Input Validation

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Today's Specials

- Handling user input

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- Canonicalizing input

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Input Validation is Trust Management

A *trust relationship* is a relationship among the different participants in a software system and concerns the assumptions that those participants make about security properties of the other part.

For example, a function might assume that its inputs are shorter than some maximum length; or it might assume that its input is a valid user name.

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We can then say that the library routine *trusts* its caller to provide legal arguments.

An attacker is often interested in *violating* the assumptions that parts of a program make, because "interesting" things often happen if they are violated.

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Therefore, programmers are encouraged to think about software development in small steps.

But when they do that, they lose sight of the system as a whole and forget to make their assumptions explicit. (That happens especially with routines that are deep in the guts of a system, because the assumption is that user input will only get this far after extensive validations in the upper layers.)

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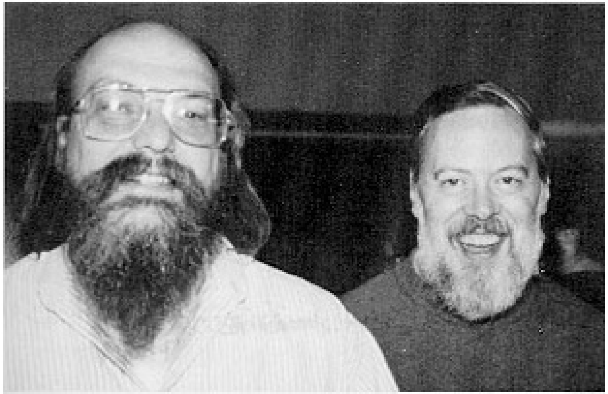
- the callee can *return an error code*. Error codes are often not appropriate for returning detailed information about the error; or
- the callee can *set a global variable* to the detailed error description and return an error value in-band. This is prone to error on multithreaded systems, besides being confusing in certain circumstances (see exercises).

Why is Trust Management So Difficult? (4)



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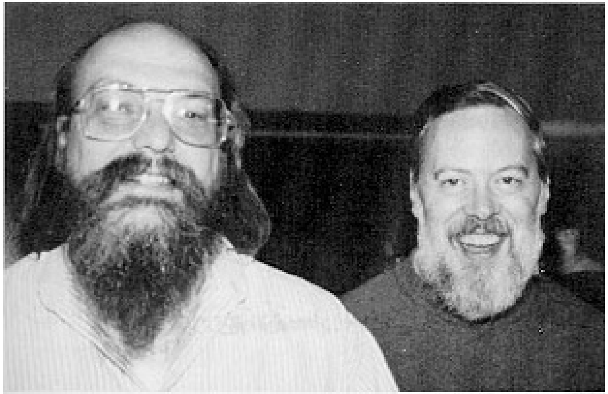

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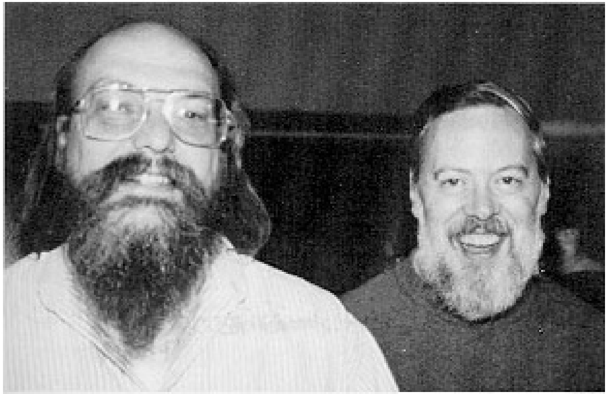

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For this achievement, he was awarded the ACM Turing Award in 1984 (a hightly appropriate year).

In his award lecture, he outlined how he modified the Unix C compiler so that he got access to any Unix system.

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What did Thompson do next?

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> "The moral is obvious. You can't trust code that you did not totally create yourself. (Especially code from companies that employ people like me.)"
>
> —Ken Thompson

Trusting Input (1)

Trust in input is often not warranted and sometimes downright dangerous.

```
#include <stdio.h>

int main() {
  int a;

  scanf("%d", &a);
  printf("%d\n", a);
  return 0;
}
```

What happens if the user enters something that is not a number? The value of a is undefined, and therefore could be anything.

