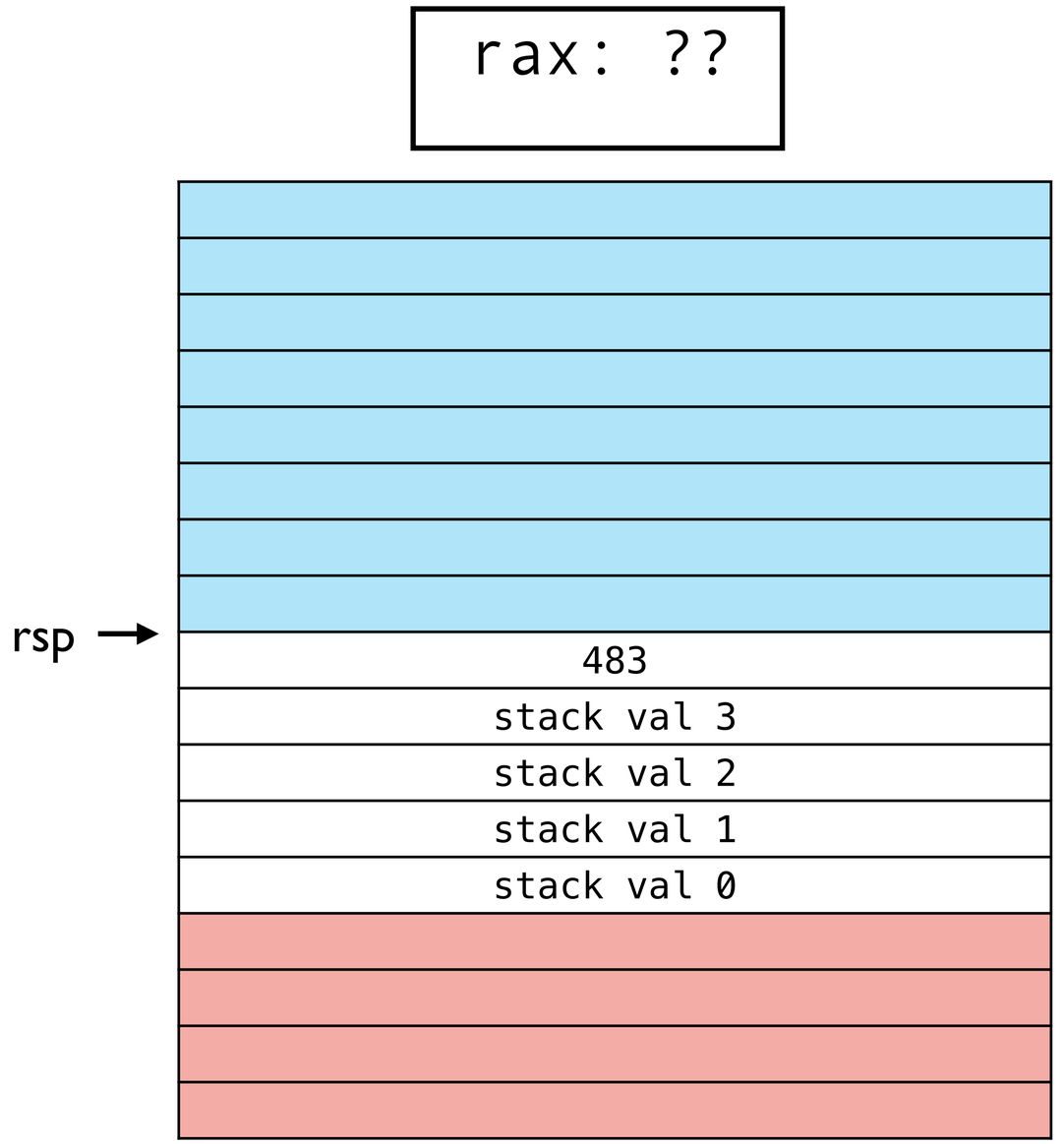
mov [rsp], arg

If rsp is the pointer to the "top" of the stack, this pushes a new value on top.

Example:

```
push 483
pop rax
```

rip →



x86 Instructions: push

push arg

Semantics:

sub rsp, 8

mov [rsp], arg

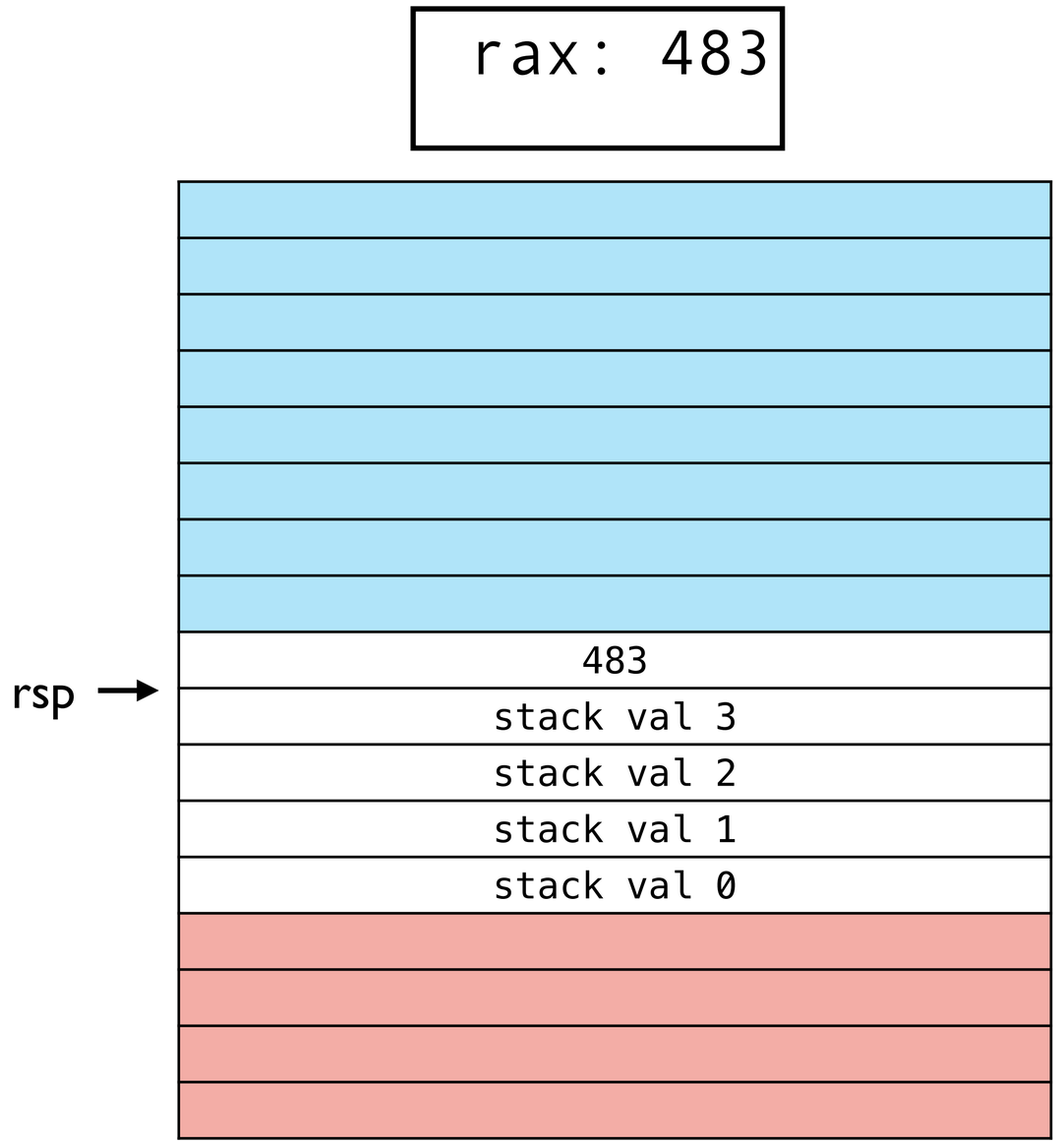
If rsp is the pointer to the "top" of the stack, this pushes a new value on top.

