Functions
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?
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(y);
}
```
Reference parameters

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

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

• What do the print statements print?
```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}

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

• 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

```c
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

What do the print statements print?

```c
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

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

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

```c
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

```c
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?

```java
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?

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

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

void foo(int y) {
    if ( ... ) {
        z = y;
    } else {
        z = 3;
    }
    print(z);
}
```
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
z = SubOne(x, 2*y);

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

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

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

```
3-address code:
push x
push 2*y t1
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
```
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);
```

```
3-address code:
push
push x
mul 2 y t1
push t1
jsr SubOne
pop
pop
pop  z
```

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

```
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
```