

Programming Languages

Control Flow

Onur Tolga Şehitoğlu

Computer Engineering



Outline

1 Control Flow

2 Jumps

3 Escapes

4 Exceptions

5 Co-routines

Control Flow

- Usual control flow: a command followed by the other.
Executed in sequence. [single entrance - single exit](#)
- Commands to change control flow and transfer execution to another point: [sequencers](#)
 - Jumps
 - Escapes
 - Exceptions

Jumps

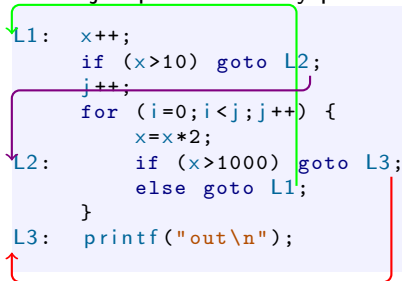
- Jumps transfer control to a point in the code. The destination is marked with **labels**
- When jumps to arbitrary positions are possible...:

```
L1:  x++;  
    if (x>10) goto L2;  
    j++;  
    for (i=0; i<j; j++) {  
        x=x*2;  
L2:    if (x>1000) goto L3;  
        else goto L1;  
    }  
L3:  printf("out\n");
```

- Called **spaghetti coding**

Jumps

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L3:  printf("out\n");
```

The diagram illustrates the execution flow of the provided code. A green line starts at L1, goes down to the 'for' loop, and then loops back to the 'if (x>10) goto L2;' statement. A purple line starts at the 'for' loop, goes down to L2, and then loops back to the 'else goto L1;' statement. A red line starts at L3 and goes back to the 'for' loop. These lines represent the jumps between different parts of the code, creating a 'spaghetti' pattern.

- Called **spaghetti coding**

- Unrestricted jumps \Rightarrow spaghetti coding.
- GCC extension allows storing labels in variables. Would you like to debug that code? 😊
- Further problems. Which jumps have problems?:

```
L1: ....
    goto L2;           ①
    ....
    for (i=0; i<10; i++) {
        int x=t;
L2:    ....
        goto L1;       ②
        ...
        goto L2:       ③
    }
```

- Lifetime and values of local variables? Values of index variables?
- C: Labels are local to enclosing block. No jumps allowed into the block. Newer languages avoid jumps.
- Single entrance multiple exit is still desirable. \rightarrow escapes

Escapes

- Restricted jumps to out of textually enclosing block(s)
- Depending on which enclosing block to jump out of:
 - loop: `break` sequencer.
 - loops: `exit` sequencer.
 - function: `return` sequencer.
 - program: `halt` sequencer.

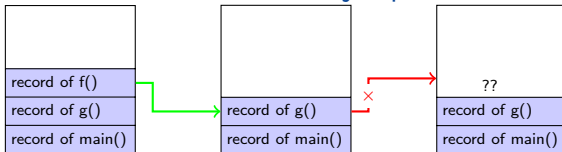
- **break sequencer** in C, C++, Java terminates the innermost enclosing loop block.
- **continue** in C, C++ stays in the same block but ends current iteration.
- **exit sequencer** in Ada or labeled break in Java can terminate multiple levels of blocks by specifying labels. Java code:

```
L1:  for (i=0;i<10;i++) {
        for (j=i;j<i;j++) {
            if (...) break;
            else if (...) continue;
            else if (...) break L1;
            else if (...) continue L1;
            s+=i*j;
        }
    }
```


- **return sequencer** exist in most languages for terminating the innermost function block.
- **halt sequencer** either provided by operating system or PL terminates the program.
- Consider jump inside of a block or jump out of a block for the function case:

```
int f(int n) {  
    int a;  
  
L1: if (n<0) goto L2;    ①  
    else if (n=1) return 1;  
    else return f(n-1)*n;  
}  
  
int main() {  
    ...  
    f(12);  
L2: ....  
    goto L1:              ②  
}
```

- Jump out of a function block, jump inside of a function block
- Jumps update current instruction pointer. But what about environment, activation record (run-time stack)?
- Possible only for one direction if stack position can be recovered. Called **non-local jumps**



- Are non-local jumps useful? One of the uses: unexpected error occurring inside of many levels of recursion. Jump to the outer-most related caller function. **Exceptions**

Exceptions

- Controlled jumps out of multiple levels of function calls to an outer control point (handler or catch)
- C does not have exceptions but non-local jumps possible via `setjmp()`, `longjmp()` library calls.
- C++ and Java: `try {...} catch(...) {...}`
- Each try-catch block introduces a non-local jump point. try block is executed and whenever a `throw expr` command is called in any functions called (even indirectly) inside try block execution jumps to the `catch()` part.
- try-catch blocks can be nested. Execution jumps to closes catch block with a matching type in the parameters with the thrown expression.

- Conventional error handling. Propagate errors with return values.

```

...
int searchopen(char *f) { ...
    /* if search fails error occurs here*/
    return -5;
...}
int openparse(char *f) { ...
    if ((r = searchopen(f)) < 0)
        return r;
    else ...
}
int main() { ...
    if ((rv=openparse("file.txt")) < 0) {
        /*handle error here */
    }
    ...
}

```

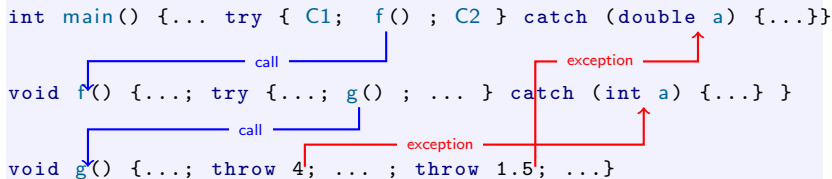
■ Error handling with try-catch. (based on run-time stack)

```

...
enum Exception { NOTFOUND, ..., PERMS};
void searchopen(char *f) { ...
    /* if open fails error occurs here */
    throw PERMS;
...}
void openparse(char *f) { ...
    searchopen(f);
    ...
}
int main() { ...
    try {...
        openparse("file.txt");
        ...
    } catch(Exception e) {
        /*handle error here */
    }
    ...
}

```

Nested exceptions are handled based on types. C++:



```

int main() {... try { C1; f() ; C2 } catch (double a) {...}}

void f() {...; try {...; g() ; ... } catch (int a) {...} }

void g() {...; throw 4; ... ; throw 1.5; ...}
  
```

The diagram illustrates the flow of control and exception handling in the provided C++ code. Blue arrows labeled 'call' show the sequence of function calls: from `main()` to `f()`, and from `f()` to `g()`. Red arrows labeled 'exception' show the path of an exception being thrown: from `g()` (where `throw 1.5` is executed) up to the `catch (double a)` block in `main()`. This occurs because `g()` has a `catch (int a)` block, but the thrown exception is of type `double`, which is not handled by `g()`'s catch block, so it propagates to the caller's catch block.

In case no handlers found a run time error generated. Program halts.

Co-routines

- Sequential flow: local jumps, subroutine calls, exceptions
- Concurrent flow: multiple contexes (stack and instruction pointer). Execution switches between them.
- Multiple uses: [callbacks](#), [generators](#) (iterators), [threads](#), [fibers](#), [asynchronous](#) or [concurrent](#) programming