Functions
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

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

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

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

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

```c
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

```c
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:

```c
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

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

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

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

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

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

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

• What do the print statements print?
• Answer:

  print(x); //prints 3
  print(x); //prints 3
  print(y); //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”

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

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

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

void foo(int& y,
    value result int z) {
    y = 2;
    z = 3;
    print(x);
    print(w);
}```
Value-result parameters

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

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

• What do the print statements print?
Value-result parameters

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

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

- What do the print statements print?
- Answer:
  ```c
  print(x) //prints 3
  print(w) //prints 2
  print(x) //prints 1
  print(w) //prints 2
  ```
What about this?

```c
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?

```c
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?

```c
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 can be tricky when in the presence of aliasing and control flow
  
  ```c
  void foo(const int x, int y) {
      int * p;
      if (...) p = &x else p = &y
      *p = 4
  }
  ``
- Is this legal? Hard to tell!
- gcc will not let the assignment happen
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.

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

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

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

void foo(int y) {
    z = x + 2 + 2;
    print(z);
}
```
Why is this useful?

• Consider the code on the left
• Normally, we must evaluate bar() before calling foo()
• But what if bar() runs for a long time?
• In call by name, we only evaluate bar() if we need to use it
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

Return value
Actual parameters
Caller's return address
Caller's frame pointer
Static links (other FPs)
Register save area
Local variables

Caller's responsibility

Callee's responsibility

Stack Growth

FP register

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

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

```c
z = SubOne(x, 2*y);
```
Example Subroutine Call and Stack Frame

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

```
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

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

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

3-address code:

```c
push x
push 2*y t1
push t1
jsr SubOne
pop
pop
pop z
```

```c
link 3
move $P1 $L1
move $P2 $L2
add $L1 $L2 t2
move t2 $R
unlink
ret
```
Example Subroutine Call and Stack Frame

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

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

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

```
3-address code:
push
push x
mul 2 y t1
push t1
jsr SubOne
pop
t2
unlink
ret
```

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

```
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
```

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