Procedures II

CSE 351 Winter 2024

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http://xkcd.com/1270/

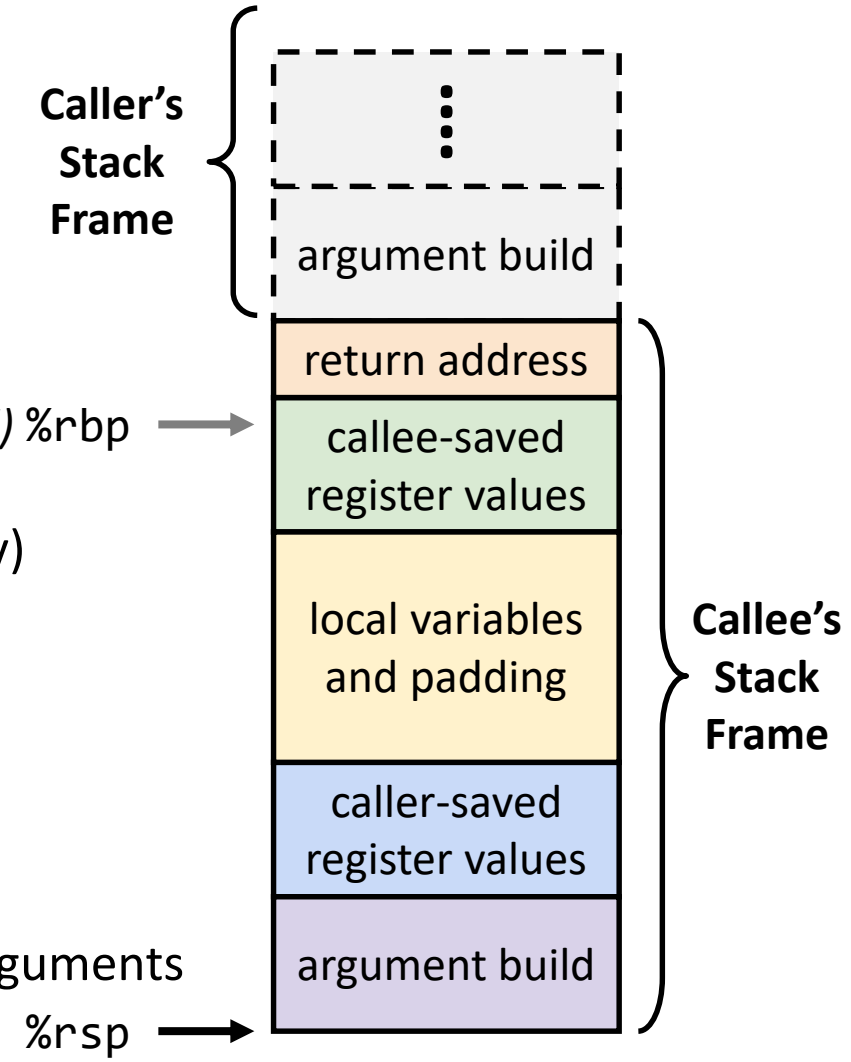
Relevant Course Information

- Lab 1b grades released later this week
  - Regrade requests open ~24 hours after grade release (rounded to 12:00 am), close ~72 hours after grade release (rounded to 11:59 pm)
- Lab 2 due Friday (2/2)
  - Since you are submitting a text file (`defuser.txt`), there won't be any Gradescope autograder output about compilation this time – check the Code tab after submission to make sure that everything looks right
  - Extra credit (bonus) needs to be submitted to the extra credit assignment
- Midterm (take home, 2/8–10)
  - Make notes and use the midterm reference sheet
  - Form study groups and look at past exams!

