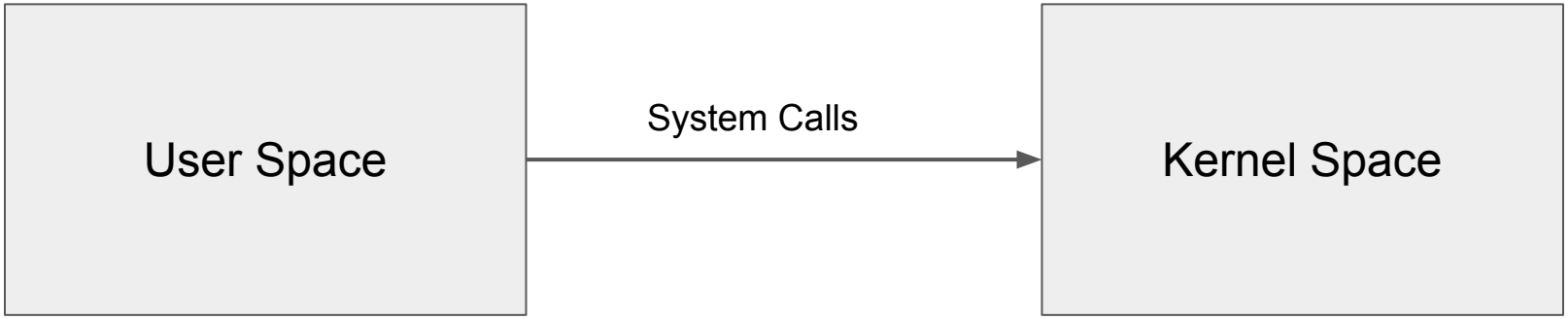
Fuzzing Kernel Drivers with Interface Awareness

By Jake Corina and Chris Salls

Linux Kernel

- Generally:



- Kernel takes care of many things (process management, memory management, filesystems, **device control**, etc).
- Device handling is done in the kernel.

Device Drivers

- Generally implemented as kernel modules
- There must be an interface exported to userland
- Same as standard interface
- How is this done?
- “Everything is a file”
- Special *device files* on disk

Operations on Files

- Let’s look at how it’s done for a “normal” file.
- Common syscalls: open, read, write, lseek, etc.
- file_operations structure -- “fops”, “f_ops”

```
const struct file_operations ext4_file_operations = {
    .llseek     = ext4_llseek,
    .read       = new_sync_read,
    .write      = new_sync_write,
    .read_iter  = generic_file_read_iter,
    .write_iter = ext4_file_write_iter,
    .unlocked_ioctl = ext4_ioctl,
    .mmap       = ext4_file_mmap,
    .open       = ext4_file_open,
    .release    = ext4_release_file,
};
```

Device Files

- As we said, device drivers generally create special files on disk to represent the physical device (for which they drive).
- How is this done?
- What’s the process, from device registration, to having a file to talk to?

```
static inline MINT32 ISP_RegCharDev(void)
{
        MINT32 Ret = 0;
        /*      */
        LOG_DBG("- E.");
        /*      */
        Ret = alloc_chrdev_region(&IspDevNo, 0, 1, ISP_DEV_NAME);
        if (Ret < 0) {
                LOG_ERR("alloc_chrdev_region failed, %d", Ret);
                return Ret;
        }
        /* Allocate driver */
        pIspCharDrv = cdev_alloc();
        if (pIspCharDrv == NULL) {
                LOG_ERR("cdev_alloc failed");
                Ret = -ENOMEM;
                goto EXIT;
        }
        /* Attatch file operation. */
        cdev_init(pIspCharDrv, &IspFileOper);
        /*      */
        pIspCharDrv->owner = THIS_MODULE;
        /* Add to system */
        Ret = cdev_add(pIspCharDrv, IspDevNo, 1);
        if (Ret < 0) {
                LOG_ERR("Attatch file operation failed, %d", Ret);
                goto EXIT;
        }
        /*      */
EXIT:
        if (Ret < 0)
                ISP_UnregCharDev();

        /*      */

        LOG_DBG("- X.");
        return Ret;
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Request a region of char device numbers.
Place the allocated region into **IspDevNo**.
Associate the range with **ISP_DEV_NAME**

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```

Request a region of char device numbers.
Place the allocated region into **IspDevNo**.
Associate the range with **ISP_DEV_NAME**

```
#define ISP_DEV_NAME                    "camera-isp"
```

```
1  static inline MINT32 ISP_RegCharDev(void)
2  {
3          MINT32 Ret = 0;
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38 }
```

Associate the allocated device with **IspFileOper**, a file_operations structure.

```
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```

Add the device to the system. At this point, the device is “live”.

```
root@F3116:/ # ls -l /dev/ | grep "camera-isp"
crw-rw---- system   camera   243,   0 2017-05-18 08:43 camera-isp
```

```
static const struct file_operations IspFileOper = {
    .owner = THIS_MODULE,
    .open = ISP_open,
    .release = ISP_release,
    .mmap = ISP_mmap,
    .unlocked_ioctl = ISP_ioctl
};
```

ioctl(s)

- **I**nput **O**utput **C**on**t**ro**l**.
- System call to allow device operations that can’t be well modeled as a “normal” syscall.

Things to Note

- Modular: Allows vendors to add support for hardware!
- Security implications?
- Where is this especially prevalent?

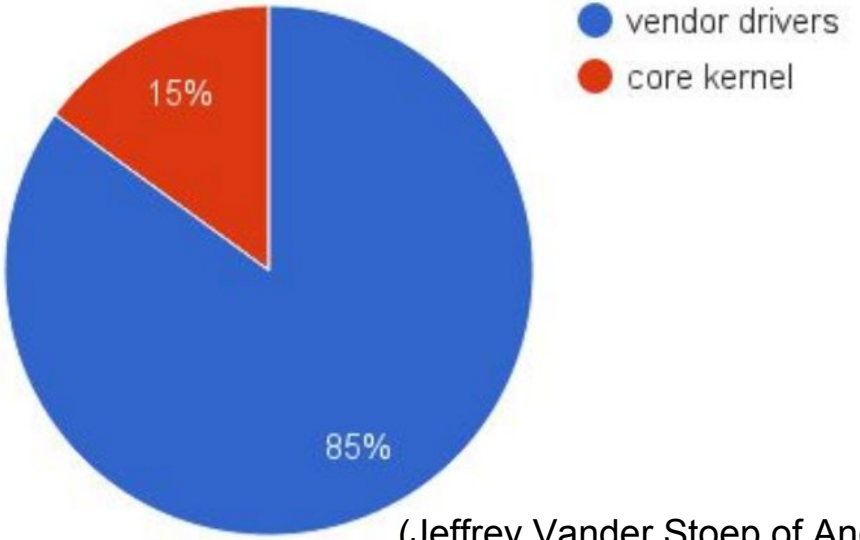
Android

- Based on Linux.
- Dominates the smartphone OS market. 86.8% of the market in 2016 Q3 (Source: IDC, Nov 2016)
- LOTS of hardware to support → Lots of drivers
- So what, are drivers really an issue?

Where Android's kernel bugs are born

Data includes multiple vendors

Some vendor drivers are in upstream, others are out-of-tree



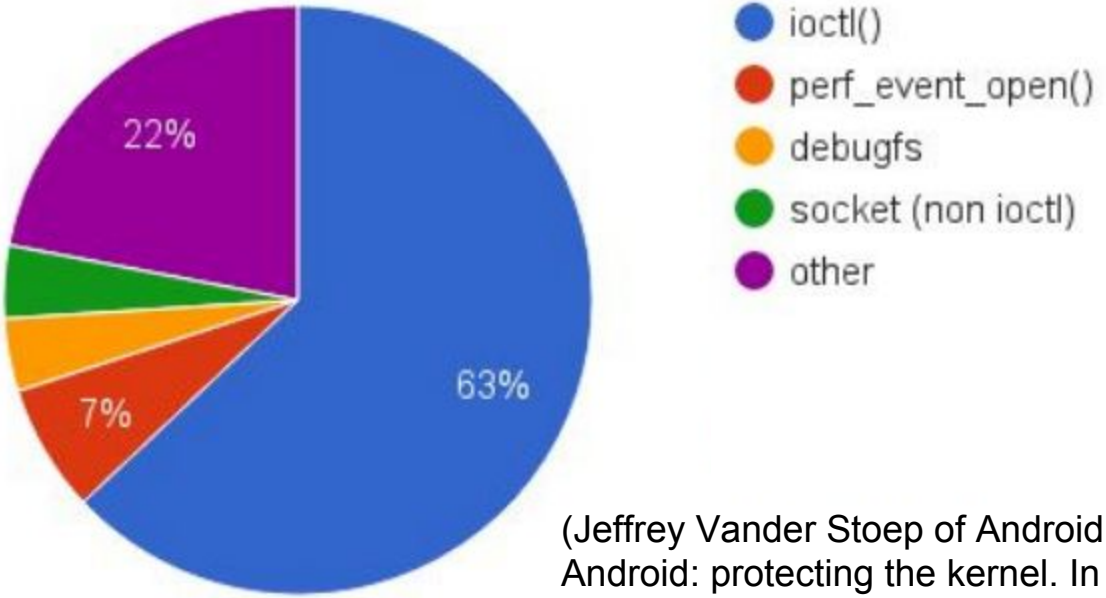
(Jeffrey Vander Stoep of Android Security. 2016. Android: protecting the kernel. In *Linux Security Summit*. Linux Foundation.)

