Errors and Exceptions

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Introduction

- Security problems often begin with an attacker finding a way to violate a programmer’s expectations
  - Do not lead directly to exploitable vulnerabilities the way buffer overflow.
  - Provide the conditions necessary for a later security failure.
- Topics
  - Handling errors with return codes
  - Managing exceptions
  - Preventing resource leaks
  - Logging and debugging

HANDLING ERRORS WITH RETURN CODES

Overview

- Fairly straightforward to use return value of a function to communicate success or failure, but
  - It makes it easy to ignore errors
  - Connecting error information with the code for handling the error makes programs harder to read.
  - There is no universal convention for communicating error information.

- C++ and JAVA provides exceptions rather than error codes.

Checking Return Values in C

- Programmer expects buf will contain a null-terminated string of length 9 or less.

```
char buf[10], cp_buf[10];
fgets(buf, 10, stdin);
strcpy(cp_buf, buf);
```

- What if an I/O Error with fgets occurs?
- What if <EOF> is found instead of characters?

- buf may not have a null terminating character

Checking the Results

```
char buf[10], cp_buf[10];
char* ret = fgets(buf, 10, stdin);
if (ret != buf) {
  report_error(errno);
  return;
}
strcpy(cp_buf, buf);
```

Must Know Your “tool”

- System functions (such as unlink(), ioctl(), and exec()) return -1 when they fail and 0 (NULL) when they succeed
- fgets() returns NULL when it fails and a pointer to the string it has read when it succeeds

Cleaning up Errors

```
char buf[10], cp_buf[10];
char* ret = fgets(buf, 10, stdin);
if (ret != buf) { goto ERR; }
strcpy(cp_buf, buf);
...
return;
ERR:
report_error(errno);
... /* cleanup allocated resources */
return;
```

Structured Programming

```
char buf[10], cp_buf[10];
char* ret;

ret = fgets(buf, 10, stdin);
if (ret != buf) {
  report_error(errno);
  ... /* cleanup allocated resources */
}
else {
   strcpy(cp_buf, buf);
   ...
}
return;
```

Facilitating Programmer Change

```
int checked_chdir(const char* path) {
  int ret = chdir(path);
  if (ret != 0) {
    fatal_err("chdir failed for %s: %s", path,
               strerror(errno));
  }
  return ret;
}
```

Checking Return Values in Java

- Most errors and unusual events in Java result in an exception being thrown.
- Stream and reader classes do not consider it unusual or exceptional if less data available to read than the programmer requested
  - Add whatever data available to the return buffer
  - Set the return value to the number of bytes or characters read
  - No guarantee that the amount of data returned is equal to the amount of data requested.

```
FileInputStream fis;
byte[] byteArray = new byte[1024];
for (Iterator i=users.iterator(); i.hasNext();) {
    String userName = (String) i.next();
    String pFileName = PFILE_ROOT + "/" + userName;
    FileInputStream fis = new FileInputStream(pFileName);
    try {
      fis.read(byteArray); // the file is always 1k bytes
      processPFile(userName, byteArray);
    } finally {
      fis.close();
    }
}
```

Programmer assumes 1K!

```
for (Iterator i=users.iterator(); i.hasNext();) {
  String userName = (String) i.next();
  String pFileName = PFILE_ROOT + "/" + userName;
  fis = new FileInputStream(pFileName);
  try {
    int bRead = 0;
    while (bRead < 1024) {
      int rd = fis.read(byteArray, bRead, 1024 - bRead);
      if (rd == -1) {
        throw new IOException("file is unusually small");
      }
      bRead += rd;
    }
  }
  finally {
    fis.close();
  }
  // could add check to see if file is too large here
  processPFile(userName, byteArray) ;
}
```

MANAGING EXCEPTIONS

Overview

- Exceptions solve many error handling problems.
- Programmer has to write code specifically to ignore it
- Exceptions allow for separation between:
  - code that follows an expected path and
  - code that handles abnormal circumstances.
- Exceptions come in two flavors: checked and unchecked.
  - A method that declares it throws a checked exception, all methods that call it must either handle the exception or declare that they throw it as well
  - Unchecked exceptions do not have to be declared or handled.
- All exceptions in C++ are unchecked

