A2C: Self Destructing Exploit Executions via Input Perturbation

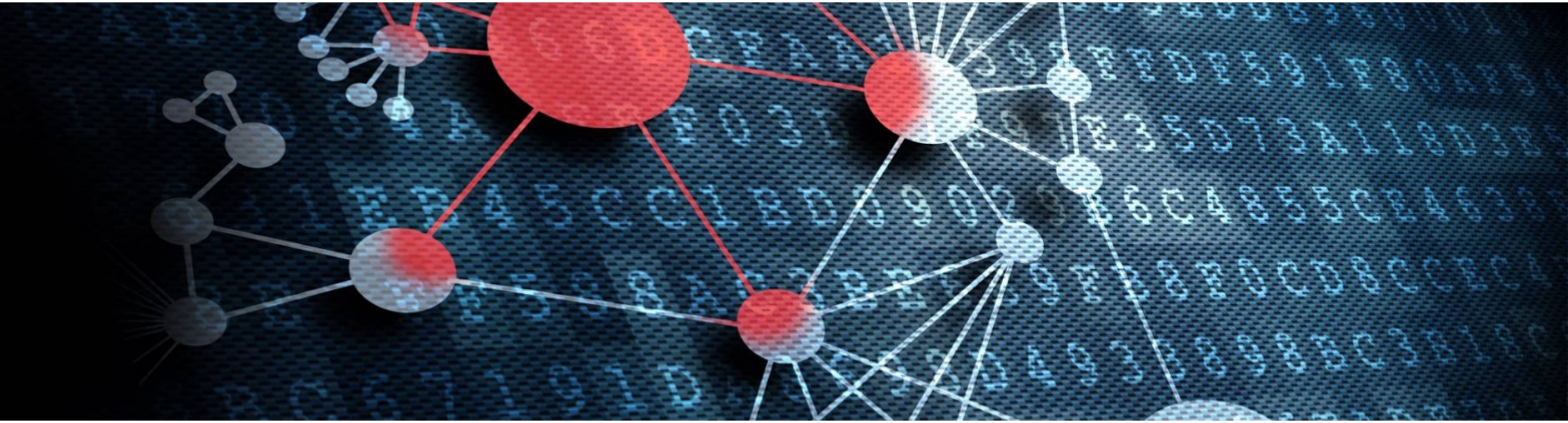
Yonghwi Kwon[1], Brendan Saltaformaggio[1], I Luk Kim[1], Kyu Hyung Lee[2], Xiangyu Zhang[1], and Dongyan Xu[1]

[1]Department of Computer Science, Purdue University

[2]Department of Computer Science, University of Georgia

Observation

In most attacks, attackers need to inject malicious payloads



and they are brittle

Our Solution: A2C

Observation

Malicious Input: ...01010101010...

Malicious Payload: Shellcode/ROP

Shellcode (Payload)	Corresponding Instructions
31 c0 31 f6 50 5f 50 b0 66 6a 01 5b 53 6a 02 89 e1 cd 80 96 ...	xor eax, eax; xor esi, esi; push eax; pop edi; push eax; ...

