Subroutines

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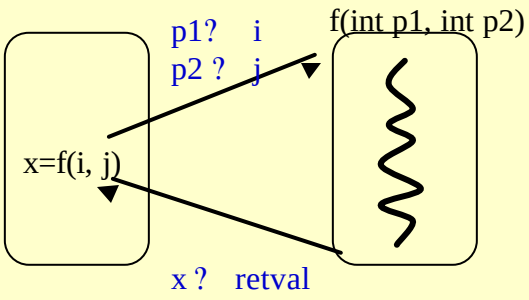
Anatomy of a subroutine call


```
boolean ? true f(int i ? main.i) {
  return i < 100
}


main() {
  int i = 10; boolean b;
  b = f(i);
  print(i);
}
```

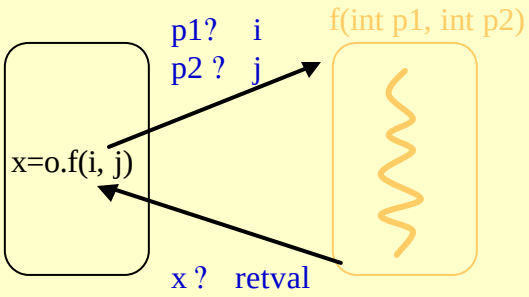
Another example

```
boolean ? false f(int i ? g*g) {
  g = g + 1;
  return i < 100
}

int g = 10;
main() {
  boolean b;
  b = f(g*g);
  print(g);
}
```

Main components of a subroutine call



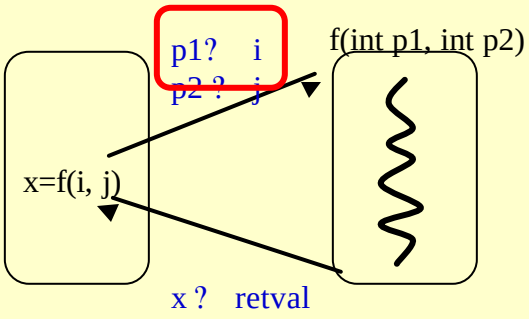
Issue 1:
Finding which routine to call



What is the routine being called?

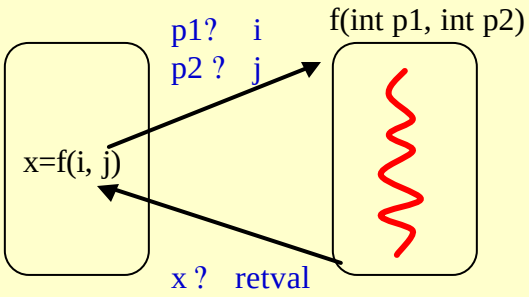
An important issue for object-oriented languages (more on this later)

Issue 2:
How to pass parameters



Two obvious possibilities: pass value, pass address, e.g.,
f(10, 20)
f(x, x)
f(x+y, z+w)

Issue 3:
What happens inside the callee?



What happens when the callee use the values of its parameters?
What happens when the callee modifies its parameters?

Passing parameters

- Three methods:
  - Pass-by-value: pass the value of arguments
  - Pass-by-var: create an alias to an argument
    - Names “a” and “b” are aliases if they both names for the same memory
  - Pass-by-name: Pass the “name” of arguments

Pass-by-value

```
boolean ? true f(int i = main.i) {
  i = i + 1;
  return i < 100
}

main() {
  int i = 10; boolean b;
  b = f(i);
  print(i);
}
```

Pass-by-value (another example)

```
boolean ? false f(int i ???) {
  i = i + 1;
  return i < 100
}

int g = 10;
main() {
  boolean b;
  b = f(g*g);
  print(g);
}
```

A conceptual implementation of pass-by-value

```
boolean f(int i) {
  i = i + 1;
  return i < 100
}

int g = 10;
main() {
  boolean b;
  b = f(g*g);
  print(g);
}
```

```
boolean f() {
  arg = arg + 1;
  return arg < 100
}

int g = 10;
main() {
  boolean b;
  arg = g*g;
  b = f();
  print(g);
}
```

What happens when you change the value of a parameter?

```
boolean f(int i) {
  i = i + 1;
  return i < 100
}

int g = 10;
main() {
  boolean b;
  b = f(g);
  print(g);
}
```

Implementation of pass-by-value

- *For each formal parameter, f, in the program, create a global variable arg_f. Callers assign to arg_f, callees grab arguments from arg_f*

```
boolean f() {
  arg_i = arg_i + 1;
  return arg_i < 100
}
```

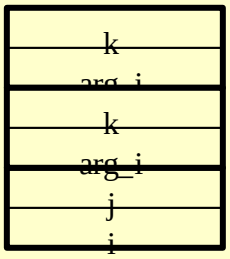
```
int g = 10;
main() {
  boolean b;
  arg_i = g*g;
  b = f();
  print(g);
}
```

Does this work?

Solution
one copy of arg_i for each call

```
main() {
 int i = ...; int j = ...;
 arg_i_1 = i;
 foo()
}
```

```
f() {
  int k;
  if (arg_i_1>10) {
    arg_i_2 =
      arg_i_1-1;
    foo()
  }
```



Pass by var

alias

```
boolean f(int i main.i) {
  i = i + 1;
  return i < 100
}

main() {
   int i = 10; boolean b;
   b = f(i);
   print(i);
}
```

Any use of 'i' in f is the same as using 'main.i'
What is the output of the above code?

Pass-by-var (another example)

```
boolean f(int i) {
  i = i + 1;
  return i < 100
}

main() {
   int i = 10; boolean b;
   b = f(i*i);
   print(i);
}
```

Does this make sense?