Trusting Input (2)

```
#include <stdio.h>
#include <string.h>

int main() {
  char filename[1024];
  char command[sizeof(filename) + 4];

  fgets(filename, sizeof(filename));
  filename[sizeof(filename) - 1] = '\0';
  strcpy(command, "cat ");
  strcat(command, filename);
  system(command);          /* Executes a shell */

  return 0;
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What happens if a user enters “*/dev/null; rm -rf **”?

Trusting Input (3)

Many Web servers (Apache and IIS among them) have had problems in the past with access controls like these:

```
extern const char* document_root;
extern int check_htaccess(pathname);
extern char* concat(const char*, const char*);

void serve_page(char* relative_path) {
  char* absolute_path = concat(document_root, relative_path);

  if (directory_contains_htaccess(absolute_path))
    access_ok = check_htaccess(absolute_path);
  else
    access_ok = true;

  if (access_ok)
    put_page(absolute_path);
}
```

What’s wrong with this code?

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A Web page can similarly be known under different names.

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When you are regulating access based on an object's *name*, you *must* canonicalize the object's name *before* making the access decision.

That can be difficult (see exercises)

Validating Input: An Example


```
#include <stdio.h>

static const char* maildir = "/var/spool/mail/";

int main(int argc, const char* argv[]) {
  char* path = (char*) malloc (strlen(maildir) + strlen(argv[1]) + 1);
  char buffer[100];
  size_t byres_read;

  strcpy(path, maildir);
  strcat(path, argv[1]);

  FILE* fp = fopen(path);
  while ((bytes_read = fread(buffer, sizeof(buffer), 1, fp)) != 0)
    fwrite(buffer, bytes_read, 1, stdout);
  fclose(fp);
  free(path);

  return 0;
}
```

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```c
#include <ctype.h>

int validate_username(const char* username) {
  int i;

  for (i = 0; username[i] != '\0'; i++) {
    if (isupper(username[i]) || iscntrl(username[i]) /* Scan for forbidden characters */
        || isspace(username[i]) || !isascii(username[i]))
      return 0;
  }
  return 1;
}
```

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#include <ctype.h>

int validate_username(const char* username) {
  int i;

  for (i = 0; username[i] != '\0'; i++) {
    /* Scan for forbidden characters */
    if (!islower(username[i]))
      return 0;
  }
  return 1;
}
```

Better, but still not a good idea because the code is still locale-dependent.

Allow-Based, Locale-Independent

```
int validate_username(const char* username) {
  int i;

  for (i = 0; username[i] != '\0'; i++) {
    /* Scan for forbidden characters. This works both in ASCII
     * and EBCDIC, but might not work in other characters sets. */
    if ('a' <= username[i] && username[i] <= 'z')
      return 0;
  }
  return 1;
}
```

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SQL Injection

```
static const char* quary_start = "SELECT COUNT(*) FROM ";

/* Return number of rows in TABLE. */
int n_rows(const char* table) {
  char* query = (char*) malloc(strlen(query_start) + strlen(table) + 1);
  int ret;

  strcpy(query, query_start);
  strcat(query, table);

  ret = make_query(query);
  free(query);

  return ret;
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}
```

What if the argument isn’t checked and the user can somehow enter “*customers; DROP TABLE customers*”?

Invoking Programs (Unix)


```
#include <stdlib.h>

void call_ls() {
  system("ls");
}
```

"*system*() executes a command specified in string by calling `/bin/sh -c` *string*, and returns after the command has been completed. During execution of the command, *SIGCHLD* will be blocked, and *SIGINT* and *SIGQUIT* will be ignored." —*system*(3) manual page

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Calling *call_ls*() like this is indeed safe.

But: The PATH variable is not controlled by the application, but by the user calling the application.

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Oops.

Putting . Last Is No Help

Some people say that putting the current directory last will help avoid executing bogus programs. Not so:

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$ PATH=${PATH}:.; export PATH
$ cp evil_binary l
$ ln -s call-ls x
$ IFS=s ./x  # Call the suid program
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```
$ PATH=.; export PATH
$ cp evil_binary ls
$ IFS='IP \n\t' ./call-ls
```

Next Try (1)


```
#include <stdlib.h>

void call_ls() {
  system("IFS=' \n\t'; PATH='/bin:/usr/bin'; export IFS PATH; ls");
}
```

Not good. We can attack this program as follows:

```
$ PATH=.; export PATH
$ cp evil_binary ls
$ IFS='IP \n\t' ./call-ls
```

This causes the variable FS to be set to the value intended for IFS and the variable ATH to be set to the value intended for PATH ⇒ attacker still gets to run `./ls` instead of `/bin/ls`.

