P2C:

Understanding Output Data Files via On-the-Fly Transformation from Producer to Consumer Execution

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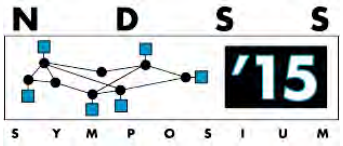


Motivation

- ***Understanding unknown data files and network messages is a prominent security challenge***

Downloads and Installs
few freeware programs

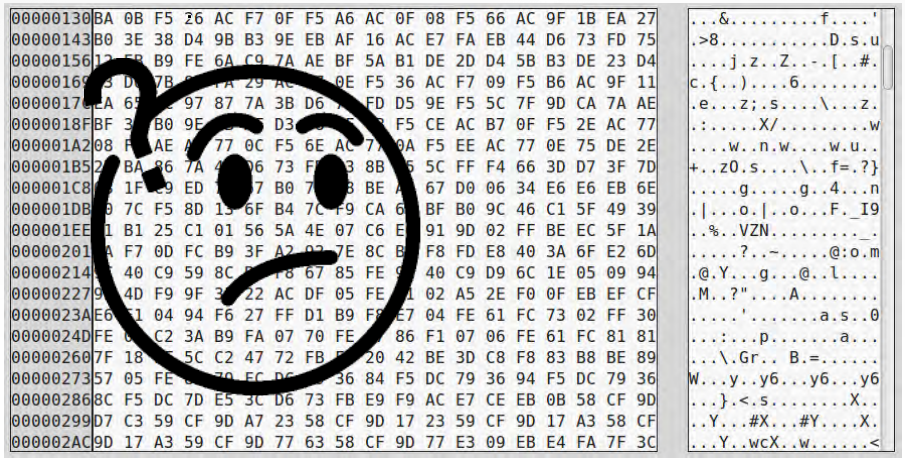
Weeks later

Found mysterious
binary files

Motivation

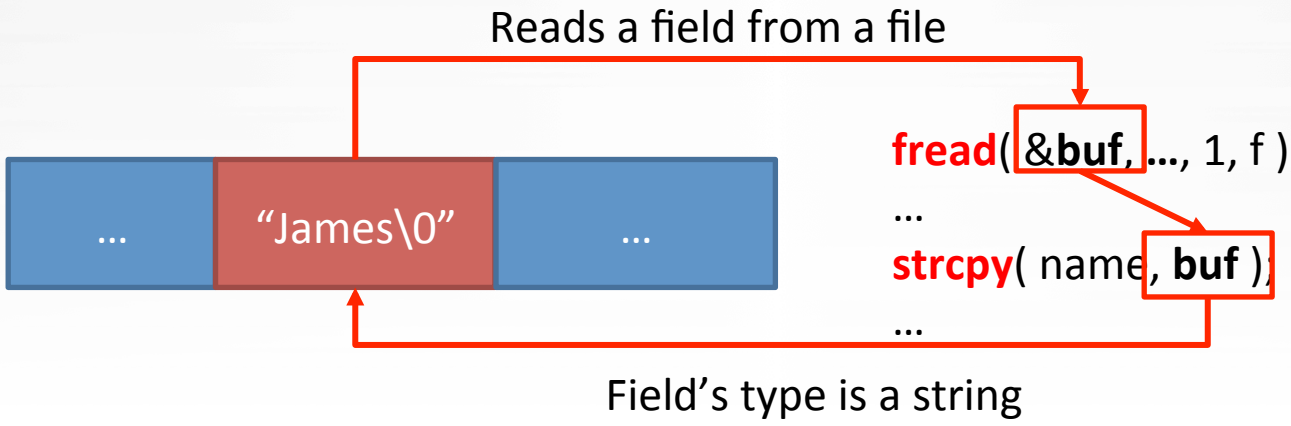
- ***Without audit logging/monitoring systems***
  - Who created the files?
  - Do they contain private data?
    - Personal profile
    - Contact list
    - Key-strokes

Found mysterious binary files



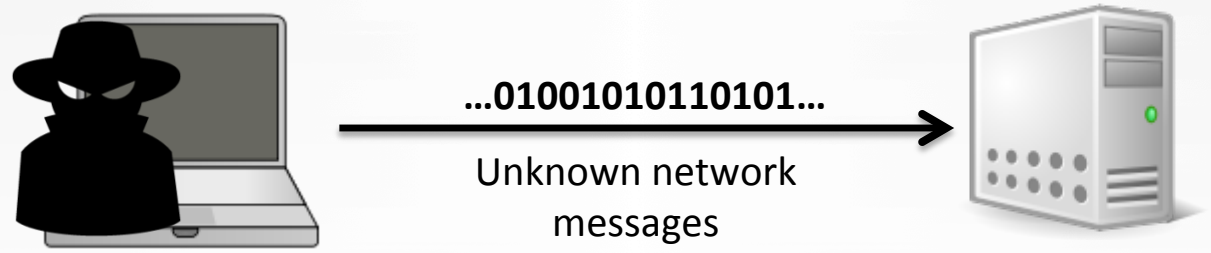
Motivation

- ***Existing solutions require consumer programs***
  - Input format reverse engineering based on consumers
    - Prospex, Tupni, REWARDS, Dispatcher, Reformat, …
  - Monitoring the execution of consumer to analyze how the files/messages are parsed



Motivation

- ***What if we only have the producer program?***
  - Botnet Command and Control (C&C) protocol
    - No consumer is present on the victim machine
    - Consumer exists on the attacker's server



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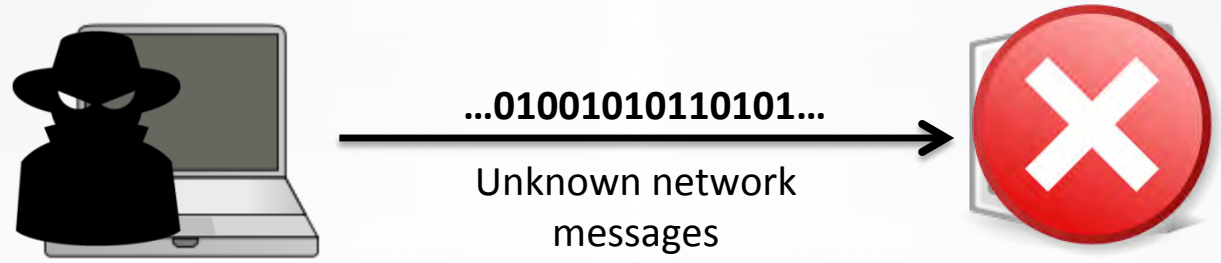