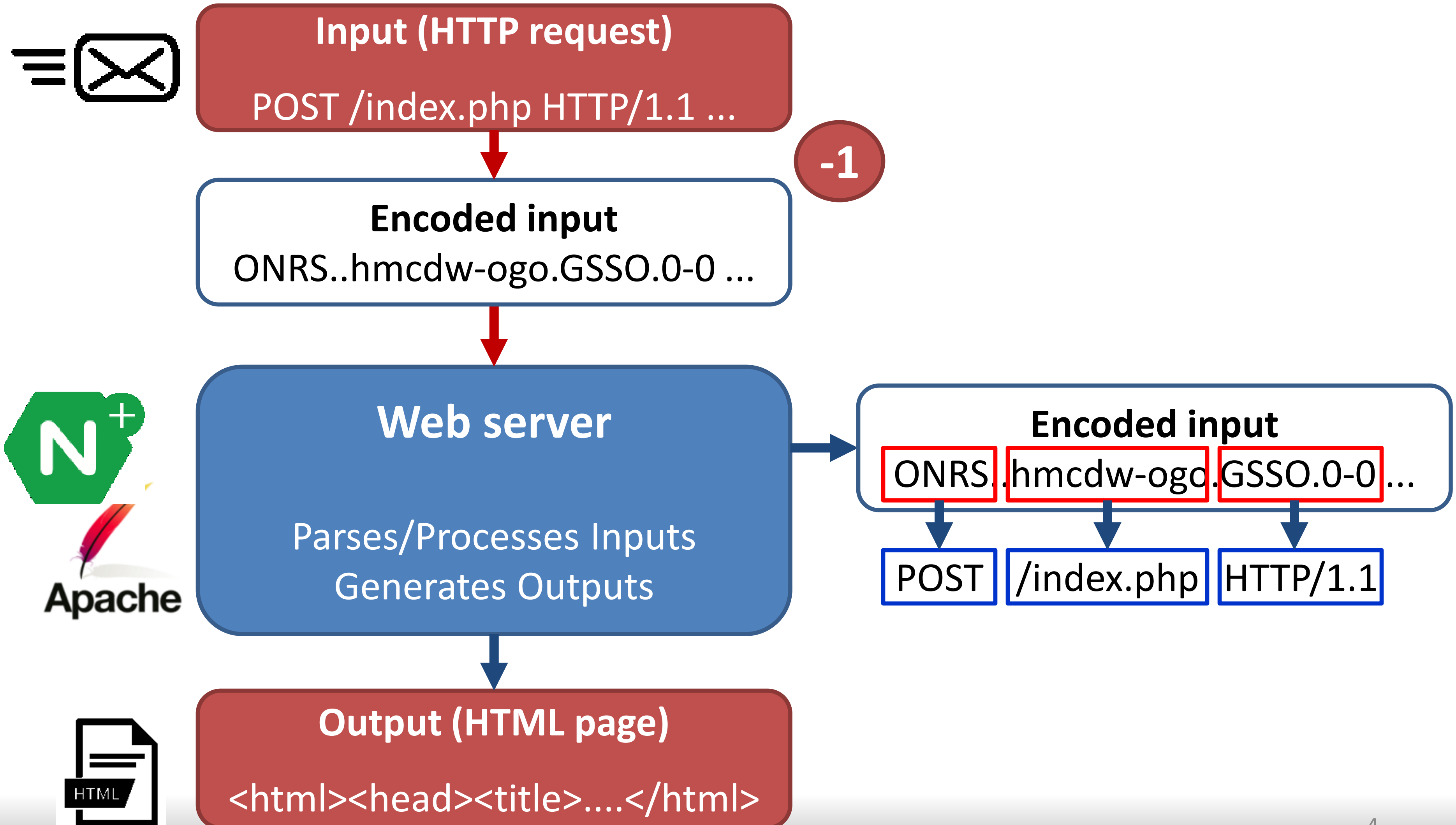
XOR 0xAA

9b 6a 9b 5c fa f5 fa 1a cc c0 ab f1 f9 c0 a8 23 4b 67 2a 3c ...	fwait; push 0xffffff9b; pop esp; cli; cmc; cli; sbb cl, ah; shr ...

Payload is broken!

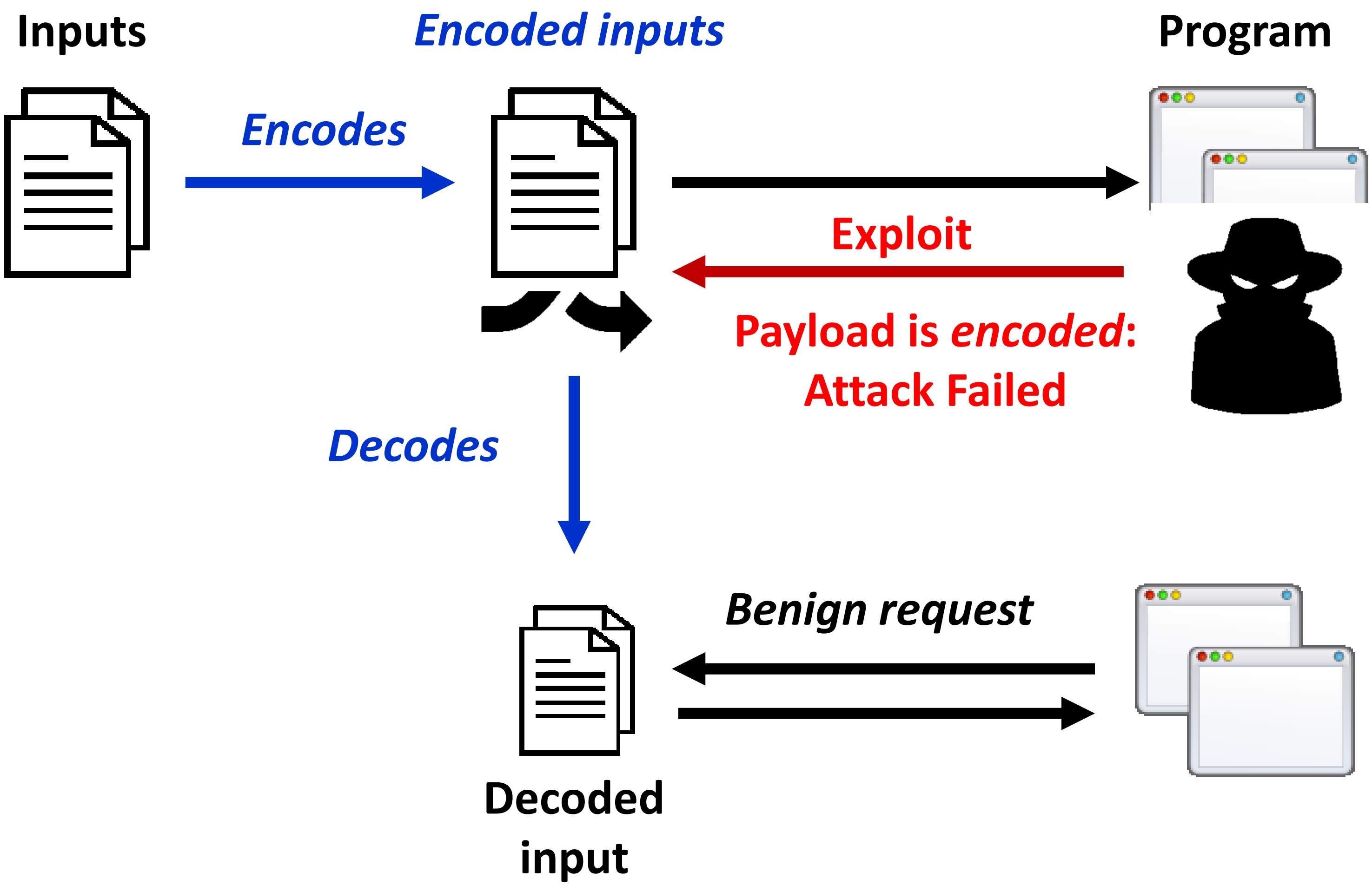
Our Solution: A2C

Benign execution



Our Solution: A2C

Idea



Our Solution: A2C

Why payloads are not decoded?

