Tutorial 4: Integers & Format String

presented by

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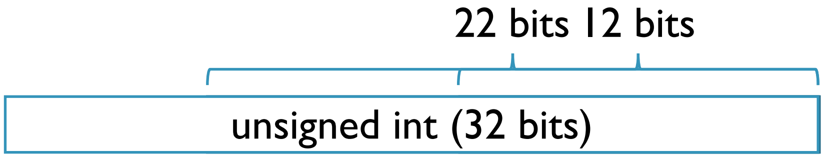
Working with Integers



22 bits 12 bits

unsigned int (32 bits)

Spot the problem in this ASLR routine, and its impact

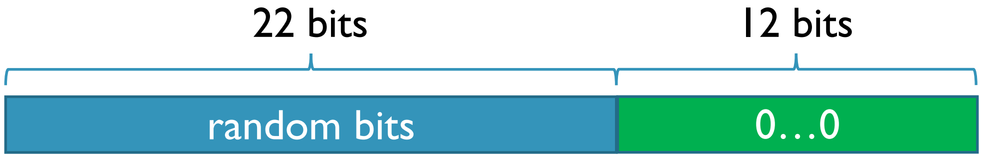
```
static unsigned long randomize_stack_top(unsigned long stack_top)
{
   unsigned int random_variable = 0;
   if ((current->flags & PF_RANDOMIZE) &&
       !(current->personality & ADDR_NO_RANDOMIZE))
      {
        random_variable = get_random_int() & STACK_RND_MASK;
        random_variable <<= PAGE_SHIFT;
      }
#ifdef CONFIG_STACK_GROWSUP
   return PAGE_ALIGN(stack_top) + random_variable;
#else
   return PAGE_ALIGN(stack_top) - random_variable;
#endif
}
```

0x3FFFFF

12 on x86_64

http://hmarco.org/bugs/linux-ASLR-integer-overflow.html

CVE-2015-1593



- Code switches from unsigned long to unsigned int

```
static unsigned long randomize_stack_top(unsigned long stack_top)
{
   unsigned int random_variable = 0;
   if ((current->flags & PF_RANDOMIZE) &&
       !(current->personality & ADDR_NO_RANDOMIZE))
      {
        random_variable = get_random_int() & STACK_RND_MASK;
        random_variable <<= PAGE_SHIFT;
      }
#ifdef CONFIG_STACK_GROWSUP
   return PAGE_ALIGN(stack_top) + random_variable;
#else
   return PAGE_ALIGN(stack_top) - random_variable;
#endif
}
```