Example:

```
push 483

pop rax
```

rip →



x86 Instructions: pop

pop reg

Semantics:

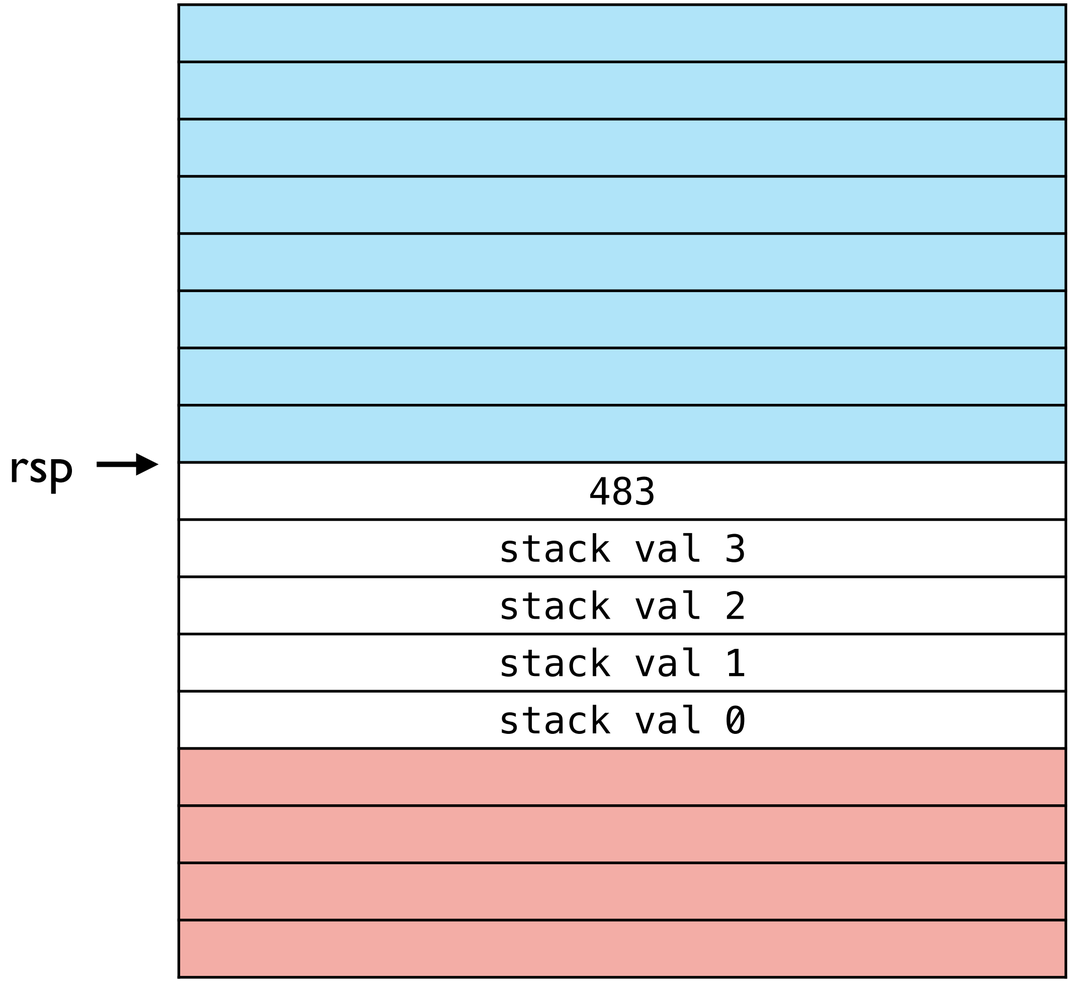
mov reg, [rsp]

add rsp, 8

If rsp is the pointer to the "top" of the stack, this pops the current value off of it

Example:

