Functions

Terms

```
void foo() {
  int a, b;
  ...
  bar(a, b);
}


void bar(int x, int y) {
   ...
}
```

- foo is the *caller*
- bar is the *callee*
- a, b are the *actual parameters* to bar
- x, y are the *formal parameters* of bar
- Shorthand:
  - argument = actual parameter
  - parameter = formal parameter

Different kinds of parameters

- Value parameters
- Reference parameters
- Result parameters
- Value-result parameters
- Read-only parameters

Value parameters

- "Call-by-value"
- Used in C, Java, default in C++
- Passes the value of an argument to the function
- Makes a copy of argument when function is called
- Advantages? Disadvantages?

Value parameters

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

void foo(int y, int z) {
    y = 2;
    z = 3;
    print(x);
}
```

Value parameters

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

void foo(int y, int z) {
    y = 2;
    z = 3;
    print(x);
}
```

- What do the print statements print?

Value parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y, int z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?
- Answer:

  print(x); //prints 1

  print(x); //prints 1

Reference parameters

- "Call-by-reference"
- Optional in Pascal (use "var" keyword) and C++ (use "&")
- Pass the *address* of the argument to the function
- If an argument is an expression, evaluate it, place it in memory and then pass the address of the memory location
- Advantages? Disadvantages?

Reference parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int &y, int &z) {
   y = 2;
   z = 3;
   print(x);
}
```

Reference parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int &y, int &z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?

Reference parameters

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

void foo(int &y, int &z) {
    y = 2;
    z = 3;
    print(x);
}
```

- What do the print statements print?
- Answer:

print(x); //prints 3

print(x); //prints 3

Result parameters

- Return values of a function
  - Some languages let you specify other parameters as result parameters – these are un-initialized at the beginning of the function
- Copied at the end of function into the arguments of the caller
  - C++ supports "return references"

    ```
    int& foo( ... )
    ```

    compute return values, store in memory, return address of return value

Result parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y, result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

Result parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y, result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?

Result parameters

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

void foo(int y, result int z) {
    y = 2;
    z = 3;
    print(x);
}
```

- What do the print statements print?
- Answer:

  print(x); //prints 3

  print(x); //prints 1

Value-result parameters

- "Copy-in copy-out"
- Evaluate argument expression, copy to parameters
- After subroutine is done, copy values of parameters back into arguments
- Results are often similar to pass-by-reference, but there are some subtle situations where they are different

Value-result parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y,
    value result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

Value-result parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y,
    value result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?

Value-result parameters

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(int y,
    value result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?
- Answer:

  print(x); //prints 3

  print(x); //prints 1

What about this?

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(value result int y,
    value result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

What about this?

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

void foo(value result int y,
    value result int z) {
    y = 2;
    z = 3;
    print(x);
}
```

- What do the print statements print?

What about this?

```
int x = 1;
void main () {
   foo(x, x);
   print(x);
}

void foo(value result int y,
    value result int z) {
   y = 2;
   z = 3;
   print(x);
}
```

- What do the print statements print?
- Answer:

  print(x); //undefined!

  print(x); //prints 1

Read only parameters

- Used when callee will not change value of parameters
- Read-only restriction must be enforced by compiler
- This becomes tricky when in the presence of aliasing and control flow

```
void foo(readonly int x, int y) {
  int * p;
  if (...) p = &x else p = &y
  *p = 4
}
```

- Is this legal? Hard to tell!

Esoteric: "name" parameters

- "Call-by-name"
  - Usually, we evaluate the arguments before passing them to the function. In call-by-name, the arguments are passed to the function before evaluation
  - Not used in many languages, but Haskell uses a variant

```
int x = 2;
void main () {
   foo(x + 2);
}

void foo(int y) {
   z = y + 2;
   print(z);
}
```

→

```
int x = 2;
void main () {
   foo(x + 2);
}

void foo(int y) {
   z = x + 2 + 2;
   print(z);
}
```

Why is this useful?

```
int x = 2;
void main () {
   foo(bar());
}

void foo(int y) {
   z = 3;
   print(z);
}
```