Decoding based on input processing semantics

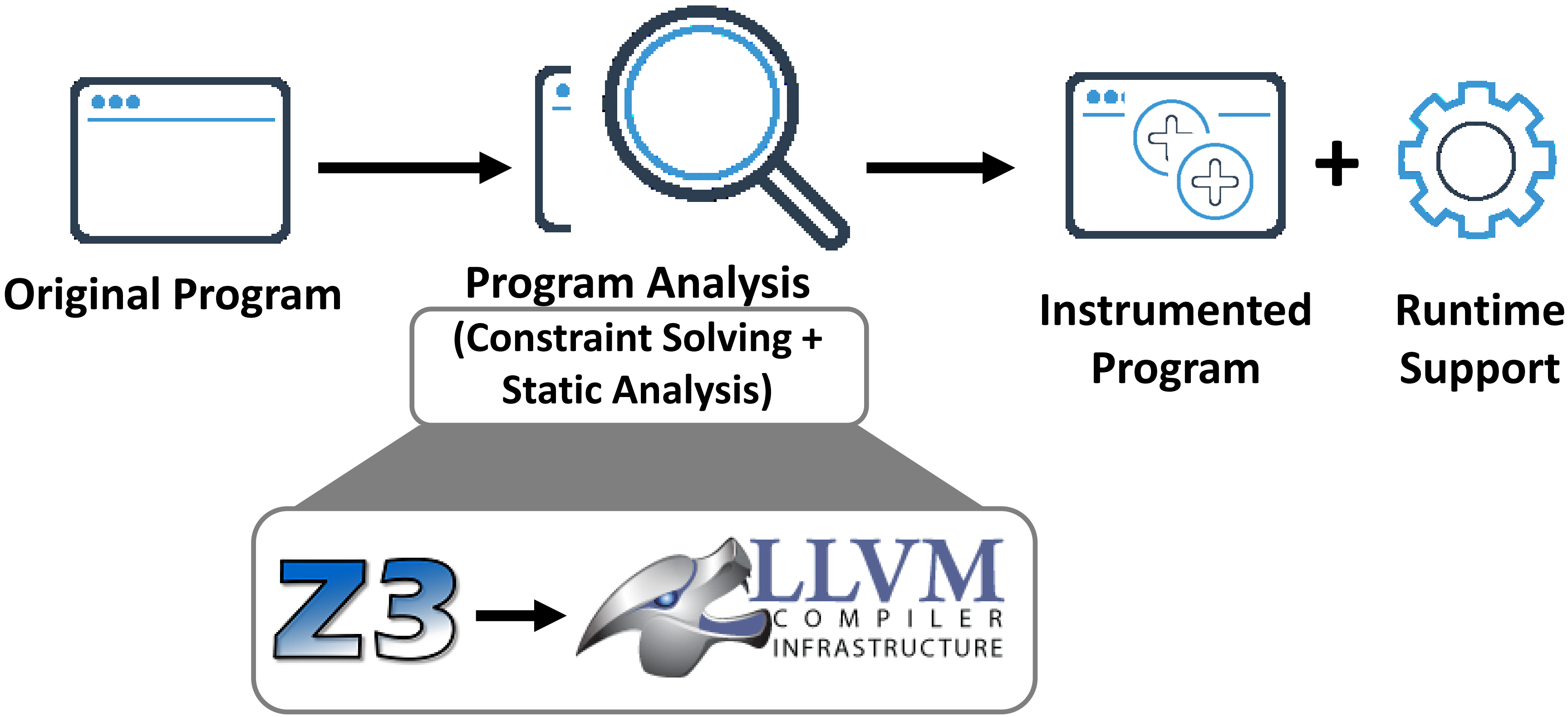
We statically analyze a program and decode when inputs are used *by the program (as intended data)*

Inputs should be *data*, not *code*

A2C allows inputs to be accessed as (intended types of) data, but breaks if they are code (or unintended types of data (e.g., ROP gadgets))

Our Solution: A2C

Overview



Step 1: Program Analysis

When to encode and decode?

When to encode?

Encode incoming inputs from *untrusted sources* at library calls (e.g., recv, read)

When to decode?

