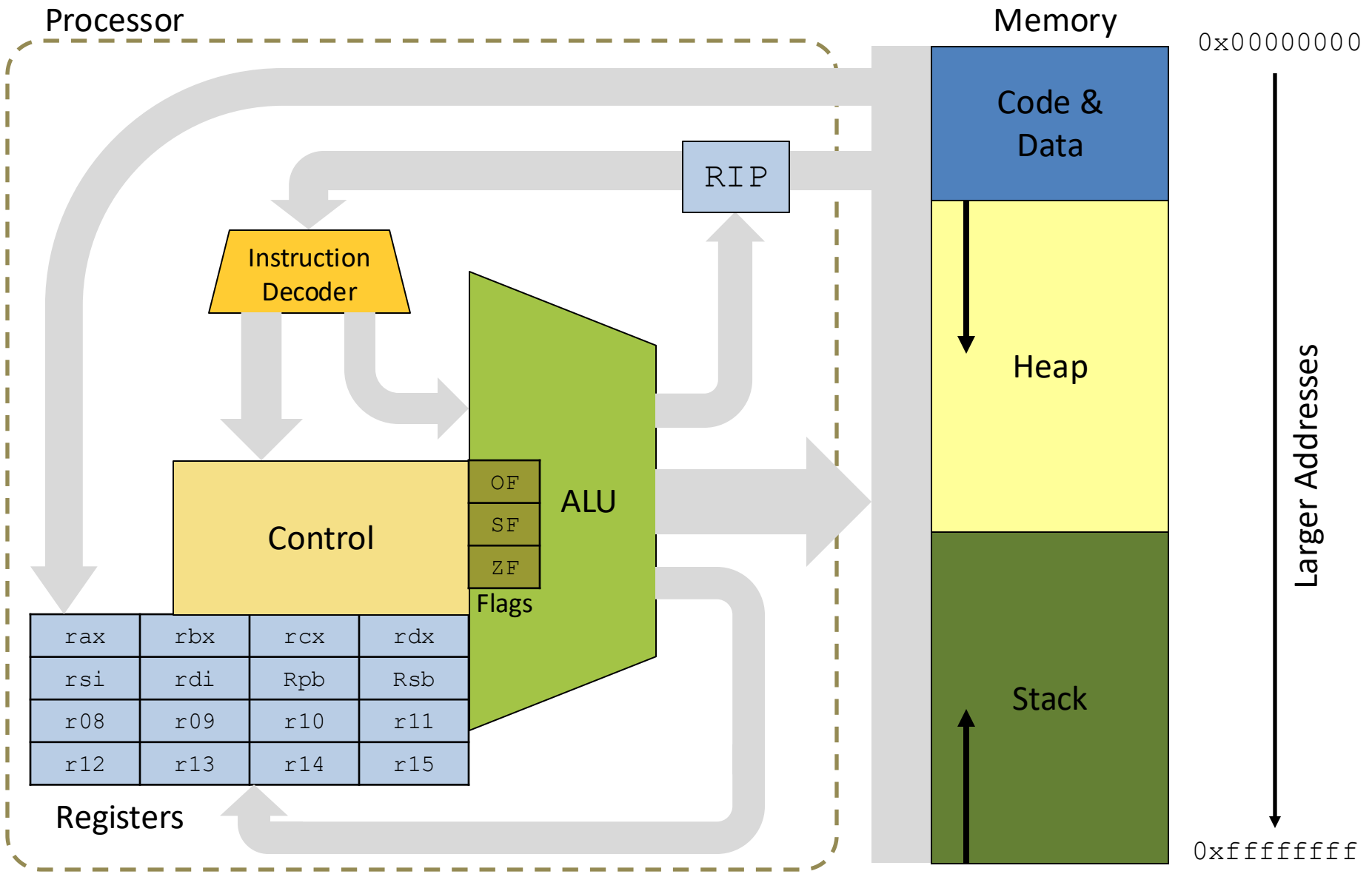
Lecture 4

CIS 3410/7000: COMPILERS

Announcements

- HW2: X86lite
  - Available on the course web pages soon. (look for announcement on Blackboard / Piazza).
  - Due: October 21st.
  - Pair-programming project
  - NOTE: much more difficult than hw1, so please start early!

X86 Schematic



X86lite State: Condition Flags & Codes

- X86 instructions set flags as a side effect
- X86lite has only 3 flags:
  - `OF`: "overflow" set when the result is too big/small to fit in 64-bit reg.
  - `SF`: "sign" set to the sign or the result (0=positive, 1 = negative)
  - `ZF`: "zero" set when the result is 0

- From these flags, we can define *Condition Codes*
  - To compare SRC1 and SRC2, compute SRC1 – SRC2 to set the flags
  - `eq` equality holds when `ZF` is set
  - `ne` inequality holds when (not `ZF`)
  - `gt` greater than holds when (not le) holds,
    - i.e. (SF = OF) && not(ZF)
  - `lt` less than holds when `SF` <> `OF`
    - Equivalently: ((`SF` && not `OF`) || (not `SF` && `OF`))
  - `ge` greater or equal holds when (not lt) holds, i.e. (SF = OF)
  - `le` than or equal holds when `SF` <> `OF` or `ZF`

Code Blocks & Labels

- X86 assembly code is organized into *labeled blocks*:

```
label1:
        <instruction>
        <instruction>
        …
        <instruction>

label2:
        <instruction>
        <instruction>
        …
        <instruction>
```

- Labels indicate code locations that can be jump targets (either through conditional branch instructions or function calls).
- Labels are translated away by the linker and loader – instructions live in the heap in the "code segment"
- An X86 program begins executing at a designated code label (usually "main").

Conditional Instructions

- `cmpq` SRC1, SRC2 — Compute SRC2 – SRC1, set condition flags
- `setb`CC DEST — DEST's lower byte ← if CC then 1 else 0
- `j`CC SRC — `rip` ← if CC then SRC else fallthrough
- Example:

```
cmpq %rcx, %rax
je __truelbl
```

Compare `rax` to `ecx`
If `rax` = `rcx` then jump to `__truelbl`

Jumps, Call and Return

- `jmp` SRC `rip` ← SRC Jump to location in SRC

- `callq` SRC Push `rip`; `rip` ← SRC
  - Call a procedure: Push the program counter to the stack (decrementing `rsp`) and then jump to the machine instruction at the address given by SRC.

- `retq` Pop into `rip`
  - Return from a procedure: Pop the current top of the stack into `rip` (incrementing `rsp`).
  - This instruction effectively jumps to the address at the top of the stack

See: runtime.c and x86.ml in lec04.zip

DEMO: HANDCODING X86LITE

Compiling, Linking, Running

- To use hand-coded X86:
  1. Compile main.ml (or something like it) to either native or bytecode
  2. Run it, redirecting the output to some .s file, e.g.:
     ./main.exe >> test.s
  3. Use gcc to compile & link with runtime.c:
     gcc -o test runtime.c test.s
  4. You should be able to run the resulting exectuable:
     ./test

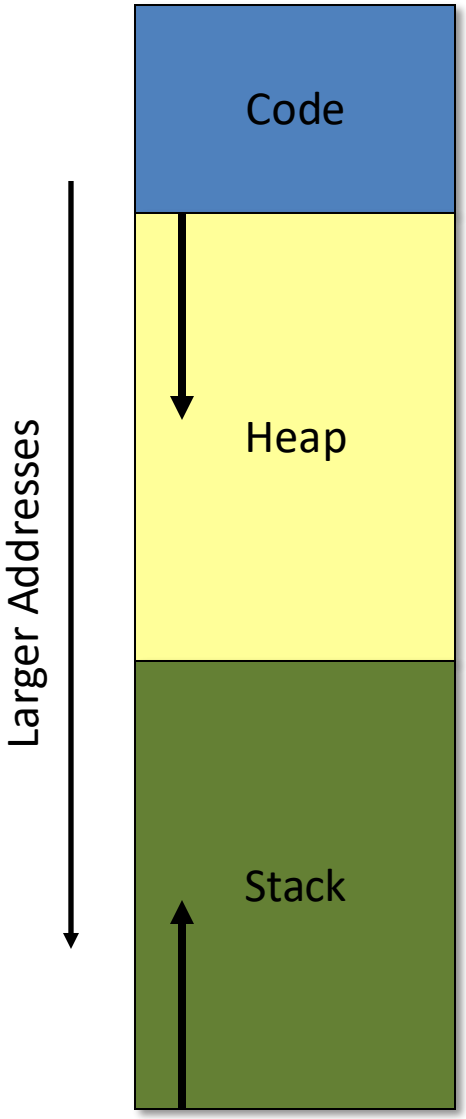
- If you want to debug in gdb:
  - Call gcc with the –g flag too

PROGRAMMING IN X86LITE

3 parts of the C memory model

- The code & data (or "text") segment
  - contains compiled code, constant strings, etc.
- The Heap
  - Stores dynamically allocated objects
  - Allocated via "malloc"
  - Deallocated via "free"
  - managed by C runtime system
- The Stack
  - Stores local variables
  - Stores the return address of a function

- In practice, most languages use this model.