Observation

- Producer and consumer are **symmetric**
  - **"Checking Conformance of a Producer and a Consumer"**, Evan Driscoll, Amanda Burton, and Thomas Reps, FSE'11
  - The **correctness of a producer** can be verified by checking its conformance to the **corresponding consumer**

Observation

- Producer and consumer are **symmetric**
  - Consumer and Producer follow the same rule
  - ((boolean, double, boolean) | (boolean))*

Producer

```
1 sendReading(Sensor* device, int prev)
2 if device→setting == prev then
3    writeBool(false);
4 else
5    writeBool(true);
6    writeDouble(device→setting);
7    writeBool(device→valid);
```

Consumer

```
1 updateReading(int* setting, bool* valid)
2    *setting = readDouble();
3    *valid = readBool();
4 main()
5    int setting;
6    bool valid;
7    while ... do
8    if readBool() then
9       updateReading (&setting, &valid);
10   ... // do something with current readings
```

Observation

- Producer and consumer are **symmetric**
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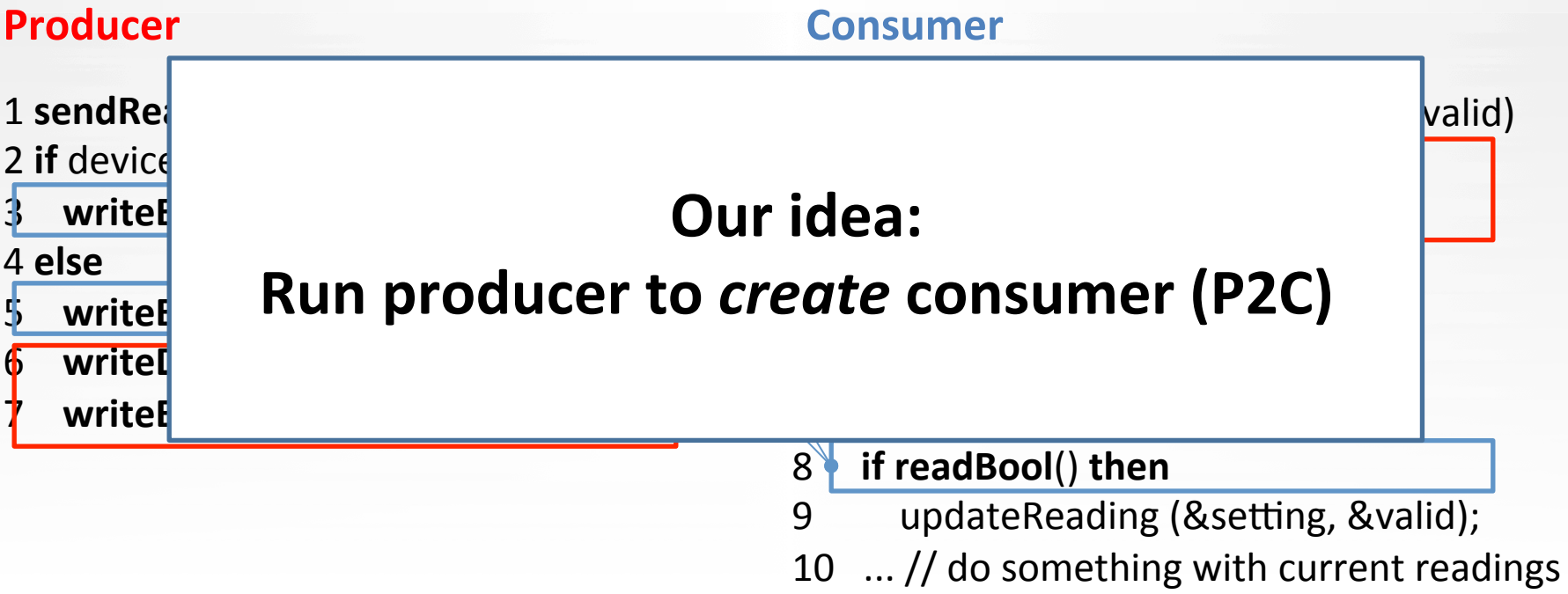
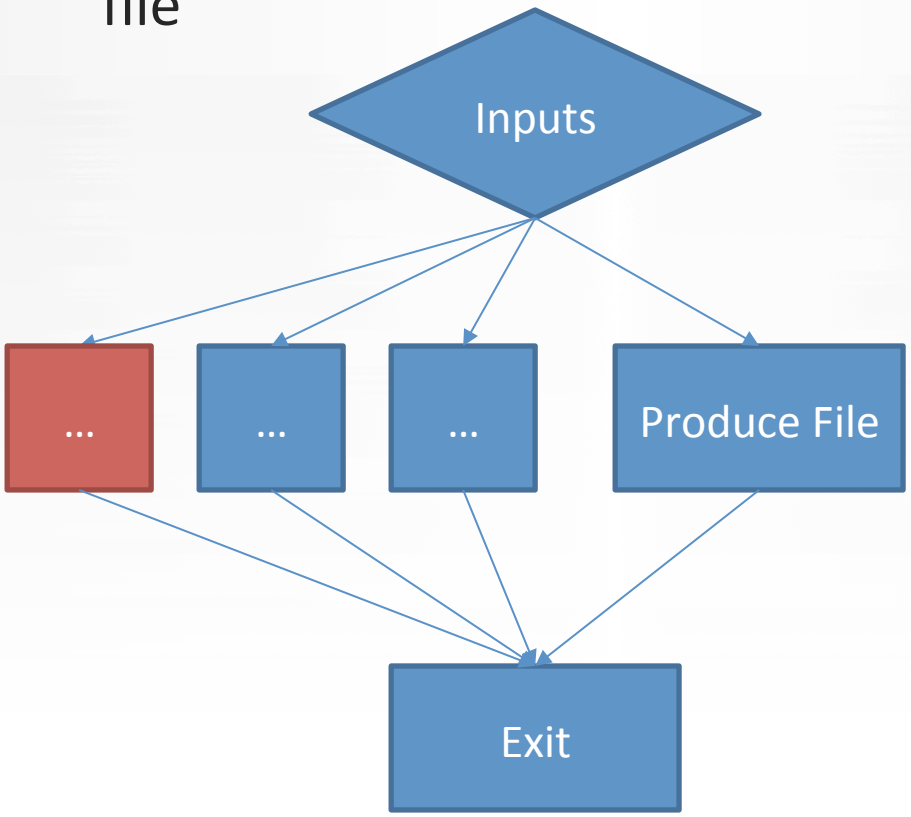