Decode when the encoded values are consumed by the *program's input processing logic*

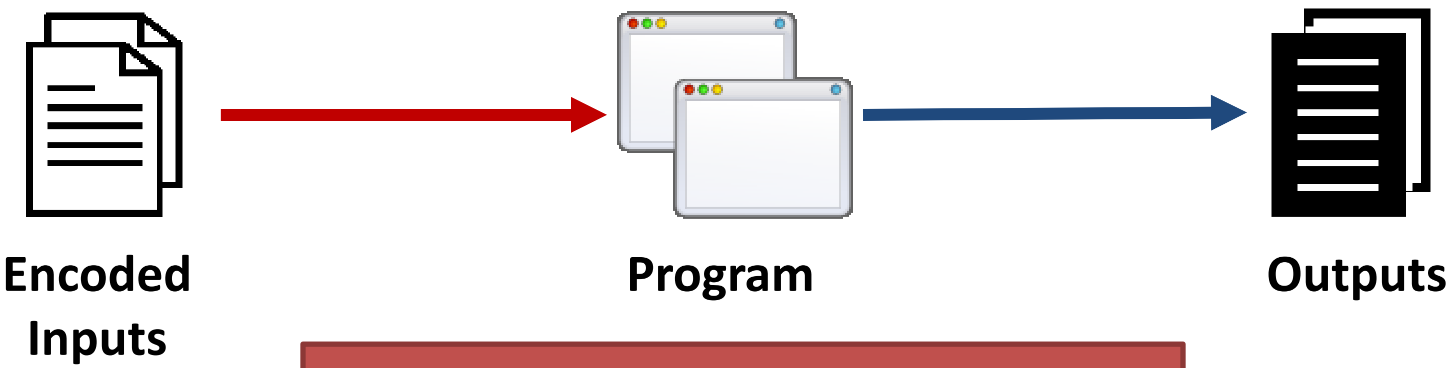
Program Analysis

When to decode?

- Copy
- Read/Compare (Parse)
- Conversion (e.g., Charset conversion)
- Computation

Program Analysis

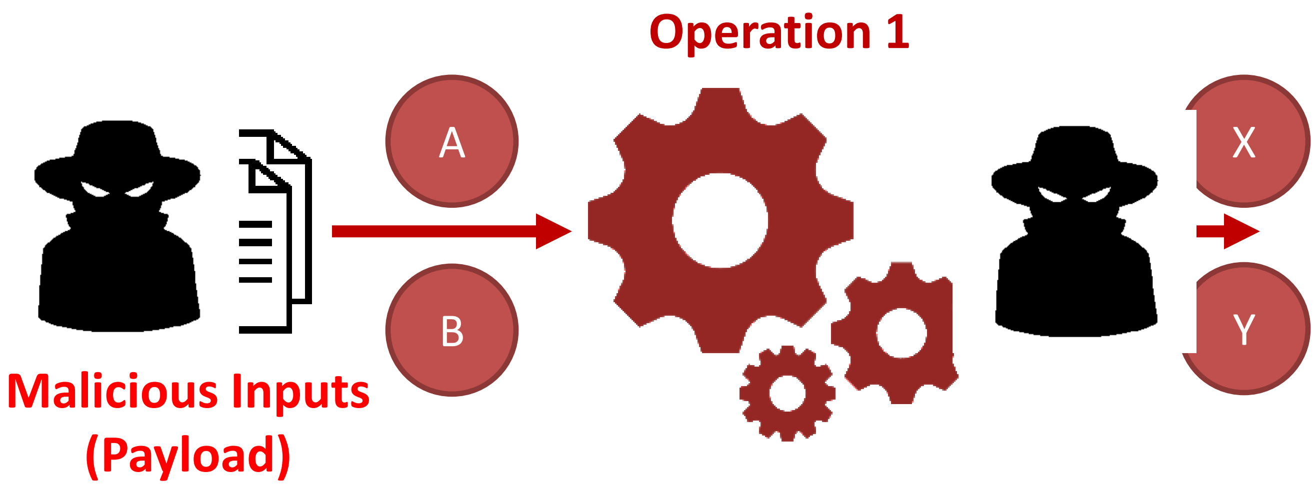
When to decode?



Copy	**No Decode**
Read/Compare (Parse)	**Decode**
Conversion (e.g., Charset conversion)	?
Computation	?

Program Analysis

Can an attacker control results?

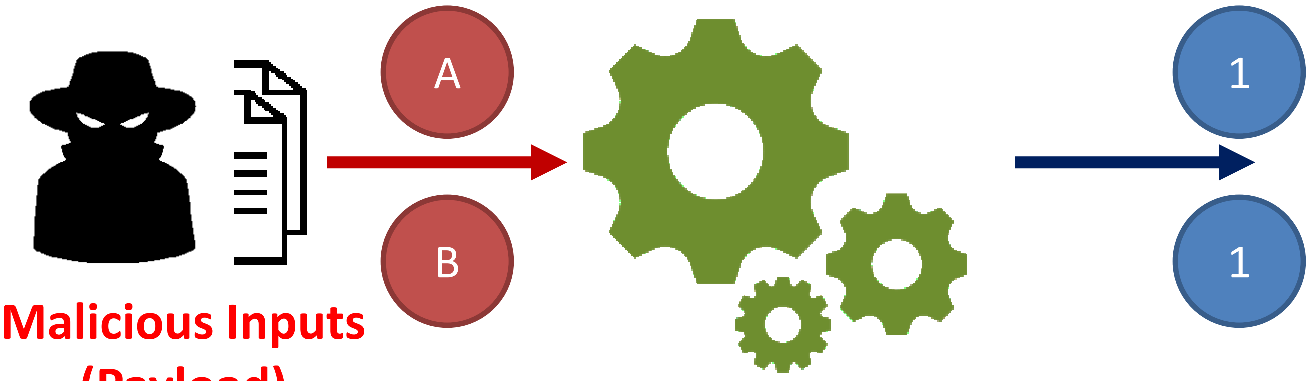


Conversion (e.g., Charset conversion)	?
Computation	?