pop rax



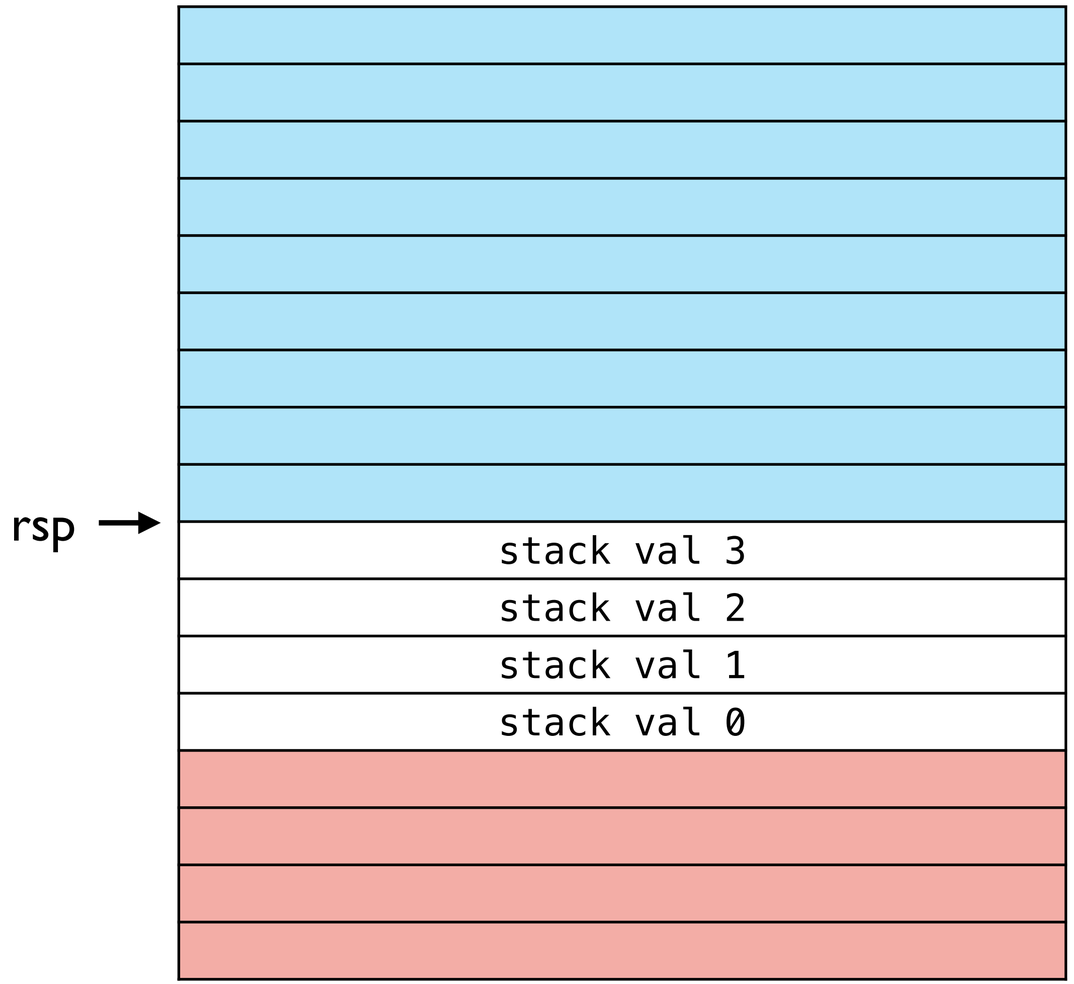
x86 Instructions: call

call loc

Semantics is a combination of **jmp** and **push**

sets rip to loc (like jmp loc)

and pushes the address of the next instruction onto the stack (like **push** next)



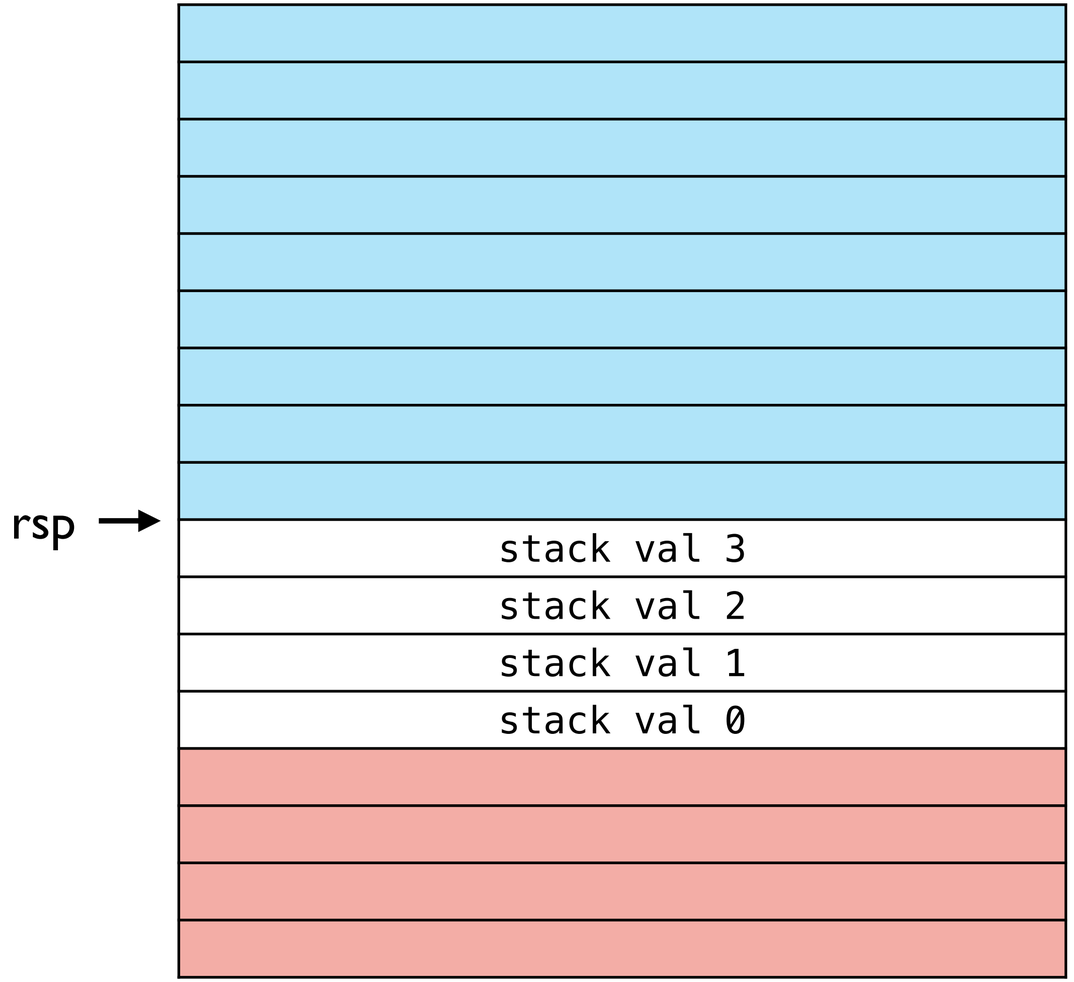
x86 Instructions: call

`call` loc

Semantics is a combination of **jmp** and **push**

Example:

```
rip →  call f
  return_here:
      mov rbx, rax
      ...
  f:
      ...
```