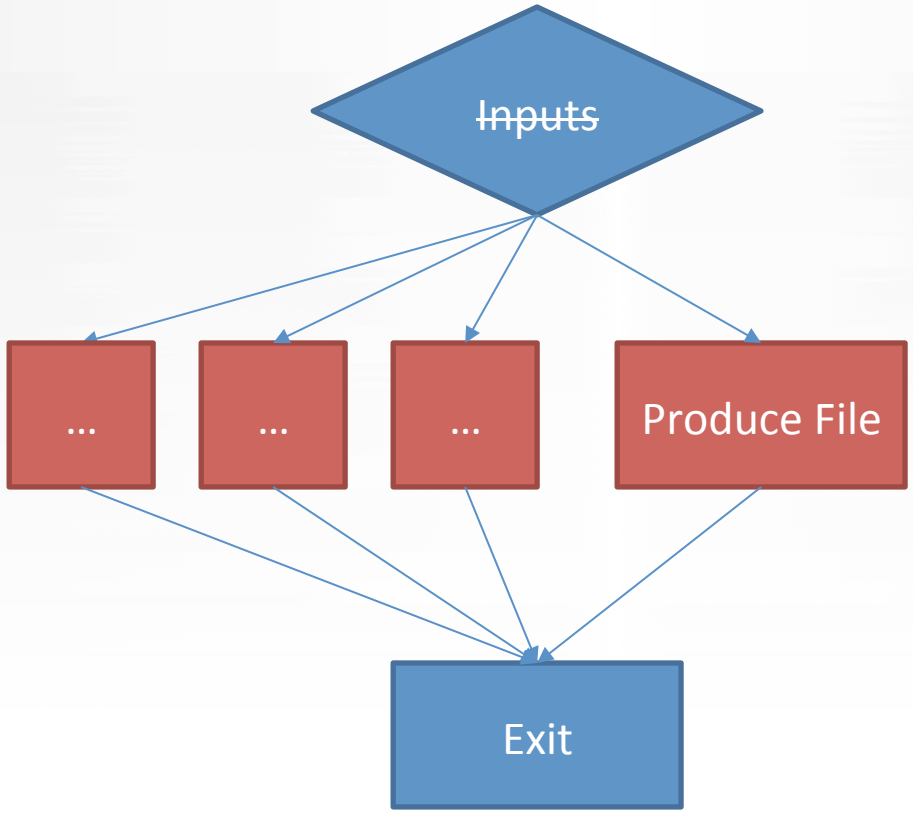
Forced execution

- Executing producer w/o proper inputs
  - May do different tasks and quit, without creating a file



Forced execution

- Our earlier tool comes to the rescue
  - Our forced execution engine: X-force



- Generating random inputs
- Recovering from faults

Overview

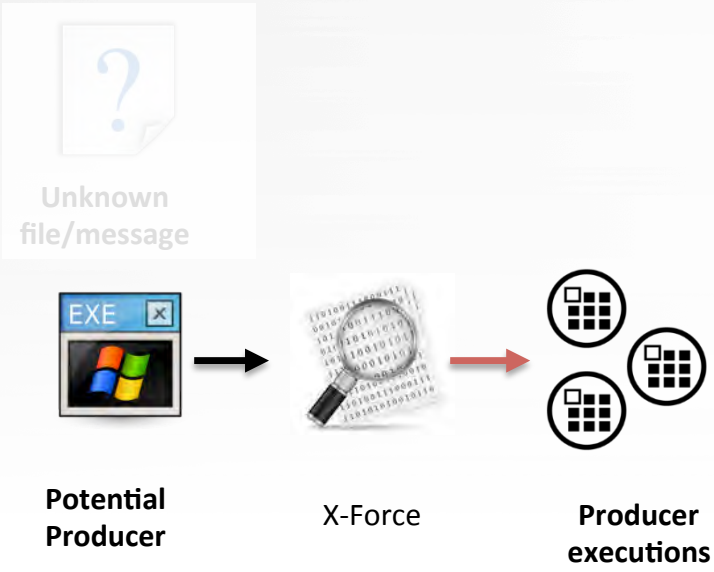
- Basic idea
  - Given an **unknown file/message** and a **potential producer**