Catch Everything at the Top Level

- To shut down gracefully and avoid leaking a stack trace or other system information, programs should declare a safety-net exception handler that deals with any exceptions (checked or unchecked) that percolate to the top of the call stack
- DNS lookup failure throws an exception

```
protected void doPost (HttpServletRequest req,
                    HttpServletResponse res)
              throws IOException {
    String ip = req.getRemoteAddr();
    InetAddress addr = InetAddress.getByName(ip);
    out.println("hello
"+Utils.processHost(addr.getHostName()));
}
```

Top-level Java methods

- All remotely accessible top-level Java methods should catch Throwable.

```
protected void doPost (HttpServletRequest req,
                    HttpServletResponse res) {
      try {
          String ip = req.getRemoteAddr();
          InetAddress addr = InetAddress.getByName(ip);
          out.println("hello
"+Utils.processHost(addr.getHostName()));
      }
      catch (UnknownHostException e) {
          logger.error("ip lookup failed", e);
      catch (Throwable t) {
          logger.error("caught Throwable at top level", t);
      }
  }
}
```

The Vanishing Exception

- Both Microsoft C++ and Java support a try/finally syntax. The finally block is always executed after the try block, regardless of whether an exception is thrown.
- If the finally block contains a return statement, it will squash the exception.

Catch Only What You're Prepared to Consume

- Catching all exceptions at the top level is a good idea.
- Catching exceptions too broadly deep within a program can cause problems.
- Tomcat example
  - If any exception derived from java.lang.Exception occurs
    - NullPointerException,
    - IndexOutOfBoundsException, and
    - ClassCastException
  - The code silently falling back on an insecure source of random numbers: java.util.Random.
  - No error message is logged.

Tomcat 5.5.12 Session ID Flaws

```
protected synchronized Random getRandom() {
  if (this.random == null) {
      try {
        Class clazz = Class.forName(randomClass);
        this.random = (Random) clazz.newInstance();
        long seed = System.currentTimeMillis();
        char entropy[] = getEntropy().toCharArray();
        for (int i = 0; i < entropy.length; i++) {
            long update = ((byte) entropy[i]) << ((i % 8)*8);
            seed ^= update;
        }
        this.random.setSeed(seed);
      } catch (Exception e) {
          this.random = new java.util.Random();
      }
  }
  return (this.random) ;
}
```

When Exception Handling Goes Too Far

- Static analysis tools look for code that catch exceptions
  - NullPointerException
  - OutOfMemoryError
  - StackOverflowError.
- Normally, these exceptions should NOT be caught.
- Poor NullPointerException Practices
  - The program contains a null pointer dereference. Catching the resulting exception was easier than fixing the underlying problem.
  - The program explicitly throws a NullPointerException to signal an error condition.
  - The code is part of a test harness that supplies unexpected input to the classes under test.
- The last is the only acceptable use.

Keep Checked Exceptions in Check

- An overabundance of checked exceptions can lead programmers in a number of bad directions.
- The first is to collapse a long list of exception types into the base type for all the exceptions.
- Instead of writing this

```
throws IOException, SQLException, IllegalAccessException
```

- it might seem preferable to write this:

```
throws Exception
```

- Defeats the purpose of meaningful checked exceptions

PREVENTING RESOURCE LEAKS

Overview

- Failing to release resources can affect performance
  - can be hard to track down
  - Surface sporadically under unusual circumstances or heavy load
- Resources include
  - heap-allocated memory,
  - file handles,
  - database connections
- Resource leaks might permit a denial-of-service attack or a quality problem (performance implications),
  - the solution is the same: Make your resource management systematic.