- Consider the code on the left
- Normally, we must evaluate bar() before calling foo()
- But what if bar() has an infinite loop?
- In call by name, this program still terminates

Other considerations

- Scalars
  - For call by value, can pass the address of the actual parameter and copy the value into local storage within the procedure
    - Reduces size of caller code (why is this good?)
  - For machines with a lot of registers (e.g., MIPS), compilers will save a few registers for arguments and return types
    - Less need to manipulate stack

Other considerations

- Arrays
  - For efficiency reasons, arrays should be passed by reference (why?)
    - Java, C, C++ pass arrays by reference by default (technically, they pass a pointer to the array by value)
  - Pass in a fixed size dope vector as the actual parameter (not the whole array!)
  - Callee can copy array into local storage as needed

Dope vectors

- Remember: store additional information about an array
  - Where it is in memory
  - Size of array
  - # of dimensions
  - Storage order
- Can sometimes eliminate dope vectors with compile-time analysis

Strings

- Requires a descriptor
  - Like a dope vector, provides information about string
- May just need to pass a pointer (if string contains information about its length)
- May also need to pass information about length

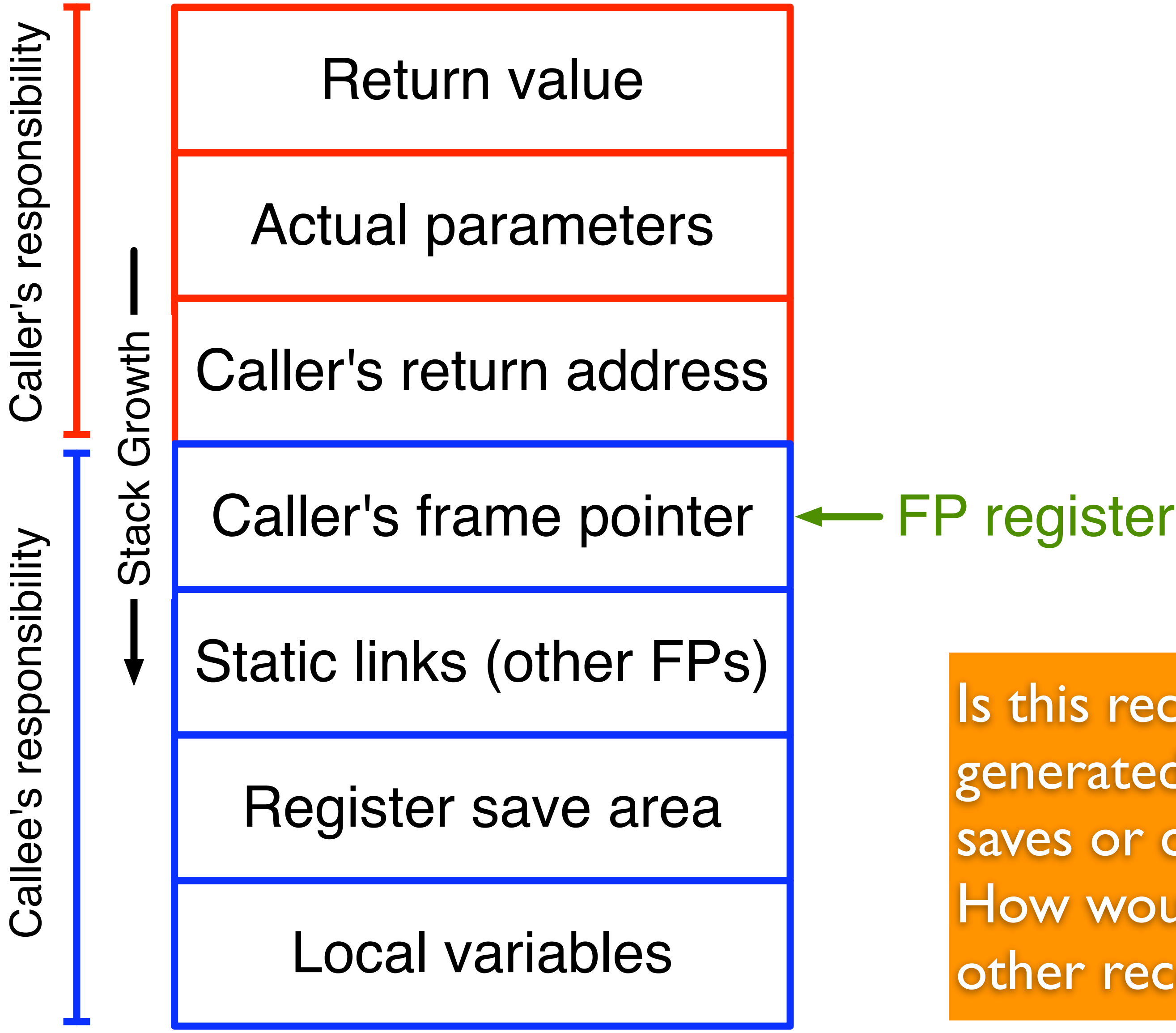
Calling a function

- What should happen when a function is called?