Unknown file/message

Potential Producer

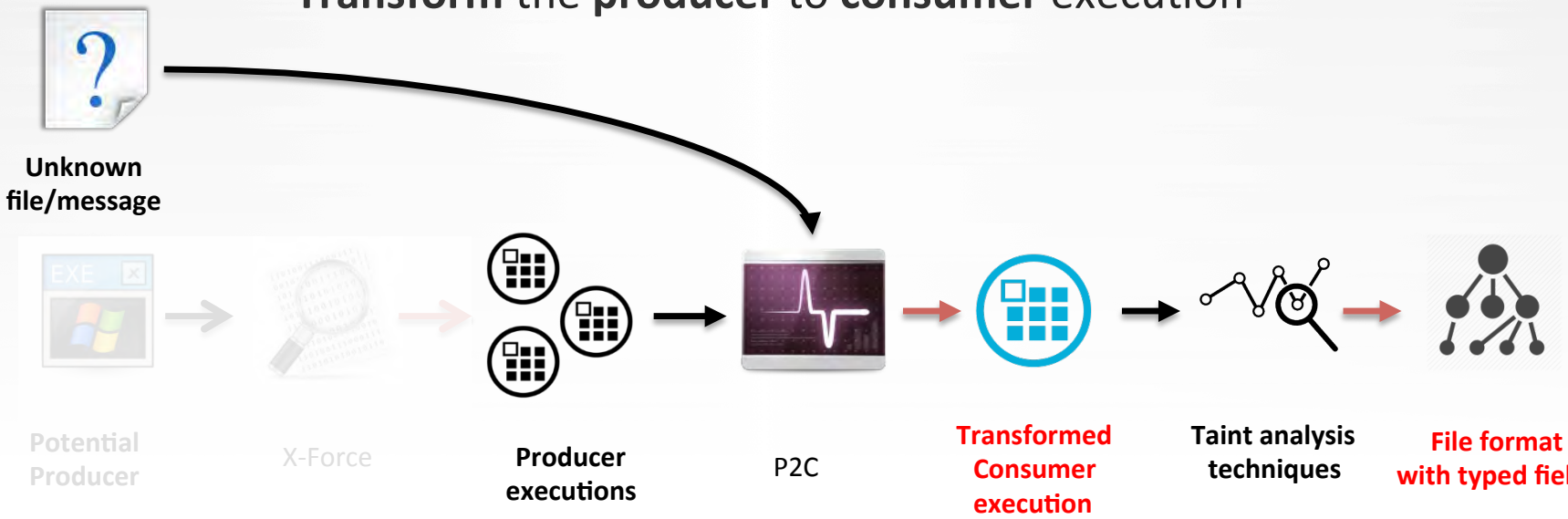
Overview

- Basic idea
  - Given an **unknown file/message** and a **potential producer**
  - Explore execution paths that contain “file open-for-write” operations (Producer executions)
    - Leveraging a binary forced execution technique (X-force)



Overview

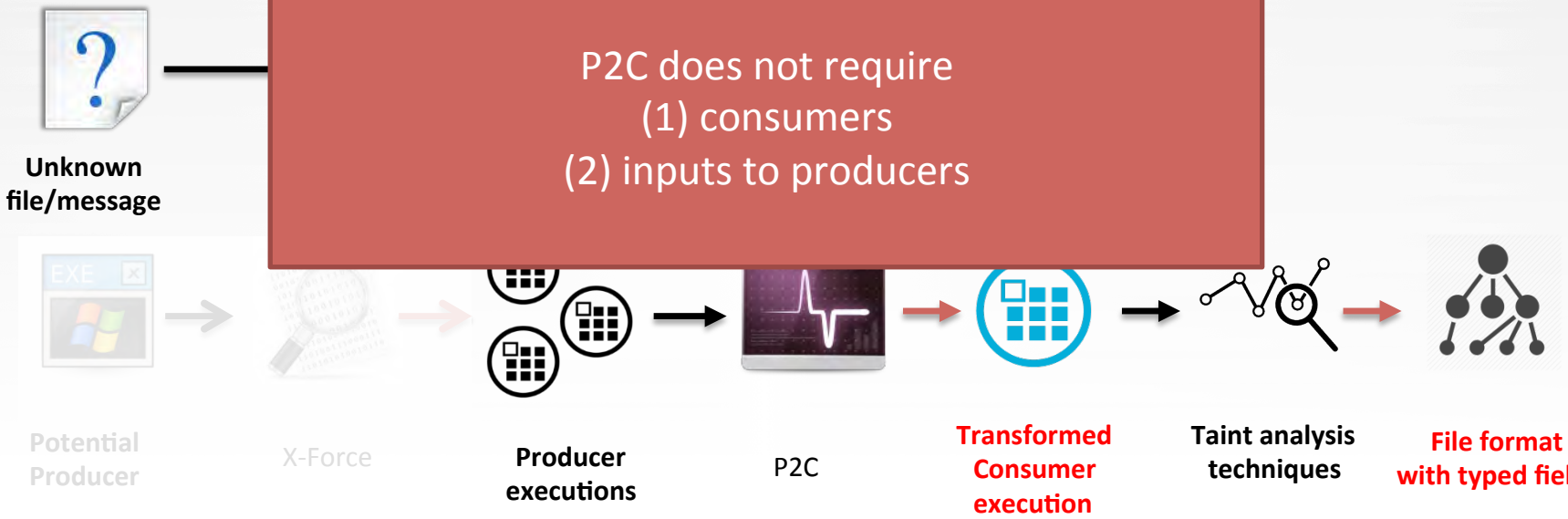
- Basic idea
  - Given an **unknown file/message** and a **potential producer**
  - Explore execution paths that contain "file open-for-write" operations (Producer executions)
    - Leveraging a binary forced execution technique (X-force)
  - **Transform** the **producer** to **consumer** execution



Overview

- Basic idea
  - Given an **unknown file/message** and a **potential producer**
  - Explore execution paths that contain "file open-for-write" operations (Producer executions)
  - -force)
  - P2C directly works on potential producer programs