Data: Jan 2014 → April 2016

Why?

- Well defined interface
- Which syscall is the problem?

How are kernel bugs reached - syscall (before mitigations)



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Ioctl

ioctl(int *fd*,
unsigned long *command*,
unsigned long *param*);

```
static const struct file_operations IspFileOper = {
    .owner = THIS_MODULE,
    .open = ISP_open,
    .release = ISP_release,
    .mmap = ISP_mmap,
    .unlocked_ioctl = ISP_ioctl
};
```

```
1 static long ISP_ioctl(struct file *pFile, unsigned int Cmd, unsigned long Param)
2 {
3     ...
4     switch (Cmd) {
5         case ISP_READ_REGISTER:
6             if (copy_from_user(&RegIo, (void *)Param, sizeof(ISP_REG_IO_STRUCT)) == 0) {
7                 Ret = ISP_ReadReg(&RegIo);
8             } else {
9                 LOG_ERR("copy_from_user failed");
10                Ret = -EFAULT;
11            }
12            break;
13        case ISP_WRITE_REGISTER:
14            if (copy_from_user(&RegIo, (void *)Param, sizeof(ISP_REG_IO_STRUCT)) == 0) {
15                Ret = ISP_WriteReg(&RegIo);
16            } else {
17                LOG_ERR("copy_from_user failed");
18                Ret = -EFAULT;
19            }
20            break;
21        case ISP_WAIT_IRQ:
22            if (copy_from_user(&IrqInfo, (void *)Param, sizeof(ISP_WAIT_IRQ_STRUCT)) == 0) {
23                ...
24            }
25            break;
26        ...
27    }
28 ...
29 }
```

```
copy_from_user(void * to,
               void __user  * from,
               unsigned long n)
```

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23                ...
24            }
25            break;
26        ...
27    }
28 ...
29 }
```

Solutions

- Static Analysis
  - Tons of false positives, huge amount of work to manually check every warning.
- Dynamic Analysis
  - Fuzzing

Fuzzing

- General idea: send random input to a program in hopes of triggering a bug
- Guaranteed real bugs, and we have a POC to go with it! :)

Kernel Fuzzing

- Model each syscall so we know how to call it and what to pass as arguments
- This is very hard for ioctls
- Recovering this interface requires LOTS of manual effort, and as such, ioctls are often neglected when fuzzing.
- Even with a recovered interface, it can be very hard to generate the correct arguments (super complex structs with embedded substructs, pointers, etc).

Fuzzing Drivers

Inputs:

Cmd: 43256
Param: 65443

Cmd: 1337
Param: 123654

Cmd: 1337
Param: → 4

Cmd: 1337
Param: → 500

```
1 int gTable[128];
2
3 ioctl_handler(struct file *pFile, unsigned int cmd, unsigned long param) {
4     int idx;
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6     switch(cmd) {
7         case 1337:
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15     }
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Fuzzing Drivers

```
typedef enum {
    WRITE = 77,
    CLEAR = 78
} my_enum;

typedef struct {
    my_enum type;
    int idx;
    int val;
} foo_t;
```

Fuzzing Drivers

Inputs:

Cmd: 1337
Param: → [564645, 0...]