C and C++: Multiple Returns

```
char* getBlock(int fd) {
  char* buf = (char*) malloc(BLOCK_SIZE);
  if (!buf) {
    return NULL;
  }
  if (read(fd, buf, BLOCK_SIZE) != BLOCK_SIZE) {
    return NULL;
  }
  return buf;
}
```

Better (according to Book)

```
char* getBlock(int fd) {
  char* buf = (char*) malloc(BLOCK_SIZE);
  if (!buf) {
    goto ERR;
  }
  if (read(fd, buf, BLOCK_SIZE) != BLOCK_SIZE) {
    goto ERR;
  }
  return buf;

  ERR:
  if (buf) {
    free(buf);
  }
  return NULL;
}
```

Best (guideline from "Writing Solid Code" 1993)

- Structured programming disallows “goto”

```
char* szGetBlock (int ifd) {
  char* cpBuf;
  unsigned int uiReadResult;

  cpBuf = (char*) malloc(BLOCK_SIZE)
  if (cpBuf) {
      uiReadResult = read(fd, cpBuf, BLOCK_SIZE);
    if (uiReadResult != BLOCK_SIZE) {
       free (cpBuf);
       cpBuf = NULL;
    }
  }
  return cpBuf;
}
```

Single Return Location

Error Handling C/C++

- C++ programs use exceptions, easier then C.
- C++ destructors always free memory when object goes out of scope.
- If you build your objects correctly, you never need to have an explicit call to close().
- Known by the unusual name Resource Acquisition Is Initialization (RAII).

File_handle “leaks” upon error

```
void decodeFile(char* fName) {
int return;  char buf[BUF_SZ]; FILE* f;

  f = fopen(fName, "r");
  if (!f) {
      printf("cannot open %s\n", fName);
      throw Open_error(errno);
  } else {
      while (fgets(buf, BUF_SZ, f)) {
          if (checkChecksum(buf) == -1) {
            throw Decode_failure();
          } else {
            decodeBlock(buf);
          }
      }
  }
  fclose(f);
}
```

File_handle Class

```
class File_handle {
FILE* f;
public:
  File_handle(const char* name, const char* mode) {
    f = fopen(name,mode);
      if (f==0) throw Open_error(errno);
    }
    ~File_handle() {
       if (f) {
          fclose(f);
       }
    }
    operator FILE*() { return f; }
    ...
};
```

Use File_handle class

```
void decodeFile(const char* fName) {
   char buf[BUF_SZ];
   File_handle f(fName, "r");

   while (fgets(buf, BUF_SZ, f)) {
      if (!checkChecksum(buf)) {
         throw Decode_failure();
      } else {
         decodeBlock(buf);
      }
   }
}
```

Java Example: DB Query

```
try {
  Statement stmt = conn.createStatement();
  ResultSet rs = stmt.executeQuery(CXN_SQL);
  harvestResults(rs);
  stmt.close();
}
catch (SQLException e){
  log logger.log(Level.ERROR, "error executing sql query", e);
}
```

If an exception occurs while executing the SQL or processing the results, the Statement object will not be closed

The close() location

- In Java, always call close() in a finally block to guarantee that resources are released under all circumstances. Moving close() into a finally block has a number of complicating effects:
  - The resource object must now be declared outside the try block.
  - The resource object must be initialized to null (so that it will always be initialized, even if createStatement() throws an exception).
  - The finally block must check to see if the resource object is null.
  - The finally block must deal with the fact that, in many cases, close() can throw a checked exception.

Object Always Closed

```
Statement stmt=null;
try {
  stmt = conn.createStatement();
  ResultSet rs = stmt.executeQuery(CXN_SQL);
  harvestResults(rs);
}
catch (SQLException e){
  logger.log(Level.ERROR, "error executing sql query", e);
}
finally {
  if (stmt != null) {
    try {
      stmt.close();
    } catch (SQLException e) {
      log(e);
    }
  }
}
```

Alternative Method (helper function)

```
…
…

finally {
  safeClose(stmt);
}

public static void safeClose(Statement stmt) {
  if (stmt != null) {
    try {
      stmt.close();
    } catch (SQLException e) {
      log(e);
    }
  }
}
```