Next Try (2)

```
#include <stdlib.h>

void call_ls() {
  system("/bin/ls");
}
```

Next Try (2)


```
#include <stdlib.h>

void call_ls() {
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Still not good. We can attack this program as follows:

Next Try (2)


```c
#include <stdlib.h>

void call_ls() {
  system("/bin/ls");
}
```

Still not good. We can attack this program as follows:

```
$ PATH=.; export PATH
```

Next Try (2)


```
#include <stdlib.h>

void call_ls() {
  system("/bin/ls");
}
```

Still not good. We can attack this program as follows:

```
$ PATH=.; export PATH
$ cp evil_binary bin
```

Next Try (2)


```
#include <stdlib.h>

void call_ls() {
  system("/bin/ls");
}
```

Still not good. We can attack this program as follows:

```
$ PATH=.; export PATH
$ cp evil_binary bin
$ IFS='/ \n\t' ./call-ls
```

Next Try (2)

```
#include <stdlib.h>

void call_ls() {
  system("/bin/ls");
}
```

Still not good. We can attack this program as follows:

```
$ PATH=.; export PATH
$ cp evil_binary bin
$ IFS='/ \n\t' ./call-ls
```

This causes the program `./bin` to be run with the argument `ls` instead of `/bin/ls`.

Next Try (3)


```
#include <stdlib.h>

static const char* default_environment[] = {
  "PATH=/bin:/usr/bin",
  0,
};

void call_ls() {
  int i;

  for (i = 0; default_environment[i] != 0; i++)
    putenv(default_environment[i]);

  system("ls");
}
```

Next Try (3)

```
#include <stdlib.h>

static const char* default_environment[] = {
  "PATH=/bin:/usr/bin",
  0,
};

void call_ls() {
  int i;

  for (i = 0; default_environment[i] != 0; i++)
    putenv(default_environment[i]);

  system("ls");
}
```

An environment variable is *not* unique. You can have two PATH variables. You overwrite one, but which one is used when looking for executables?

Next Try (4)


```c
#include <stdlib.h>

extern char* environ[];

static const char* default_environment[] = {
  "PATH=/bin:/usr/bin",
  0,
};

void call_ls() {
  int i;

  if (environ != 0) {
    for (i = 0; environ[i] != 0; i++)
      environ[i] = 0;
  }
  for (i = 0; default_environment[i] != 0; i++)
    putenv(default_environment[i]);

  system("ls");
}
```

Why Use A Shell At All?


```c
#include <sys/types.h>
#include <unistd.h>
#include <sys/wait.h>

static const char* args[] = { "/bin/ls", 0 };
void call_ls() {
  pid_t pid = fork();

  if (pid == 0) {                /* Child */
    execve(args[0], args, 0);
    handle_exec_error();         /* If we get here, execve(2) has failed */
  } else if (pid > 0) {          /* Parent */
    int status;

    waitpid(pid, &status, 0);    /* Check status after this line */
  } else
    handle_fork_error();         /* fork(2) has failed, check errno */
}
```

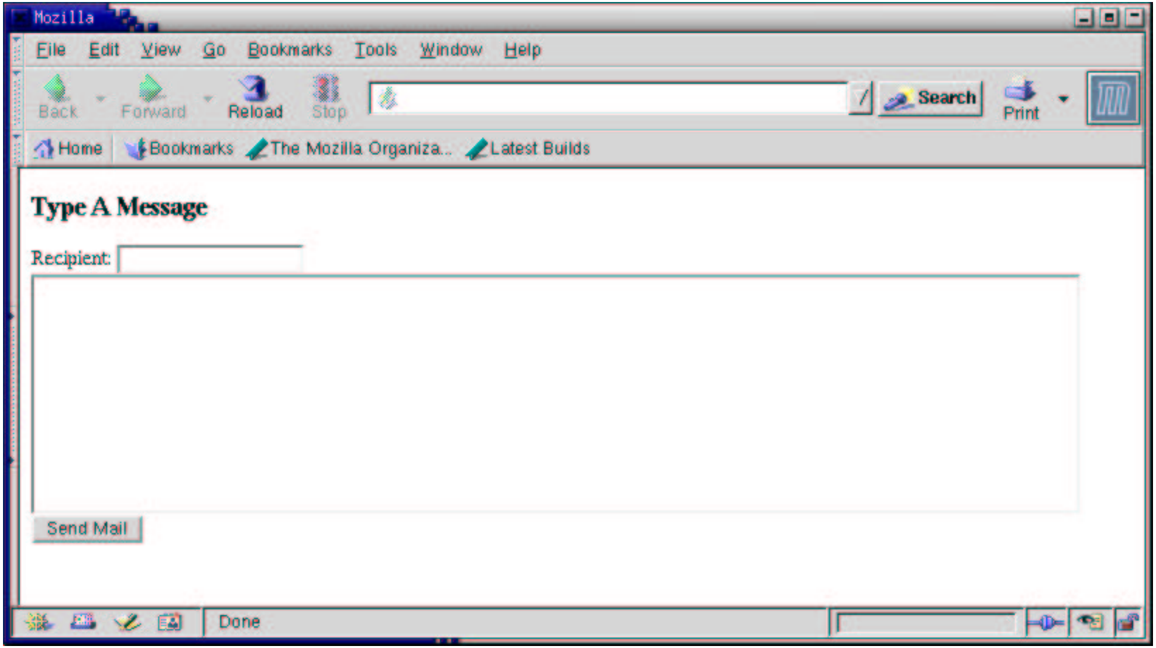
A Common CGI Script