Cmd: 1337
Param: → [77, 321...]

```
1  int gTable[128];
2
3  ioctl_handler(struct file *pFile, unsigned int cmd, unsigned long param) {
4      int idx;
5      foo_t foo;
6      switch(cmd) {
7          case 1337:
8              if (copy_from_user(&foo, (void *)param, sizeof(foo_t)) != 0)
9                  return -1;
10
11             /* WRITE */
12             if (foo.type == 77)
13                 gTable[foo.idx] = foo.val;
14
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Fuzzing Drivers

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Param: → [564645, 0...]

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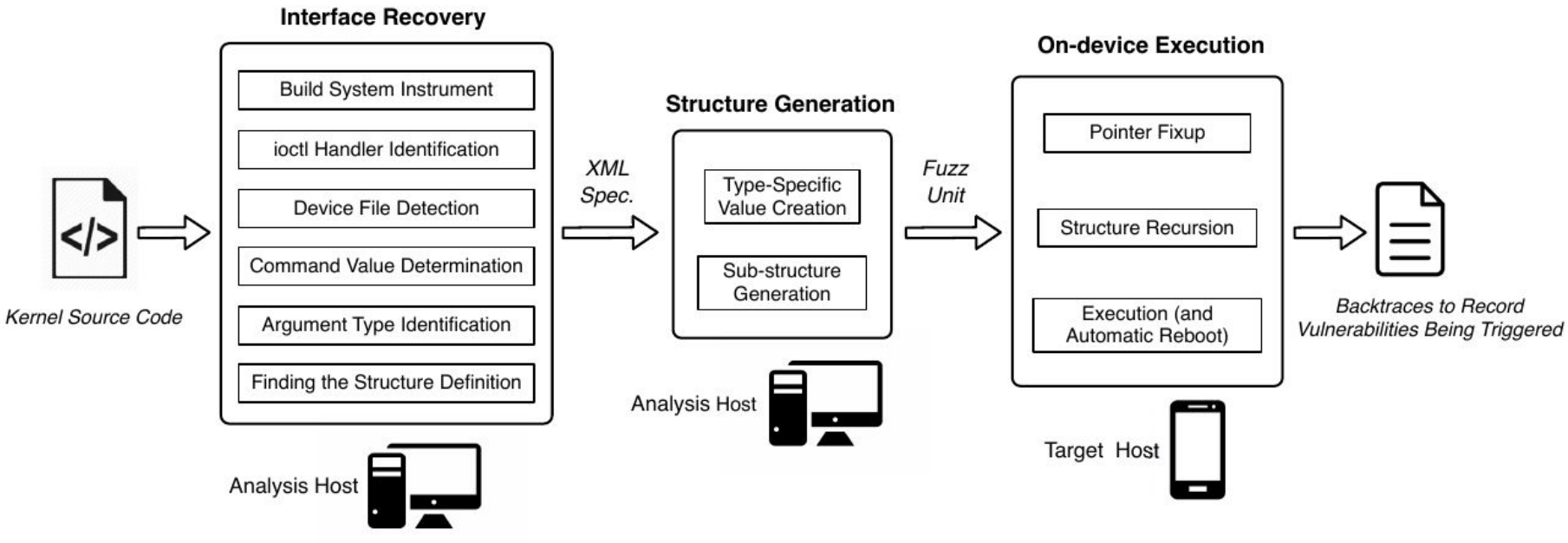
DIFUZE

- Our system that attempts to solve this problem *automatically*.



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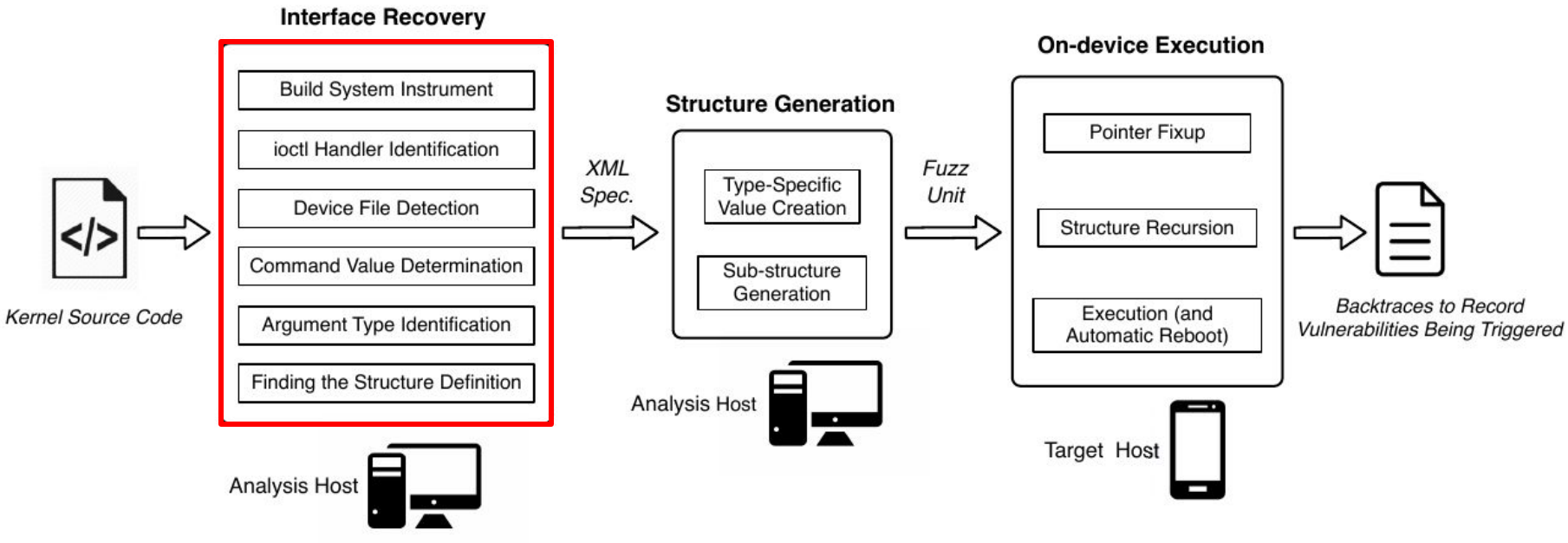

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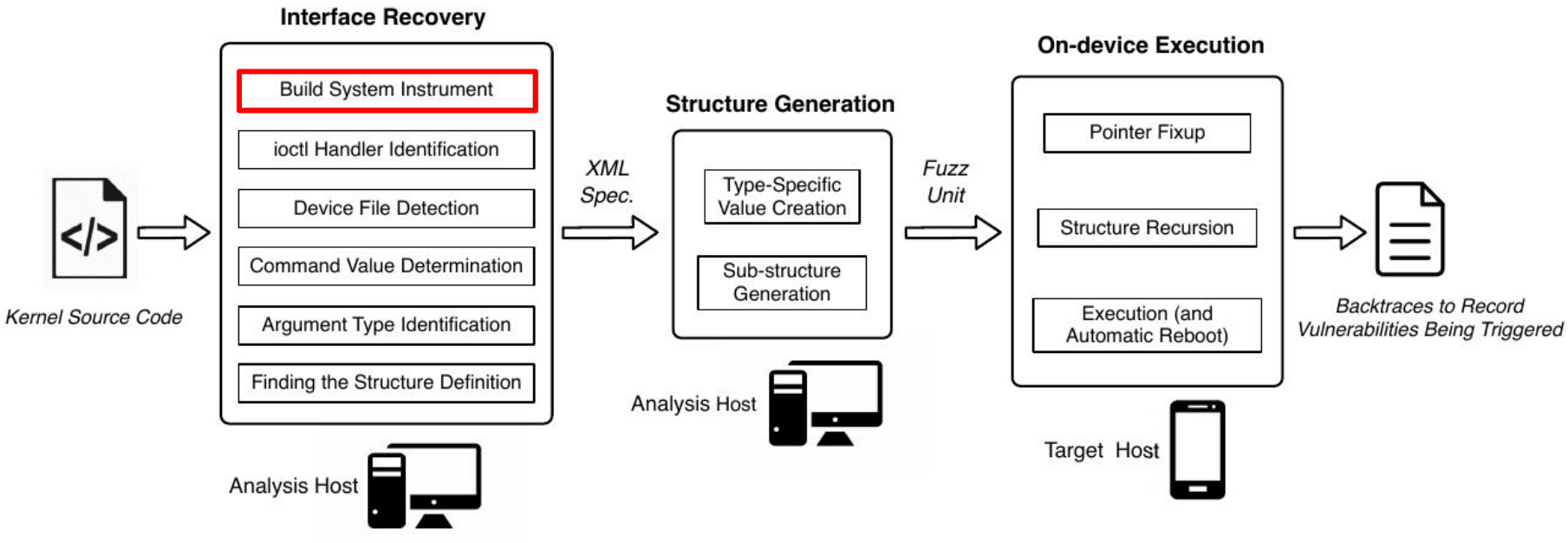

Build Process Instrumentation

- For the majority of our analyses we use LLVM
- Want LLVM bitcode
- Linux Kernel uses GCC
- Build the kernel normally with the provided makefile
- Capture output (build commands)
- Transform GCC commands to Clang commands
- Link bitcode files

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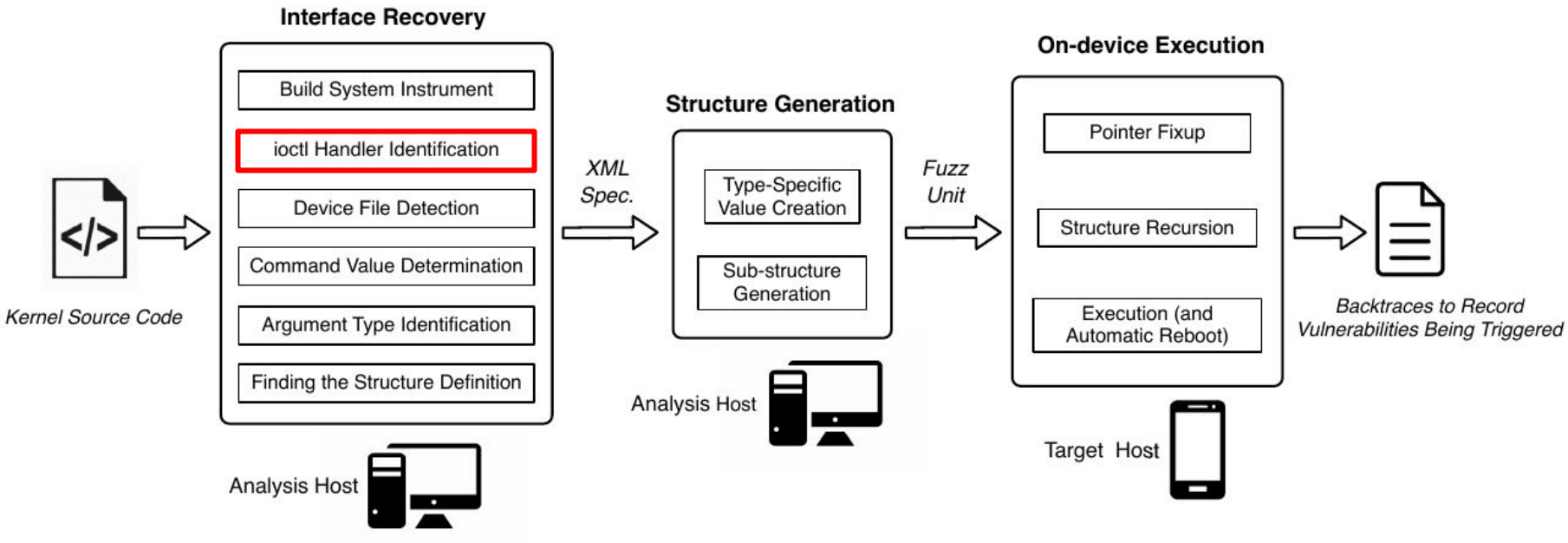

“Operations” Structure Recovery

- List of “operation” structures
- Grep for definitions in includes
- Use c2xml on relevant header files
- Recover .unlocked_ioctl offset

Ioctl Handler Recovery

- Run analyses on the linked driver bitcode files and search for uses of the “operations” structures.
- Look for assignments at the offsets recovered
- If found, we’ve found the ioctl handler for that driver, and we store the name.