Local/Temporary Variable Storage

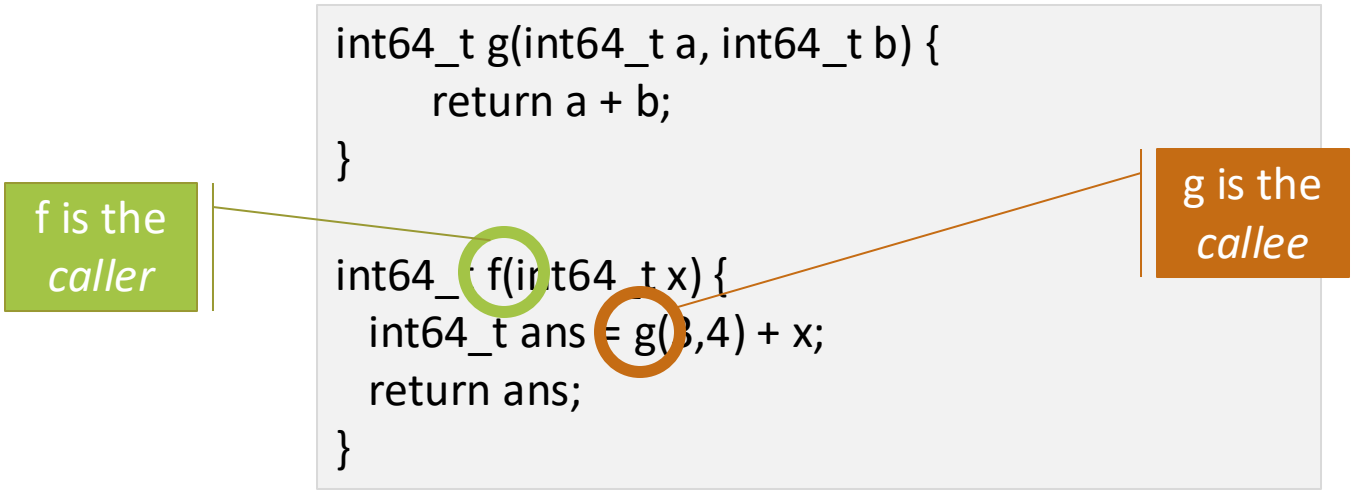
- Need space to store:
  - Global variables
  - Values passed as arguments to procedures
  - Local variables (either defined in the source program or introduced by the compiler)

- Processors provide two options
  - Registers: fast, small size (64 bits), very limited number
  - Memory: slow, very large amount of space (2 GB)
    - caching important

- In practice on X86:
  - Registers are limited (and have restrictions)
  - Divide memory into regions including the *stack* and the *heap*

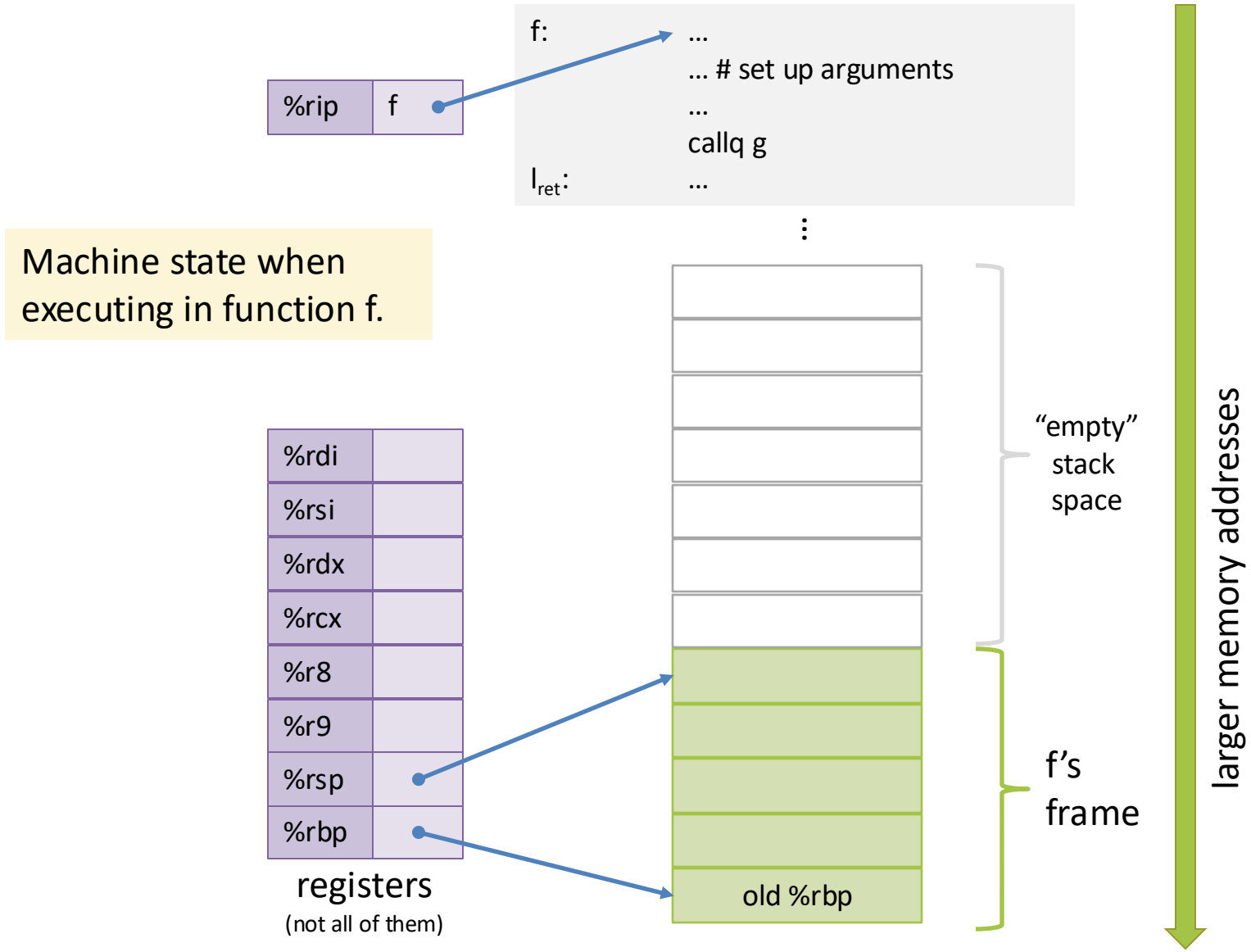
Calling Conventions

- Specify the locations (*e.g.*, register or stack) of arguments passed to a function and returned by the function



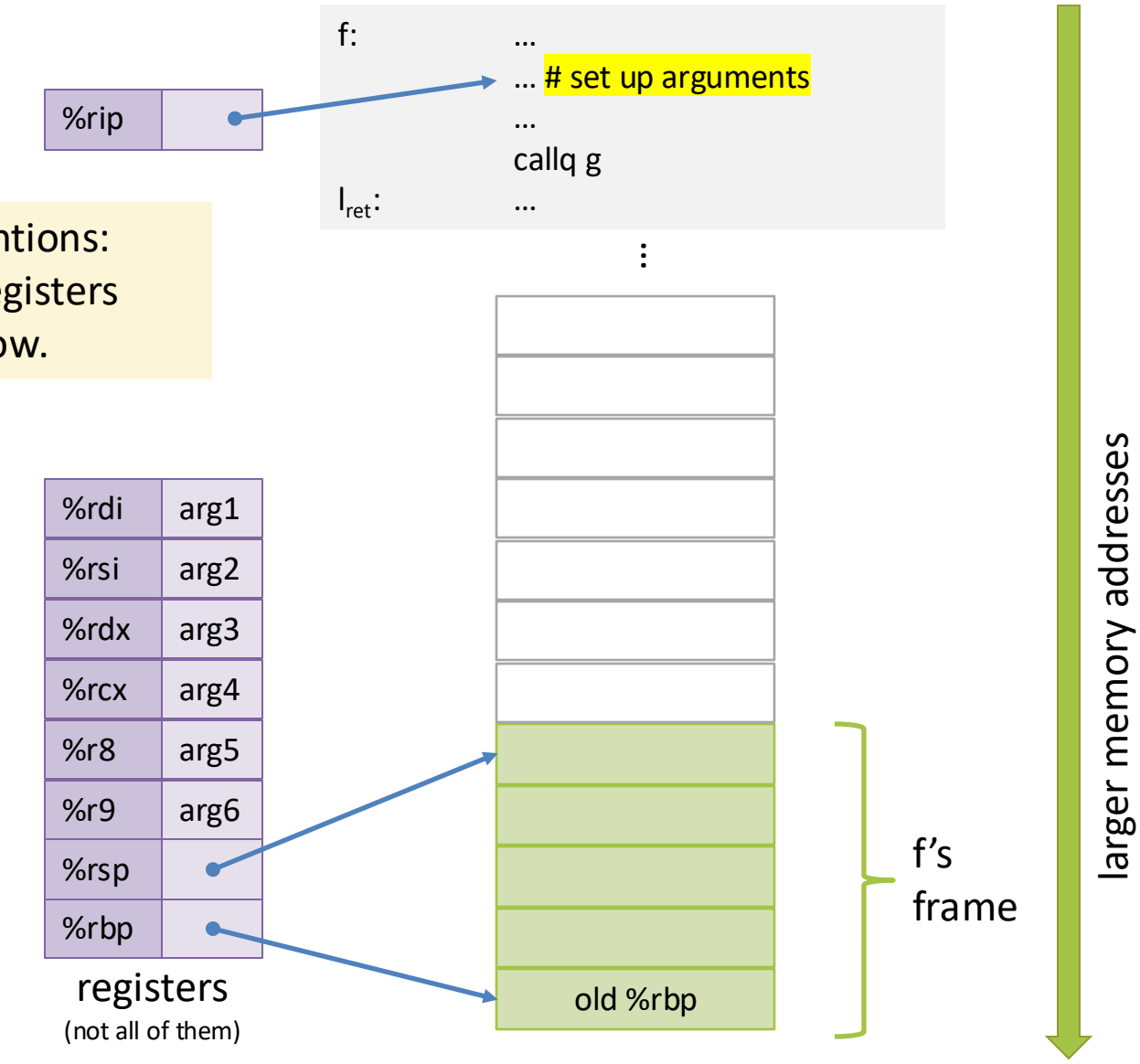
- Designate registers either:
  - Caller Save – *e.g.*, freely usable by the called code
  - Callee Save – *e.g.*, must be restored by the called code
- Define the protocol for deallocating stack-allocated arguments
  - Caller cleans up
  - Callee cleans up (makes supporting variable number of arguments harder)