ERROR MESSAGE BEST PRACTICES

Error Handling

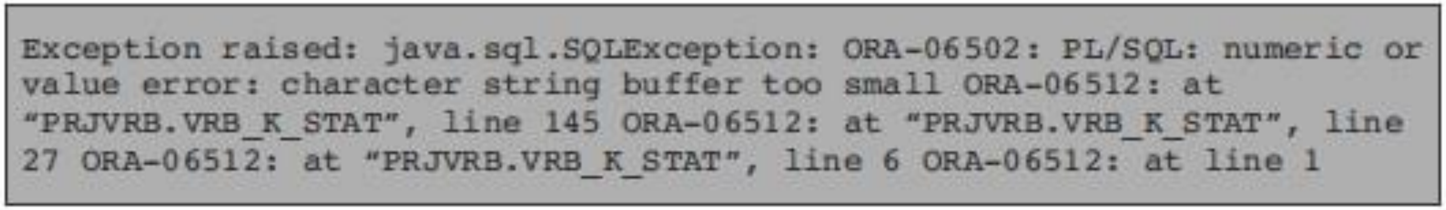
- Rather than using HTTP error codes for communicating about errors, there should be a single generic error page (details of the error should be logged behind the scenes).

- HTTP codes make it easier for attackers to write simple tools to probe your application.

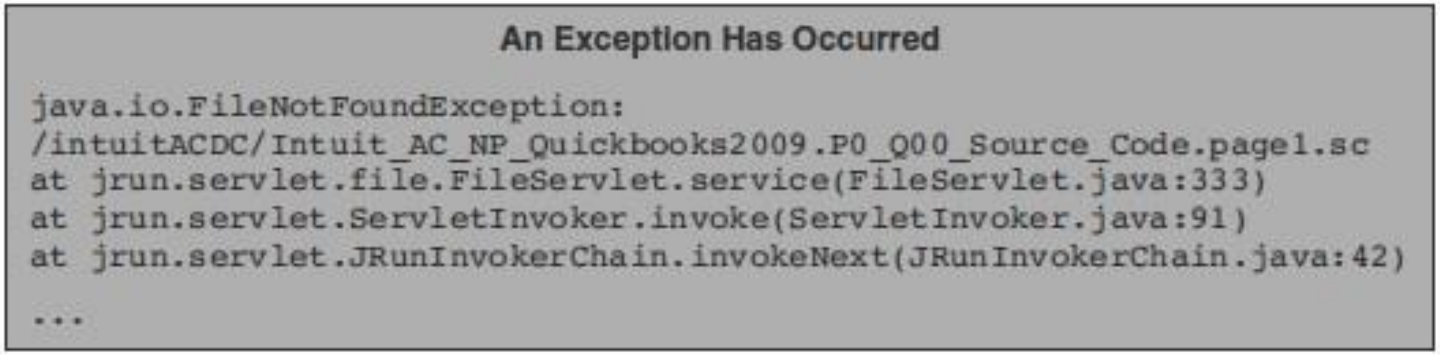
- This approach is a specific manifestation of a general security principle: **fail securely.**

Bad Error Messages

- Here are some bad error messages such as Exception raised and file not found



```
Exception raised: java.sql.SQLException: ORA-06502: PL/SQL: numeric or
value error: character string buffer too small ORA-06512: at
“PRJVRB.VRB_K_STAT”, line 145 ORA-06512: at “PRJVRB.VRB_K_STAT”, line
27 ORA-06512: at “PRJVRB.VRB_K_STAT”, line 6 ORA-06512: at line 1
```

