Function Calls and Stack

HW5 due Friday Nov 8th

Philipp Koehn

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functions

Another Example

- C code with an undefined function

```
int main(void) {
  int a = 2;
  int b = do_something(a);
  return b;
}
```

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- This can be successfully compiled into an object file

```
linux> gcc -w -Og -c function.c
```

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int main(void) {
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  return b;
}
```

- This can be successfully compiled into an object file

```
linux> gcc -w -Og -c function.c
```

- Only linker will complain about the non-existing function

```
linux> gcc -Og function.o
function.o: In function ‘main’:
function.c:(.text+0xf): undefined reference to ‘do_something’
collect2: error: ld returned 1 exit status
```

Separate Function Definition

- Definition of function in separate file do-something.c

```
int do_something(int x) {
  return x*x;
}
```

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linux> gcc -w -Og -c do-something.c
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int do_something(int x) {
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}
```

- Compilation

```
linux> gcc -w -Og -c do-something.c
```

- Linking

```
linux> gcc -Og function.o do-something.o
linux> ./a.out
linux> echo $?
4
```

Assembly Code

- function.s

```
        movl        $2, %edi
        call        do_something
        ret
```

- do-something.s

```
        movl        %edi, %eax
        imull       %edi, %eax
        ret
```

- Convention
  - integer argument is in register %edi
  - return value is in register %eax

No Type Checking → for asm & C

- Change of data types in do-something.c

```
float do_something(float x) {
  return x*x;
}
```

- Still links

```
linux> gcc -w -Og -c do-something.c
linux> gcc -Og function.o do-something.o
```

- But fails in execution

```
linux> ./a.out
linux> echo $?
0
```

(should return 4)

Solution: Header Files

- Header file do-something.h

```
int do_something(int);
```

- Include it in both do-something.c and function.c

```
#include "do-something.h"
```

- Compiler will now complain if there is a mismatch

function calls in x86

Example: plus.c

```
int plus(int a, int b) {
  return a+b;
}

int main(void) {
  return plus(37,10);
}
```

x86 (32-bit)

obsolete

- Compile: `gcc -Og -S -m32 plus.c`

```
plus:
        movl    8(%esp), %eax
        addl    4(%esp), %eax
        ret
main:
        pushl   $10
        pushl   $37
        call    plus
        addl    $8, %esp
        ret
```

- Call values are pushed onto the stack: `pushl $10`
- Afterwards stack pointer is moved back up: `addl $8, %esp`
- Function reads directly from stack: `movl 8(%esp), %eax`
- Return value is in %eax

Stack Organization

- Stack is filled downwards

%esp points here when main is called

Stack Organization

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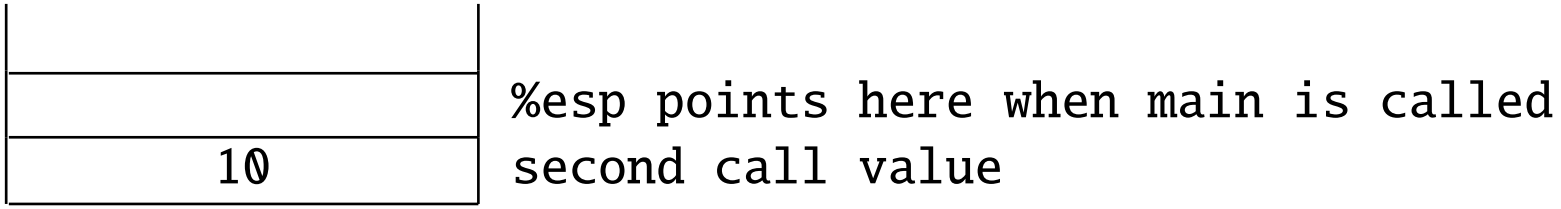

