Computer Systems 1
Lecture 16

Nested Conditionals

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Topics

1. Blocks
   - Syntax for blocks
   - Enter at beginning, exit at end
2. Nested conditionals
3. Case and jump tables
4. Real world incident: the SSL Bug

Blocks

- You'll need to learn many programming languages, eventually
- There are concepts that appear in most languages
- It's useful to focus on the general concept
- One important concept is a block
- A block or compound statement is a single statement that contains several statements
- The purpose is to let you have a group of statements in a loop, or controlled by a conditional
- The syntax is the detailed punctuation used to indicate a block, and this varies in different languages
    - There are lots of small syntax differences between languages
    - Some languages use := to mean assign, = to mean equals
    - Some languages use = to mean assign, == to mean equals

Python syntax style for blocks: layout

The layout (the indentation) determines what is inside the if statement

```
a = 1
if  x < y :
  b = 2
  c = 3
d = 4
```

If you change the indentation, you change the meaning of the program

In Python, you write `:` to mean *then*, and `else` to mean *else*

Algol/Pascal style for blocks: begin—end

```
a := 1;
if x<y
  then begin b := 2;
             c := 3
       end
  else begin d := 4;
             e := 5
       end;
f := 6;
```

You write `then` to mean *then*, and `else` to mean *else*

Statements must be separated by semicolon ;

C style for blocks: braces

```
a = 1;
if (x < y) b = 2;
else
   { d = 4;
     e = 5; }
f = 6;
```

In C you don't write `then` at all, but this means the condition `x < y` must be enclosed in parentheses so the compiler can tell where the condition ends and the then-statement begins

Block structured style for blocks: matching keywords

```
a := 1;
if x<y
  then b := 2;
       while i<n do
           sum := sum+x[i];
          i := i+1
       endwhile
  else d := 4
       e := 5
endif;
f := 6;
```

This style introduces a lot of keywords (endif, endwhile, endfor, endrepeat) but you don't need braces around a block. It makes code more readable and enables the compiler to produce better error messages

Enter at beginning, exit at end

- A common programming style is to require
  - Each block enters only at the beginning of the block
  - Each block exits only at the end of the block
- This style is helpful in some programming languages, but in some languages it sometimes makes code less readable
- In assembly language, and for compilation patterns, it is necessary to follow this style
- In high level languages this style is sometimes helpful, but not always

Single entrance/exit for compilation patterns

- It is straightforward to translate high level control constructs using the compilation patterns
- These *require* that the blocks of code always start at the beginning and finish at the end
- It's bad to jump into the middle of a block, or exit out of the middle because
  - The compilation patterns won't work correctly
  - You'll have to duplicate a lot of code
  - Example: returning from a procedure requires restoring the registers, resetting the stack pointer, loading the return address
  - That code should not be duplicated in several places in a procedure

Systematic approach to programming?

- Start by understanding what your program should do
- Express the algorithm using high level language notation (and it's ok to mix in some English too)
- Translate the high level to the low level
    - Assignment statements: x := expression
    - I/O statements: Write string
    - goto L
    - if boolean then goto L
- Translate the low level to assembly language
- Retain the high and low level code as comments
- Do hand execution at every level

Why use this systematic approach to programming?

- It enables you to write correct code at the outset, and minimise debugging
- If there is a bug, it helps you to catch it early (e.g. in translation to goto form)
- If there's a bug in an instruction, the comments enable you to find it quickly
  - A common error is to use a wrong register number: add R9,R3,R4
  - Poor comments don't help: add R9,R3,R4 ; R9 := R3+R4
  - Good comments help a lot: add R9,R3,R4 ; x := alpha + (a[i]*b[i])
  - Look at the register usage comments (oops, x is in R8, not R9, now I know how to fix it and I don't have to read the entire program)
- Professional software needs to be maintained; the comments make the software easier to read and more valuable

Nested if-then-else

Conditional statements can be nested deeply

```
if b1
  then S1
       if b2
         then S3
         else S4
       S5
  else S6
       if b3
         then S7
       S8
```