  - Set the frame pointer (sets the base of the activation record)
  - Allocate space for local variables (use the function's symbol table for this)
  - What about registers?
    - Callee might want to use registers that the caller is using

Saving registers

- Two options: *caller saves* and *callee saves*
- Caller saves
    - Caller pushes all the registers it is using on to the stack before calling function, restores the registers after the function returns
- Callee saves
    - Callee pushes all the registers it is *going to use* on the stack immediately after being called, restores the registers just before it returns
- Why use one vs. the other?
- Simple optimizations are good here: don't save registers if the caller/callee doesn't use any

Activation records



Is this record generated for callee-saves or caller-saves? How would the other record look?

The frame pointer

- Manipulate with instructions like `link` and `unlink`
    - Link: push current value of FP on to stack, set FP to top of stack
    - Unlink: read value at current address pointed to by FP, set FP to point to that value
    - In other words: link pushes a new frame onto the stack, unlink pops it off

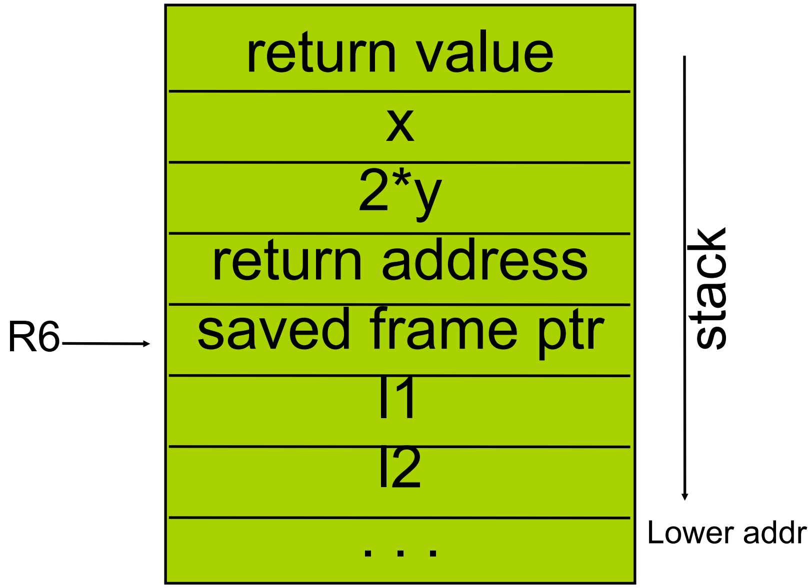
Example Subroutine Call and Stack Frame

Lower addr

```
z = SubOne(x,2*y);
```

```
int SubOne(int a, int b) {
      int l1, l2;
      l1 = a;
      l2 = b;
      return l1+l2;
   };
```