    P2C does not require
    (1) consumers
    (2) inputs to producers

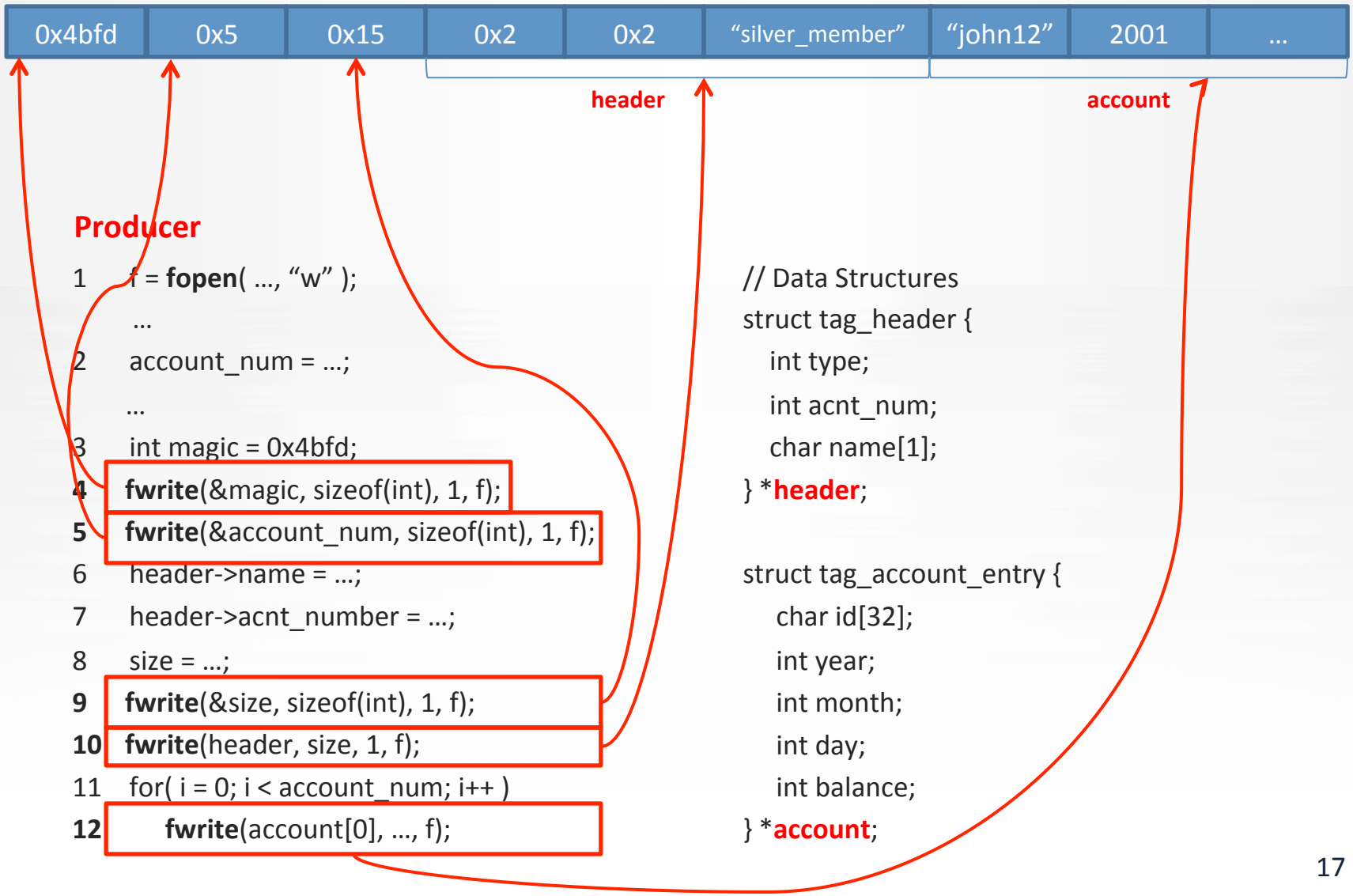


An unknown binary file

0x4bfd	0x5	0x15	0x2	0x2	“silver_member”	“john12”	2001	…

How it is generated?

- **Unknown file**



Producer w/o proper inputs (X-force)

- ~~Unknown file~~

Producer

```
1    f = fopen( …, “w
     …
2    account_num = …; // 2
     …
3    int magic = 0x4bfd
4    fwrite(&magic, siz
5    fwrite(&account_n
6    header->name = …; // “#  ”
7    header->acnt_number = …;  // 2
8    size = …;
9    fwrite(&size, sizeof(int), 1, f);
10   fwrite(header, size, 1, f);
11   for( i = 0; i < account_num; i++ )
12       fwrite(account[0], …, f);
```

Randomly generated

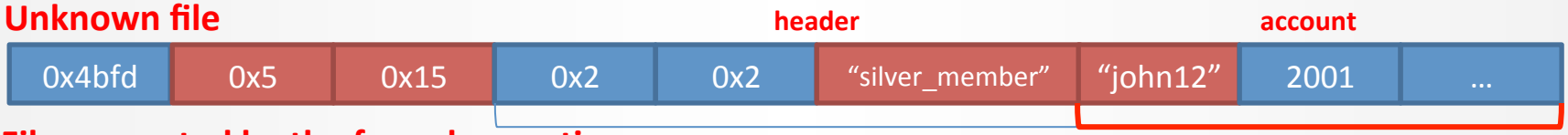
Randomly generated

```
// Data Structures
struct tag_header {
   int type;
   int acnt_num;
   char name[1];
} *header;

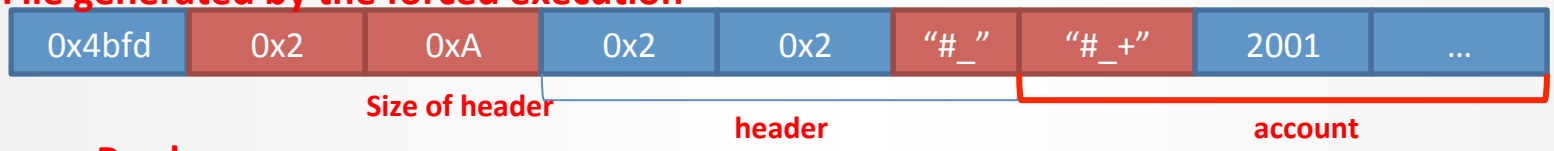
struct tag_account_entry {
    char id[32];
    int year;
    int month;
    int day;
    int balance;
} *account;
```

Producer w/o proper inputs (X-force)