Special case of nested if-then-else

Often the nesting isn't random, but has this specific structure:

```
if b1
  then S1
  else if b2
         then S2
         else if b3
                then S3
                else if b4
                       then S4
                       else if b5
                              then S5
                              else S6
```

(Some languages require punctuation to avoid ambiguity)

Another way to write it

To avoid running off the right side of the window, it's usually indented like this:

```
if b1
  then S1
else if b2
  then S2
else if b3
  then S3
else if b4
  then S4
else if b5
  then S5
else S6
```

Some programming languages have elsif or elif

```
if b1 then S1
  elif b2 then S2
  elif b3 then S3
  elif b4 then S4
  eleif b5 then S5
  else S6
```

- It avoids ambiguity
- It signals to the compiler and to a human programmer that this specific construct is being used
- It allows good indentation layout without violating the basic principle of indentation
- Some languages have this, some don't

A common application: numeric code

Nested if-then-else but the boolean conditions are not arbitrary: they are checking the value of a code:

```
if code = 0
  then S1
else if code = 1
  then S2
else if code = 2
  then S3
else if code = 3
  then S4
else if code = 4
  then S5
```

The case statement

```
case n of
   0 -> Stmt
   1 -> Stmt
   2 -> Stmt
   3 -> Stmt
   4 -> Stmt
   5 -> Stmt
   else -> Stmt // handle error
```

This means: execute the statement corresponding to the value of n

Many programming languages have this; the syntax varies a lot but that isn't what's important

Example: numeric code specifies a command

```
; The input data is an array of records, each specifying an operation
;    Command : record
;       code : Int     ; specify which operation to perform
;       i    : Int     ; index into array of lists
;       x    : Int     ; value of list element

; The meaning of a command depends on the code:
;    0  terminate the program
;    1  insert x into set[i]
;    2  delete x from set[i]
;    3  return 1 if set[i] contains x, otherwise 0
;    4  print the elements of set[i]
```

Selecting the command with a case statement

```
; Initialize
;    BuildHeap ()

; Execute the commands in the input data
;    finished := 0
;    while InputPtr <= InputEnd && not finished
;       CurrentCode := (*InputPtr).code
;       p := set[*InputPtr]      ; linked list
;       x := (*InputPtr).x       ; value to insert, delete, search

;       case CurrentCode of
;          0 : <CmdTerminate>
;          1 : <CmdInsert>
;          2 : <CmdDelete>
;          3 : <CmdSearch>
;          4 : <CmdPrint>
;          else : <>
;       InputPtr := InputPtr + sizeof(Command)
; Terminate the program
;    halt
```

Finding a numeric code

- It's tedious and inefficient to go through the possible values of a numeric code in sequence
  - If you're looking up Dr Zhivago in the phone book, do you look at Arnold Aardvark, and Anne Anderson, on on and on?
  - You go straight to the end of the book
- We want to find the statement corresponding to a numeric code directly, without checking all the other values

A problem with efficiency

- The problem
  - There are many applications of case statements
  - They are executed frequently
  - The number of cases can be large (not just 4 or 5; can be hundreds)
  - The implementation of the if-then-else requires a separate compare and jump for each condition
- The solution
  - A technique called jump tables

Jump tables: the basic idea

- For each target statement (S1, S2, S3, etc) in the conditional, introduce a jump to it: jump S1[R0], jump S2[R0], etc
- Make an array "jt" of these jump instructions

```
jt[0] = jump S0[R0]
jt[1] = jump S1[R0]
jt[2] = jump S2[R0]
jt[3] = jump S3[R0]
jt[4] = jump S4[R0]
```

- Given the *code*, Jump to jt[code]
- Each element of the array is an instruction that requires two words
- So jump to &jt $+ 2 \times$ code

Jump table

```
; Jump to operation specified by code
    add     R4,R4,R4             ; code := 2*code
    lea     R5,CmdJumpTable[R0] ; R5 := pointer to jump table
    add     R4,R5,R4             ; address of jump to operation
    jump    0[R4]                ; jump to jump to operation
CmdJumpTable
    jump    CmdTerminate[R0]     ; code 0: terminate the program
    jump    CmdInsert[R0]        ; code 1: insert
    jump    CmdDelete[R0]        ; code 2: delete
    jump    CmdSearch[R0]        ; code 3: search
    jump    CmdPrint[R0]         ; code 4: print

CmdDone
    load    R5,InputPtr[R0]
    lea     R6,3[R0]
    add     R5,R5,R6
    store   R5,InputPtr[R0]
    jump    CommandLoop[R0]
```

We have to be careful!

