Programming Languages

Control Flow

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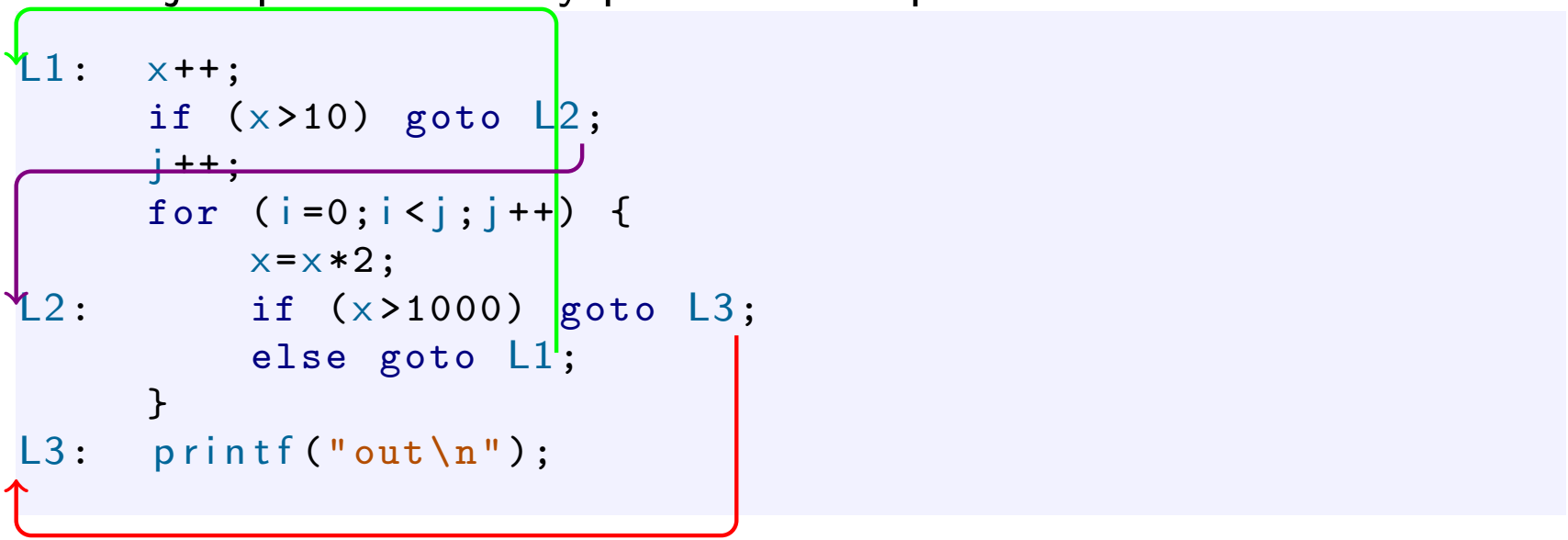
Outline

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

- Unrestricted jumps ⇒ 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.→ 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:

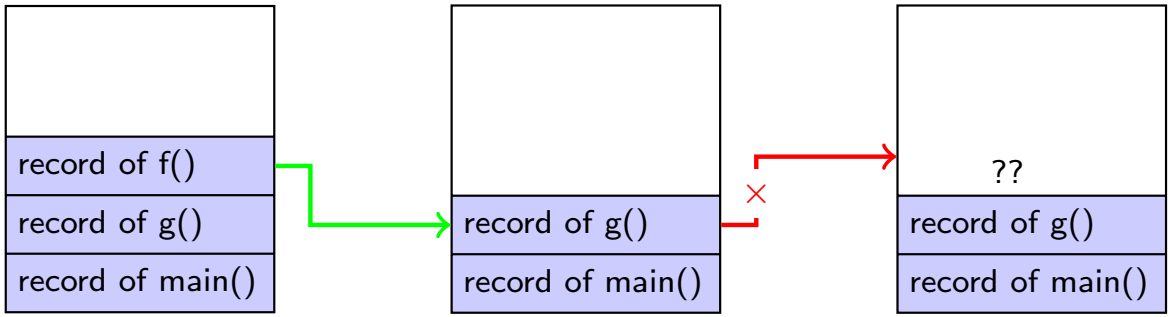
```
L1:  for (i=0;i<10;i++) {
        for (j=i;j<i;j++) {
           if (...) break;
           else if (...) continue;
           else if (...) break L1;
           else if (...) continue L1;
           s+=i*j;
        }
     }
```

