# CS443: Compiler Construction

Lecture 23: Calling Conventions

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Based on material by Yan Garcia and Rujia Wang

# “Application Binary Interface” (ABI) defines conventions for calling functions

- ABI names (e.g., ra, sp, fp, a0, etc.) specify conventional use of registers
- Conventions:
  - Use of stack
  - Passing arguments/return values
  - Saving values of registers
    - (Callee promises not to overwrite some registers)

# ABI register names and conventions

| Register | ABI Name | Description | Saved By Callee? |
|---|---|---|---|
| `x0` | `zero` | Always Zero | N/A |
| `x1` | `ra` | Return Address | No |
| `x2` | `sp` | Stack Pointer | Yes |
| `x3` | `gp` | Global Pointer | N/A |
| `x4` | `tp` | Thread Pointer | N/A |
| `x5-7` | `t0-2` | Temporary | No |
| `x8` | `s0/fp` | Saved Register/Frame Pointer | Yes |
| `x9` | `s1` | Saved Register | Yes |
| `x10-x17` | `a0-7` | Function Arguments/Return Values | No |
| `x18-27` | `s2-11` | Saved Registers | Yes |
| `x28-31` | `t3-6` | Temporaries | No |

# Registers are “caller-saved” or “callee-saved”

- Caller = function performing the call
- Callee = function that is called

- Caller-saved registers
  - Callee can do whatever it wants to them!
  - Caller needs to save values if it needs them later
- Callee-saved registers
  - Callee promises to restore original value
  - Must store and restore old value before returning (if it uses them)

# Conventions give us some preferences for register allocation!

- If you don’t call any functions:
  - Use only caller-saved registers if you can!
  - (In general, do this for any variables not live across function calls)

- For variables live across a bunch of function calls:
  - Use callee-saved registers if you can!

More on this later

# Basic Steps in Calling a Function

**Caller**

- Save caller-saved registers (if needed)
- Put parameters in a place where function can access them
- Transfer control to function

**Callee**

- Save callee-saved registers (if needed)
- Acquire (local) storage resources needed for function
- Perform desired task of the function
- Put result value in a place where calling code can access it and maybe restore any registers you used
- Return control to point of origin.

# Conventions for Registers

- ra/x1: Return Address
- a0-a7/x10-x17: Function arguments
  - If more than 8 arguments, put the rest on the stack
- a0(-a1): Return values
- sp/x2: Stack pointer (bottom of stack)
- fp/x8: Frame pointer (top of stack frame)

# More Detailed Steps in Calling a Function

**Caller**

- Save caller-saved registers (if needed)
- Put first 8 arguments in a0-a7
- Put remaining arguments on stack
- Transfer control to function, linking to ra

**Callee**

- Save callee-saved registers (if needed)
- Acquire (local) storage resources needed for function
- Perform desired task of the function
- Put result value in a0
- Pop callee stack frame, restoring saved registers
- Return control to ra

- Pop saved arguments, registers (restore registers)

# Function Call Example

```
int Leaf(int g, int h, int i, int j)
{
   int f;
   f = (g + h) - (i + j);
   return f;
}
```

- Parameter variables **`g`**, **`h`**, **`i`**, and **`j`** in argument registers **`a0`**, **`a1`**, **`a2`**, and **`a3`**.
- Assume we compute **`f`** by using **`s0`** and **`s1`**