Procedures II

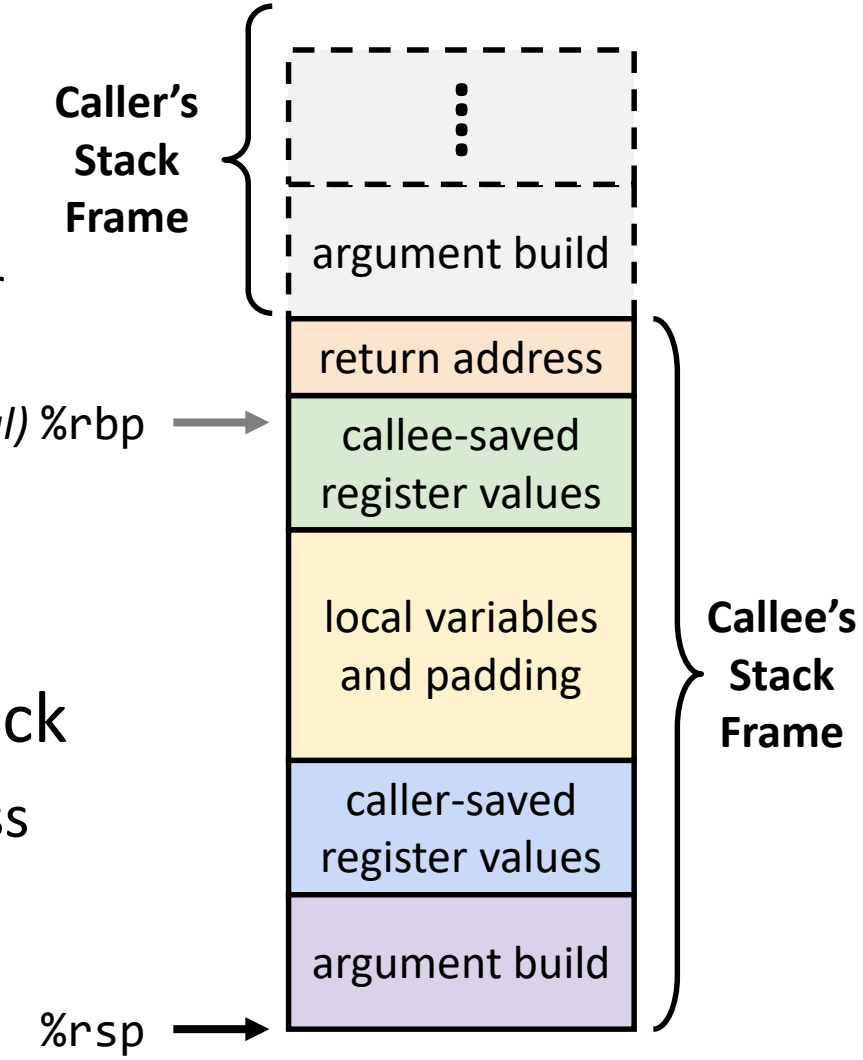
Lesson Summary (1/3)

- Each stack frame organized in the same way:
  1) Return address pushed by `call`
     - The address of the instruction after `call`
  2) Callee-saved registers
     - Only if procedure modifies/uses them
  3) Local variables
     - Unavoidable if variable is too big for a register (*e.g.*, array)
     - Unavoidable if variable needs an address (*i.e.*, uses `&var`)
  4) Caller-saved registers
     - Only if values are needed *across* a procedure call
  5) Argument build
     - Only if procedure calls a procedure with more than six arguments



Lesson Summary (2/3)

- Important Points
  - Procedures are a combination of *instructions* and *conventions*
    - Conventions prevent functions from disrupting each other
  - Stack is the right data structure
    - "Last in, first out" matches lifetime of procedures
  - Recursion handled by normal calling conventions
- Generally want to minimize the use of the stack
  - Lean heavily on registers, which are faster to access



Lesson Summary (3/3)

%rax	Return value - Caller saved
%rbx	Callee saved
%rcx	Argument #4 - Caller saved
%rdx	Argument #3 - Caller saved
%rsi	Argument #2 - Caller saved
%rdi	Argument #1 - Caller saved
%rsp	Stack pointer
%rbp	Callee saved

%r8	Argument #5 - Caller saved
%r9	Argument #6 - Caller saved
%r10	Caller saved
%r11	Caller Saved
%r12	Callee saved
%r13	Callee saved
%r14	Callee saved
%r15	Callee saved

Silly Register Convention Analogy

1) Parents (***caller***) leave for the weekend and give the keys to the house to their child (***callee***)
   - Being suspicious, they put away/hid the valuables (***caller***-*saved*) before leaving
   - Warn child to leave the bedrooms untouched: "These rooms better look the same when we return!"