x64 Calling Conventions: Caller Protocol

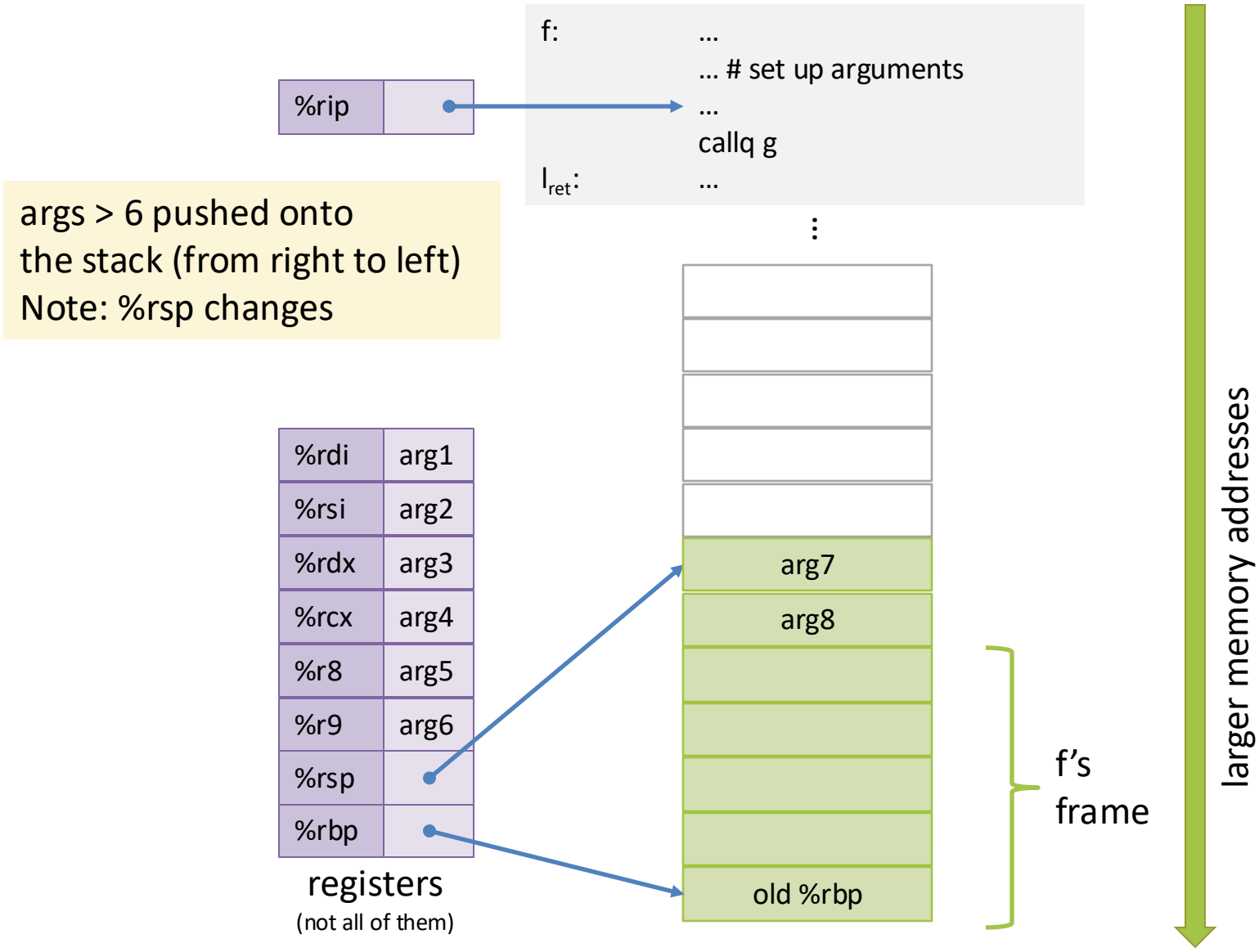


x64 Calling Conventions: Caller Protocol

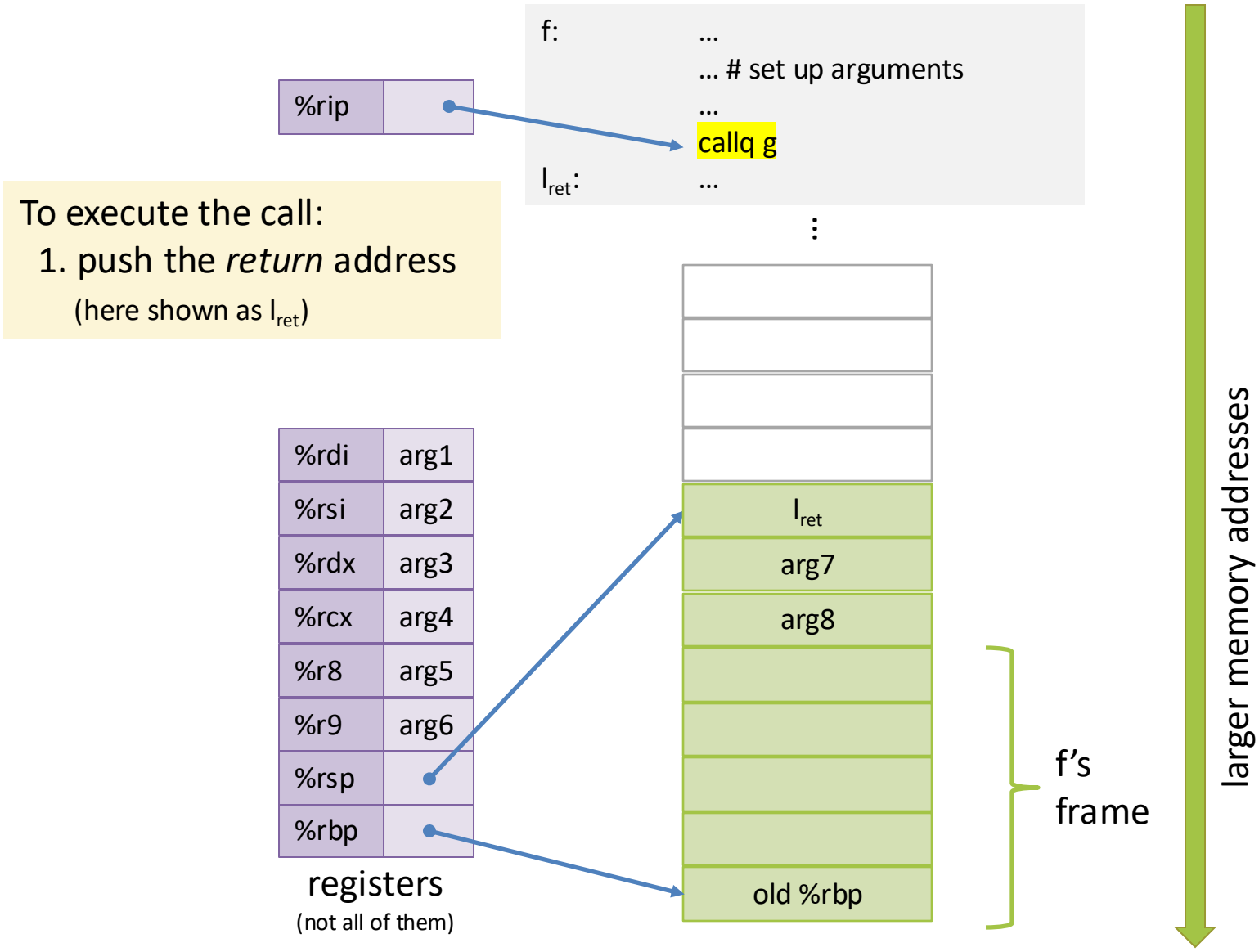
Calling conventions:
args 1…6 in registers
as shown below.