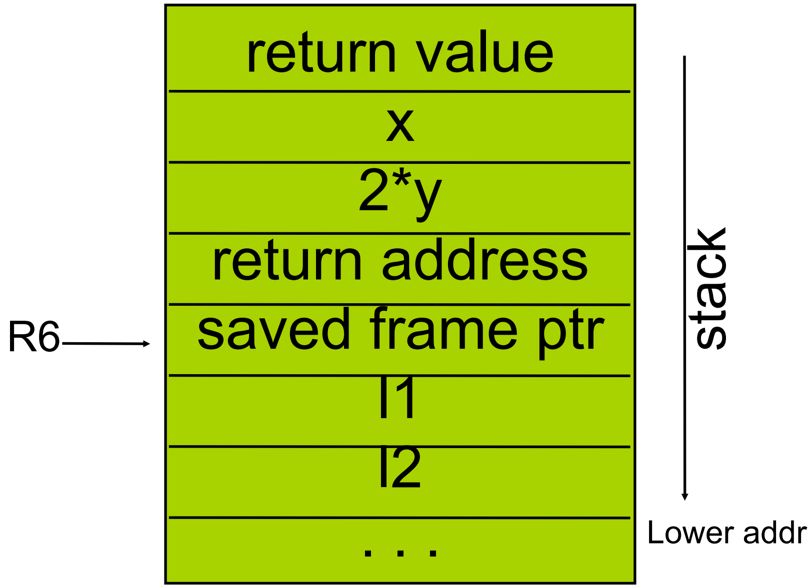
Example Subroutine Call and Stack Frame




```
z = SubOne(x,2*y);
```

```
int SubOne(int a, int b) {
      int l1, l2;
      l1 = a;
      l2 = b;
      return l1+l2;
   };
```

Example Subroutine Call and Stack Frame



3-address code:

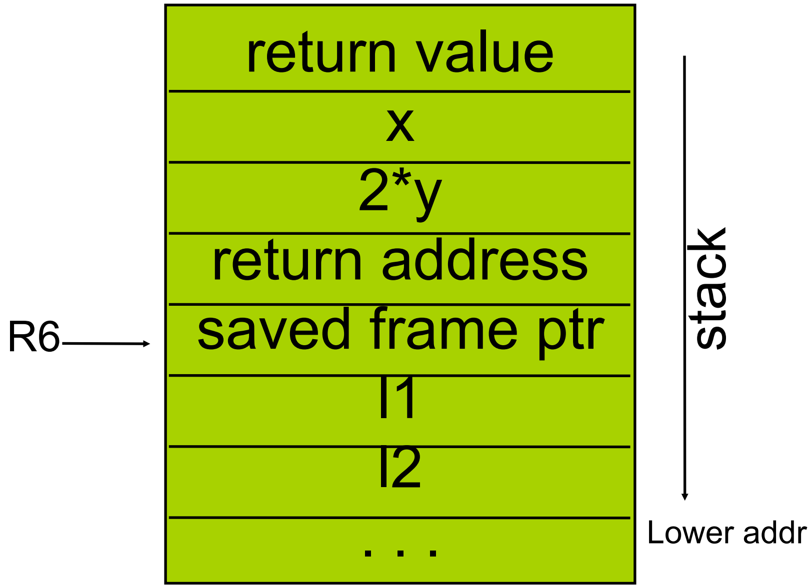
```
push
push x
mul  2  y  t1
push t1
jsr SubOne
pop
pop
pop  z
```

```
z = SubOne(x,2*y);
```

```
int SubOne(int a, int b) {
      int l1, l2;
      l1 = a;
      l2 = b;
      return l1+l2;
   };
```

```
link  3
move $P1 $L1
move $P2 $L2
add $L1 $L2 t2
move t2 $R
unlink
ret
```

Example Subroutine Call and Stack Frame




```
z = SubOne(x,2*y);
```

```
int SubOne(int a, int b) {
      int l1, l2;
      l1 = a;
      l2 = b;
      return l1+l2;
   };
```

3-address code:

```
push
push x
mul  2  y  t1
push t1
jsr SubOne
pop
pop
pop  z
```

```
link  3
move $P1 $L1
move $P2 $L2
add $L1 $L2 t2
move t2 $R
unlink
ret
```

assembly code:

```
push
push x
load  y R1
muli  2 R1
push R1
jsr SubOne
pop
pop
pop  R1
store R1 z
```

```
link R6 3
load  3(R6)  R1
store R1 -1(R6)
load  2(R6)  R2
store R2 -2(R6)
load  -1(R6)  R1
add   -2(R6)  R1
store R1  4(R6)
unlink
ret
```