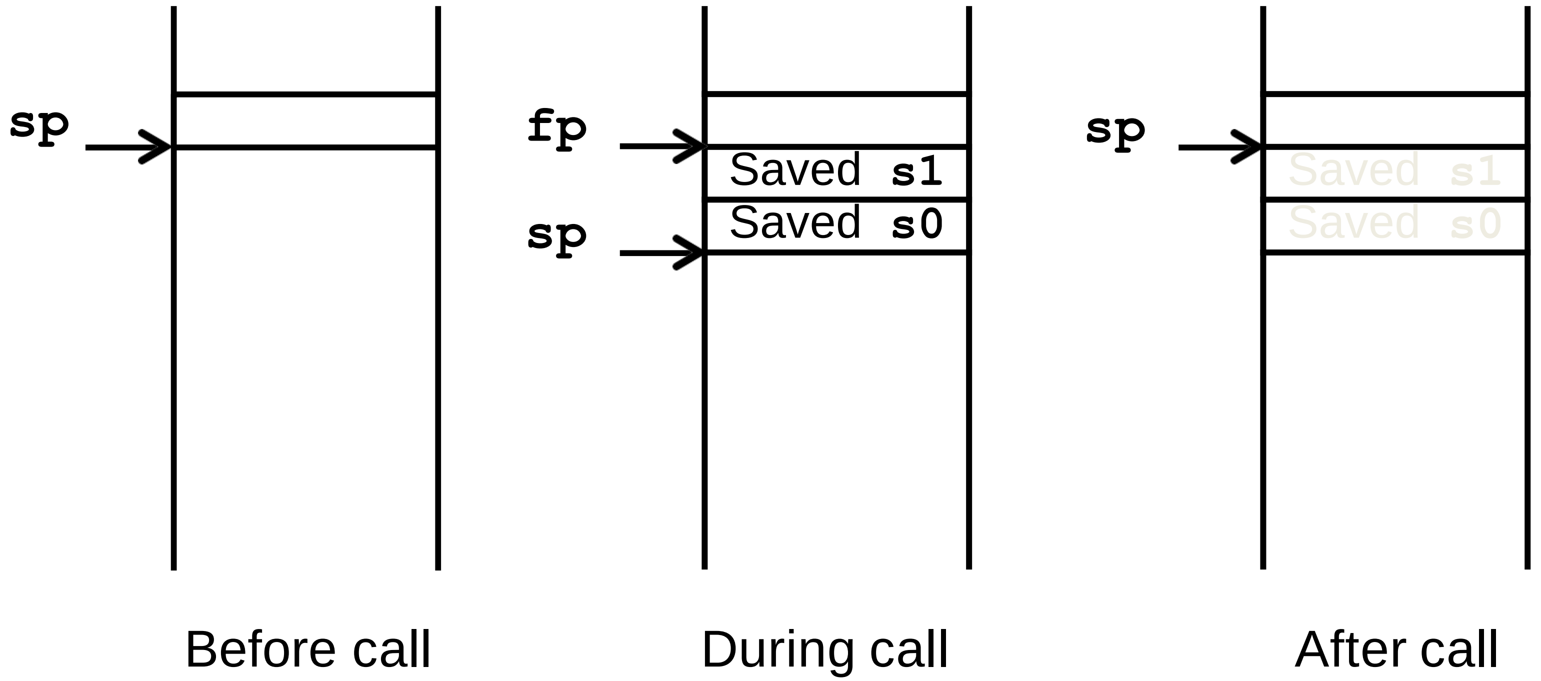
# RISC-V code for Leaf

```
Leaf: addi sp,sp,-8 # adjust stack for 2 items
      sw s1, 4(sp)   # save s1 for use afterwards
      sw s0, 0(sp)   # save s0 for use afterwards

      add s0,a0,a1 # s0 = g + h
      add s1,a2,a3 # s1 = i + j
      sub a0,s0,s1 # return value (g + h) – (i + j)

      lw s0, 0(sp) # restore register s0 for caller
      lw s1, 4(sp) # restore register s1 for caller
      addi sp,sp,8 # adjust stack to delete 2 items
      jr ra # jump back to calling routine
```

# Stack


sp
fp
Saved s1
Saved s0
sp
sp
Saved s1
Saved s0
Before call
During call
After call

