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?

```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
- What do the print statements print?

```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?
• Answer:
  ```c
  print(x); //prints 1
  print(x); //prints 1
  ```

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);
}
```

• “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);
}
```

• What do the print statements print?

Result 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

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

• 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”
  ```c
  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);
}

What do the print statements print?

Answer:
print(x); // prints 3
print(x); // prints 1

“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);
}
```

- 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 do the print statements print?
- Answer: print(x); //undefined!
- print(x); //prints 1

What about this?

```
int x = 1;
void main () {
    foo(x, x);
    print(x);
}
void foo(readonly int x, int y) {
    int * p;
    if (...) p = &x else p = &y
    *p = 4
}
```

- Is this legal? Hard to tell!

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
}
```

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

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

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

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

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

Example Subroutine Call and Stack Frame

```
3-address code:
push x
push y
mul 2
push l1
push l2
jsr SubOne
unt
move $P1 $L1
move $P2 $L2
add $L1 $L2 t2
move t2 $R
```

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

```
return value
x
2*y
return address
saved frame ptr
l1
l2
... 
stack
```

```
return value
x
2*y
return address
saved frame ptr
l1
l2
... 
stack
```

```
return value
x
2*y
return address
saved frame ptr
l1
l2
... 
stack
```

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2*y
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Example Subroutine Call and Stack Frame

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int SubOne(int a, int b) {
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    l1 = a;
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z = SubOne(x, 2*y);
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```
int SubOne(int a, int b) {
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    l1 = a;
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