

Functions

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

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

Terms

- 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

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Different kinds of parameters

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

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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?

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Value parameters

```
int x = 1;  
void main () {  
    foo(x, x);  
    print(x);  
}  
  
void foo(int y, int z) {  
    y = 2;  
    z = 3;  
    print(x);  
}
```

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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?

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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

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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?

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Reference parameters

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

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

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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?

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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

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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

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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);
}
```

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Result parameters

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

- What do the print statements print?

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

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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

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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

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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);
}
```

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Value-result parameters

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

- What do the print statements print?

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

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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

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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);
}
```

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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?

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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

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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!

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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);
}
```

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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

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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?)
 - If scalar is a constrained type (e.g., a Pascal range type), must insert type check for return values
 - 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

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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

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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

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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

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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

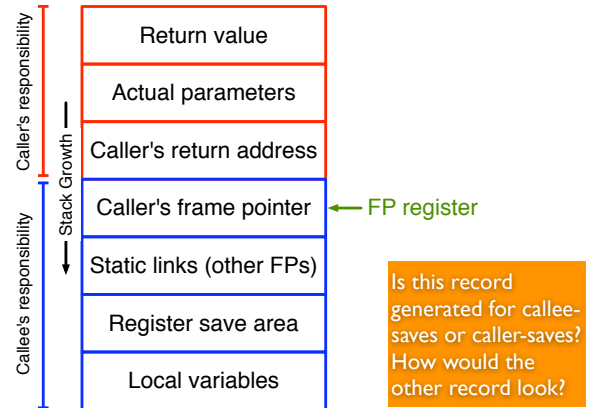
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Saving registers

- 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

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Activation records

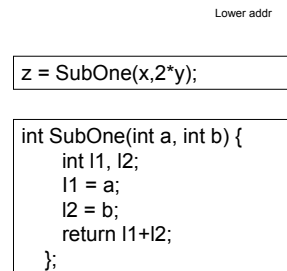


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Example Subroutine Call and Stack Frame

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

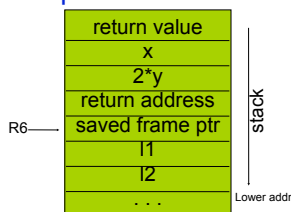


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Example Subroutine Call and Stack Frame



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

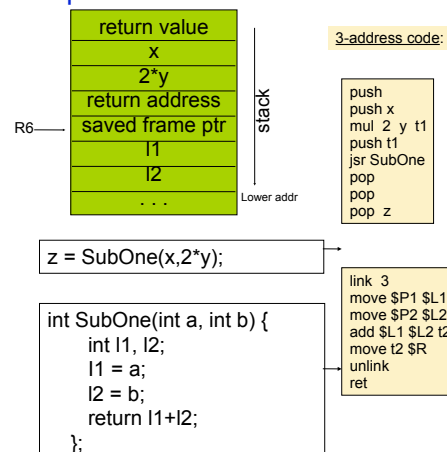
```

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

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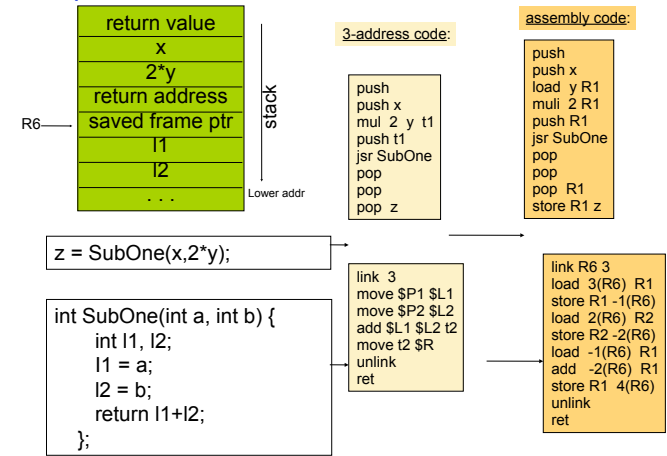
Example Subroutine Call and Stack Frame



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Example Subroutine Call and Stack Frame



Example2