```
static const struct file_operations IspFileOper = {
    .owner = THIS_MODULE,
    .open = ISP_open,
    .release = ISP_release,
    .mmap = ISP_mmap,
    .unlocked_ioctl = ISP_ioctl
};
```

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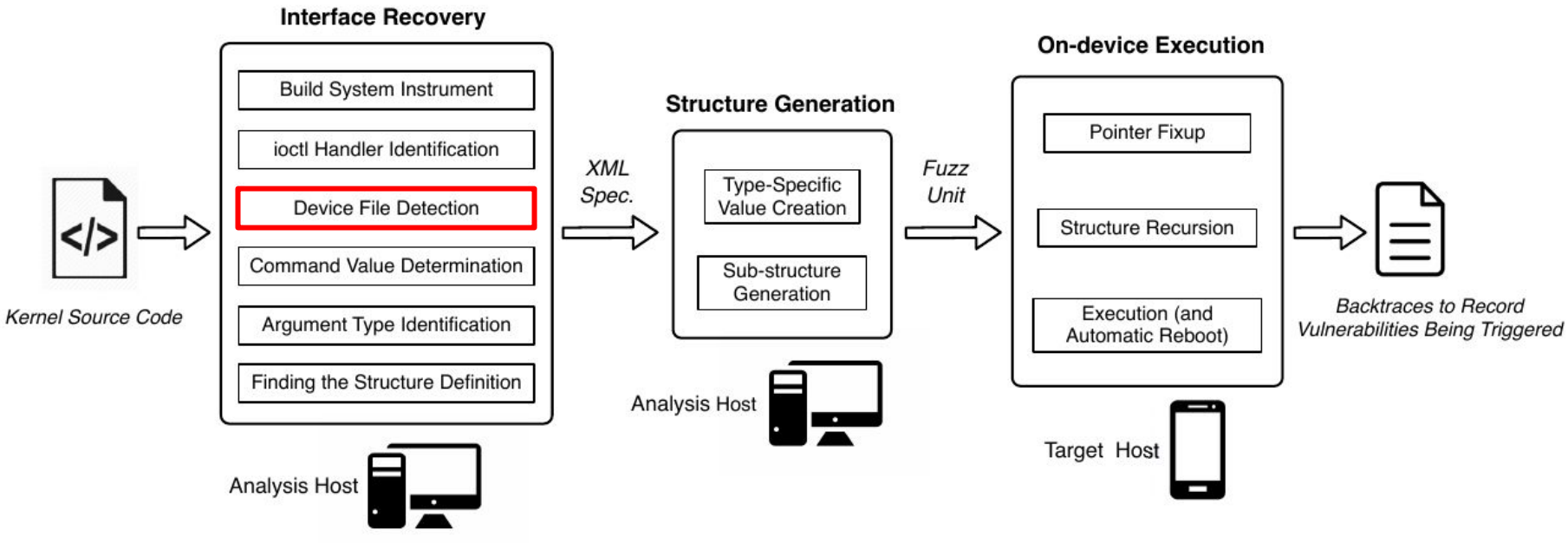

Device Name Recovery

```
root@F3116:/ # ls -l /dev/ | grep "camera-isp"
crw-rw---- system   camera   243,   0 2017-05-18 08:43 camera-isp
```

- Where is this device file and what is it called?
- Recall our journey through the registration of a device.
- If there’s a device file created, it must be associated with the operations structure we’ve found!
- We use analysis to recover static names

Dynamic Names

- Unfortunately the names aren’t always static.
- We miss dynamic names and must fallback to manual analysis.

```
VOS_INT __init RNIC_InitNetCard(VOS_VOID)
{
    ...
    snprintf(pstDev->name, sizeof(pstDev->name),
      "%s%s",
      RNIC_DEV_NAME_PREFIX,
      g_astRnicManageTbl[ucIndex].pucRnicNetCardName);
    ...
}
```

DIFUZE

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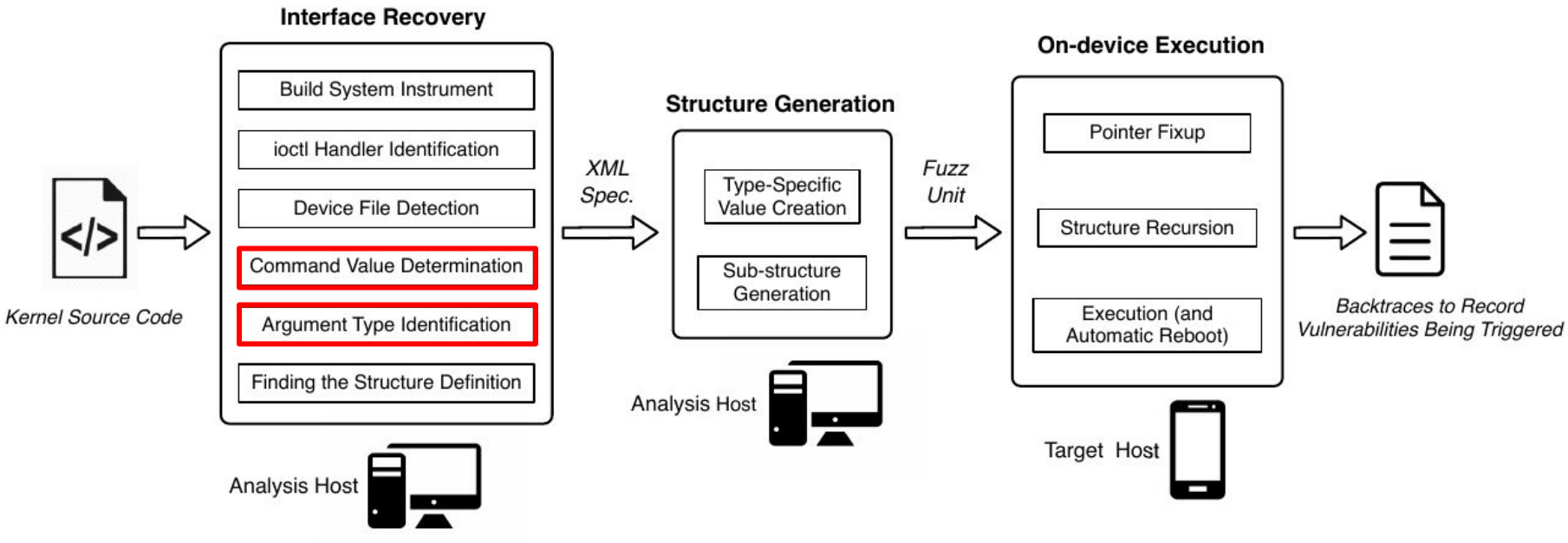

Command Value + Type Recovery

- Found the ioctl handler function, we run LLVM analyses on the function.
- Know the arguments of interest.
- We search for equality comparisons on “command”, and keep track of the constraints on a given path.
- Search for copy_from_user using “param”
- If found, we find the type associated with the first argument.
- Follow functions that are passed “param” and/or “command”

```
1 static long ISP_ioctl(struct file *pFile, unsigned int Cmd, unsigned long Param)
2 {
3     ...
4     switch (Cmd) {
5         ...
6         case ISP_BUFFER_CTRL:
7             Ret = ISP_Buf_CTRL_FUNC(Param);
8             break;
9         ...
10    }
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12 }
13
14 static long ISP_Buf_CTRL_FUNC(unsigned long Param)
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16    ...
17    ISP_BUFFER_CTRL_STRUCT rt_buf_ctrl;
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Type: ISP_BUFFER_CTRL_STRUCT