Program Analysis

Can an attacker control results?

Operation 2



Malicious Inputs
(Payload)

Conversion (e.g., Charset conversion)	?
Computation	?

Program Analysis

Not Sure? Ask Constraint Solver!

```
// Declarations (Data Types)
unsigned int      m7[...][...];
unsigned short    img[...][...];
unsigned short    mpr[...][...];
   ...
// Transformative Operations
for (int x = 0; ...; x++ )
  for (int y = 0; ...; y++ )
    m7[x][y] = img[...][...] - mpr[...][...];
```

Program Analysis

Not Sure? Ask Constraint Solver!

6. **m7**[x][y] = **img**[...][...] - **mpr**[...][...];

; Constraints for Operations (img - mpr)

m7[0,1,2,3] = **img**[0,1,2,3] - **mpr**[0,1,2,3] $\wedge$

; Constraints for the range of unsigned short

0 <= **img**[0,1,2,3] $\wedge$ 0 <= **mpr**[0,1,2,3] $\wedge$

img[0,1,2,3] <= 65535 $\wedge$ **mpr**[0,1,2,3] <= 65535 $\wedge$

; Constraints for Payloads (*n* will select a payload)

m7[0,1,2,3] = **payload**[*n*, *n*+1, *n*+2, *n*+3]

Large Payload Pool (1.4G)

Z3 → LLVM COMPILER INFRASTRUCTURE

Program Analysis

Not Sure? Ask Constraint Solver!

Microsoft Research

z3

Z3 Solver

EXPLOIT DATABASE

ROPgadget tool

metasploit®

shell-storm.org

Ropper tool

Payloads

Program Analysis

Not Sure? Ask Constraint Solver!

Constraint Solver returns ...

SAT: Attackers *can* control

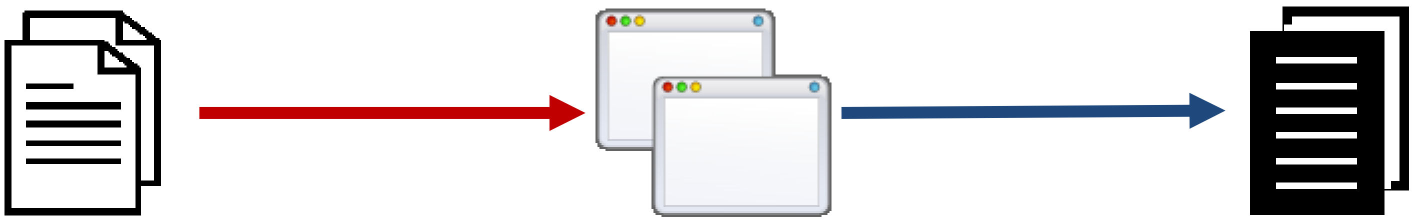
TIMEOUT and UNKNOWN: Don't know → Attackers *might* control!

UNSAT

→ Attackers *cannot* control!

Decoding Frontier

Exploitable and Post-Exploitable Space

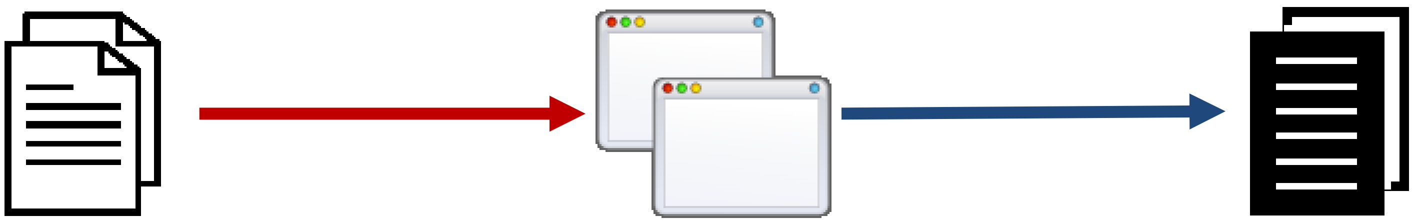


Encoded Inputs — **Program** — **Outputs**

Copy	No Decode
Conversion (e.g., Charset conversion)	No Decode
Simple Computation	No Decode
Read/Compare (Parse)	Decode
Certain Complex Computation	Decode

Decoding Frontier

Exploitable and Post-Exploitable Space



Encoded Inputs — **Program** — **Outputs**

Encoded	***Decoded***
Copy	Read/Compare (Parse)
Conversion (e.g., Charset conversion)	Certain Complex Computation
Simple Computation	

Exploitable Space ← | → **Post-exploitable Space**

Decoding Frontier

Step 2: Instrumentation

When to encode?