- **Unknown file**



- **File generated by the forced execution**



Producer

```
1    f = fopen( …, “w” );
     …
2    account_num = …; // 2
     …
3    int magic = 0x4bfd;
4    fwrite(&magic, sizeof(int), 1, f);
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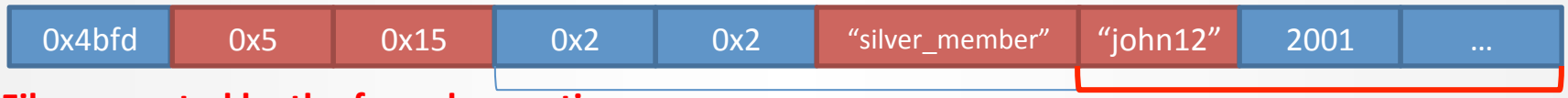

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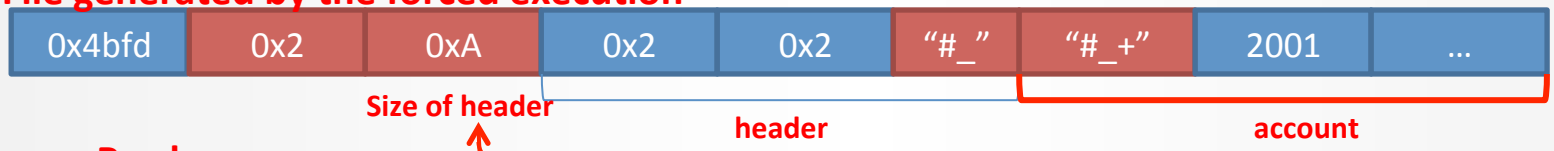

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Producer w/o proper inputs (X-force)

- **Unknown file**

- **File generated by the forced execution**

Size of header

header

account

Producer

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1    f = fopen( …, “w” );
     …
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     …
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Transforming a producer to a consumer

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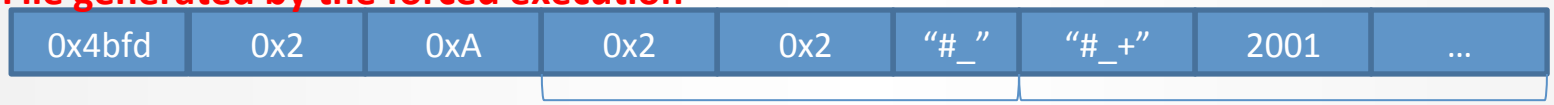

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Consumer

```
1   f = fopen( …, “r” );
    …
2   account_num = …; // 2
    …
3   int magic = 0x4bfd;
4   fread(&magic, sizeof(int), 1, f);
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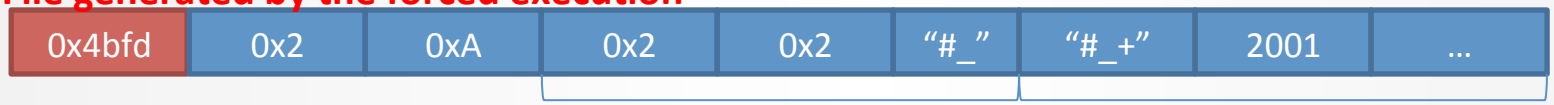

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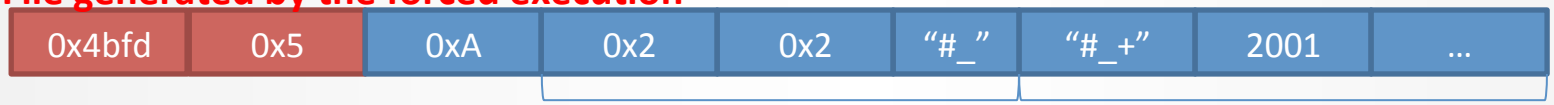

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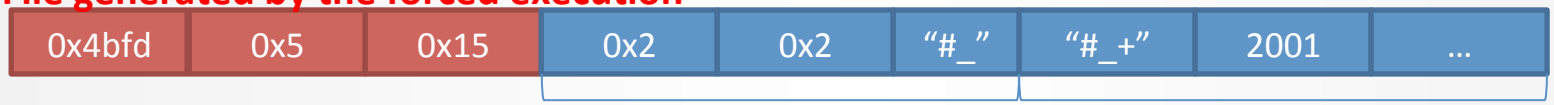

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```
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Technical Challenges

- ***Unexposed field correlations***
  - *Symmetric read operations do not help*
  - *Semantically related read operations do not have explicit dependence*

Producer

```
1  f = fopen( … );
2  …
3  len = strlen(buf);
4  …
5  fwrite(&len, sizeof(int), 1, f);
6  fwrite(buf, strlen(buf), 1, f);
```

Consumer

```
1  f = fopen( … );
2  …
3  len = strlen(buf);
4  …
5  fread(&len, sizeof(int), 1, f); // (1)
6  fread(buf, strlen(buf), 1, f); // (2)
7  // no dependence path between (1) and (2)
```

Technical Challenges

- ***Unexposed field correlations***
  - *Original Definition Tracking*
    - *Change the original definition of variables*
  - *Patching and Tracing*
    - *Iteratively run the program for consistency checking*
    - *Inconsistency indicates the presence of unexposed field correlations*
    - *Try a different value*
      (e.g. try to read more bytes)

Evaluation

- ***5 programs generate files / 4 programs generate network messages***

Program	Program Size	Unknown file size	# of iteration (Matched / Unmatched)	# of typed fields/ # of fields	Elapsed Time	Coverage / # of total inst.	# of paths explored
InfoZip	37KB	5KB	12 / 0	19 / 35	2m 45s	6015/6015	385
Steganography	17KB	4219KB	24 / 0	3 / 3	9m 27s	631/974	12
FreePiano	2296KB	6KB	12 / 0	6 / 6	28m 35s	47991/286571	2531
Mp3gain	109KB	1304KB	17 / 0	6 / 10	24m 42s	21672/21672	754
Yamdi	225KB	102KB	38 / 0	34 / 72	1h 16m 38s	21491/24577	1183
Zbot	26KB	30Bytes	7 / 2	5 / 7	8m 48s	3089/3089	199
Winping	244KB	45Bytes	5 / 0	4 / 8	2m 27s	14758/29620	983
PowerOn	25KB	102Bytes	1 / 0	2 / 2	2s	709/1058	29
NetworkMorris	1049KB	52Bytes	20 / 4	15 / 39	8m 6s	3057/7814	186

5 programs generate **files**

4 programs generate **network messages**

Evaluation

- ***Matched: When the file is correctly parsed***
- ***Unmatched: When it fails to parse the file***