x86 Instructions: call

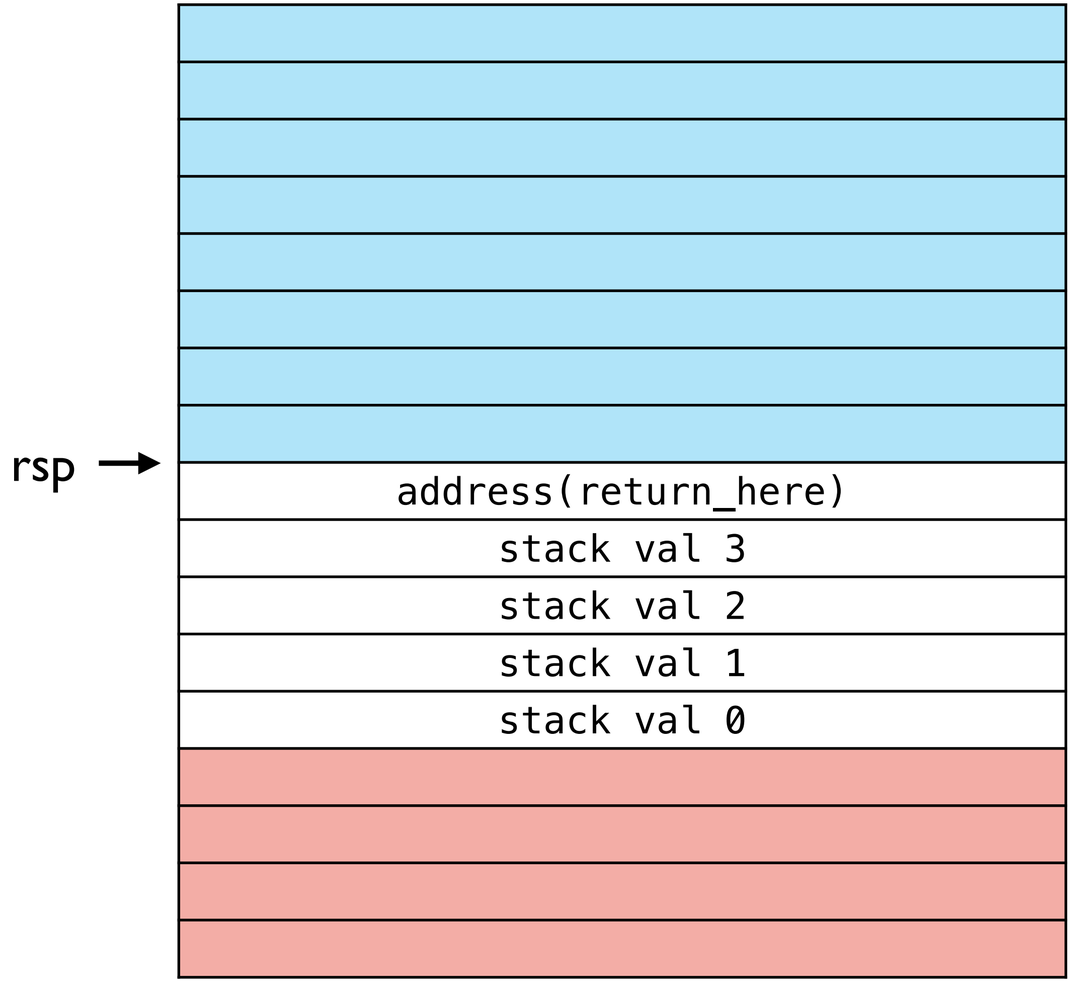
`call` loc

Semantics is a combination of **jmp** and **push**

Example:

```
    call f
return_here:
    mov rbx, rax
    ...
f:
    ...
```

rip →



x86 Instructions: ret

ret

Semantics is a combination of **pop** and **jmp**

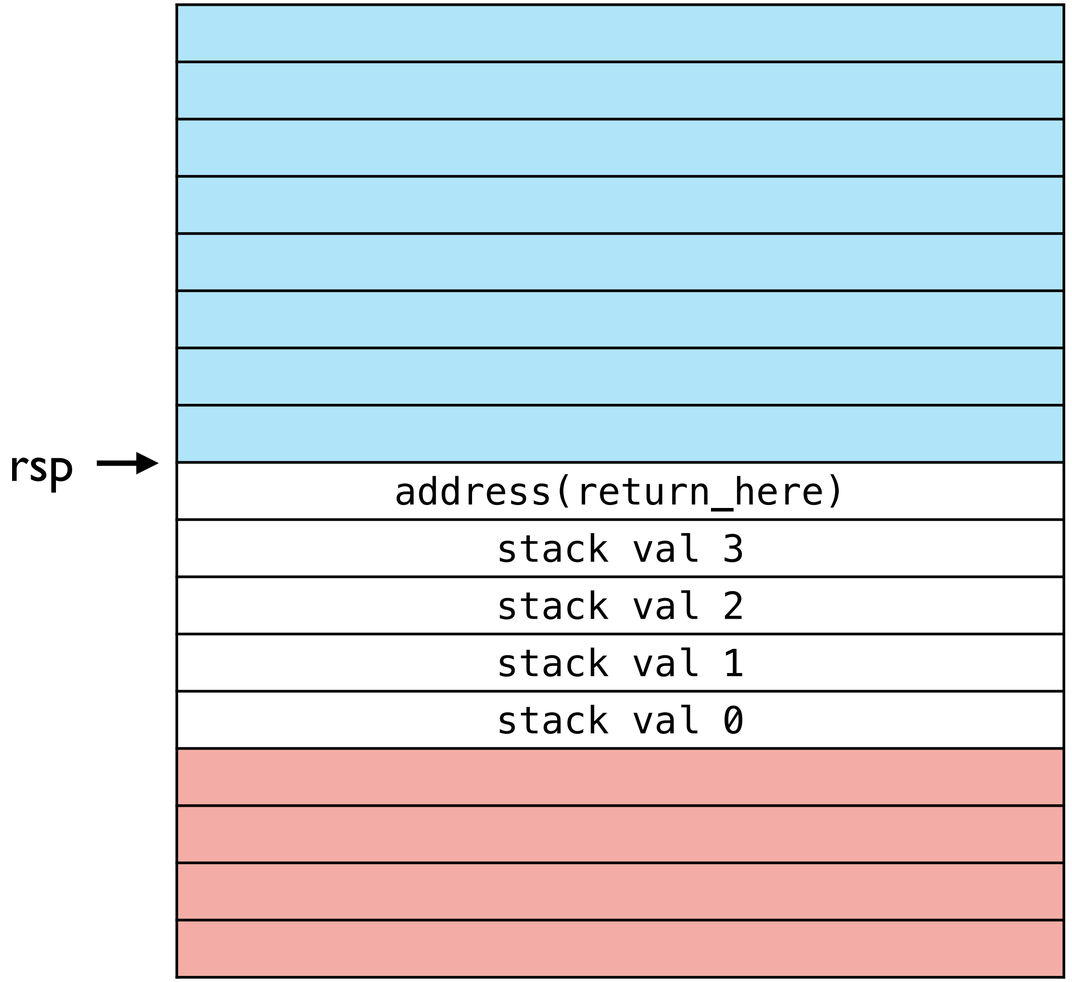
pops the return address off of the stack and jumps to it