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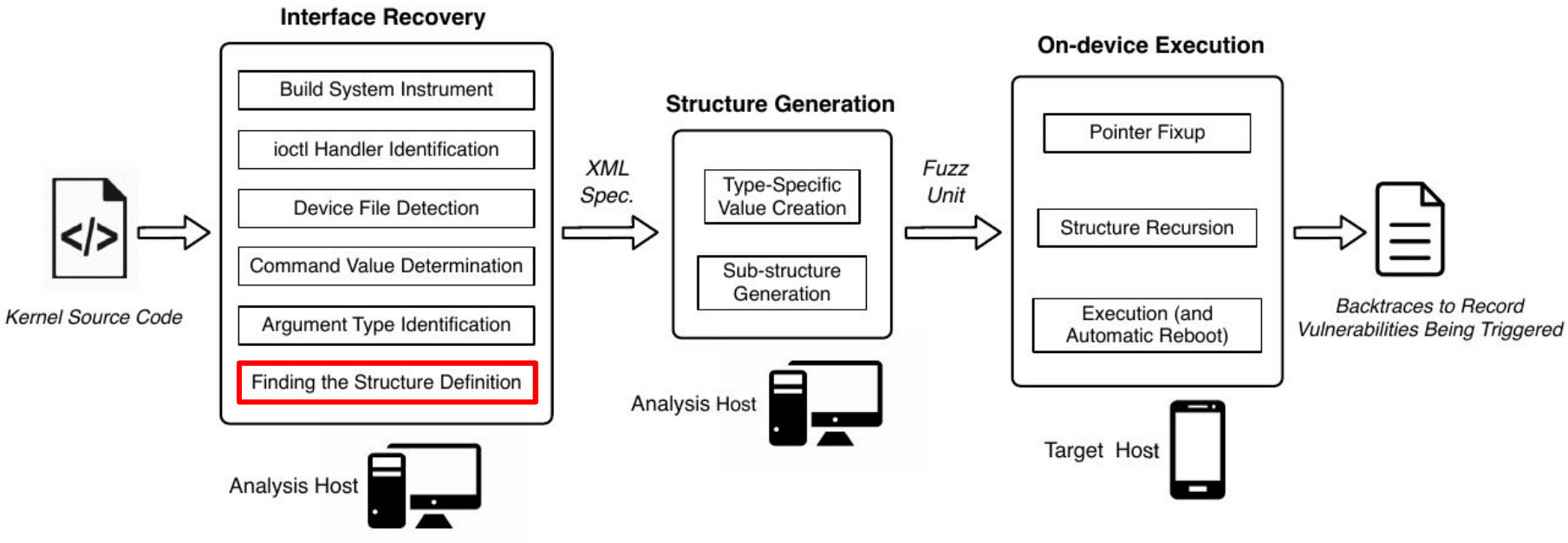


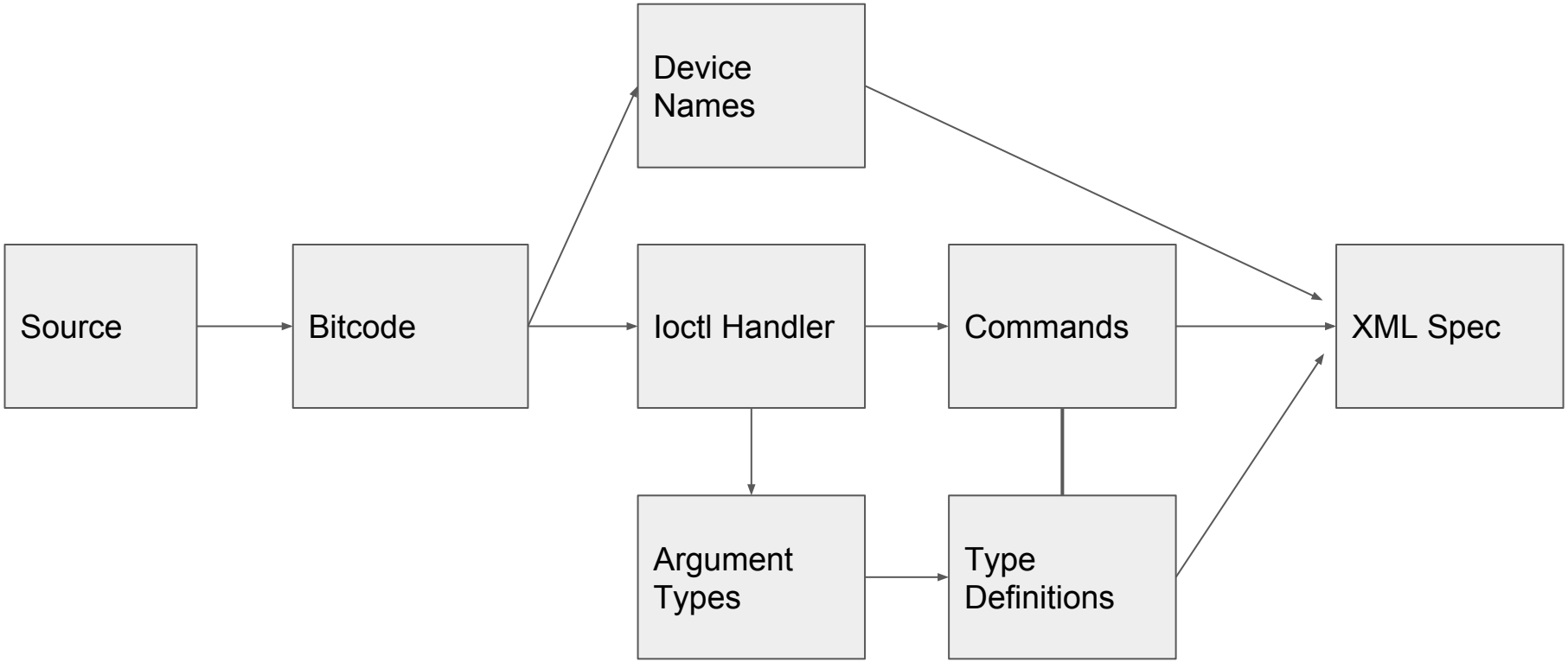
Structure Definition Recovery

- Have the GCC build commands
- Know the file we're looking at
- Use GCC command with -E
- Get a HUGE (40k+ line) file which **somewhere** will include the structure definition.
- Run our good friend c2xml on the file and get an equally massive xml file.
- Python passes to extract the struct + struct dependencies, account for padding, recover enum values, etc.

```
bit-size="16" alignment="2" offset="0" base-type-builtin="signed short"/>
  <symbol type="node" id="_11" ident="u16" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="78" start-col="24" end-line="78" end-col="27"
bit-size="16" alignment="2" offset="0" base-type-builtin="unsigned short"/>
  <symbol type="node" id="_12" ident="s32" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="80" start-col="20" end-line="80" end-col="23"
bit-size="32" alignment="4" offset="0" base-type-builtin="signed int"/>
  <symbol type="node" id="_13" ident="u32" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="81" start-col="22" end-line="81" end-col="25"
bit-size="32" alignment="4" offset="0" base-type-builtin="unsigned int"/>
  <symbol type="node" id="_14" ident="s64" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="83" start-col="26" end-line="83" end-col="29"
bit-size="64" alignment="8" offset="0" base-type-builtin="signed long long"/>
  <symbol type="node" id="_15" ident="u64" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="84" start-col="28" end-line="84" end-col="31"
bit-size="64" alignment="8" offset="0" base-type-builtin="unsigned long long"/>
  <symbol type="struct" id="_16" ident="ftrace_branch_data" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="123" start-col="8" end-
line="138" end-col="2" bit-size="320" alignment="8" offset="0">
    <symbol type="node" id="_17" ident="func" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="124" start-col="13" end-line="124" end-
col="18" bit-size="64" alignment="8" offset="0" base-type="_18"/>
    <symbol type="node" id="_19" ident="file" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="125" start-col="13" end-line="125" end-
col="18" bit-size="64" alignment="8" offset="8" base-type="_20"/>
    <symbol type="node" id="_21" ident="line" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="126" start-col="11" end-line="126" end-
col="15" bit-size="32" alignment="4" offset="16" base-type-builtin="unsigned int"/>
    <symbol type="node" id="_22" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="137" start-col="3" end-line="137" end-col="3" bit-
size="128" alignment="8" offset="24" base-type="_23"/>
  </symbol>
  <symbol type="pointer" id="_18" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="124" start-col="13" end-line="124" end-col="14" bit-
size="64" alignment="8" offset="0" base-type-builtin="char"/>
  <symbol type="pointer" id="_20" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="125" start-col="13" end-line="125" end-col="14" bit-
size="64" alignment="8" offset="0" base-type-builtin="char"/>
  <symbol type="union" id="_23" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="127" start-col="8" end-line="137" end-col="3" bit-
size="128" alignment="8" offset="0">
    <symbol type="node" id="_24" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="131" start-col="4" end-line="131" end-col="4" bit-
size="128" alignment="8" offset="0" base-type="_25"/>
    <symbol type="node" id="_28" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="135" start-col="4" end-line="135" end-col="4" bit-
size="128" alignment="8" offset="0" base-type="_29"/>
    <symbol type="node" id="_32" ident="miss_hit" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="136" start-col="17" end-line="136" end-
col="28" bit-size="128" alignment="8" offset="0" base-type="_33"/>
  </symbol>
  <symbol type="struct" id="_25" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="128" start-col="10" end-line="131" end-col="4" bit-
size="128" alignment="8" offset="0">
    <symbol type="node" id="_26" ident="correct" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="129" start-col="18" end-line="129" end-
col="25" bit-size="64" alignment="8" offset="0" base-type-builtin="unsigned long"/>
    <symbol type="node" id="_27" ident="incorrect" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="130" start-col="18" end-line="130" end-
col="27" bit-size="64" alignment="8" offset="8" base-type-builtin="unsigned long"/>
  </symbol>
  <symbol type="struct" id="_29" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="132" start-col="10" end-line="135" end-col="4" bit-
size="128" alignment="8" offset="0">
    <symbol type="node" id="_30" ident="miss" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="133" start-col="18" end-line="133" end-
col="22" bit-size="64" alignment="8" offset="0" base-type-builtin="unsigned long"/>
    <symbol type="node" id="_31" ident="hit" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="134" start-col="18" end-line="134" end-
col="21" bit-size="64" alignment="8" offset="8" base-type-builtin="unsigned long"/>
  </symbol>
  <symbol type="array" id="_33" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="136" start-col="25" end-line="136" end-col="28" bit-
size="128" alignment="8" offset="0" base-type-builtin="unsigned long" array-size="2"/>
  <symbol type="node" id="_34" ident="data_access_exceeds_word_size" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="143" start-col="122"
end-line="147" end-col="1" static="1" inline="1" toplevel="1" bit-size="-1" alignment="0" offset="0" base-type="_35"/>
  <symbol type="function" id="_35" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="143" start-col="151" end-line="147" end-col="1" bit-
size="-1" alignment="0" offset="0" base-type-builtin="void"/>
  <symbol type="node" id="_36" ident="data_access_exceeds_word_size" file="/home/jay/timing/xa/llvm_out/drivers/misc/mediatek/cameraisp/src/mt6755/camera_isp.preprocessed" start-line="149" start-col="122"
end-line="150" end-col="1" static="1" inline="1" toplevel="1" bit-size="-1" alignment="0" offset="0" base-type="_37"/>
```

```
1     <DataModel byte_size="136" name="ISP_RT_BUF_INFO_STRUCT" type="struct">
2         <Number name="memID" size="32"/>
3         <Number name="size" size="32"/>
4         <Number name="base_vAddr" size="64"/>
5         <Number name="base_pAddr" size="32"/>
6         <Number name="timeStampS" size="32"/>
7         <Number name="timeStampUs" size="32"/>
8         <Number name="bFilled" size="32"/>
9         <Number name="bProcessRaw" size="32"/>
10        <Block name="image" offset="36" ref="ISP_RT_IMAGE_INFO_STRUCT"/>
11        <Block name="rrzInfo" offset="88" ref="ISP_RT_RRZ_INFO_STRUCT"/>
12        <Block name="dmaoCrop" offset="112" ref="ISP_RT_DMAO_CROPPING_STRUCT"/>
13        <Number name="bDequeued" size="32"/>
14        <Number name="bufIdx" size="32"/>
15    </DataModel>
```