# Nested function calls will clobber a0-a7, ra

```
int sumSquare (int x, int y) {
  return mult(x, x) + y;
}
```

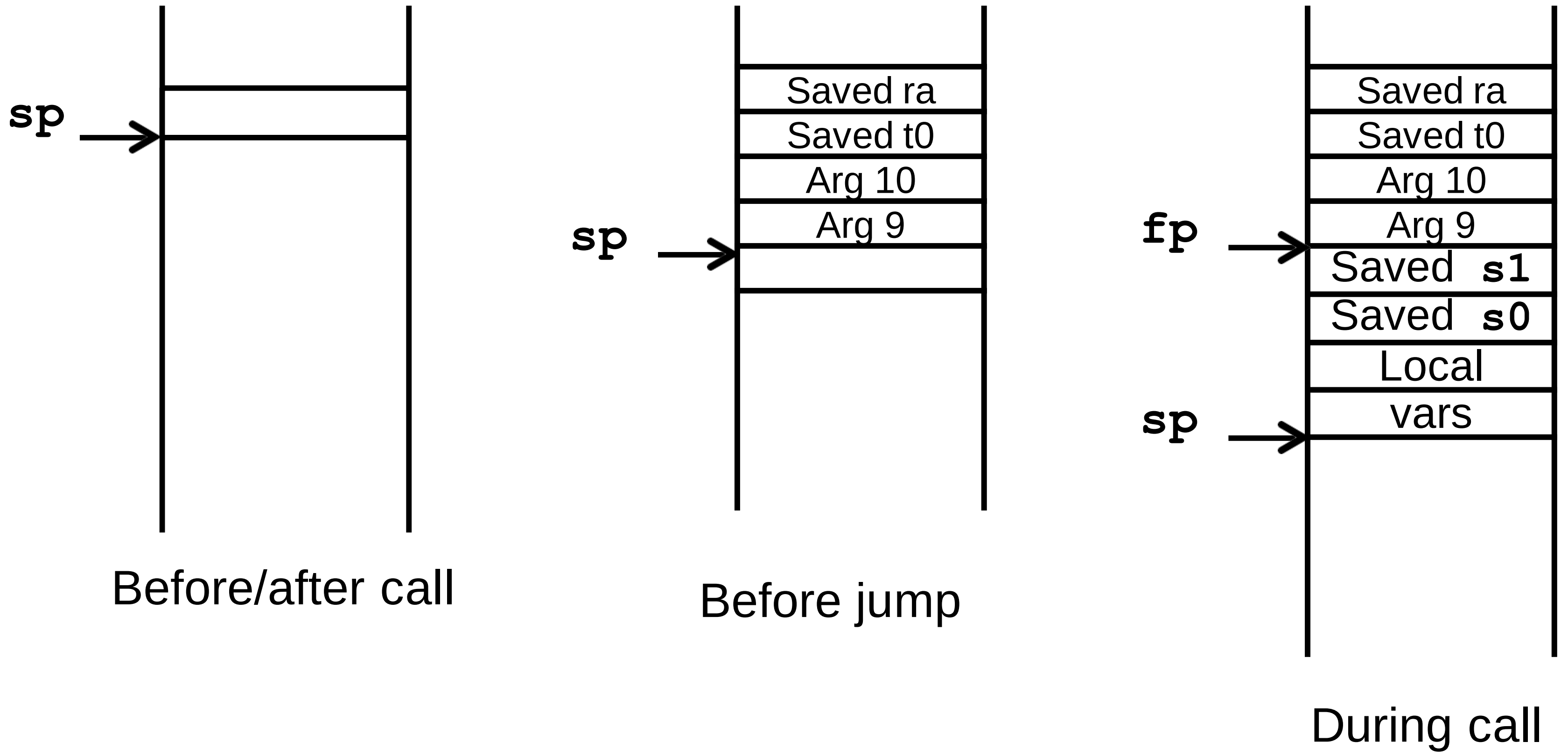
Need to save `ra`, caller-saved regs before calling