- What if code is negative, or larger than the number of cases?
- The jump to the jump table could go anywhere!
- It might not even go to an instruction
- But whatever is in memory at the place it goes to, will be interpreted as an instruction that will be executed
- The program will go haywire
- Debugging it will be hard: the only way to catch the error is to read the code and/or to single step
- Solution: before jumping into the jump table, check to see if code is invalid (too big or too small)

Checking whether the code is invalid

```
CommandLoop
    load   R5,InputPtr[R0]      ; R1 := InputPtr
    load   R4,0[R5]             ; R4 := *InputPtr.code
; Check for invalid code
    cmp    R4,R0                ; compare (*InputPtr).code, 0
    jumplt CmdDone[R0]          ; skip invalid code (negative)
    lea    R6,4[R0]             ; maximum valid code
    cmp    R4,R6                ; compare code with max valid code
    jumpgt CmdDone[R0]          ; skip invalid code (too large)

...

CmdDone
    load   R5,InputPtr[R0]
    lea    R6,3[R0]
    add    R5,R5,R6
    store  R5,InputPtr[R0]
    jump   CommandLoop[R0]
```

A real world incident!

The moral of the following true story: be meticulous!

- On 21 February 2014, Apple announced a bug in core security software
- It affected iPhone, iPad, Macintosh, Safari
- The bug is serious: it skips a crucial security check in SSL
- A security update was made available quickly
  - That's why you should always apply your security updates!
- It was fixed quickly but we can learn some important lessons from it

What is SSL?

- Secure Sockets Layer
- It arranges that communication between your device and a server is encrypted
- When you see a “padlock icon” on a browser, it means the SSL protocol is being used

Source file: sslKeyExchange.c

- 1,969 lines of code in C
- You can see the code—click on this link, or type it in:
- `http://opensource.apple.com/source/Security/Security-55471/libsecurity_ssl/lib/sslKeyExchange.c`
- The bug made it possible to break open “secure” Internet traffic
- It appears somewhere on the next three slides: can you spot it?

The function SSLVerifySignedServerKeyExchange (1)

```
static OSStatus
SSLVerifySignedServerKeyExchange(SSLContext *ctx, bool isRsa, SSLBuffer signedParams,
                                 uint8_t *signature, UInt16 signatureLen)
{
    OSStatus        err;
    SSLBuffer       hashOut, hashCtx, clientRandom, serverRandom;
    uint8_t         hashes[SSL_SHA1_DIGEST_LEN + SSL_MD5_DIGEST_LEN];
    SSLBuffer       signedHashes;
    uint8_t                     *dataToSign;
        size_t                  dataToSignLen;

        signedHashes.data = 0;
    hashCtx.data = 0;

    clientRandom.data = ctx->clientRandom;
    clientRandom.length = SSL_CLIENT_SRVR_RAND_SIZE;
    serverRandom.data = ctx->serverRandom;
    serverRandom.length = SSL_CLIENT_SRVR_RAND_SIZE;
```