Summary

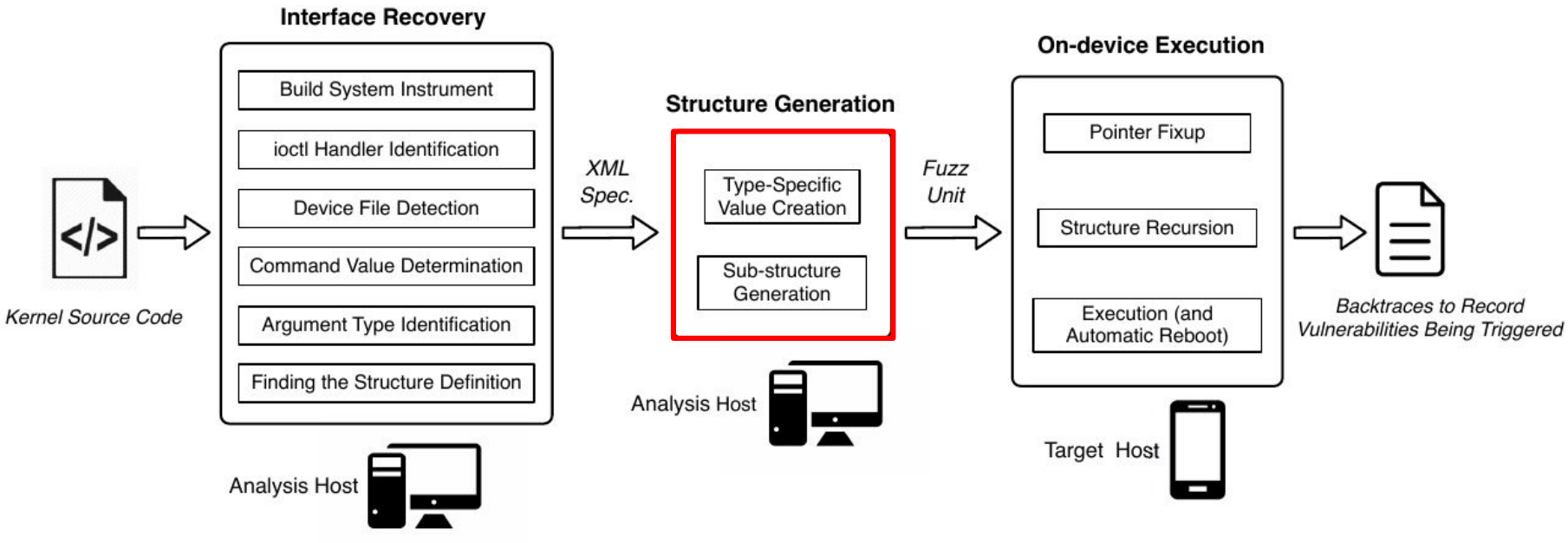

Device Names
Source
Bitcode
Ioctl Handler
Commands
XML Spec
Argument Types
Type Definitions

Awesome!

- Now we’re entirely **interface aware**.
- We know where the device file is, we know what commands we can pass it, and we know what arguments those commands take.
- Need instances of those structures so that we can actually exercise the behaviour of the device.

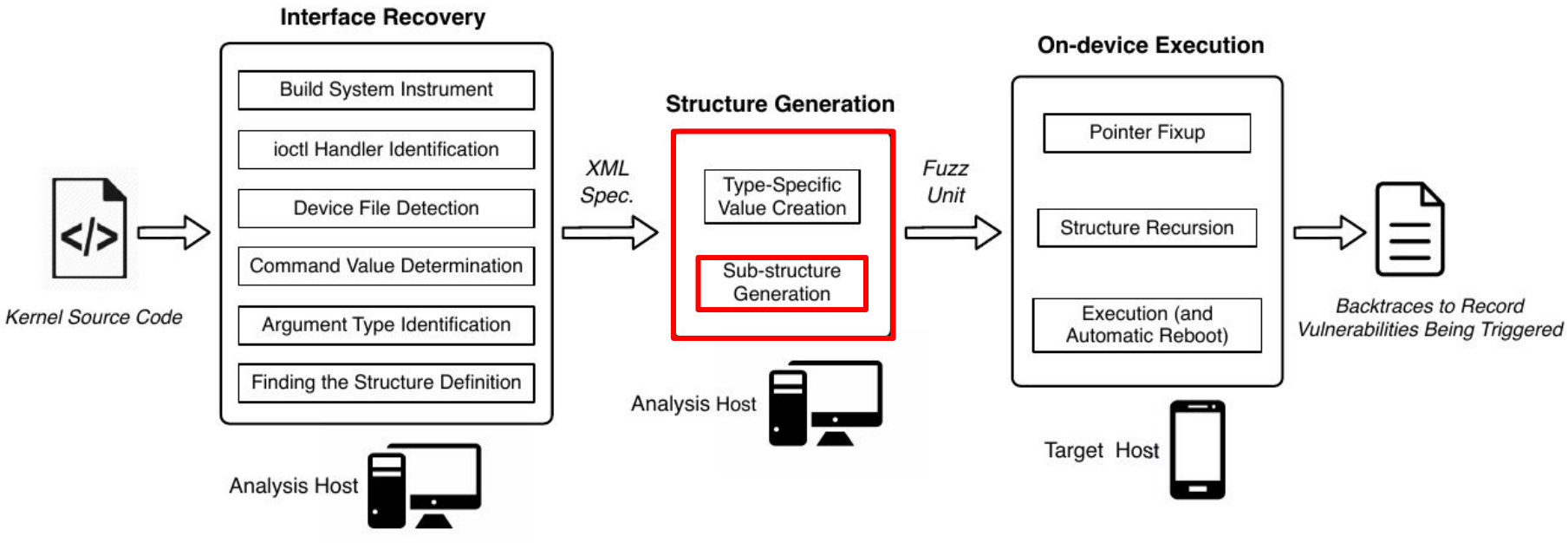
DIFUZE

- Our system that attempts to solve this problem *automatically*.