# Compiling nested (/recursive) functions

```
int sumSquare (int x, int y) {
  return mult(x, x) + y;
}
```

```
          sumSquare:
"push"    addi sp,sp,-8       # reserve space on stack
          sw  ra, 4(sp)       # save ret addr
          sw  a1, 0(sp)       # save y
          mv  a1,a0           # Store x in a1 also
          jal ra, mult        # call mult
          lw a1, 0(sp)        # restore y
          add a0,a0,a1        # mult()+y
          lw ra, 4(sp)        # get ret addr
"pop"     addi sp,sp,8        # restore stack
          jr ra
mult:     ...
```

# More detailed stack



# Does that mean we can't use a0-a7?

"push"

"pop"

```
sumSquare:
        addi sp,sp,-8      # reserve space on stack
        sw  ra, 4(sp)      # save ret addr
        sw  a1, 0(sp)      # save y
        mv  a1,a0          # Store x in a1 also
        jal ra, mult       # call mult
        lw a1, 0(sp)       # restore y
        add a0,a0,a1       # mult()+y
        lw ra, 4(sp)       # get ret addr
        addi sp,sp,8       # restore stack
        jr ra
mult:   ...
```

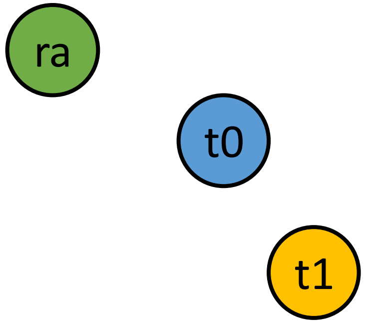
# If we do the convention stuff in LLVM, reg alloc can do a lot of work for us

```
define i32 @f() {
f__entry:
  %a = call i32 @g(i32 42)
  ret i32 %a
}
```

```
define i32 @f() {
f__entry:
  a0 = bitcast i32 42 to i32
  %a = call i32 @g(i32 a0)
  a0 = bitcast i32 %a to i32
  ret i32 a0
}
```

# Wait, what does it mean to do register allocation on registers?

- Nodes corresponding to registers are “pre-colored”
  - Assign them to themselves before we start register allocation



# Pre-colored nodes get handled specially during register allocation

- Don’t simplify them out—can’t give them a color anyway
- Definitely don’t try to spill them

# How far can we take this?

Save callee-saved registers

Restore callee-saved registers

```
define i32 @f() {
f__entry:
  %saved_s0 = bitcast i32 s0 to i32
  %saved_s1 = bitcast i32 s1 to i32
  …
  a0 = bitcast i32 42 to i32
  %a = call i32 @g(i32 42)
  a0 = bitcast i32 %a to i32
  ret i32 a0
  s0 = bitcast i32 %saved_s0 to i32
  …
}
```

# How far can we take this?

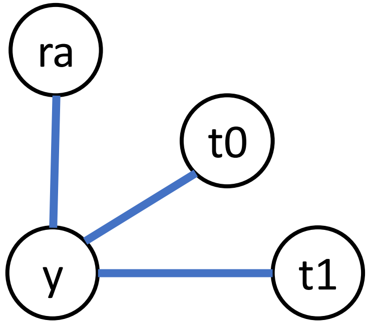
%saved_s0, etc. interfere with every local temp.

- RA will try to put %saved_si in si.
- RA will avoid callee-saved temps whenever possible

```
define i32 @f() {
f__entry:
  %saved_s0 = bitcast i32 s0 to i32
  %saved_s1 = bitcast i32 s1 to i32
  …
  a0 = bitcast i32 42 to i32
  %a = call i32 @g(i32 42)
  a0 = bitcast i32 %a to i32
  ret i32 a0
  s0 = bitcast i32 %saved_s0 to i32
  …
}
```

# Make calls interfere with caller-saved regs

```
define i32 @f() {
f__entry:
  %y = …
  %a = call i32 @g(i32 42) ; Pretend this defines all caller-saved regs
  %z = add i32 %a, %y
  ret i32 %z
}
```




- RA will try to avoid putting %y in a caller-saved reg
- … and if it can't, it'll spill(/save) %y without us doing anything!