The function continued (2)

```
    if(isRsa) {
            /* skip this if signing with DSA */
            dataToSign = hashes;
            dataToSignLen = SSL_SHA1_DIGEST_LEN + SSL_MD5_DIGEST_LEN;
            hashOut.data = hashes;
            hashOut.length = SSL_MD5_DIGEST_LEN;

            if ((err = ReadyHash(&SSLHashMD5, &hashCtx)) != 0)
                    goto fail;
            if ((err = SSLHashMD5.update(&hashCtx, &clientRandom)) != 0)
                    goto fail;
            if ((err = SSLHashMD5.update(&hashCtx, &serverRandom)) != 0)
                    goto fail;
            if ((err = SSLHashMD5.update(&hashCtx, &signedParams)) != 0)
                    goto fail;
            if ((err = SSLHashMD5.final(&hashCtx, &hashOut)) != 0)
                    goto fail;
    }
    else {
            /* DSA, ECDSA - just use the SHA1 hash */
            dataToSign = &hashes[SSL_MD5_DIGEST_LEN];
            dataToSignLen = SSL_SHA1_DIGEST_LEN;
    }
    hashOut.data = hashes + SSL_MD5_DIGEST_LEN;
hashOut.length = SSL_SHA1_DIGEST_LEN;
```

The function continued (3)

```
    if ((err = SSLFreeBuffer(&hashCtx)) != 0)
        goto fail;

    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
        goto fail;
        goto fail;
    if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
        goto fail;

        err = sslRawVerify(ctx,
                           ctx->peerPubKey,
                           dataToSign,                                /* plaintext */
                           dataToSignLen,                      /* plaintext length */
                           signature,
                           signatureLen);
        if(err) {
                sslErrorLog("SSLDecodeSignedServerKeyExchange: sslRawVerify "
                    "returned %d\n", (int)err);
                goto fail;
        }

fail:
    SSLFreeBuffer(&signedHashes);
    SSLFreeBuffer(&hashCtx);
    return err;
}
```

A bit of C

Syntax of the if-statement

```
if (condition) statement;
```

Examples:

```
if (x<y) n=n+1;

if (n==5)
  { p = 3;
    q = 4;
    printf ("hello p = %3d\n", p);
  }
```

A closer look

```
if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
    goto fail;
    goto fail;
if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
    goto fail;
```

The second goto fail is unconditional so the check in the last if statement is never executed

What can we learn from this?

- To be a good programmer you need to
  - Know your programming language
  - Be meticulous
  - Read your code carefully
  - Do thorough testing
- It was very helpful that Apple published the source code for this bug

A mystery: The Attempted Linux Trapdoor Hack of 2003

- A trapdoor is a flaw (bug? hack?) in software that allows a hostile user to gain abilities they should not have
  - It's like giving the key to the safe in a bank to a burglar
- The master copy of Linux was maintained on Bitkeeper (no longer—now git is used)
- A secondary copy was on cvs
- Someone—unknown to this day—made a small edit to an obscure piece of code on the cvs version

The offending code: can you spot the trapdoor?

- A change was made to a function that a user could call to wait for an event
- System functions typically take options, and they need to check to see if the options are valid
- If not, a return code `retval` is set to a non-zero value

So, here's the code:

```
if ((options == (__WCLONE|__WALL)) && (current->uid = 0))
        retval = -EINVAL;
```

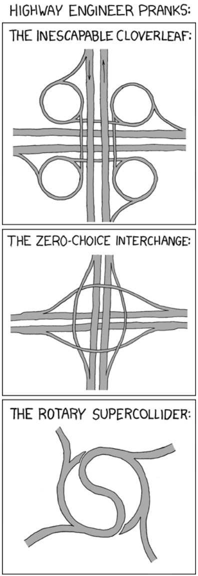
What's going on?

- In C, == is the comparison operator
- = is the assignment operator (bad notation, but we're stuck with it)
- This code looks like it is checking:
  - If either the WCLONE or WALL option flag is set and the current user is root, then return an error condition
- What it actually says is
  - Check the irrelevant flags, set the current user to be root, get the irrelevant result 0 and do nothing else

```
if ((options == (__WCLONE|__WALL)) && (current->uid = 0))
        retval = -EINVAL;
]
```

What's the significance of root?

- Many processes are running in the computer
- Each has its own set of privileges
- There is one special user "root" which has *all* privileges: root can do anything at all
- The effect of this change to the source code (a change of *one character!* is
  - If a user program calls this obscure function with just the right set of obscure options, it suddenly gains full control over the machine
- Don't worry — this faulty code never made it into the master copy of Linux



https://xkcd.com/253/