- Encode incoming inputs from *untrusted sources* at library calls (e.g., recv, read)

- Encode “*constants*” that can be written to *encoded buffers* (Details in the paper)

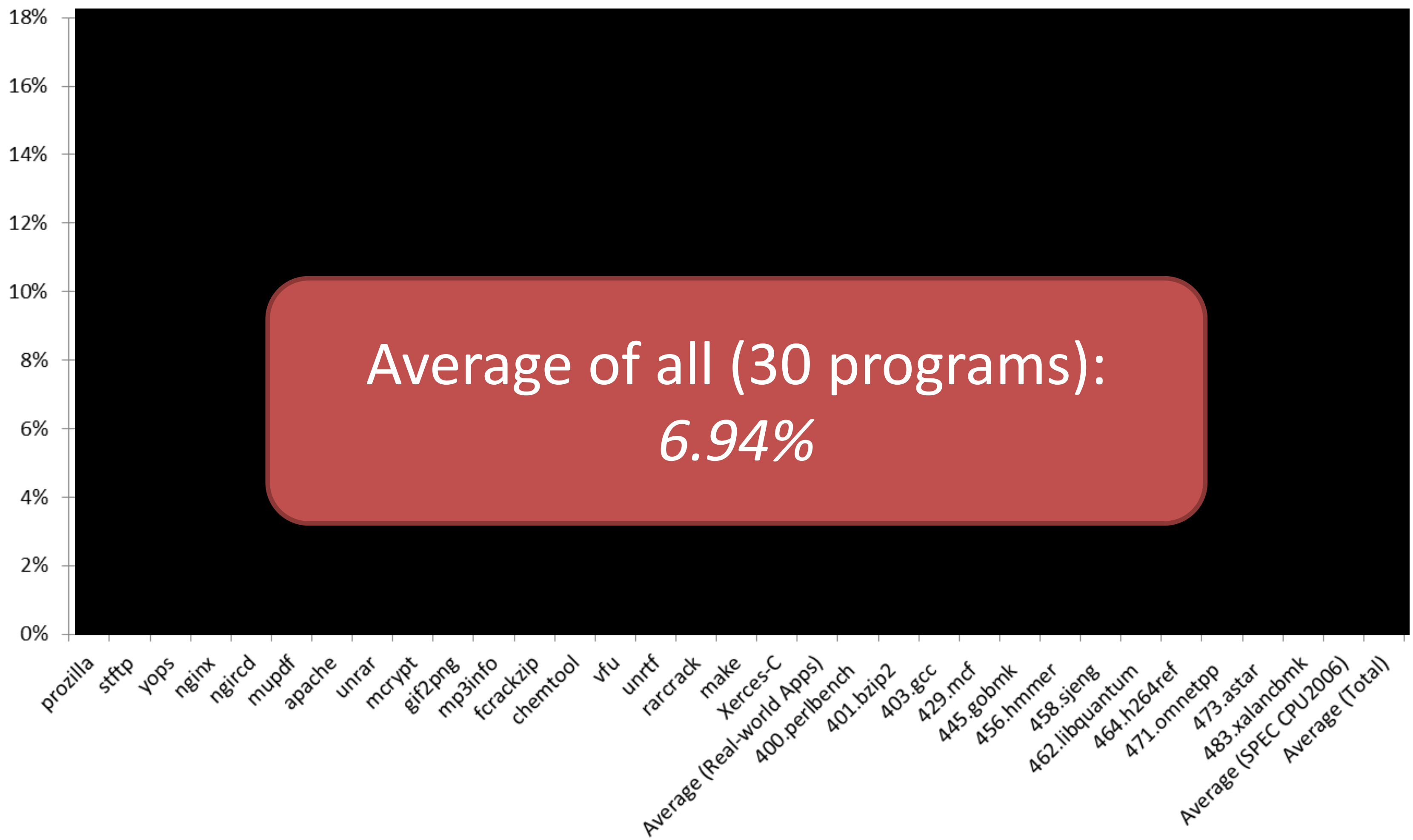
When to decode?

- Decode when encoded values are consumed by the *program’s input processing logic*

- Decode *permanently* at decoding frontier

Evaluation

Performance (18 real world apps + SPEC CPU2006)



Evaluation

Effectiveness

23 different exploits on 18 programs

Tested 100 payloads (50 shellcode/50 ROP) for each program

3.

Mutation will ***break*** malicious payloads execution, and it will break ***early***

0.1

Almost no ROP gadgets were executed.

Discussion

Limitations

Attacks in Post-exploitable Space

We use a large pool of payload test cases that models the distribution of valid payloads to determine the DF with *strong probabilistic guarantees*.

Memory Disclosure

We use a different dictionary (encoding key) for each buffer and each request. Knowing a previous buffer’s dictionary does not help in subsequent attacks.

Related Works

CFI Practical CFI (V. van der Veen et al. in CCS’15, B. Niu et al. in CCS’15, C. Tice et al. in SEC’14, C. Zhang et al. in SP’13, M. Zhang et al. in SEC’13, V. Pappas et al. in SEC’13, Y. Xia et al. in DSN’12, ...), SafeDispatch (D. Jang et al. in NDSS’14), Control Flow Locking (T. Bletsch et al. in ACSAC’11), ...

Malicious Payloads Detection Z. Liang et al. in CCS’05, T. Toth et al. in RAID’02, P. Fogla et al. in SEC’06, M. Polychronakis et al. in RAID’07, K. Snow et al. in SEC’11, ...

Randomizations ASLR (R. Wartell et al. in CCS’12, V. Pappas et al. in SP’12, D. Bigelow et al. in CCS’15, S. Crane et al. in SP’15, J. Hiser et al. in SP’12), ISA (G. Portokalidis et al. in ACSAC’10, G. S. Kc et al. in CCS’03), Data Space Randomization (S. Bhatkar et al. in DIMVA’08) ...