x64 Calling Conventions: Caller Protocol



call instruction



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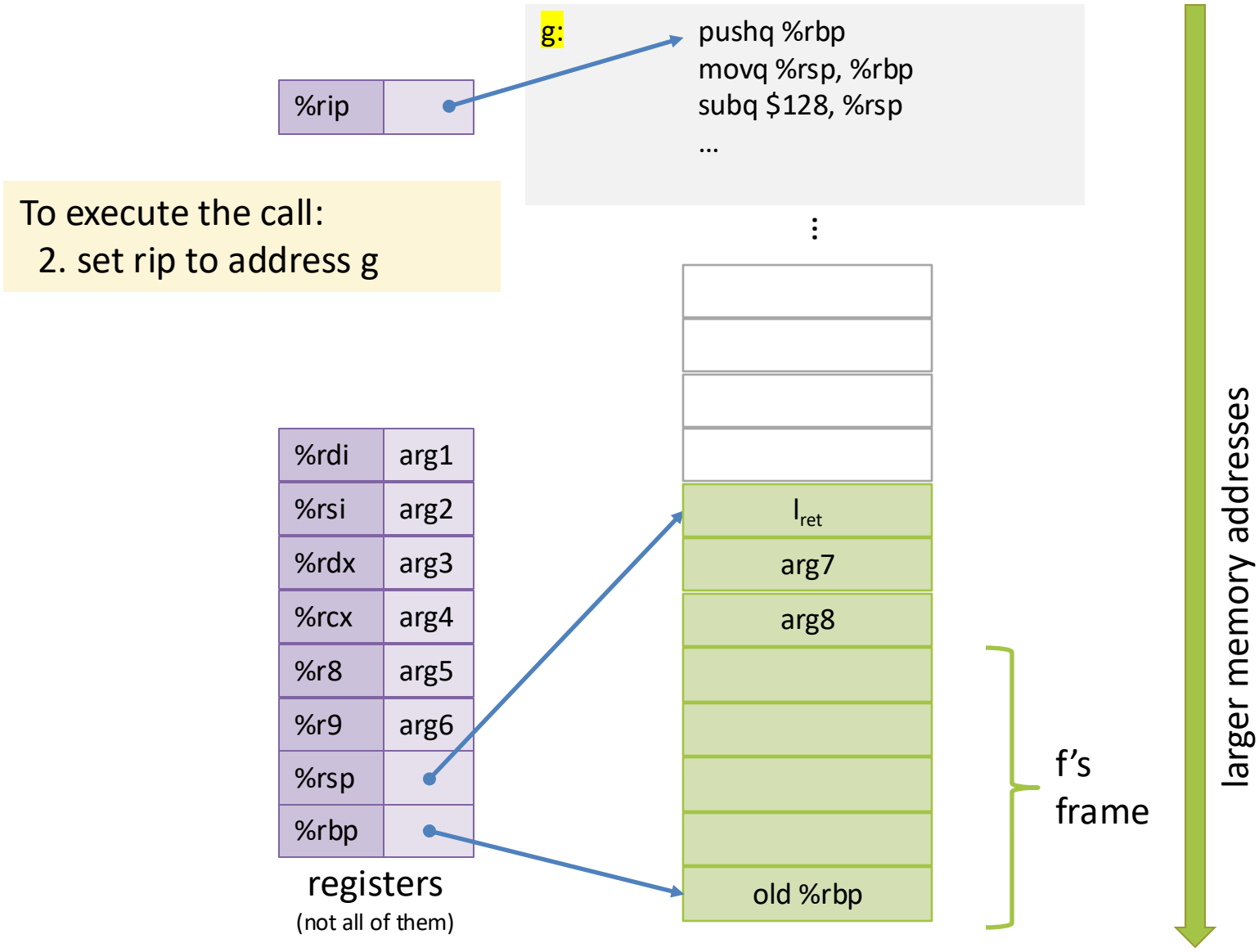
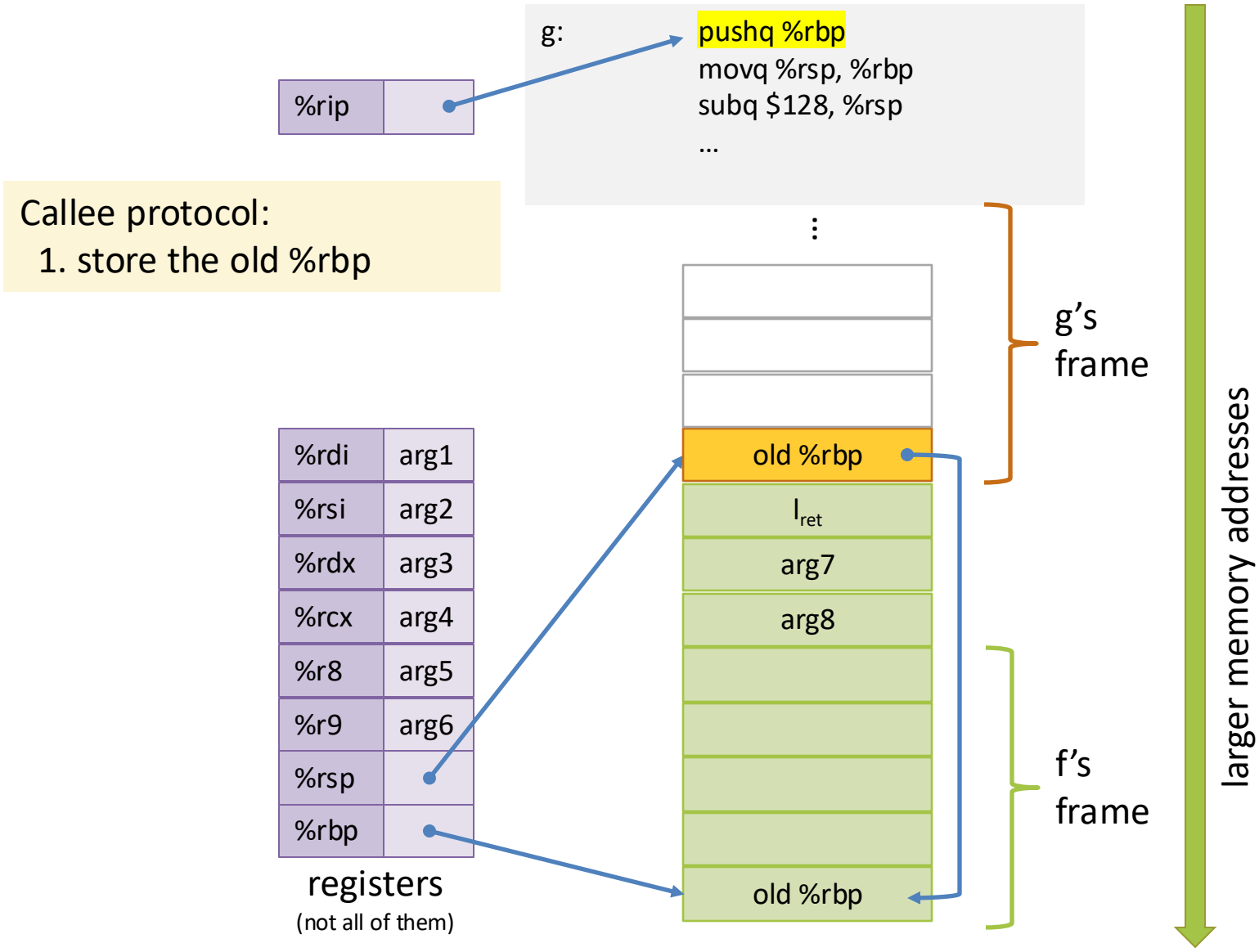


callee function prologue



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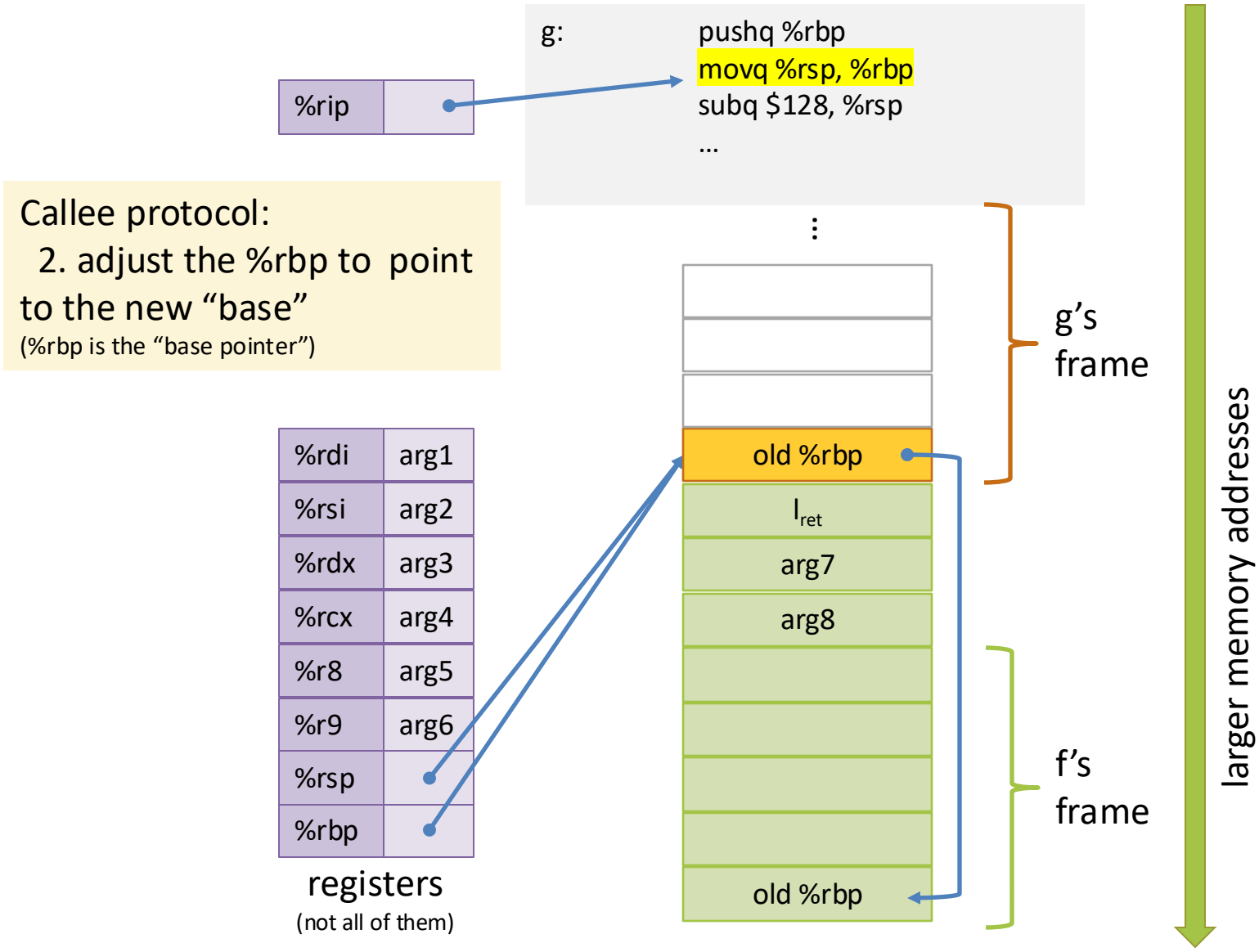