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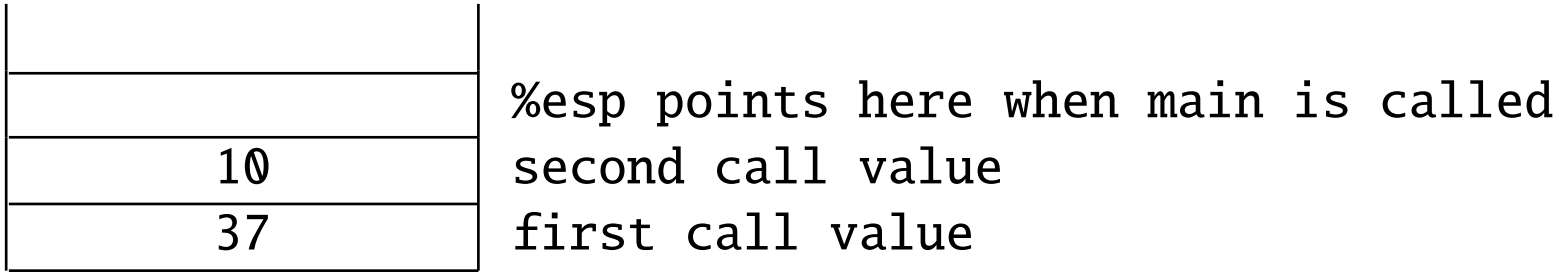

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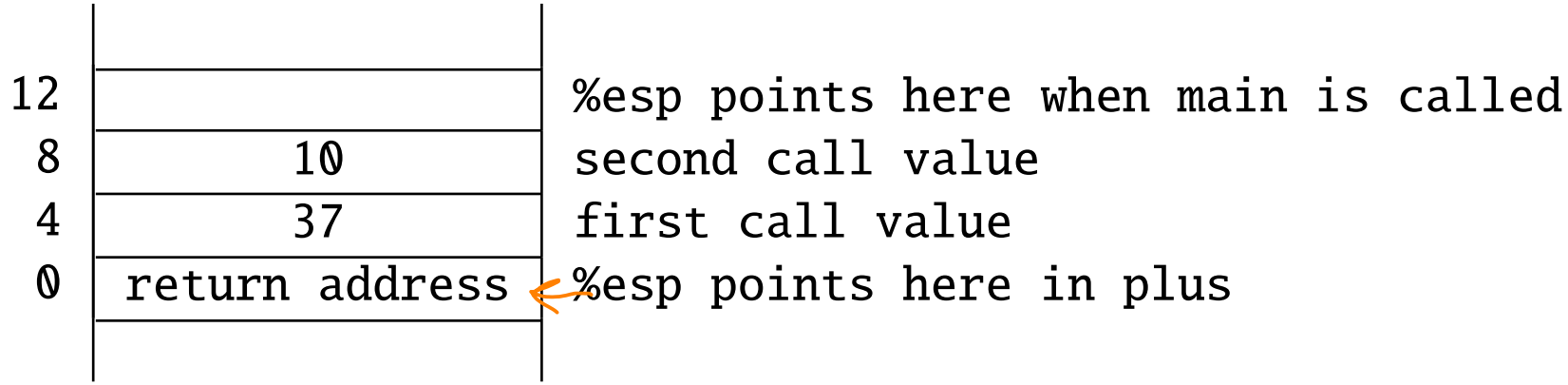

- Function has to read above the return address

function calls in x86-64

Register Conventions

- 32 bit x86 uses stack for call values (like 6502)
- Recall: MIPS had designated registers for call and return values
- 64 bit version of x86 also uses registers
- Note: all these are conventions, hardware always allows both options

Recall: Integer Registers

- 4 general purpose registers: %ax, %bx, %cx, %dx
- Stack pointer: %sp
- Base pointer: %bp
- Address registers: %si, %di

8086, 8088

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"extended"

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  8 additional registers added (%r8-%r15)

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- 32 bit registers: prefix with "e", e.g., %eax
- 64 bit registers: prefix with "r", e.g., %rax

  8 additional registers added (%r8-%r15)

x86-64

- Compile: gcc -Og -S plus.c (without -m32)

```
plus:
        leal    (%rdi,%rsi), %eax
        ret
main:
        movl    $10, %esi
        movl    $37, %edi
        call    plus
        ret
```

- Call values stored in registers (%esi,%edi)
- Function uses these directly
- Recall: %rdi is 64-bit view, %edi is 32-bit view of same register

lea

int *a = ...
int x;
⋮
&x
&a[i+3]

- lea: load effective address
- Carries out calculations typically done for memory lookup, e.g.,
  - leal (%rdi,%rsi), %eax
  - leal 4(%ebp), %eax
- But: stores result in register, makes no lookup
- Often abused to store result of math calc. in different register
- In example: addition of two register

Comparison

x86

```
plus:
  movl   8(%esp), %eax
  addl   4(%esp), %eax
  ret

main:
  pushl  $10
  pushl  $37
  call   plus
  addl   $8, %esp
  ret
```

x86-64

```
plus:
  leal   (%rdi,%rsi), %eax
  ret

main:
  movl   $10, %esi
  movl   $37, %edi
  call   plus
  ret
```