Bound Checkers Address Sanitizer (K. Serebryany et al. in ATC’12), Cling (P. Akritidis et al. in SP’08), StackGuard (C. Cowan et al. in SEC’98), ...

Conclusion

A2C provides a general protection

against a wide spectrum of payload injection attacks

- Malicious Input: program breaks, and *breaks early*
- Benign Input: program executes correctly

Key Idea: encodes inputs, decodes depending on the input processing semantics

A2C prevents payload injection with low overhead

Q&A

Thank you

Yonghwi Kwon
PhD student, Purdue University

Contact: yongkwon@purdue.edu

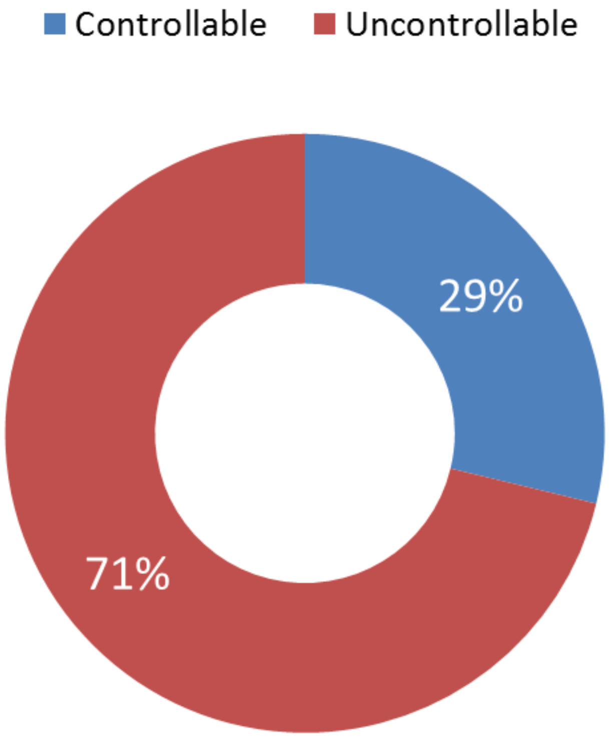
Web: http://yongkwon.info

More Slides

- Backup Slides

Evaluation

Decoding Frontier Computation



More Decoding Frontiers

71% of decoding frontiers turned out they are indeed decoding frontiers.

Exploitable-Space is *Small*

Inputs are quickly parsed and do not usually propagate deeply into a program. Exploitable-space is not huge which is a key reason of our low overhead.

Case Study

Preventing ROP Attacks

```
void process_font_table (...) {
  ...
  char name[255];
  ...
  while (w2) {
   tmp = word_string(w2);
   if ( tmp && DEC( tmp[0] ) != '\\' )
    strcat( name, tmp );
   ...
```

ROP Gadget	Instruction
0x804d820	mov ebx,0x0 ret
0x804ec7d	mov eax,0x806275c ret
...	...

XOR 0xAA

ROP Gadget	Instruction
0xa2ae728a	Invalid address
0xa2ae46d7	Invalid address
...	...

Decoding/Encoding Sets

Static Analysis

Encoding Set: When to encode?

Encode Incoming Untrusted Sources at Library Calls (e.g., recv, read)

Decoding Set: When to decode?

Decode when encoded values are used

- *Decode **permanently** at **decoding frontier***

Finding Decoding/Encoding Sets

Flow-, Context-, Field-sensitive Static Analysis

Decoding/Encoding Sets

Instrumentation

```
recv(..., untrusted_buf, ...); ENC( untrusted_buf );
...
if ( DEC( untrusted_buf[0] ) == 'C' ) {
    ...
}
...
int ret = memcmp( DEC( untrusted_buf ), ... );
```

Z3 → LLVM COMPILER INFRASTRUCTURE

Decoding/Encoding Sets

Instrumentation

Decoding is *not* simple

```
recv(..., untrusted_buf, ...); ENC( untrusted_buf );
...
if ( DEC( untrusted_buf[0] ) == 'C' ) {
    memcpy( untrusted_buf, "CONSTANT", ... );
}
...
int ret = memcmp( DEC( untrusted_buf ), ... );
```

untrusted_buf can be from 'recv' and 'constant'

Decoding/Encoding Sets

Instrumentation

Decoding ***untrusted_buf*** will break when it holds "CONSTANT"

Not Decoding ***untrusted_buf*** will break when its value is from ***recv***

Decoding/Encoding Sets

Instrumentation

We also encode ***"CONSTANT"***

Now, decoding ***untrusted_buf*** will not break in any context.