```
#! /bin/python
import cgi, os

print "Content-Type: text/html\r\n\r\n",

form = cgi.FieldStorage()
message = form["contents"].value
recipient = form["to"].value

tmpfile = open("/tmp/cgi-mail", "w")
tmpfile.write(message)
tmpfile.close()

os.system("/bin/mail " + recipient + " < /tmp/cgi-mail")
os.unlink("/tmp/cgi-mail")

print "<html><h3>Message sent.</h3></html>\r\n",
```

Used With A Web Page


```
<html>
  <head/>
  <body>
    <form action="http://www.st.cs.uni-sb.de/~neuhaus/mail.py"
          method="post">
      <h3>Type A Message</h3>
      Recipient: <input type="text" name="to"> <br/>
      <textarea name="contents" cols="80" rows="10">
      </textarea>
      <br/>
      <input type="submit" value="Send Mail"/>
    </form>
  </body>
</html>
```

This Is How It Looks



What's Bad About It?

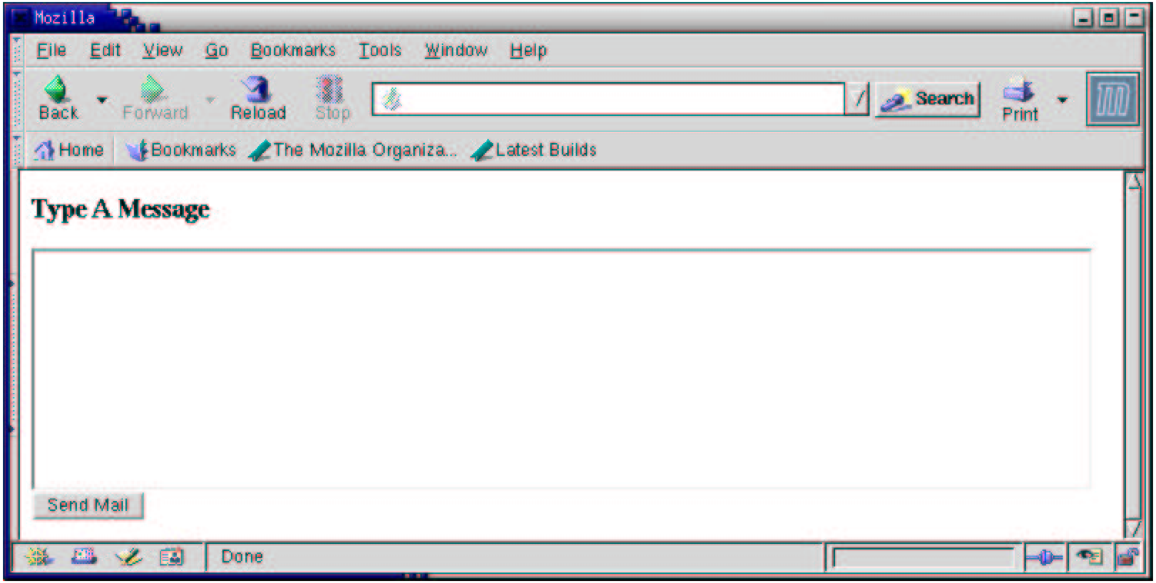
As we already know, unchecked input can be used for baad things. If the user enters "*president@whitehouse.gov; rm -rf **", everything gets removed.

But I want mail to be sent to myself only, so I put the recipient into a *hidden* field that can't be seen from the browser:

Attempted Remedy (1)