- 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



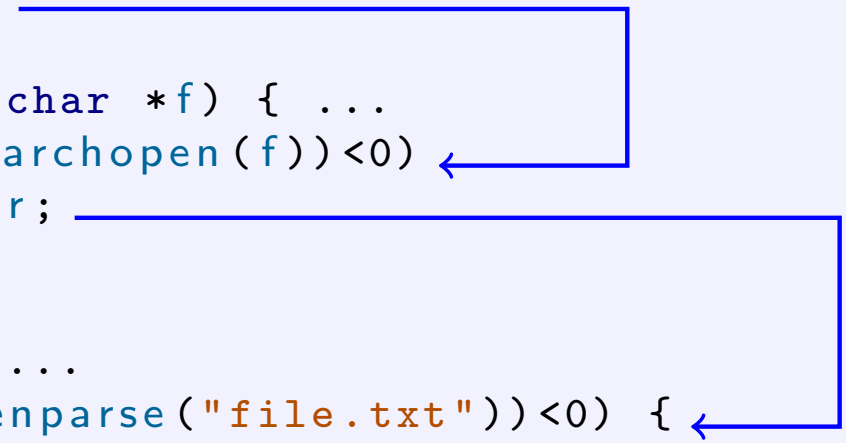
- Are non-local jumps useful? One of the uses: unexpected error occuring inside of many levels of recursion. Jump to the outer-most related caller function. Exceptions

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.

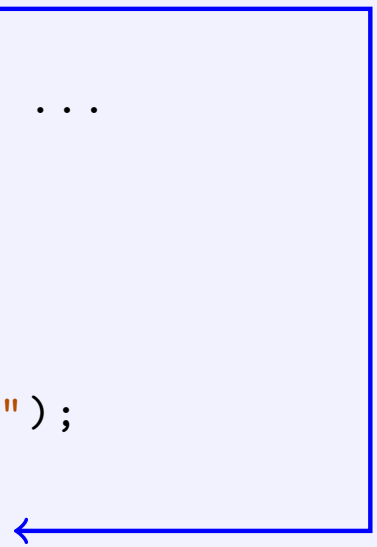
- Conventional error handling. Propagate errors with return values.

```
...
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 */
   ...
}
```

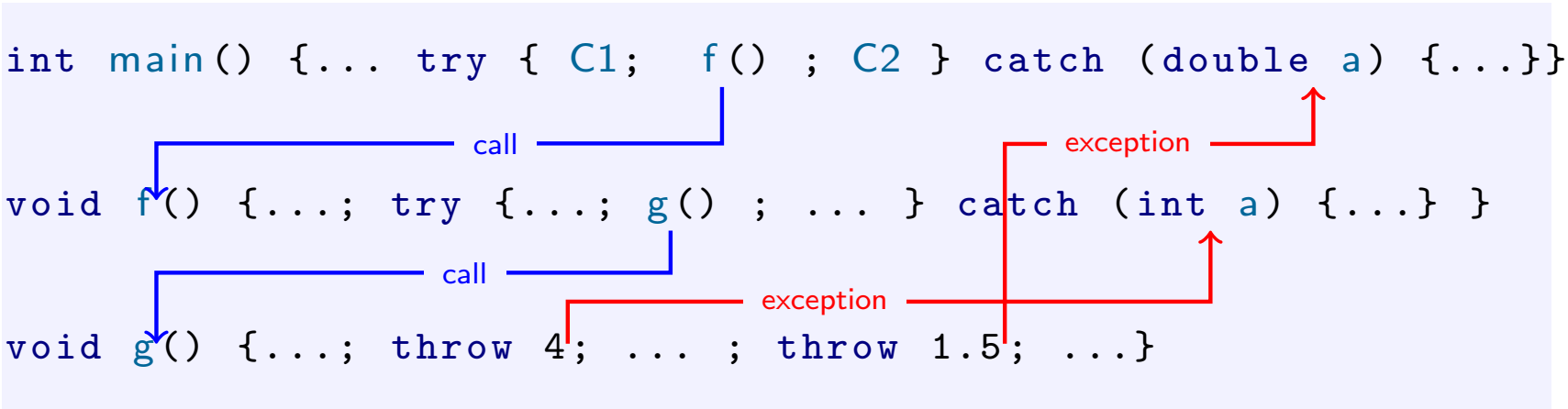


- Error handling with `try-catch`. (based on run-time stack)

```
...
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++:



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