DIFUZE

- Our system that attempts to solve this problem *automatically*.



Structure Generation

- Harder than it seems
- Embedded structures and pointers

0

```
typedef struct {
    ISP_RT_BUF_CTRL_ENUM ctrl;
    _isp_dma_enum_ buf_id;
    ISP_RT_BUF_INFO_STRUCT *data_ptr;
    ISP_RT_BUF_INFO_STRUCT *ex_data_ptr;
    unsigned char *pExtend;
} ISP_BUFFER_CTRL_STRUCT;
```

1

```
typedef enum {
    ISP_RT_BUF_CTRL_ENQUE,  /* 0 */
    ISP_RT_BUF_CTRL_EXCHANGE_ENQUE, /* 1 */
    ISP_RT_BUF_CTRL_DEQUE,  /* 2 */
    ISP_RT_BUF_CTRL_IS_RDY, /* 3 */
    ISP_RT_BUF_CTRL_DMA_EN, /* 4 */
    ISP_RT_BUF_CTRL_GET_SIZE,   /* 5 */
    ISP_RT_BUF_CTRL_CLEAR,  /* 6 */
    ISP_RT_BUF_CTRL_CUR_STATUS, /* 7 */
    ISP_RT_BUF_CTRL_MAX /* 8 */
} ISP_RT_BUF_CTRL_ENUM;
```

2

```
typedef enum {
    _imgi_ = 0,
    _vipi_,          /* 1 */
    _vip2i_,         /* 2 */
    _vip3i_,         /* 3 */
    _imgo_,          /* 4 */
    _ufdi_,          /* 5 */
    _lcei_,          /* 6 */
    _ufeo_,          /* 7 */
    _rrzo_,          /* 8 */
    _imgo_d_,        /* 9 */
    _rrzo_d_,        /* 10 */
    _img2o_,         /* 11 */
    _img3o_,         /* 12 */
    _img3bo_,        /* 13 */
    _img3co_,        /* 14 */
    _camsv_imgo_,       /* 15 */
    _camsv2_imgo_,      /* 16 */
    _mfbo_,          /* 17 */
    _feo_,           /* 18 */
    _wrot_,          /* 19 */
    _wdma_,          /* 20 */
    _jpeg_,          /* 21 */
    _venc_stream_,      /* 21 */
    _rt_dma_max_     /* 22 */
} _isp_dma_enum_;
```

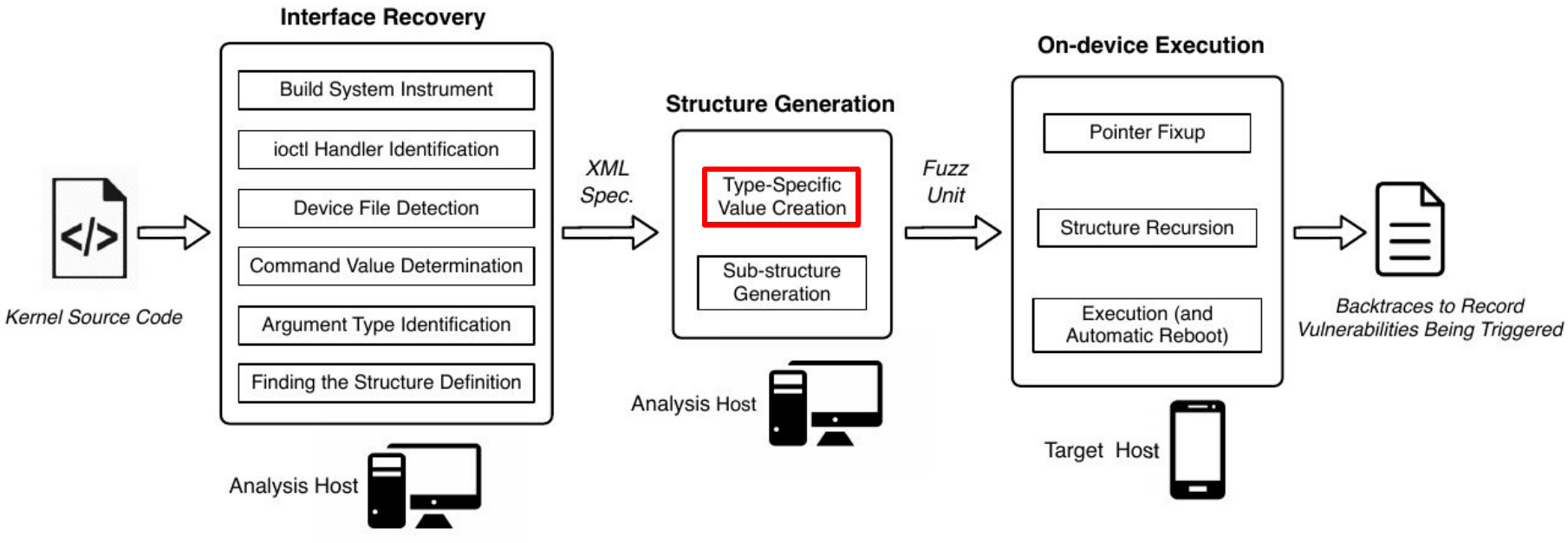
3

```
typedef struct {
    unsigned int memID;
    unsigned int size;
    long long base_vAddr;
    unsigned int base_pAddr;
    unsigned int timeStampS;
    unsigned int timeStampUs;
    unsigned int bFilled;
    unsigned int bProcessRaw;
    ISP_RT_IMAGE_INFO_STRUCT image;
    ISP_RT_RRZ_INFO_STRUCT rrzInfo;
    ISP_RT_DMAO_CROPPING_STRUCT dmaoCrop;
    unsigned int bDequeued;
    signed int bufIdx;
} ISP_RT_BUF_INFO_STRUCT;
```

4

DIFUZE

- Our system that attempts to solve this problem *automatically*.

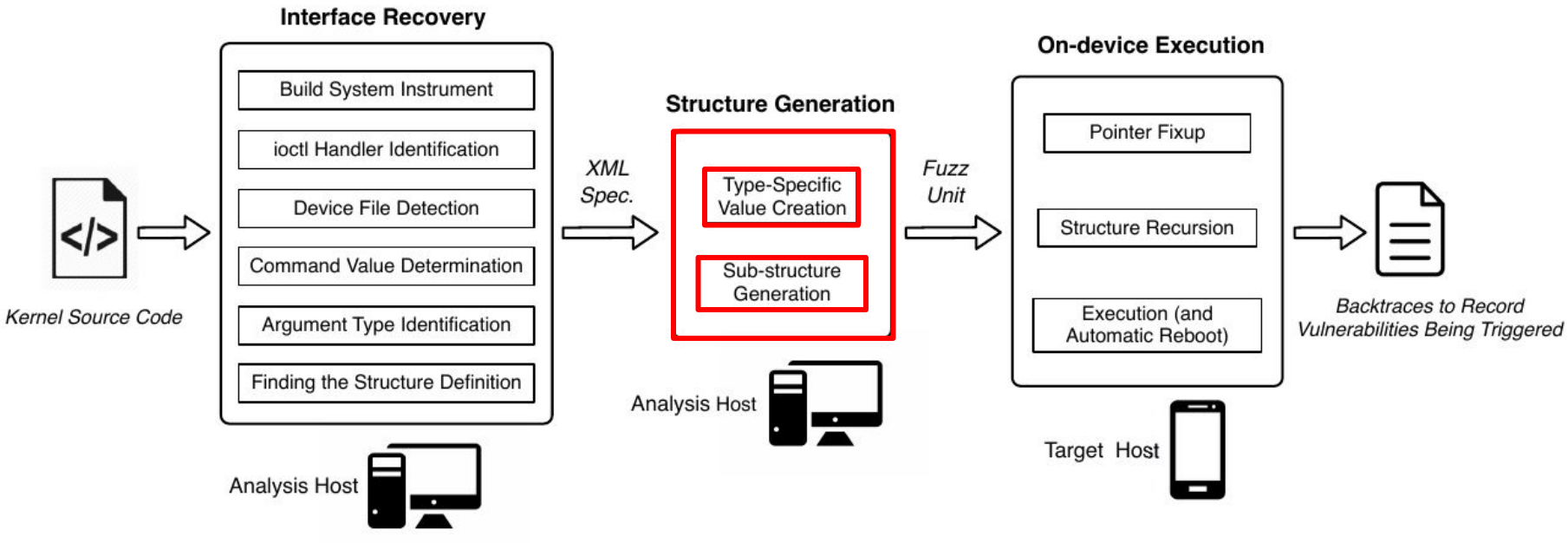


Type Specific Value Generation

- Generate value(s) for each field in the structure
  - Note that since we now have the type information, we can be intelligent about this!