```
<html>
  <head/>
  <body>
    <form action="http://www.st.cs.uni-sb.de/˜neuhaus/mail.py"
          method="post">
      <h3>Type A Message</h3>
      <textarea name="contents" cols="80" rows="10">
      </textarea>
      <br/>
      <input type="hidden" name="to" value="neuhaus@st.cs.uni-sb.de">
      <input type="submit" value="Send Mail"/>
    </form>
  </body>
</html>
```

Attempted Remedy (2)



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1. Display the web page;
2. Save a local copy of the HTML on disk;
3. Modify the copy to put a malicious value in the "`to`" field;
4. Redisplay the local copy; and
5. Submit the malicious form.

Cross-Site Scripting (XSS)

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OK, now you also filter out messages containing '%'?

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Alice clicks on Eve’s message and has Eve’s script executed on her computer.

So you filter out everything that contains a ‘<’ character?

```
%3Cscript>http://www.attacker.org/remove-all-files.scr%3C/script>
```

OK, now you also filter out messages containing ‘%’?

```
&lt;script>http://www.attacker.org/remove-all-files.scr&lt;/script>
```

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Alice clicks on Eve’s message and has Eve’s script executed on her computer.

So you filter out everything that contains a ‘<’ character?

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%3Cscript>http://www.attacker.org/remove-all-files.scr%3C/script>
```

OK, now you also filter out messages containing ‘%’?

```
&lt;script>http://www.attacker.org/remove-all-files.scr&lt;/script>
```

(This might or might not work, depending on who converts the entity `<` to a less-than character, and when)

Remember: *first* canonicalize, *then* filter

Specifying the Character Set

One solution is to preprocess outgoing text prior to sending it over the network.

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This helps only if the text does not contain one of the many alternate encodings for '<', which exist in many alternate character sets.

One way to avoid that is to *specify* the character set in advance, for example, by putting it at the top of outgoing documents (after the HTTP header, before the `<html>` tag):

```
<META http-equiv="Content-Type"
      content="text/html; charset=ISO-8859-1">
```

Format-String Attacks

```
#include <stdio.h>

extern void somefunction(const char*, const int*);
extern int check_password(const char* password);
extern char* get_password();

void login(const char* user_supplied_message) {
  int authenticated = 0;
  int tries = 0;

  somefunction("Test", &authenticated);
  printf(user_supplied_message); /* Should be printf("%s", message); */

  while (!authenticated && tries <= 3) {
    authenticated = check_password(get_password());
    tries++;
  }
}
```

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  while (!authenticated && tries <= 3) {
    authenticated = check_password(get_password());
    tries++;
  }
}
```

As usual, there is a little-known “feature” hidden here...

printf(3) and %n

The *printf*(3) function has not only the ability to print output, you can also get the number of characters that were printed up to a certain point:

```c
#include <stdio.h>

void howmany() {
  int x = 12345;
  int howmany1, howmany2;

  printf("Test 1 2 3%n%d%n\n", &howmany1, x, &howmany2);

  /* At this point, howmany1 = 10, howmany2 = 15. */
}
```

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Attacking printf

If the address of *authenticated* is left over on the stack from a previous invocation of *somefunction*(), we can attack the code by setting *user_message* to “`Hello%n`”:

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Attacking printf

If the address of *authenticated* is left over on the stack from a previous invocation of *somefunction*(), we can attack the code by setting *user_message* to “`Hello%n`”:

The *printf*(3) function will take the left-over address of *authenticated* and put the number of characters there.

This is greater than 0, therefore, *authenticated* will suddenly have the value **true**!

How To Avoid That

Always use *printf*(3) with a format string argument (i.e., `printf("%s", x)` instead of `printf(x)`).

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Nope.

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Always use *printf*(3) with a format string argument (i.e., `printf("%s", x)` instead of `printf(x)`).

Don't bother to check the user supplied string for percent characters.

Is nothing safe?!

Nope. Sorry.

References

Matt Bishop, Deborah Frinke, *Teaching Robust Programming*, IEEE Security & Privacy 2(2), March/April 2004, IEEE Press.

Ken Thompson, *Reflections on Trusting Trust*, 1984 Turing Award Lecture, *Communication of the ACM*, 27(8), August 1984, pp. 761–763.

Viega, McGraw, *Building Secure Software*.