How to implement pass-by-var?

- Value-result (or copy-in-copy-out)
- By reference (using pointers)

Conceptual implementation of pass by value-result

Passing “i” from main to “f” by value result

```
main() {
  int i = 10;
  f();
  print(i);
}
```

```
f() {
  i = main.i
  i = i + 1;
  ...
  main.i = i
}
```

Are f.i and main.i aliases?
Does it matter?

Another example of value-result

```
int glob = 1;
main() {
  f(glob);
  print(glob);
}
```

```
f(int i) {
  i = i + 1;
  print(glob);
}
```

Problem: glob and i are “fake” aliases

Conceptual implementation of pass-by-reference

Passing “i” from main to “f” by reference

```
main() {
  int i = 10;
  i_arg = &i
  f();
  print(i);
}
```

```
f() {
 *i_arg = *i_arg + 1;
  ...
}
```

Like pass-by-value, except compiler automatically passes address and does automatic dereferencing

Another example of pass-by-reference

```
int glob = 1;
main() {
  f(glob);
  print(glob);
}
```

```
f(int i) {
  i = i + 1;
  print(glob);
}
```

Are glob and *f.i aliases?
Does it matter?

Yet another example of pass-by-reference

```
f(int i, j, k) {
  i = j + k;
  i = i + j + k;
}
```

```
main() {
  int x = 1;
  int y = 2;
  f(x, x, y);
  /* would like
     x = 2*(x+y) */
}
```

Some languages that have pass-by-reference forbid aliasing of parameters for this reason!

Parameter passing and mutability

- When do pass-by-value and pass-by-var yield different results?
- When do pass-by-value-result and pass-by-reference yield different results?

Pass-by-value versus pass-by-var

- Expressiveness
  - By-var allows “multiple results” from a routine
- Simplicity
  - By-var is more subtle; by-value is simpler
- Ease of implementation
  - By-var is more work but not much more
- Efficiency
  - By-var does not copy parameters; just passes pointers which is more efficient than copying values

Pass by name

Each use of the formal reevaluates the actual in the caller's environment

```
int g = 10;
main() {
  boolean b;
  b = f(g*g);
  print(g);
}
boolean f(int i = "g*g") {
  g = g + 1;
  return evaluate "g*g" < 100
}
```

Why have pass-by-name?

```
int sum(expr, i) {
  int retval = 0;
  for (i = 0; i < 10; ++i) {
    retval = retval + expr
  }
}

main () {
  int i;
  sum(i*i + 3*i - 1, i);
}
```

What does this compute?

A naive implementation of pass-by-name (simpler example)

Copy procedure and textually substitute parameter

```
int g = 10;
main() {
 f(g);
 print(g);
}

void f(int i) {
  i = i + 1;
}
```

```
int g = 10;
main() {
  g = g + 1
  print(g);
}
```

A bigger example

```
int g = 10;
main() {
 f(g);
 print(g);
}

void f(int i) {
  g = g + 1;
  print(i)
}
```

```
int g = 10;
main() {
  {
    g = g + 1
    print(g)
   }
  print(g);
}
```

Copying the body of the callee into the caller is called inlining

A problematic example

```
int g = 10;
main() {
 f(g);
 print(g);
}
```

```
void f(int i) {
  g = g + 1;
  f(i)
}
```

An alternative approach

```
int g = 10;
main() {
 f(g);
 print(g);
}
```

```
void f(int i) {
  g = g + 1;
  print(i)
}
```

```
int g = 10;
int compute_g() {
  return g;
}
main() {
 f(compute_g);
 print(g);
}
```

```
void f(proc i_thunk) {
  g = g + 1;
  print(i_thunk())
 }
```

Key idea

- Goal: Want to compute the argument in the caller's context
- Approach:
  - Caller creates a routine that computes the argument
  - Callee invokes the routine whenever it wants the argument

But, what if callee assigns to argument?

```
int g = 10;
main() {
 f(g);
}

void f(int i) {
  i = i + 1;
}
```

```
int g = 10;
int compute_g() {
  return g;
}
main() {
 f(compute_g);
}

void f(proc i_thunk) {
  i_thunk() = i_thunk()
              + 1
}
```

What does this even mean??

Another solution

```
int g = 10;
main() {
 f(g);
}

void f(int i) {
  i = i + 1;
}
```

```
int g = 10;
int *compute_g() {
  return &g;
}
main() {
 f(compute_g);
}

void f(proc i_thunk) {
  *i_thunk() =
     *i_thunk()+ 1
}
```

Thunks

- A procedure that evaluates a reference to the actual in the appropriate environment. E.g.,

```
int *compute_g() {
  return &g;
}
```

Another example

```
main() {
 int x = 10;
 f(x);
}

void f(int i) {
  i = i + 1;
}
```

```
int *compute_x() {
  return &x;
}
main() {
 int x;
 f(compute_x);
}

void f(proc i_thunk) {
  *i_thunk() =
     *i_thunk()+ 1
}
```

What's the matter here?

Fixing the problem

```
main() {
 int x = 10;
 f(x);
}

void f(int i) {
  i = i + 1;
}
```

```
main() {
  int x;
  int *compute_x() {
    return &x;
  }
 f(compute_x);
}

void f(proc i_thunk) {
  *i_thunk() =
     *i_thunk()+ 1
}
```

Need nested functions!

Relationship to Project 2

- You will implement parameter passing by name by doing the transformation on the previous page
  - We will use Modula-3 because it has nested functions and allows functions to be passed as arguments

Next lecture: implementation

- How do we implement functions and parameter passing?
- Reading: Section 3.2 (you've already read this) and 3.4