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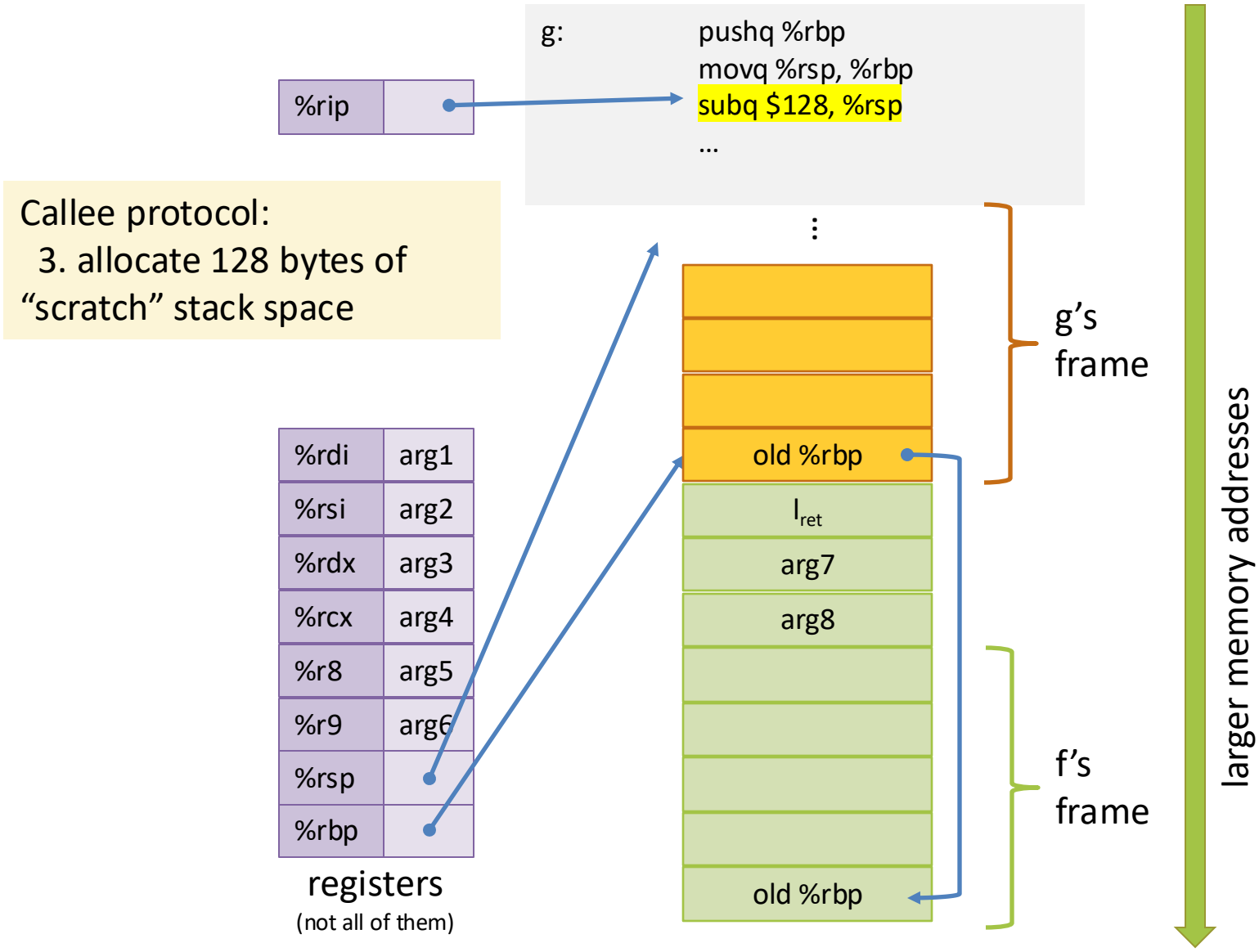
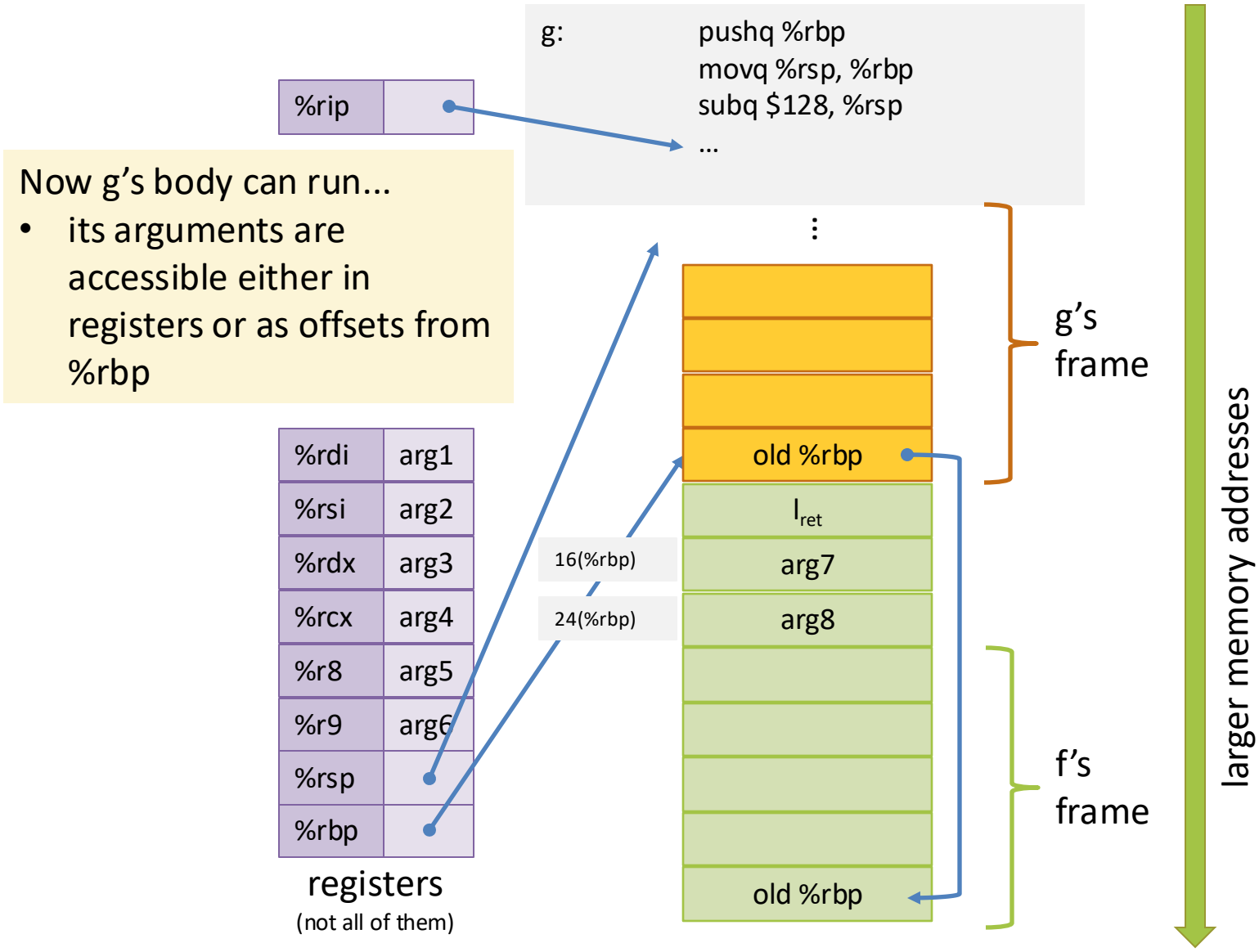
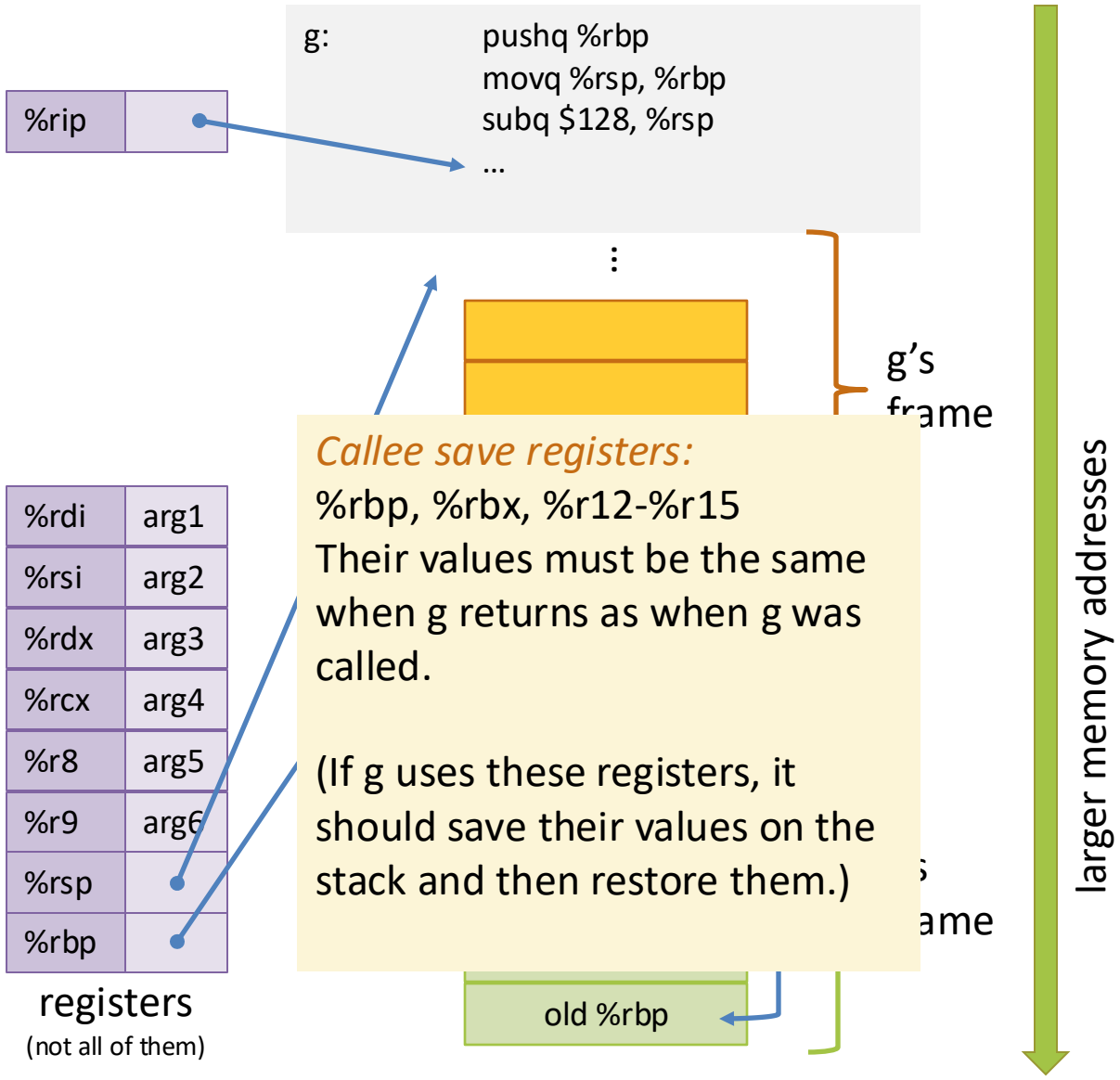