2) Child throws a wild party (*computation*), spanning the entire house
   - To avoid being disowned, child moves all of the stuff from the bedrooms to the backyard shed (***callee***-*saved*) before the guests trash the house
   - Child cleans up house after the party and moves stuff back to bedrooms

3) Parents return home and are satisfied with the state of the house
   - Move valuables back and continue with their lives

Lesson Q&A

- Learning Objectives:
  - Trace stack frame contents through the execution of x86-64 assembly instructions for both recursive and non-recursive programs.
  - Identify how x86-64 register-saving conventions allow procedures to execute without destroying each other's data.

- What lingering questions do you have from the lesson?
  - Chat with your neighbors about the lesson for a few minutes to come up with questions

Procedures II – Practice

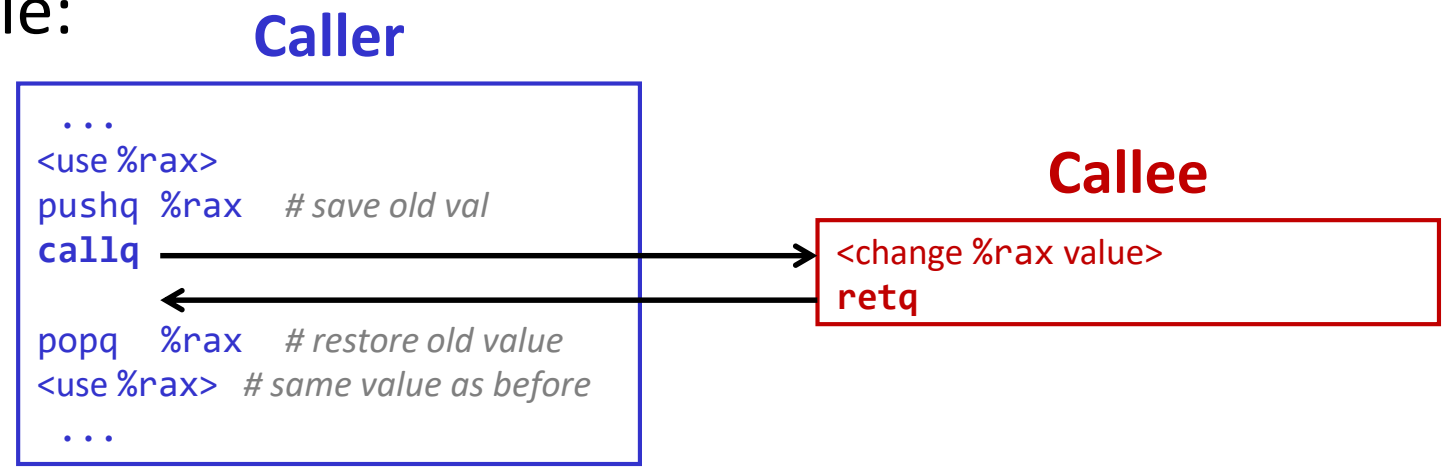
Polling Questions

- In the following function, how big is the stack frame?
  Which instruction(s) pertain to the **local variables** and **saved registers** portions of its stack frame?