Program	Program Size	Unknown file size	# of iteration (Matched / Unmatched)	# of typed fields/ # of fields	Elapsed Time	Coverage / # of total inst.	# of paths explored
InfoZip	37KB	5KB	12 / 0	19 / 35	2m 45s	6015/6015	385
Steganography	17KB	4219KB	24 / 0	3 / 3	9m 27s	631/974	12
FreePiano	2296KB	6KB	42 / 0	6 / 6	28m 35s	47991/286571	2531
Mp3gain	109KB	1304KB	17 / 0	6 / 10	24m 42s	21672/21672	754
Yamdi	225KB	102KB	38 / 0	34 / 72	1h 16m 38s	21491/24577	1183
Zbot	26KB	30Bytes	7 / 2	5 / 7	8m 48s	3089/3089	199
Winping	244KB	45Bytes	5 / 0	4 / 8	2m 27s	14758/29620	983
PowerOn	25KB	102Bytes	1 / 0	2 / 2	21s	709/1058	29
NetworkMorris	1049KB	52Bytes	20 / 4	15 / 39	8m 6s	3057/7814	186

Evaluation

- ***# of typed fields / total # of fields***

Program	Program Size	Unknown file size	# of iteration (Matched / Unmatched)	# of typed fields/ # of fields	Elapsed Time	Coverage / # of total inst.	# of paths explored
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Evaluation

- ***Elapsed time(P2C alone): 21s ~ 1h 16m***

Program	Program Size	Unknown file size	# of iteration (Matched / Unmatched)	# of typed fields/ # of fields	Elapsed Time	Coverage / # of total inst.	# of paths explored
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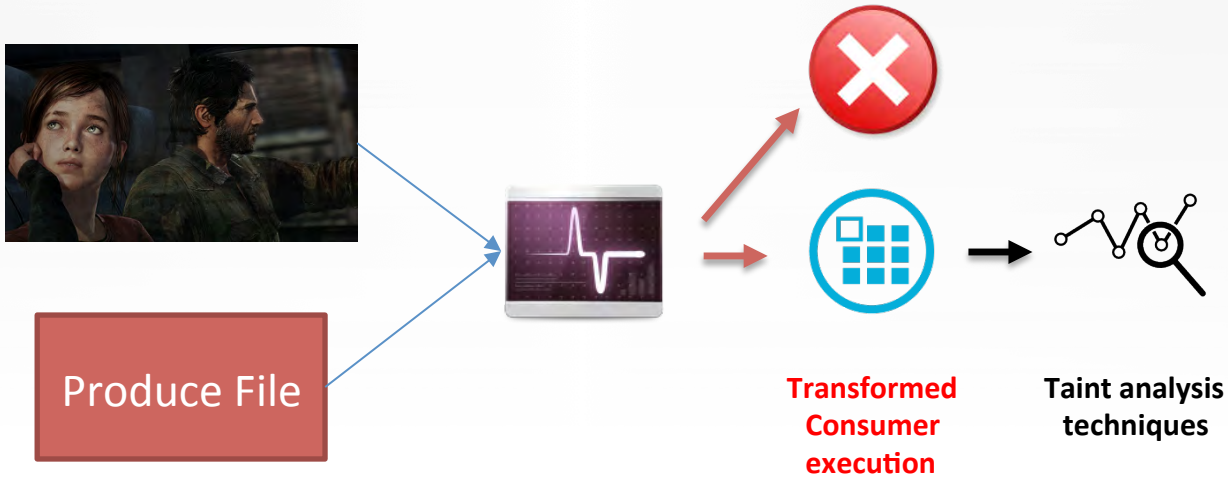
Case study

- ***Steganography***
  - Embeds a secret text by changing the LSB(Least Significant Bit)s

Is there a hidden message or not?