callee invariants: function arguments



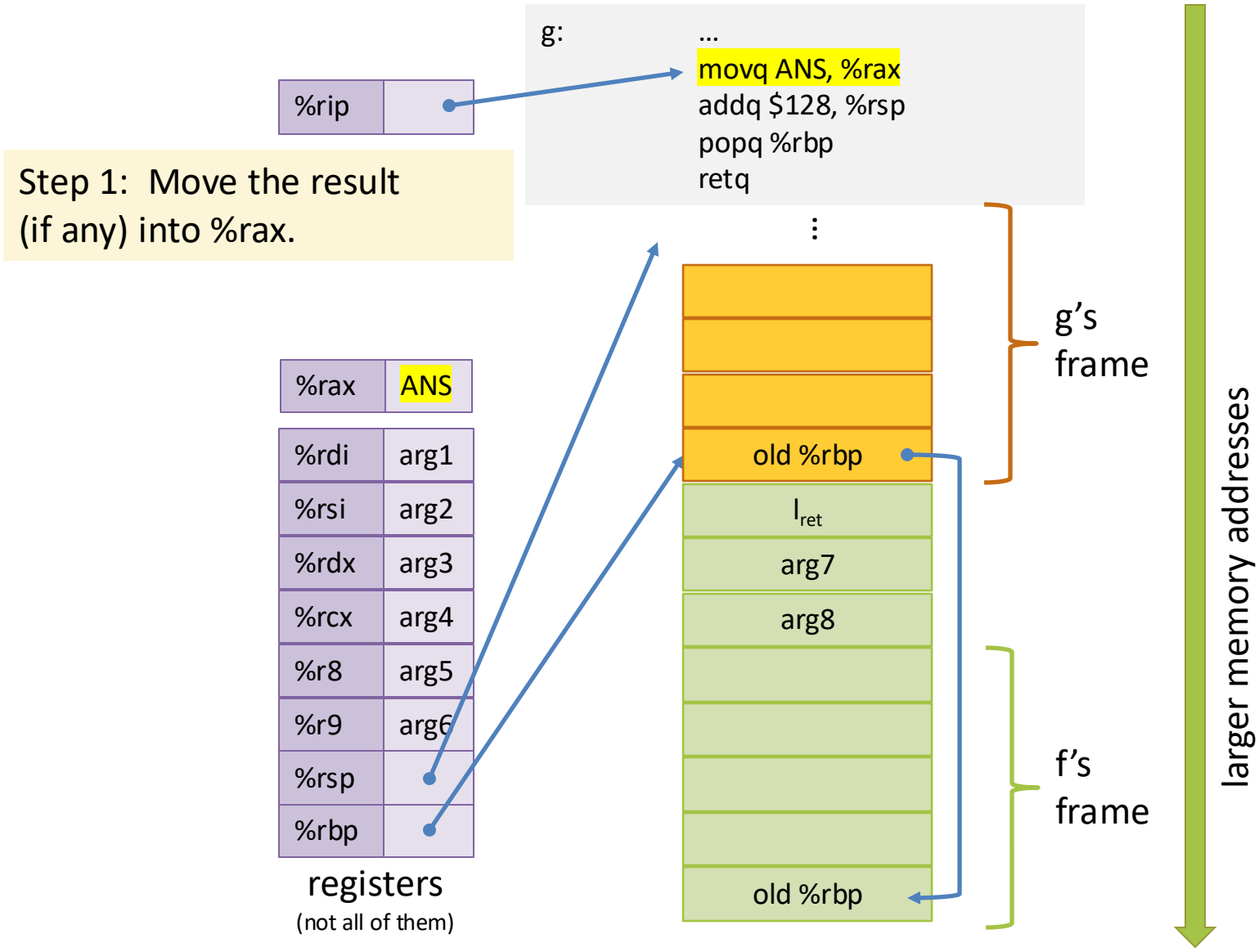
callee invariants: callee save registers



Callee save registers:
%rbp, %rbx, %r12-%r15
Their values must be the same when g returns as when g was called.

(If g uses these registers, it should save their values on the stack and then restore them.)

callee epilogue (return protocol)



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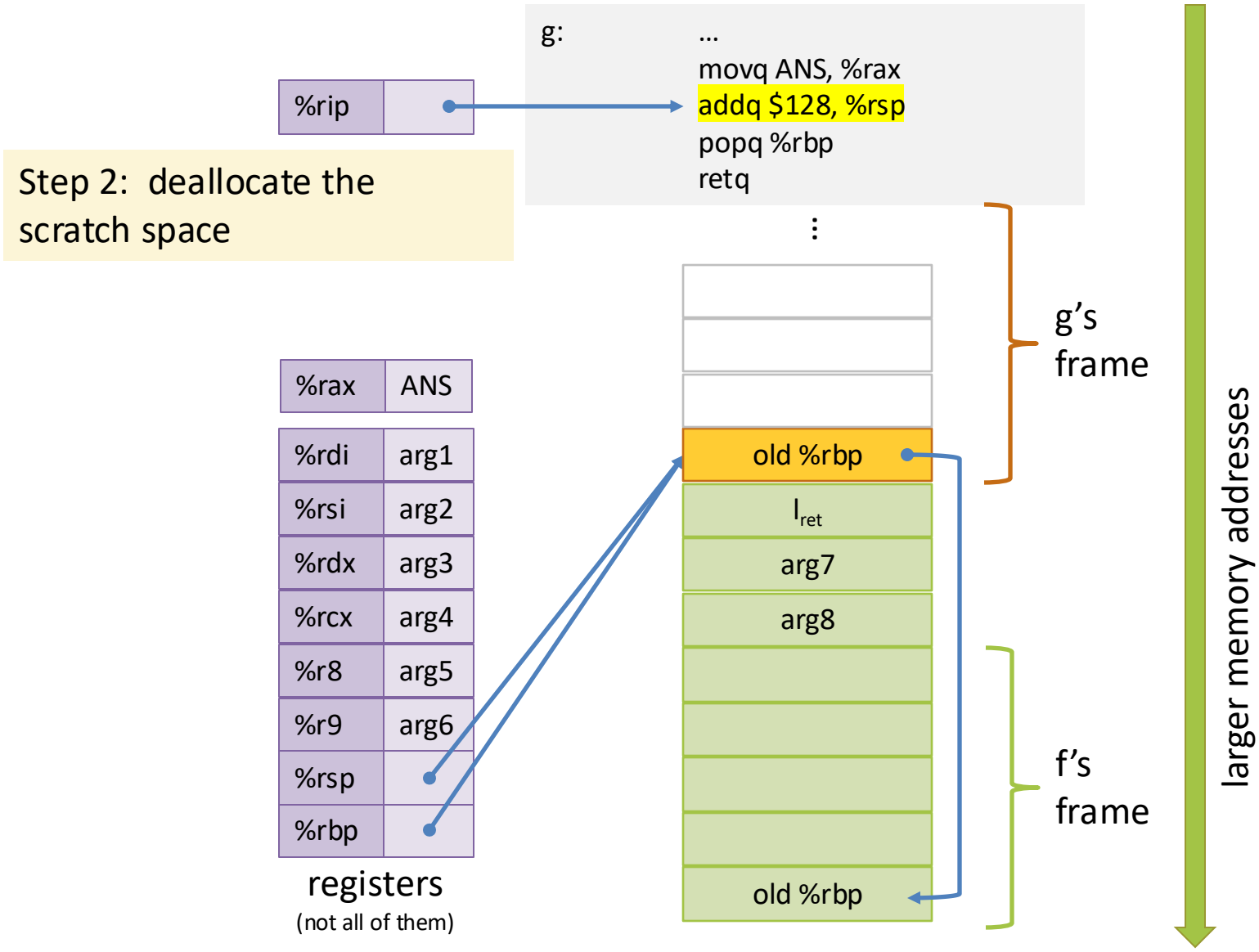