0x3FFFFF
mask 22 bits

shift by 12; 2 bits dropped: (22+12)–32 = 2

Entropy is reduced by 4: 2^{30} → 2^{28}

Stagefright

Stagefright Vulnerability

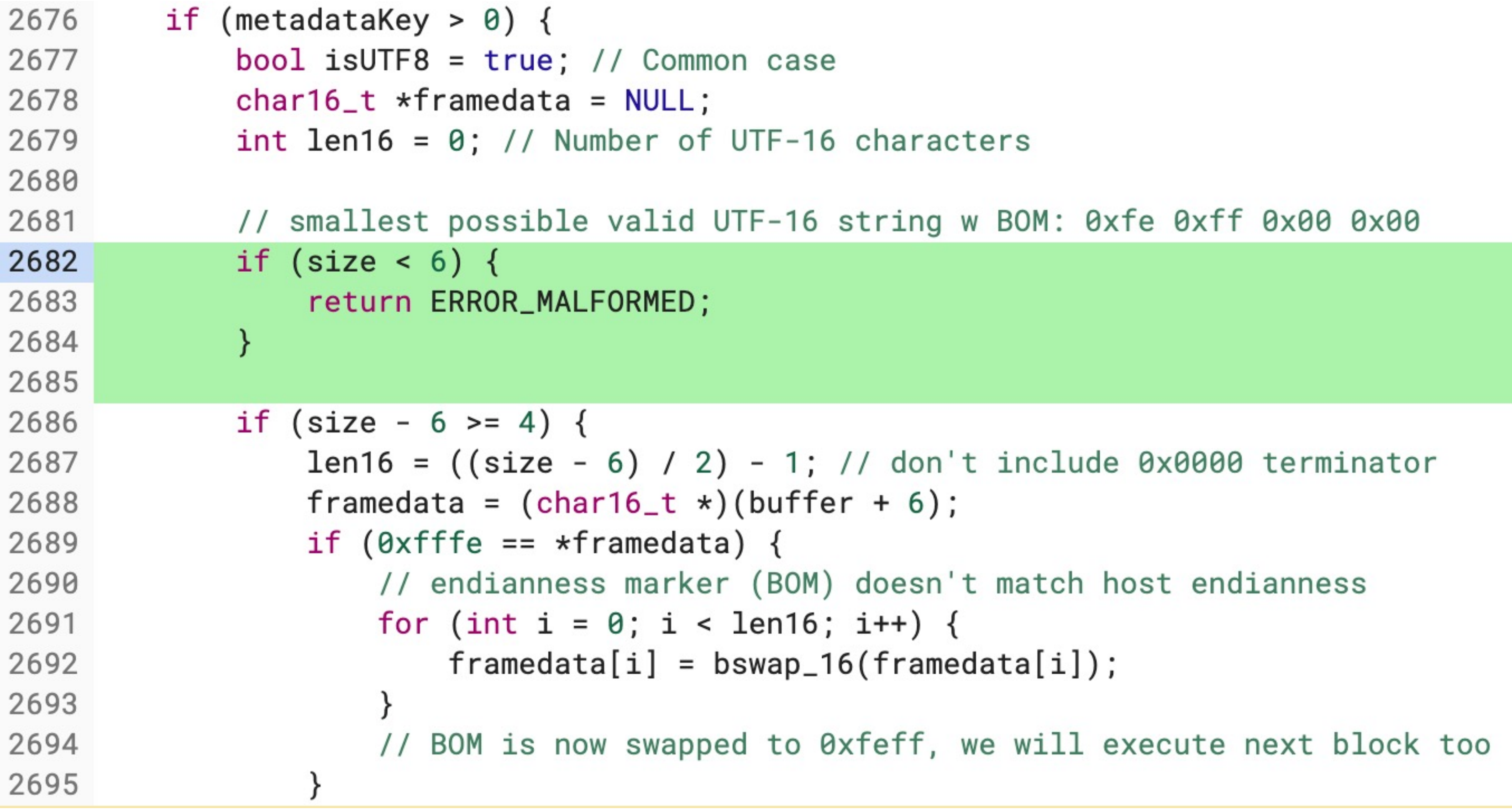
- Stagefright: Android multimedia framework library, e.g., for handling MMS messages, MP4 videos
  - Lots of low level operations on composite data structures
  - Runs with system permissions on many Android phones
- Buffer overflow vulnerability in Stagefright allows an attacker to run arbitrary code with either the "media" or "system" permissions
  - Buffer overflow is possible because of a flawed check on the length of a data structure

Stagefright Vulnerabilities

- CVE-2015-1538 #1 -- MP4 'stsc' Integer Overflow
- CVE-2015-1538 #2 -- MP4 'ctts' Integer Overflow
- CVE-2015-1538 #3 -- MP4 'stts' Integer Overflow
- CVE-2015-1538 #4 -- MP4 'stss' Integer Overflow
- CVE-2015-1539 ------ MP4 'esds' Integer Underflow
- CVE-2015-3824 ------ MP4 'tx3g' Integer Overflow
- CVE-2015-3826 ------ MP4 3GPP Buffer Overread
- CVE-2015-3827 ------ MP4 'covr' Integer Underflow
- CVE-2015-3828 ------ MP4 3GPP Integer Underflow
- CVE-2015-3829 ------ MP4 'covr' Integer Overflow
- ..and a whole slew of stability fixes

https://gerrit.omnirom.org/c/android_frameworks_av/+/14227

[CVE-2015-1539] Input too Small



```
    if (metadataKey > 0) {
        bool isUTF8 = true; // Common case
        char16_t *framedata = NULL;
        int len16 = 0; // Number of UTF-16 characters

        // smallest possible valid UTF-16 string w BOM: 0xfe 0xff 0x00 0x00
        if (size < 6) {
            return ERROR_MALFORMED;
        }

        if (size - 6 >= 4) {
            len16 = ((size - 6) / 2) - 1; // don't include 0x0000 terminator
            framedata = (char16_t *)(buffer + 6);
            if (0xfffe == *framedata) {
                // endianness marker (BOM) doesn't match host endianness
                for (int i = 0; i < len16; i++) {
                    framedata[i] = bswap_16(framedata[i]);
                }
                // BOM is now swapped to 0xfeff, we will execute next block too
            }
```