like

pop r

jmp r

except without using up a register r



x86 Instructions: ret

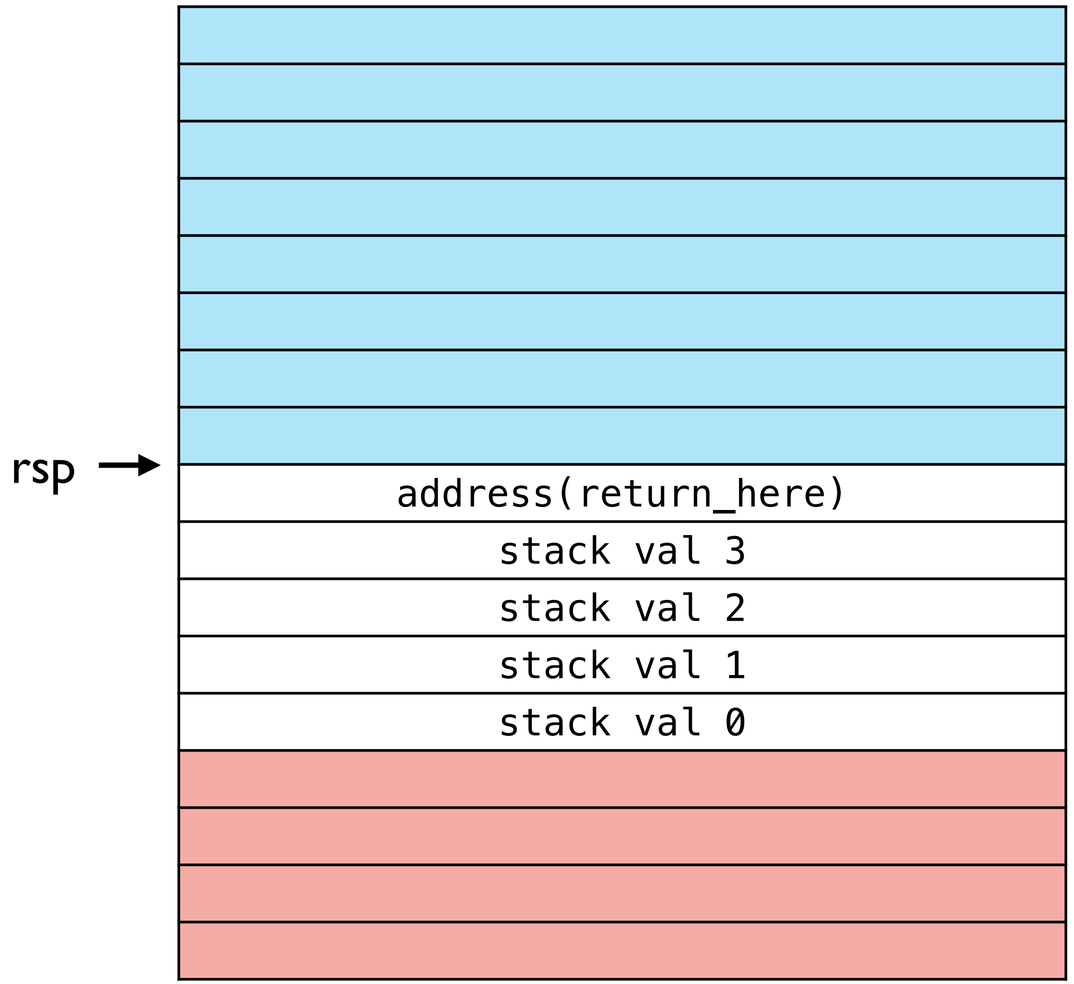
ret

Semantics is a combination of **pop** and **jmp**

Example:

```
    call f
return_here:
    mov rbx, rax
    ...
f:
    ret
```

rip →



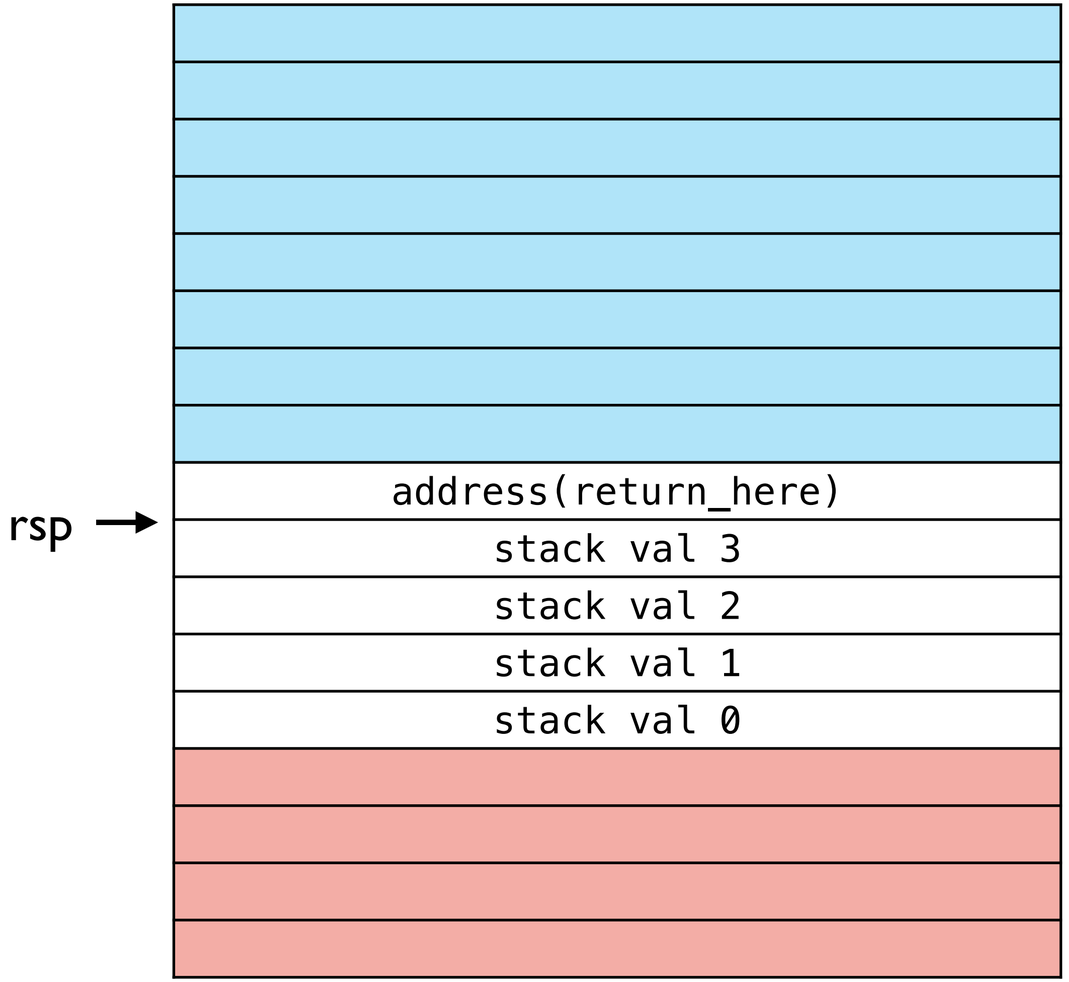
x86 Instructions: ret

ret

Semantics is a combination of **pop** and **jmp**

Example:

```
    call f
return_here:
rip → mov rbx, rax
    ...
f:
    ret
```



Calling Convention

Calling Convention

The call/ret instructions are just one component of implementing a function call in a high level language. Also need to consider

where are arguments stored?

where are return values stored?

how are registers shared between caller/calee?

how is memory shared between caller/callee?