Decoding/Encoding Sets

Instrumentation

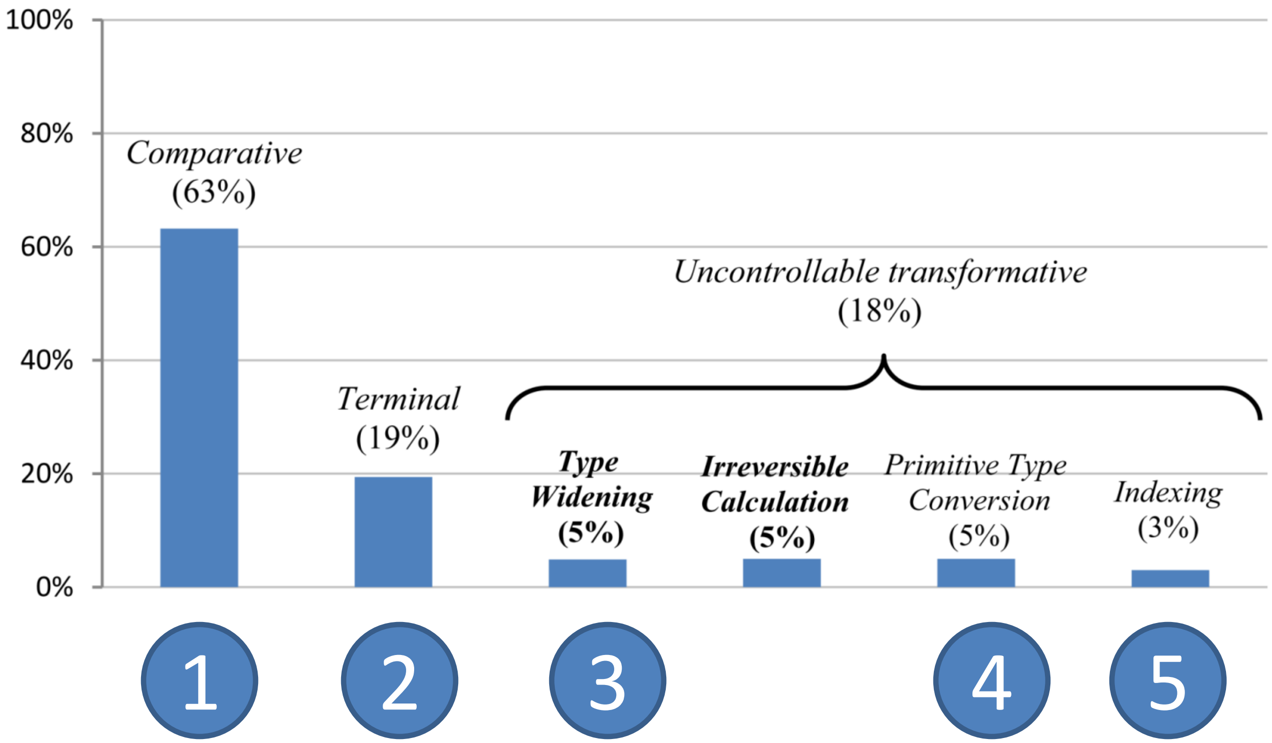
Decoding is *not* simple

```
recv(..., untrusted_buf, ...); ENC( untrusted_buf );
...
if ( DEC( untrusted_buf[0] ) == 'C' ) {
  memcpy( untrusted_buf, ENC("CONSTANT"), ... );
}
...
int ret = memcmp( DEC( untrusted_buf ), ... );
```

untrusted_buf is always encoded in any context

Evaluation

Different Types of Decoding Frontiers



1. Comparative:

x == y

2. Terminal:

send(**x**)

3. Type widening:

int y = (char)**x**;

4. Primitive Type Conversion:

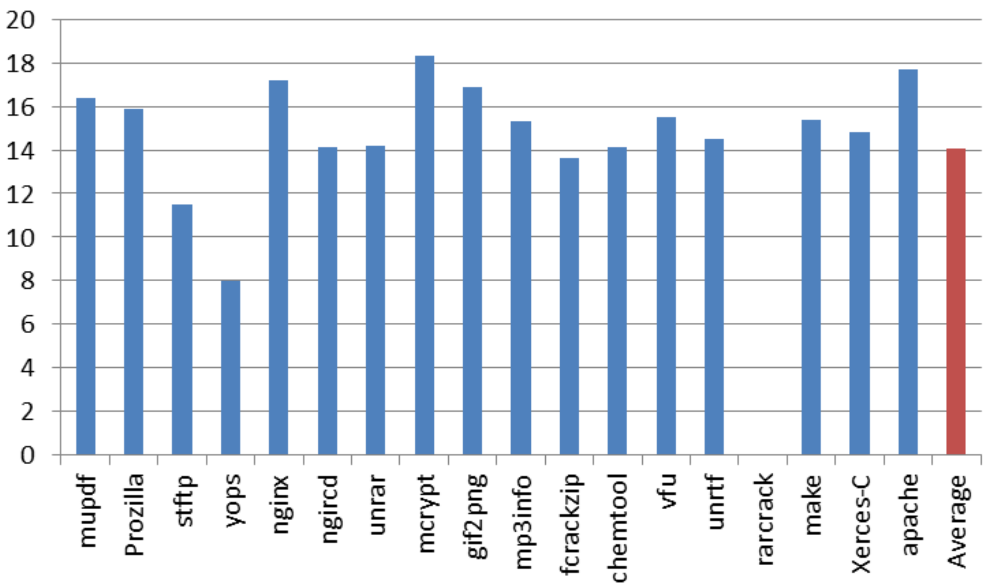
float v = atof(**x**);

5. Indexing:

y = array[**x**];

Evaluation

Decoding Frontier Computation



14 = Avg. Constraints

We mostly find that # of constraints for decoding frontier computation is not very large (10-20). This makes the fast computation possible.