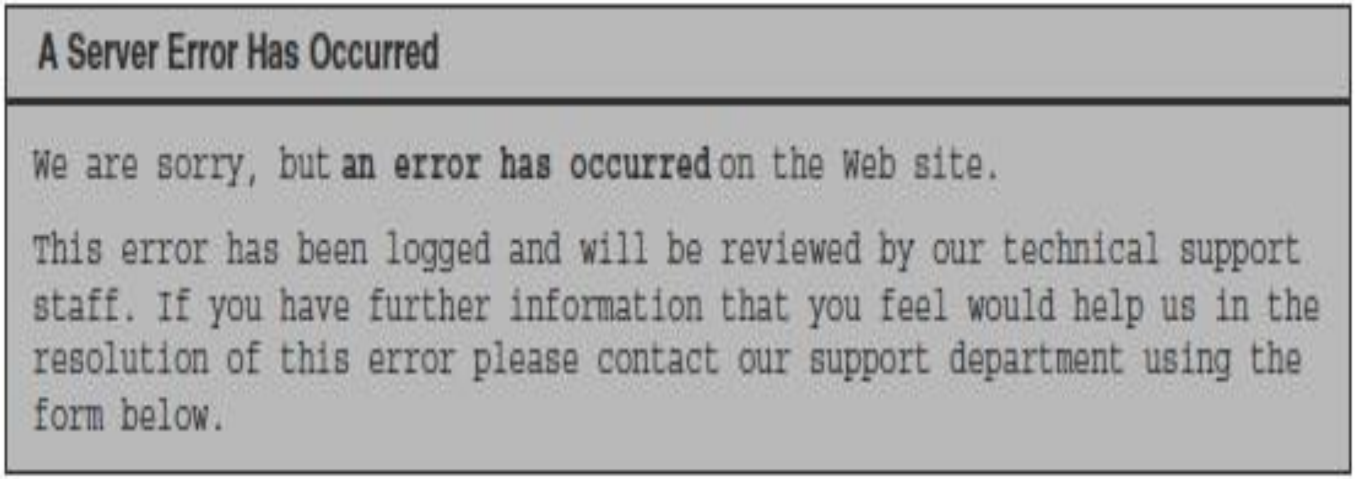


An Exception Has Occurred

```
java.io.FileNotFoundException:
/intuitACDC/Intuit_AC_NP_Quickbooks2009.P0_Q00_Source_Code.page1.sc
at jrun.servlet.file.FileServlet.service(FileServlet.java:333)
at jrun.servlet.ServletInvoker.invoke(ServletInvoker.java:91)
at jrun.servlet.JRunInvokerChain.invokeNext(JRunInvokerChain.java:42)
...
```

Good Error Messages

- The message like this which explains reasons and technical issues behind the given error are good error messages.



A Server Error Has Occurred

We are sorry, but **an error has occurred** on the Web site.

This error has been logged and will be reviewed by our technical support staff. If you have further information that you feel would help us in the resolution of this error please contact our support department using the form below.

Error Handling (Cont’d)

- There should be a default error page to guarantee that the application will never leak error messages to an attacker.
- Handling standard HTTP error codes is useful and user-friendly.
- A good configuration will also define a last-chance error handler.
- Error handling mechanism should avoid sending exceptions to the container.

Error Handling (Cont’d)

- For the default error page, server side configurations must include at least this kind of code.

```
<error-page>
<exception-type>java.lang.Throwable</exception-type>
<location>/error.jsp</location>
</error-page>

<error-page>
<error-code>404</error-code>
<location>/error.jsp</location>
</error-page>

<error-page>
<error-code>500</error-code>
<location>/error.jsp</location>
</error-page>
```

Error Handling (Cont’d)

- Error messages should not provide any clue for an attacker about how the system works.
- The message should not include identity of users, network details, or specifics about the application or its environment.
- e.g., Do not differentiate between a bad user ID and a bad password (prevents determination of legitimate user IDs).
  - Simple say “That combination of user ID and password is invalid.”
- Do not put error details in an HTML comment on the error page.
- Error messages are not for debugging.

LOGGING AND DEBUGGING

Overview

- Logging and debugging provide insight into understanding program execution
- Examine:
  - advantages of creating a constant logging behavior
  - segregating debugging aids from production code.

Centralize Logging

- A centralized framework makes it easier to do the following:
  - Provide one consistent and uniform view of the system reflected in the logs.
  - Facilitate changes, such as moving logging to another machine, switching from logging to a file to logging to a database, or updating validation or privacy measures.
- Avoid ad hoc logging through System.out and System.err,

Basic Logging Requirements

- Time-Stamp Log Entries
- Log Every Important Action
  - administration commands,
  - network communication,
  - authentication attempts,
  - an attempt to modify the ownership of an object
  - account creation,
  - password reset requests,
  - purchases,
  - sales,
  - paid downloads,
  - any other application event in which something of value changes hands

Do not log (leak) sensitive information!