Calling Convention

When implementing a call into Rust, we need to use a common **calling convention** that the Rust compiler knows how to implement

We use the System V AMD 64 ABI

- Standard "C" calling convention for 64-bit x86 code on Linux/Intel Macs
- Has some idiosyncracies from supporting C code and SSE instructions

Calling Convention

A calling convention is a protocol that a caller and callee follow in order to implement a procedure call and return

Caller and callee need to agree on:

1. State of memory/registers when the callee begins executing

2. State of memory/registers once the callee has returned

So a calling convention is really a combination of a "calling" convention and a "returning" convention

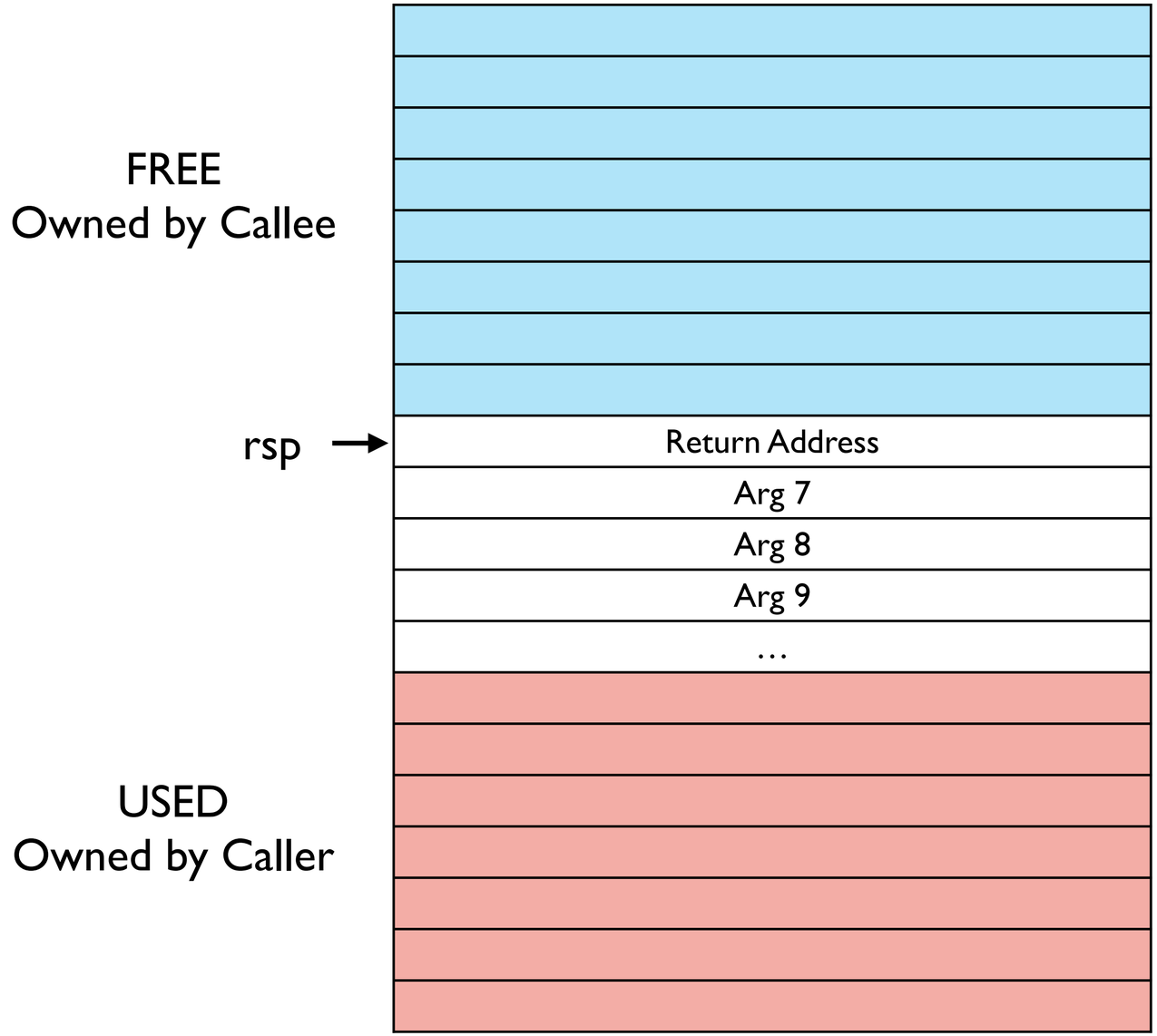
System V AMD 64

Calling protocol: When a called function starts executing the machine state is as follows:

1. Arguments 1-6 are stored in rdi, rsi, rdx, rcx, r8, r9
2. Arguments 7-N are stored in [rsp + 1 * 8], [rsp + 2 * 8],...[rsp + (N - 6) * 8]
3. rsp points to the return address.
4. Stack Alignment: rsp % 16 == 8

System V AMD 64

rdi	Arg 1
rsi	Arg 2
rdx	Arg 3
rcx	Arg 4
r8	Arg 5
r9	Arg 6
rsp	0xXX...X8



System V AMD 64

Returning protocol: When a called function returns to its caller

1. Return value is stored in rax
2. Registers rbx, rbp, r12-r15 are in their original state when the function was called **(non-volatile aka callee-save)**
3. Stack memory at higher addresses than rsp is in the original state when the function was called
4. Original value of rsp holds the return address, pop this address and jump to it

Volatile/Non-volatile Registers

A register is **volatile** if its value may be changed by a function call

This means the **callee** can set the register as they see fit, no promises on what its value will be when the callee returns

Also known as **caller-save** because if a local variable is stored in a volatile register it must be "saved" somewhere non-volatile if its value is needed after the call

A register is **non-volatile** it it must be preserved by a function call

This means the **callee** must ensure that when the function returns, the register has the same value as it did when the function began execution

Also known as **callee-save** because if the callee wants to use a non-volatile register, the original value must be saved somewhere and restored before returning

Volatile/Non-volatile Registers

Current Strategy:

We use registers as scratch registers, but always store local variable values on the stack

Should a scratch register be **volatile** or **non-volatile**?

volatile: we are free to change it without worrying about the caller

don't need to worry about saving it when we make a call because we don't store long-lived values in it

examples: rax, r10, r11, any argument register if we move its value to the stack

Revisit this once we implement **register allocation**

Stack Alignment

When a function is called, rsp % 16 == 8

Needed for certain SSE instructions which require data alignment

To ensure correct alignment: rsp % 16 == 0 **before** executing the **call** instruction (since call pushes an 8-byte address)

WARNING: this is a common cause of implementation bugs that can be hard to track down.