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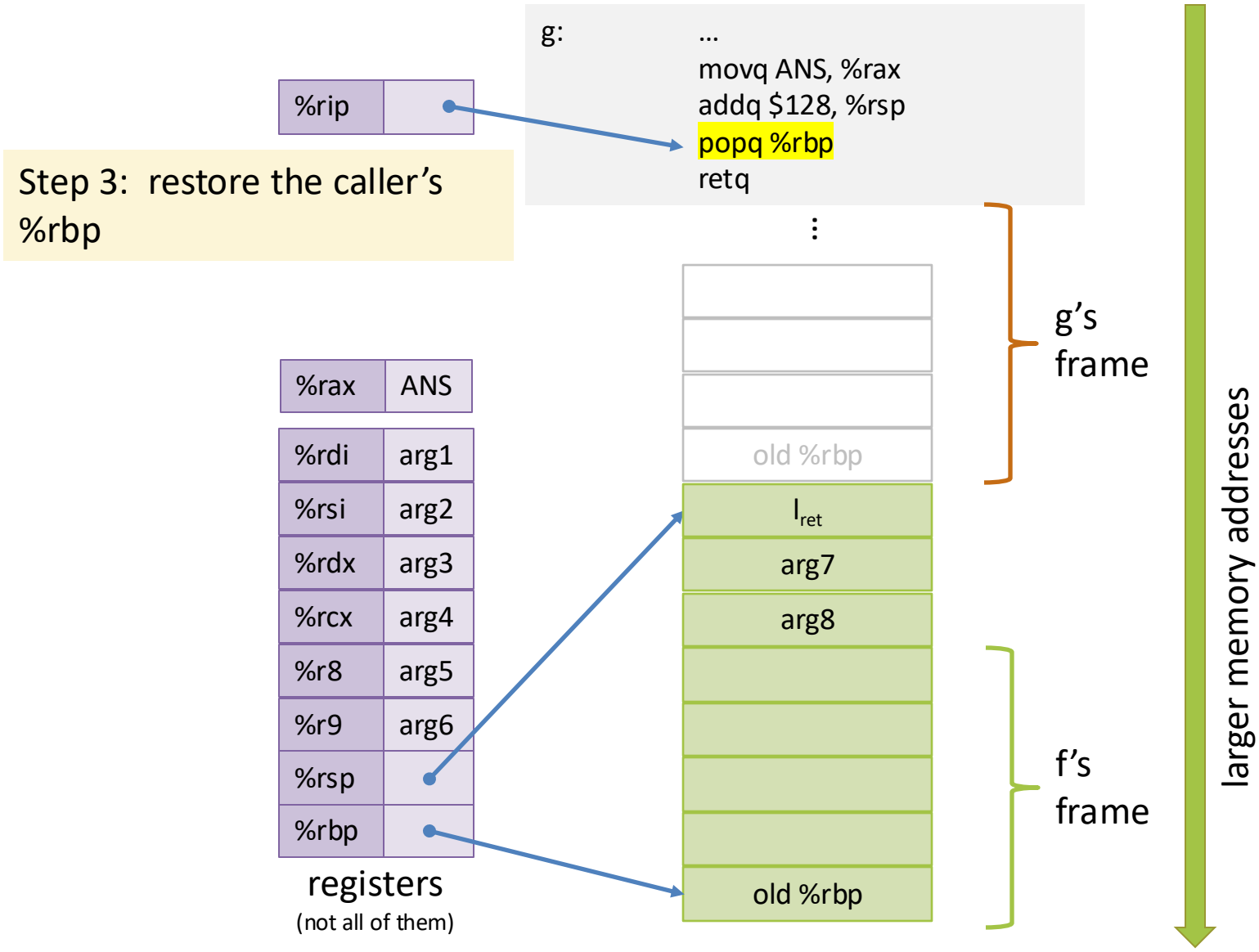

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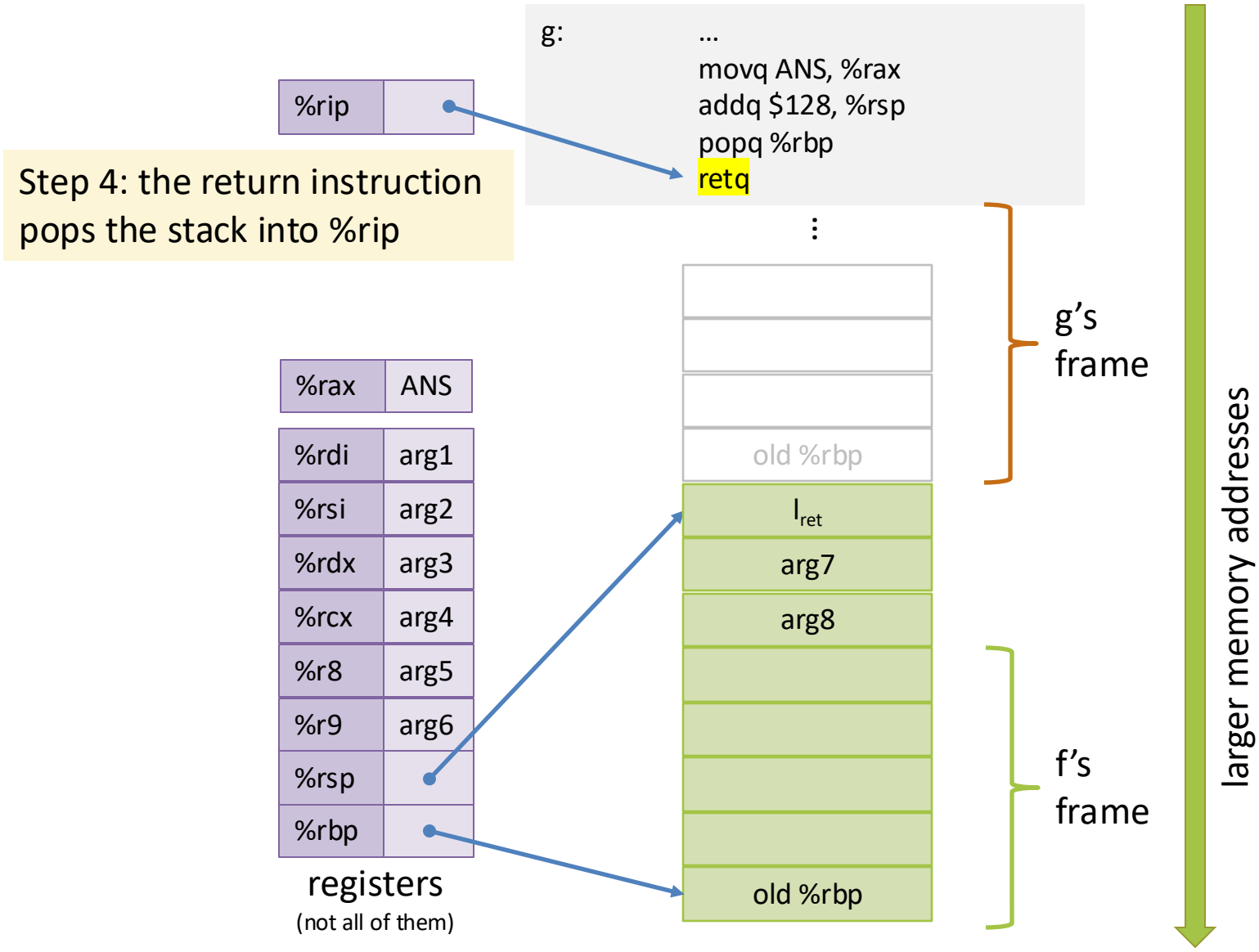