Log Success and Failure Events

```
public int createUser(String admin, String usrName, String passwd) {
  logger.log(Level.INFO, admin + "initiated createUser()
             with name '"  + usrName + "'");
  int uid = -1;
  try {
    uid = provisionUid(usrName, passwd);
    return uid;
  }
  finally {
    if (uid != -1) {
      logger.log(Level.INFO, "finished createUser(), '"
                 + usrName + "' now has uid " + uid);
    } else {
      logger.log(Level.INFO, "createUser() failed for '"
                 + usrName + "'");
    }
  }
}
```

Protect the Logs

- Whether directly writing directly into log files or using sophisticated database:

Prevent attackers from gaining access to important details about the system or manipulating log entries in their own favor!

"Guide to Computer Security Log Management"

http://csrc.nist.gov/publications/nistpubs/800-92/SP800-92.pdf

Debug Aids

- Keep Debugging Aids and Back-Door Access Code out of Production
- Debugging code does not receive the same level of review and testing as the rest of the program and is rarely written with stability, performance, or security in mind.
- The same hooks that allow developers to debug allow attackers access to the code

Always remove debug code before deploying a production version of an application.

Back-door access code

- Back-door access code is a special case of debugging code.
- Back-door access code is designed to allow developers and test engineers to access an application
- Back-door access code is often necessary to test components of an application in isolation or before the application is deployed in its production environment.
- See Passport to Trouble Side Bar

- **“Netgear and Linksys hide router backdoor instead of closing it” – April 22, 2014**

Passport to Trouble (Microsoft Passport Vulnerability in 2003)

- All you have to do is hit the following in your browser:
  - https://register.passport.net/emailpwdreset.srf?lc=1033&em=victim@hotmail.com&id=&cb=&prefem=attacker@attacker.com&rst=1
- And you'll get an email on attacker@attacker.com asking you to click on a url something like this:
  - http://register.passport.net/EmailPage.srf?EmailID=CD4DC30B34D9ABC6&URLNum=0&lc=1033
- From that URL, you can reset the password and I don't think I need to say anything more about it.

Clean Out Backup Files

- Unused, temporary, and backup files never appear in production code
- Backup files offer attackers a way to travel back in time
- Backup files likely reflect antiquated code or settings,
  - Prime location for security vulnerabilities or other bugs
- Automated Web attack tools search for backup files by riffing on filenames that are exposed through the site.
- Use input validation techniques and create a whitelist that restricts the files

Web Application Archive

```
<war
       destfile="${web.war.file}"
       webxml="${config.dir}/webxml/web.xml">

        <fileset dir="${build.dir}">
          <include name="**/*.jsp"/>
          <include name="**/*.jar"/>
          <include name="**/*.html"/>
          <include name="**/*.css"/>
          <include name="**/*.js"/>
          <include name="**/*.xml"/>
          <include name="**/*.gif"/>
          <include name="**/*.jpg"/>
          <include name="**/*.png"/>
          <include name="**/*.ico"/>
        </fileset>
</war>
```

Do Not Tolerate Easter Eggs

- Easter eggs are hidden application features usually added for the amusement of programmers.
- Easter eggs are a problem from a security perspective.
  - First, they are rarely included in the security review process, so they are more likely to ship with vulnerabilities.
  - Second, it is difficult to assess the motivation behind a vulnerability in an Easter egg.
  - A zero-tolerance policy toward Easter eggs.

- https://www.youtube.com/watch?v=dtfBBNYdcPc

Conclusion

- Every serious attack on a software system begins with the violation of a programmer’s assumptions.
- Communicating error information with return values leads to messy code – programmers are tempted to not implement.
- Exceptions are a superior way to communicate unexpected situations – can be consciously ignored.
- Java’s checked exceptions are useful because they enable the Java compiler to find bugs at compile time.
- Insure your code releases any resources it uses.
- Use a logging framework as the basis for a consistent logging discipline.