DIFUZE

- Our system that attempts to solve this problem *automatically*.



MangoFuzz

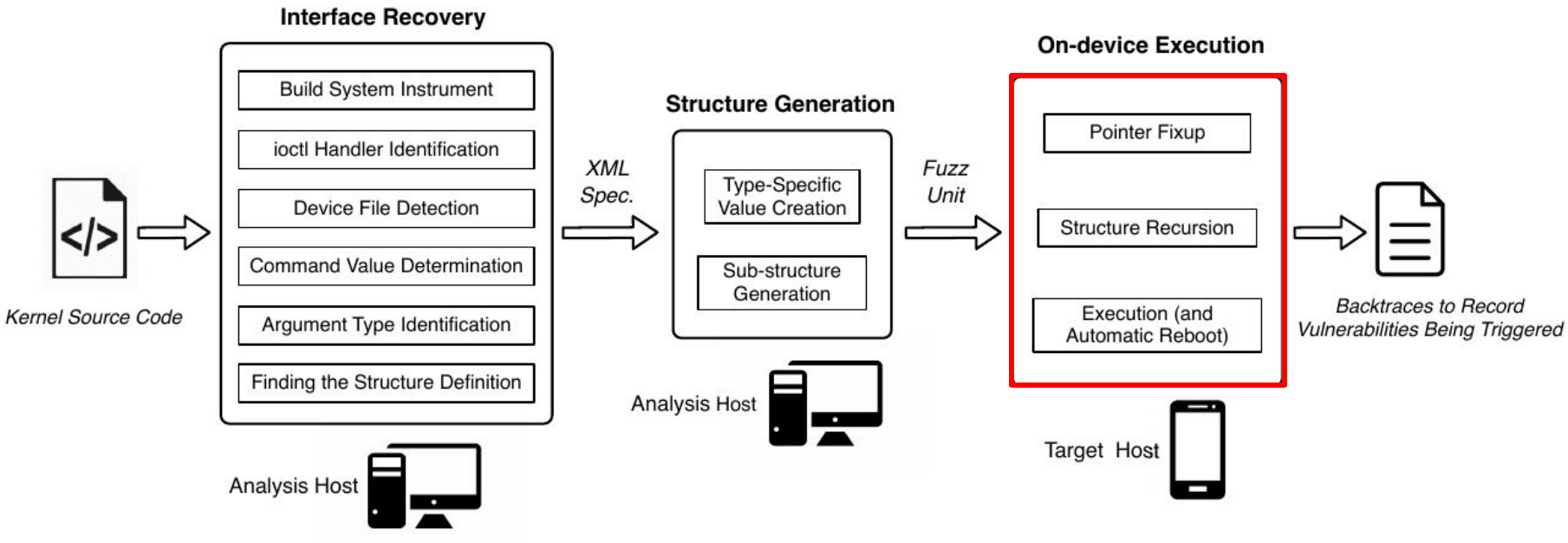
- Written in Python
- Consumes XML spec file(s)
- XML spec files detail the interface information (device path, ioctl command ID, target argument, and argument definition)
- Outputs binary blobs, an array of mappings (if needed), and interface info

XML Spec (jpit)

```xml
<Mango author="jay` bot" description="autogenerated jpit" version="1.0">

    <Config>
        <devname value="/dev/camera-isp"/>
        <ioctl_id value="2148559647"/>
        <target_struct value="ISP_REGISTER_USERKEY_STRUCT"/>
    </Config>

    <DataModel byte_size="16" name="ISP_REGISTER_USERKEY_STRUCT" type="struct">
        <Number name="userKey" size="32"/>
        <String length="4" name="padding256"/>
        <Pointer base="char" elem_size="1" length="8" name="userName" offset="8" ptr_depth="1" ptr_to="String"/>
    </DataModel>

</Mango>
```

DIFUZE

- Our system that attempts to solve this problem *automatically*.



On Device Execution

- When it comes time to actually call ioctl(), it needs to be done on the device itself.
- Must be an actual execution component running on the device.
- We connect the analysis host and the device via ADB (Android Debug Bridge).

On Device Execution

- The executor runs on the device and listens for data that will be sent by the fuzzer component
- At this point, it will map the binary data into memory, and do the necessary pointer fixups.
- It will then open the device file specified, and call ioctl() with the command value sent, and the now memory mapped argument/structure

How do we detect a bug?

- Device reboots
- the kernel backtrace/oops is saved in /sys/fs/pstore/console-ramoops
- We use this to triage crashes

Time To Test!

Manufacturer	Device	Chipset
Google	Pixel	Qualcomm
HTC	E9 Plus	Mediatek
HTC	One M9	Qualcomm
Huawei	P9 Lite	Huawei
Huawei	Honor 8	Huawei
Samsung	Galaxy S6	Samsung
Sony	Xperia XA	Mediatek

Device Name Recovery

ioctl Handlers	Device Names Automatically Identified
789	469

- We automatically identify device names for roughly 60% of the ioctl handlers.
- Most of these misses come from mainline drivers, which have a tendency to use dynamic names.

Type + Command ID Recovery

Command ID's Recovered	User Argument Types			
	Long/CTU	Scalar	Struct	Struct w/ Pointers
3565	1688	526	961	390

- For 47% of the commands, the user argument is used either as C Long, or is used as an address for copy_to_user, in these cases, no type recovery is needed.
- For the rest (53%), the user argument should be a pointer.
- Command ID recovery. Random sample verification of 5 ioctls for each phone (35 total handlers). 90% accuracy.

Fuzzing Evaluation

- 4 variants
- Syzkaller with:
  - Extracted Device Path (PATH)
  - Extracted Device Path and Ioctl Numbers (PATH+NUM)
  - Extracted Device Path, Ioctl Numbers, and Structures ($DIFUZE^{S}$)
- MangoFuzz
  - Extracted Device Path, Ioctl Numbers, and Structures ($DIFUZE^{M}$)

Fuzzing Results

	PATH	PATH+NUM	DIFUZE^{s}	DIFUZE^{m}	Total Unique
E9 Plus	0	4	6	6	6
Galaxy S6	-	-	-	0	0
Honor 8	0	1	2	2	2
One M9	0	3	3	2	3
P9 Lite	0	2	5	5	6
Pixel	1	2	5	3	5
Xperia XA	2	10	13	12	14
Total	3	22	34	30	36

Some Fun Bugs

M4U Out Of Bounds Write

```
1 int config_mau(M4U_MAU_STRUCT mau)
2 {
3     int free_id = -1;
4     for (i = 0; i < M4U0_MAU_NR; i++) {
5         if (0 != gM4u0_mau[i].Enabled) {
6             // Start Monitor
7         } else {
8             free_id = i;
9         }
10    }
11    ...
12    if (free_id == -1) {
13        if (mau.force == 0)
14            return -1;
15        }
16    else {
17        free_id = gMAU_candidate_id;
18        ...
19    }
20
21    gM4u0_mau[free_id].Enabled = 1;
22    gM4u0_mau[free_id].MVAStart = MVAStart;
23    gM4u0_mau[free_id].MVAEnd = MVAEnd;
24    gM4u0_mau[free_id].port = mau.port;
25 }
```

`free_id` set to -1

Incorrect `else` and `free_id` is still -1

Out of Bounds write to index -1

BUG() - CVE-2017-0636

Saw the following in the last kmsg:

```
“Unable to handle kernel paging request at virtual
address 0000dead”
```

BUG() - CVE-2017-0636

```
1#define BUG() do { \
2     printk("BUG: failure at %s:%d/%s()!\n", \
3             __FILE__, __LINE__, __func__); \
4     *((unsigned *)0xdead) = 0x0aee; \
5     unreachable();  \
6} while (0)
```

BUG() - CVE-2017-0636

mmap(0xd000, ...) = 0xd000

Bypass assert and trigger memory corruption

CVE-2017-15307

- Suddenly, fuzzer could no longer find device
- Serial Number had changed to “^Rï£¡DO>l”

Conclusion

- Driver fuzzing can yield a lot of bugs
- Modelling the interface correctly is important
- DIFUZE automatically extracts this info to make fuzzing easy

Questions?