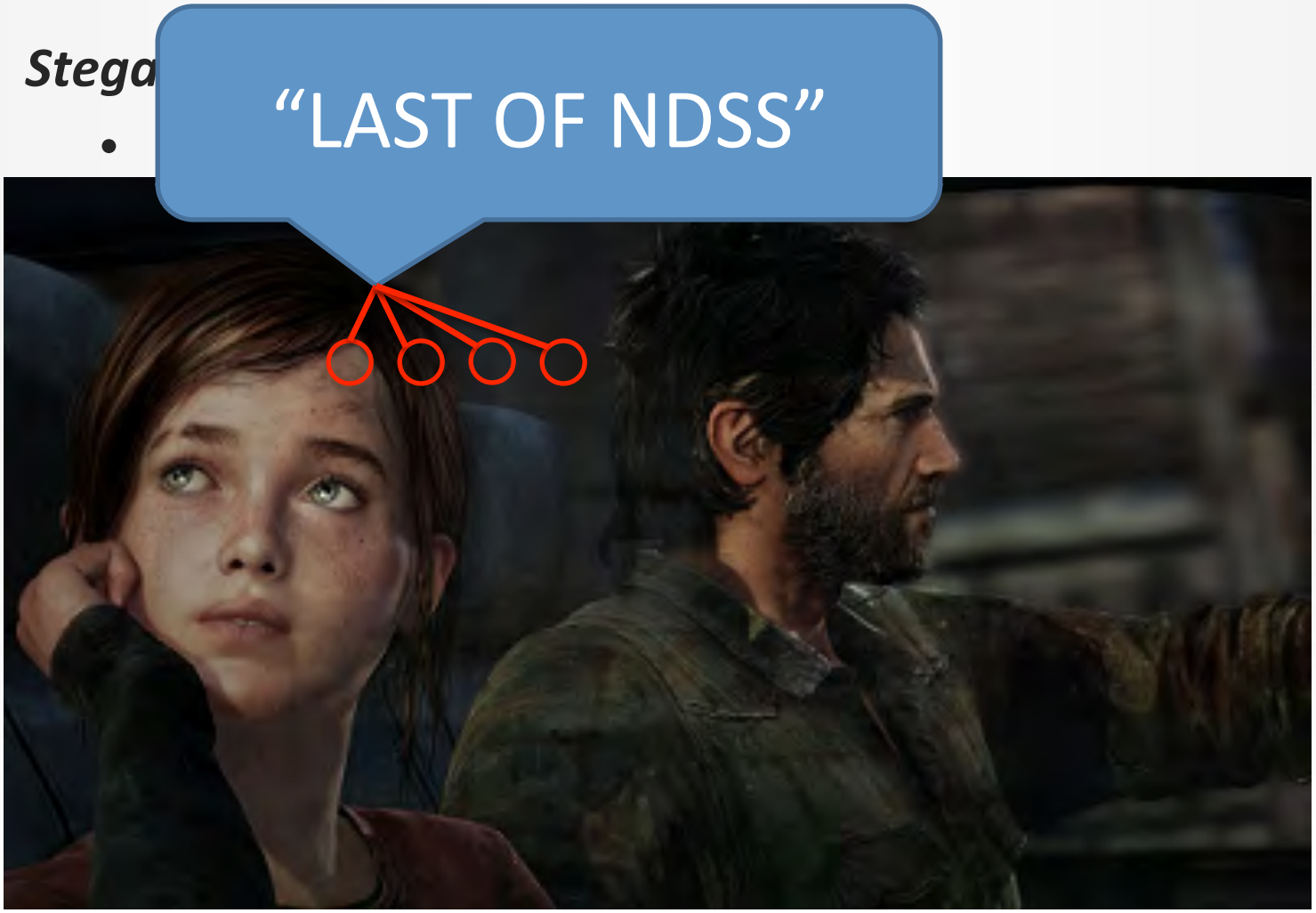
Evaluation

- ***Steganography***
  - Apply P2C to transform producer to consumer
  - Use existing taint analysis techniques to understand the secret message format



Case study

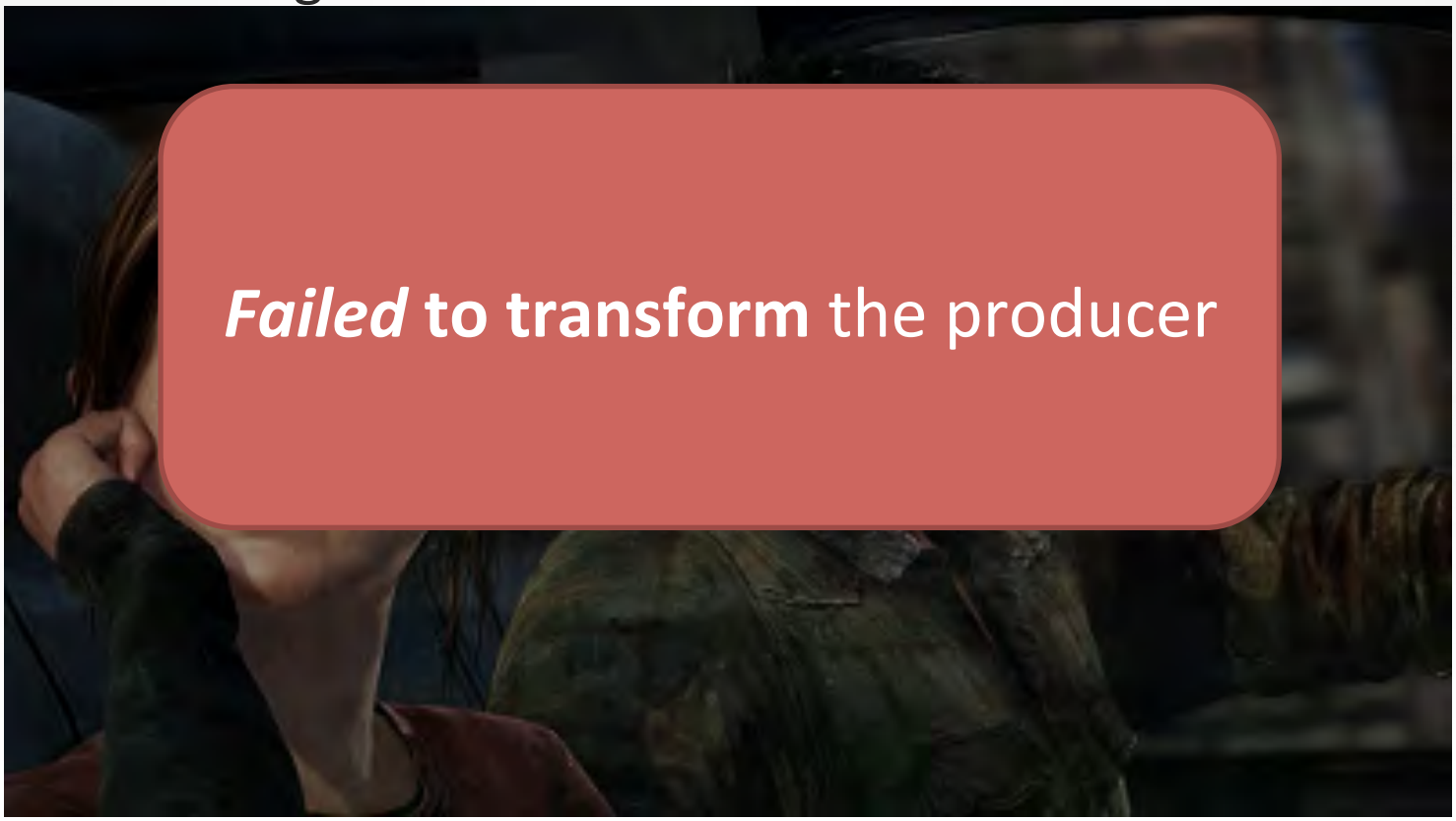
- ***Stega***
  -



Is there a hidden message or not?

Case study

- ***Steganography***
  - Benign



Is there a hidden message or not?

Evaluation

- ***Observations***
  - *# of iterations to find the correct transformation is not large*
    - *In most cases, program dependences are exposed.*
  - *Can precisely identify all the fields in the given files/ message*
    - *Yamdi: Floating Point*
    - *NetworkMorris/WinPing/InfoZip: fields are not related to any standard API*
  - *Transformed consumer execution recognizes more fields than some typical consumers (mp3tag)*

Conclusion

- *P2C: an output format reverse-engineering tool*
  - *Understand the structure and meaning of unknown file/message*
  - *Based only on producer, without consumer*
- *Key Idea*
  - *Transforming a producer execution to the ideal consumer execution*
- *Key Features*
  - *Highly accurate*
  - *No need to know exact producer*
  - *No need to know how to run it*

Question?

Thank you!

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