Use of registers more efficient

But: requires more attention to which registers may be overwritten

x86-64 Argument Conventions

- Arguments are stored in
  - %rdi
  - %rsi
  - %rdx
  - %rcx
  - %r8
  - %r9
  - %xmm0-7
- Return value is in %rax
- These are Linux conventions, Windows conventions are different
- Caller has to preserve any register values that may be overwritten

Recursive Call

```
int main(void) {
  return fibonacci(10);
}

int fibonacci(int x) {
  if (x <= 1)
    return x;
  return fibonacci(x-2) + fibonacci(x-1);
}
```

x86-64 Assemby

```
fibonacci:
        cmpl    $1, %edi
        jle     .L3             ; special case <=1
        pushq   %rbp            ; function will preserve bp and bx
        pushq   %rbx
        subq    $8, %rsp        ; stack pointer must be multiple of 16
        movl    %edi, %ebx      ; save x from di in bx
        leal    -2(%rdi), %edi  ; x-2
        call    fibonacci       ; f(x-2) -> eax
        movl    %eax, %ebp      ;        -> ebp
        leal    -1(%rbx), %edi  ; x-1
        call    fibonacci       ; f(x-1) -> eax
        addl    %ebp, %eax      ; f(x-2) in ebp + f(x-1) in eax
        addq    $8, %rsp        ; restore sp
        popq    %rbx            ; restore bx and bp
        popq    %rbp
        ret
.L3:    movl    %edi, %eax      ; special case handling f(x) = x
        ret
```

Preserve Registers

- Function uses registers
  - bp to store result from first recursive call (f(x-2))
  - bx to store call value (x)

- These need to be stored on the stack

```
pushq       %rbp
pushq       %rbx
subq        $8, %rsp    ; stack pointer must be multiple of 16
```

- ... and retrieved

```
addq        $8, %rsp
popq        %rbx
popq        %rbp
```

Preserve Registers

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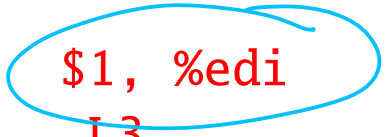
        jle     .L3             ; special case <=1
        pushq   %rbp            ; function will preserve bp and bx
        pushq   %rbx
        subq    $8, %rsp        ; stack pointer must be multiple of 16
        movl    %edi, %ebx      ; save x from di in bx
        leal    -2(%rdi), %edi  ; x-2
        call    fibonacci       ; f(x-2) -> eax
        movl    %eax, %ebp      ;        -> ebp
        leal    -1(%rbx), %edi  ; x-1
        call    fibonacci       ; f(x-1) -> eax
        addl    %ebp, %eax      ; f(x-2) in ebp + f(x-1) in eax
        addq    $8, %rsp        ; restore sp
        popq    %rbx            ; restore bx and bp
        popq    %rbp
        ret
.L3:    movl    %edi, %eax      ; special case handling f(x) = x
        ret
```

Special Case

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        addl    %ebp, %eax          ; f(x-2) in ebp + f(x-1) in eax
        addq    $8, %rsp            ; restore sp
        popq    %rbx                ; restore bx and bp
        popq    %rbp
        ret
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First Recursive Call


```
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        call    fibonacci       ; f(x-1) -> eax
        addl    %ebp, %eax      ; f(x-2) in ebp + f(x-1) in eax
        addq    $8, %rsp        ; restore sp
        popq    %rbx            ; restore bx and bp
        popq    %rbp
        ret
.L3:    movl    %edi, %eax      ; special case handling f(x) = x
        ret
```

Second Recursive Call

```
fibonacci:
        cmpl    $1, %edi
        jle     .L3             ; special case <=1
        pushq   %rbp            ; function will preserve bp and bx
        pushq   %rbx
        subq    $8, %rsp        ; stack pointer must be multiple of 16
        movl    %edi, %ebx      ; save x from di in bx
        leal    -2(%rdi), %edi  ; x-2
        call    fibonacci       ; f(x-2) -> eax
        movl    %eax, %ebp      ;        -> ebp
        leal    -1(%rbx), %edi  ; x-1
        call    fibonacci       ; f(x-1) -> eax
        addl    %ebp, %eax      ; f(x-2) in ebp + f(x-1) in eax
        addq    $8, %rsp        ; restore sp
        popq    %rbx            ; restore bx and bp
        popq    %rbp
        ret
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