If your compiler produces misaligned calls, it might be the case that the code errors on the autograder but not on your local machine.

Caller cleanup

In the SysV AMD 64 calling convention, the **caller** is responsible for "cleanup" of the arguments.

That is, when a function returns, the arguments that are passed on the stack are still there, even though they are not necessarily needed

Why?

> Used to implement C-style variadic function. In C, a variadic function doesn't know how many arguments have been passed, so impossible for it to perform caller cleanup.

Downside:

> Impossible to perform tail call to a function that takes more stack-allocated arguments than the caller using SysV AMD 64 calling convention.

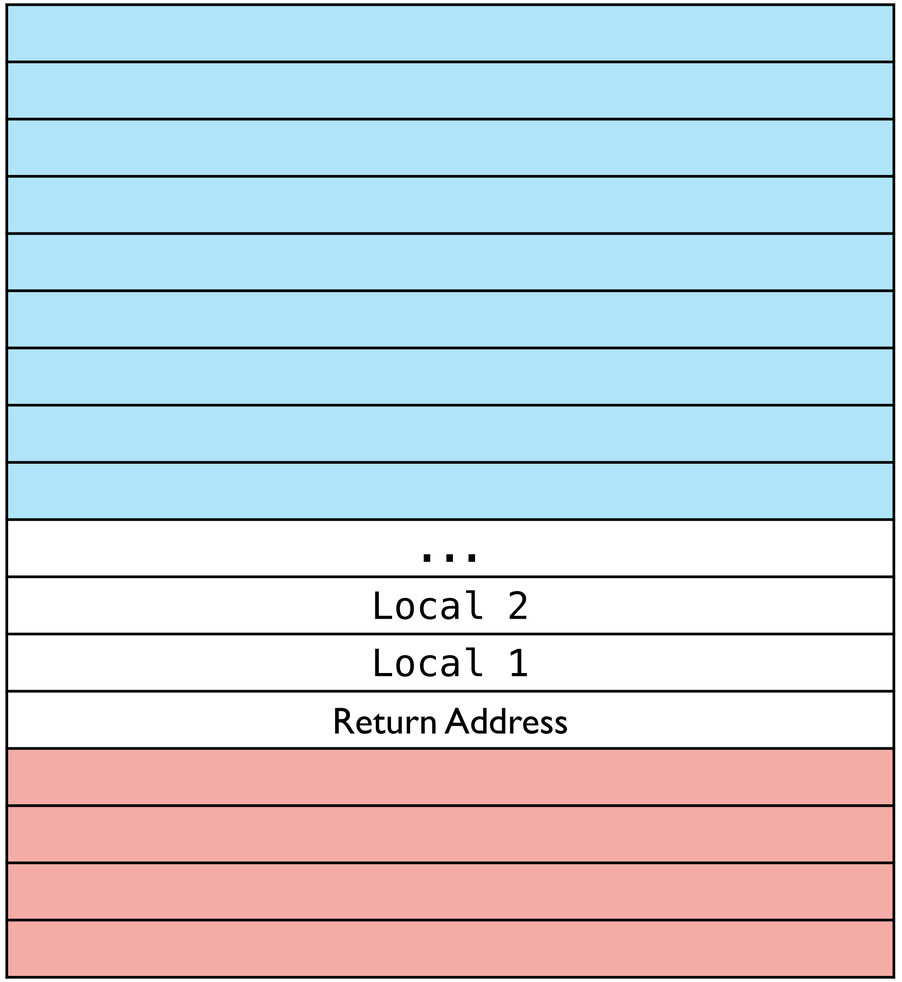
Stack Frames

The region of the stack used by a function is called the stack "frame".

When making a function call we need to ensure that the newly allocated stack frame for the callee is "above" all of our local variables, so that the callee doesn't overwrite their values.

So we need to know where the "top" of our stack frame is in order to determine **where** to create the callee's stack frame.

Two common strategies to do so.



Stack Frame Management: Two Registers

Strategy: use two different pointers

rbp is the "base pointer" points to the base of the stack frame

rsp is the "stack pointer" points to the top of the stack frame

Downside:

takes up two registers

Benefit:

allows for dynamically sized stack allocation e.g., C alloca

Stack Frame Management: One Pointer

Strategy: use only a base pointer

rsp is the "base pointer" points to the base of the stack frame

top of the stack frame is statically determined by how much space our locals take up

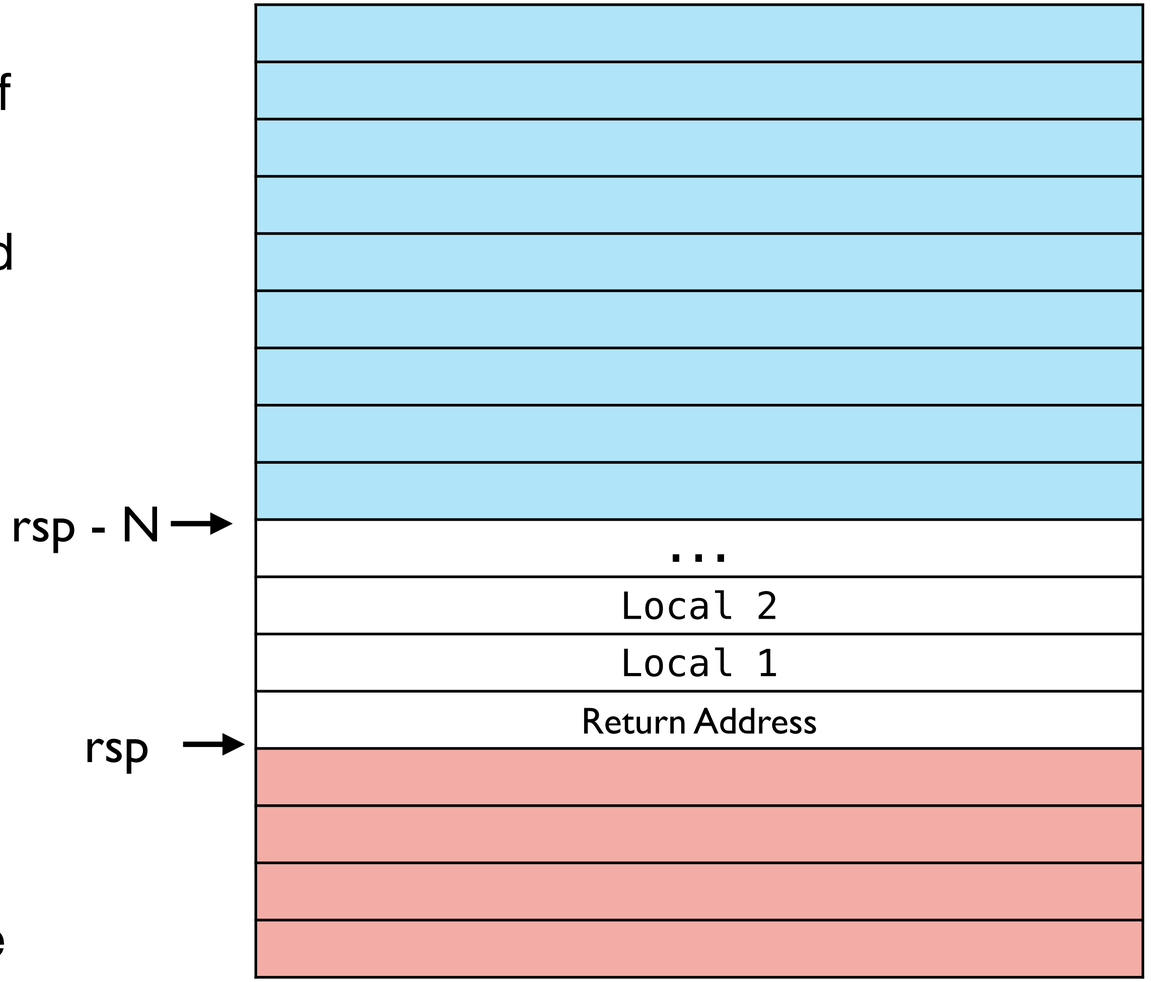
Benefit:

frees up rbp to be used for other purposes

Downside:

size of the stack frame must be statically computable (no alloca)

complicates the implementation of stack walking mechanisms like debuggers/garbage collectors



Stack Frame Management

The calling convention dictates an **interface** between the caller and the callee.

It does not dictate **internal** details of a function implementation, e.g., where in registers, memory, local variables are stored

2 common strategies for managing stack-allocated variables

1. Two pointers: Use rbp as the base pointer of the stack frame and rsp as the pointer to the **top** of the stack frame

2. Single pointer: Use rsp as the base pointer of the stack frame

We will use the single pointer approach because we don't need to support dynamic stack allocation.

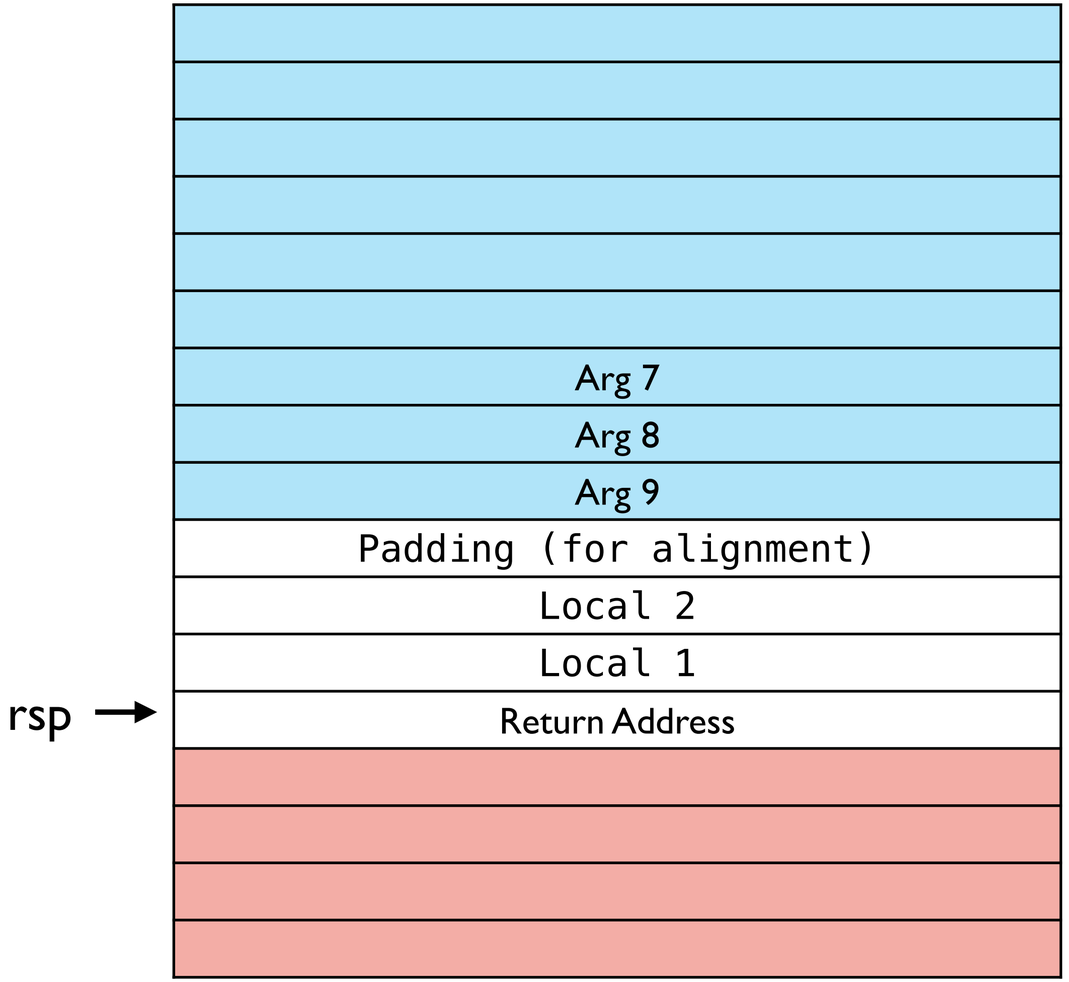
Modern C/C++ compilers will use the single pointer approach for functions that don't require dynamic stack allocation.

Sys V AMD64 Calls

Live code: implement and compile function calls into Rust functions manually in assembly code

Sys V AMD64 Call

```
mov rdi, arg1
mov rsi, arg2
mov rdx, arg3
mov rcx, arg4
mov r8, arg5
mov r9, arg6
mov QWORD [rsp - 48], arg7
mov QWORD [rsp - 40], arg8
mov QWORD [rsp - 32], arg9
sub rsp, 48
call big_fun
add rsp, 48
```



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mov r8, arg5
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mov QWORD [rsp - 40], arg8
mov QWORD [rsp - 32], arg9
sub rsp, 48
call big_fun
add rsp, 48
```