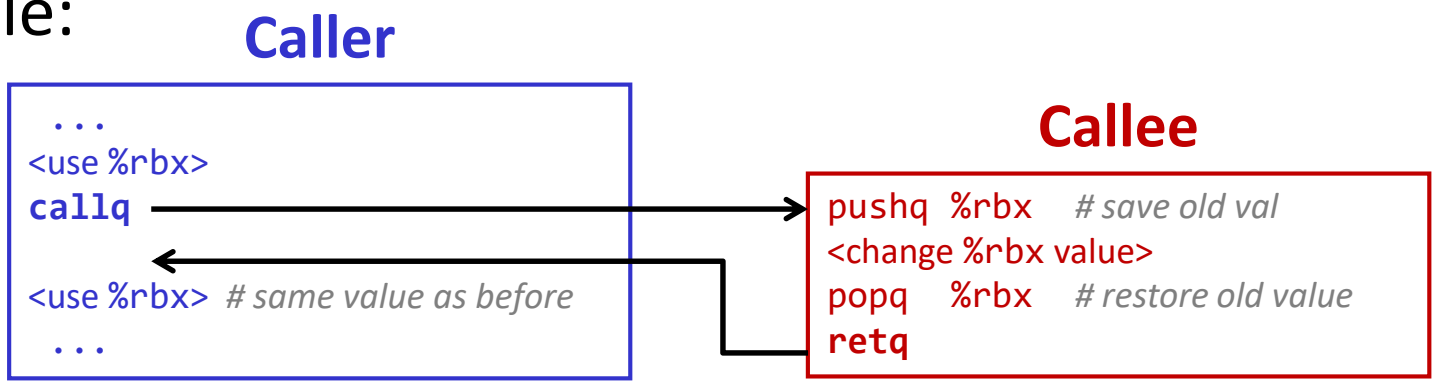
```
 call_mem_add2:
 1  pushq   %rbx
 2  subq    $16, %rsp
 3  movq    %rdi, %rbx
 4  movq    $351, 8(%rsp)
 5  movl    $100, %esi
 6  leaq    8(%rsp), %rdi
 7  call    mem_add
 8  addq    %rbx, %rax
 9  addq    $16, %rsp
10  popq    %rbx
11  ret
```

Homework Setup

- Caller-saved register example:
  - Saving is done just before calling the callee and restoring is done right after the call



- Callee-saved register example:
  - Saving is done early in procedure (before use) and restoring is done just before returning to caller



Procedures II – Context

Recursive Example: Popcount

```
/* Recursive popcount */
long pcount_r(unsigned long x) {
  if (x == 0)
    return 0;
  else
    return (x & 1) + pcount_r(x >> 1);
}
```

logical right shift

stop once all 1's shifted off

value of LSB

shift off LSB and recurse

```
pcount_r:
  movl    $0, %eax
  testq   %rdi, %rdi
  jne     .L8
  ret
.L8:
  pushq   %rbx
  movq    %rdi, %rbx
  shrq    %rdi
  call    pcount_r
  andl    $1, %ebx
  addq    %rbx, %rax
  popq    %rbx
  ret
```

- Counts the 1's in the binary representation of x
  - https://godbolt.org/z/P8Mened14
  - Compiled with -O1 instead of -Og for more natural instruction ordering
- Register usage:
  - Need x (in %rdi) after procedure call
  - Chooses to save %rdi by copying into %rbx
  - Chooses to save %rbx by pushing to stack (only in recursive case)

GDB Demo #2

- Let's examine the `pcount_r` stack frames on a real machine!
  - Using `pcount.c` from the course website
- You will need to use GDB to get through the Midterm
  - Useful debugger in this class and beyond!
- Pay attention to:
  - Checking the current stack frames (`backtrace`)
  - Getting stack frame information (`info frame <#>`)
  - Examining memory (x)

Group Work Time

- During this time, you are encouraged to work on the following:
  1) If desired, continue your discussion
  2) Work on the homework problems
  3) Work on the lab (if applicable)

- Resources:
  - You can revisit the lesson material
  - Work together in groups and help each other out
  - Course staff will circle around to provide support