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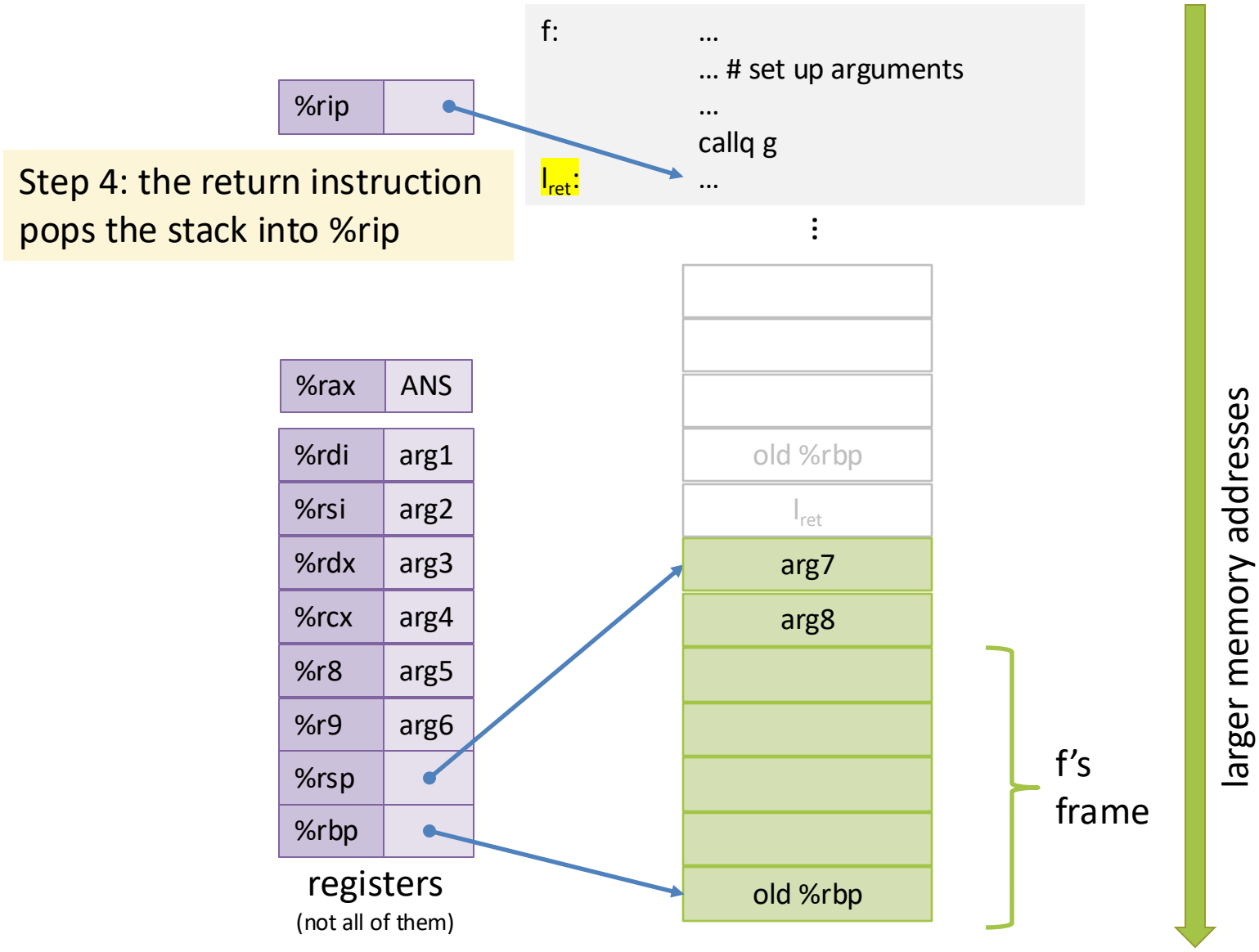
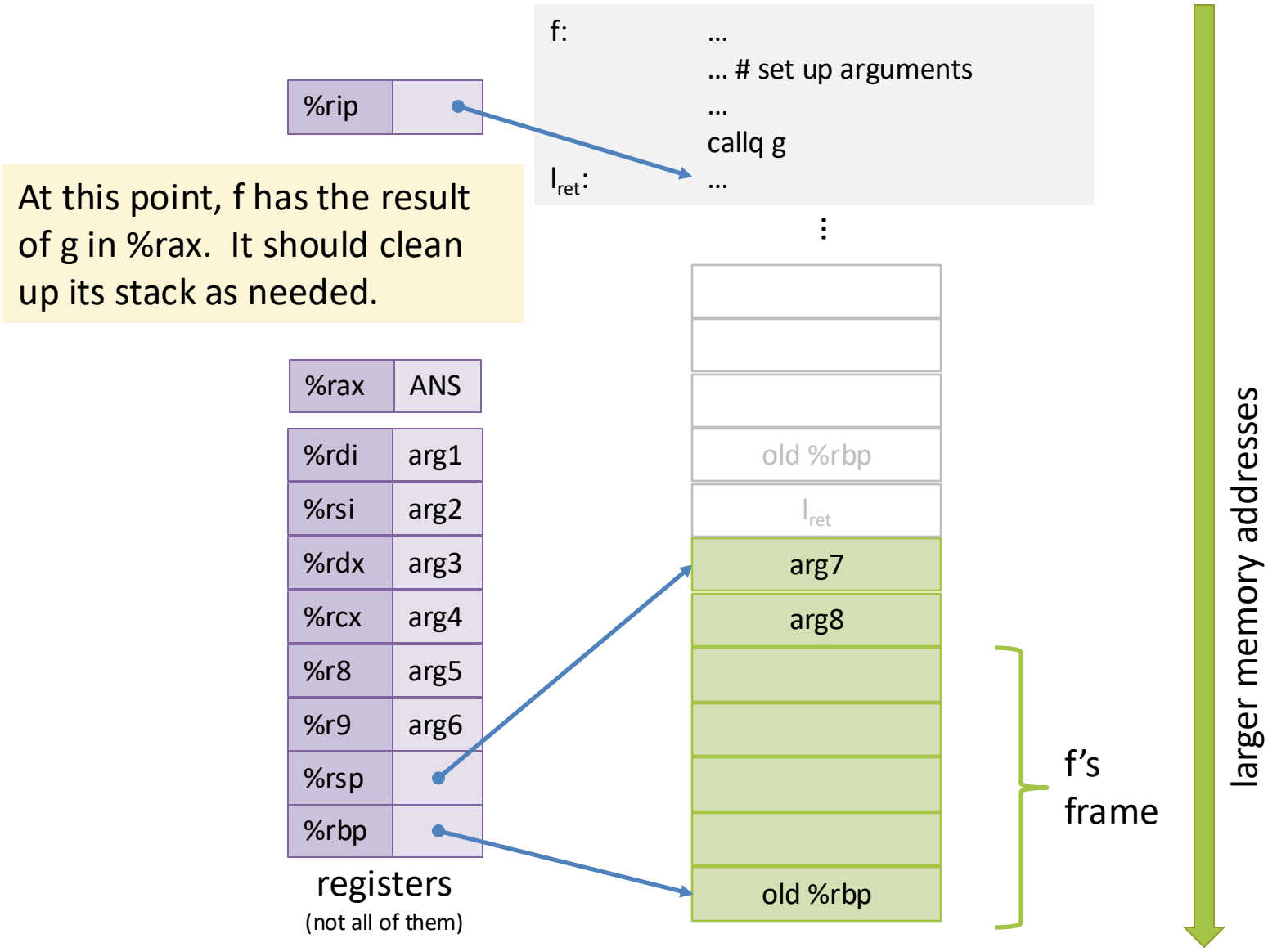


back in f


f:
...
... # set up arguments
...
callq g
l_{ret}:
...
%rip
At this point, f has the result of g in %rax. It should clean up its stack as needed.
%rax
ANS
%rdi
arg1
%rsi
arg2
%rdx
arg3
%rcx
arg4
%r8
arg5
%r9
arg6
%rsp
%rbp
registers
(not all of them)
old %rbp
l_{ret}
arg7
arg8
old %rbp
f's frame
larger memory addresses

X86-64 SYSTEM V AMD 64 ABI

- Modern variant of C calling conventions
  - used on Linux, Solaris, BSD, OS X

- Callee save: %rbp, %rbx, %r12-%r15
- Caller save: all others

- Parameters 1 .. 6 go in: %rdi, %rsi, %rdx, %rcx, %r8, %r9
- Parameters 7+ go on the stack (in right-to-left order)
  - so: for n > 6, the n^{th} argument is located at (((n-7)+2)*8)(%rbp)
  - e.g.: argument 7 is at 16(%rbp) and argument 8 is at 24(%rbp)

- Return value: in %rax

- 128 byte "red zone" – scratch pad for the callee's data
  - typical of C compilers, not required
  - can be optimized away

32-bit cdecl calling conventions

- Still "Standard" on X86 for many C-based operating systems
  - Still some wrinkles about return values
    (*e.g.*, some compilers use EAX and EDX to return small values)
  - 64 bit allows for packing multiple values in one register
- All arguments are passed on the stack in right-to-left order
- Return value is passed in EAX
- Registers EAX, ECX, EDX are caller save
- Other registers are callee save
  - Ignoring these conventions will cause havoc (bus errors or seg faults)