http://drippler.com/drip/stagefright-explained-exploit-changed-android

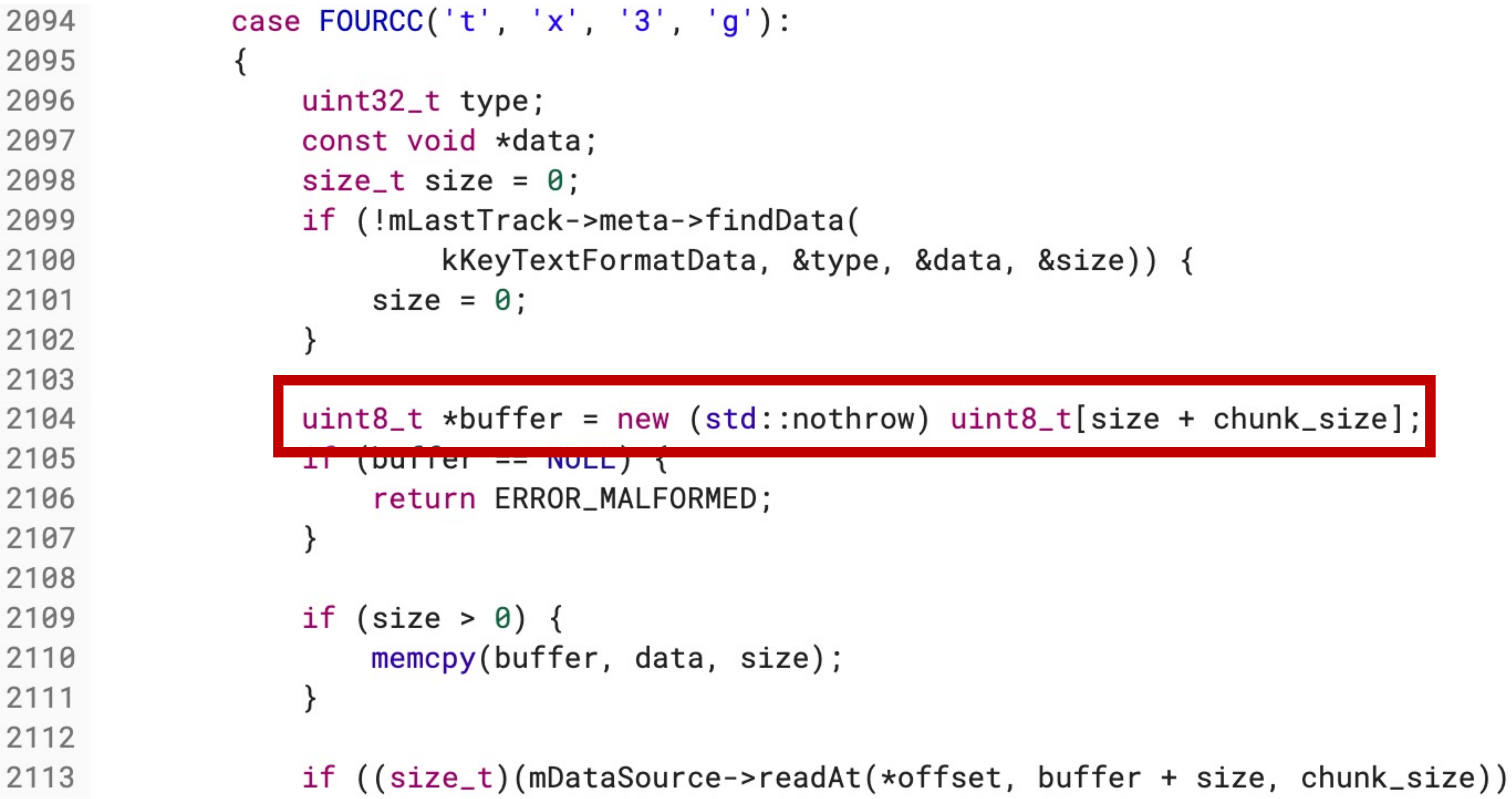
[CVE-2015-1539] Input too Small

- Metadata given as a UTF-16 string
- Shortest possible size of metadata is 6 bytes
- Code that handles metadata subtracts 6 from **`size`**
- For **`size < 6`**, the subtraction underflows and wraps around
  - Result is a very large number
- Frames could then be incorrectly decoded as **`byteswap`** uses a variable whose value is calculated using **`size - 6`**

- Stagefright was not the first to fall into this type of trap!

https://gerrit.omnirom.org/c/android_frameworks_av/+/14228

Integer Overflow [CVE-2015-3824]



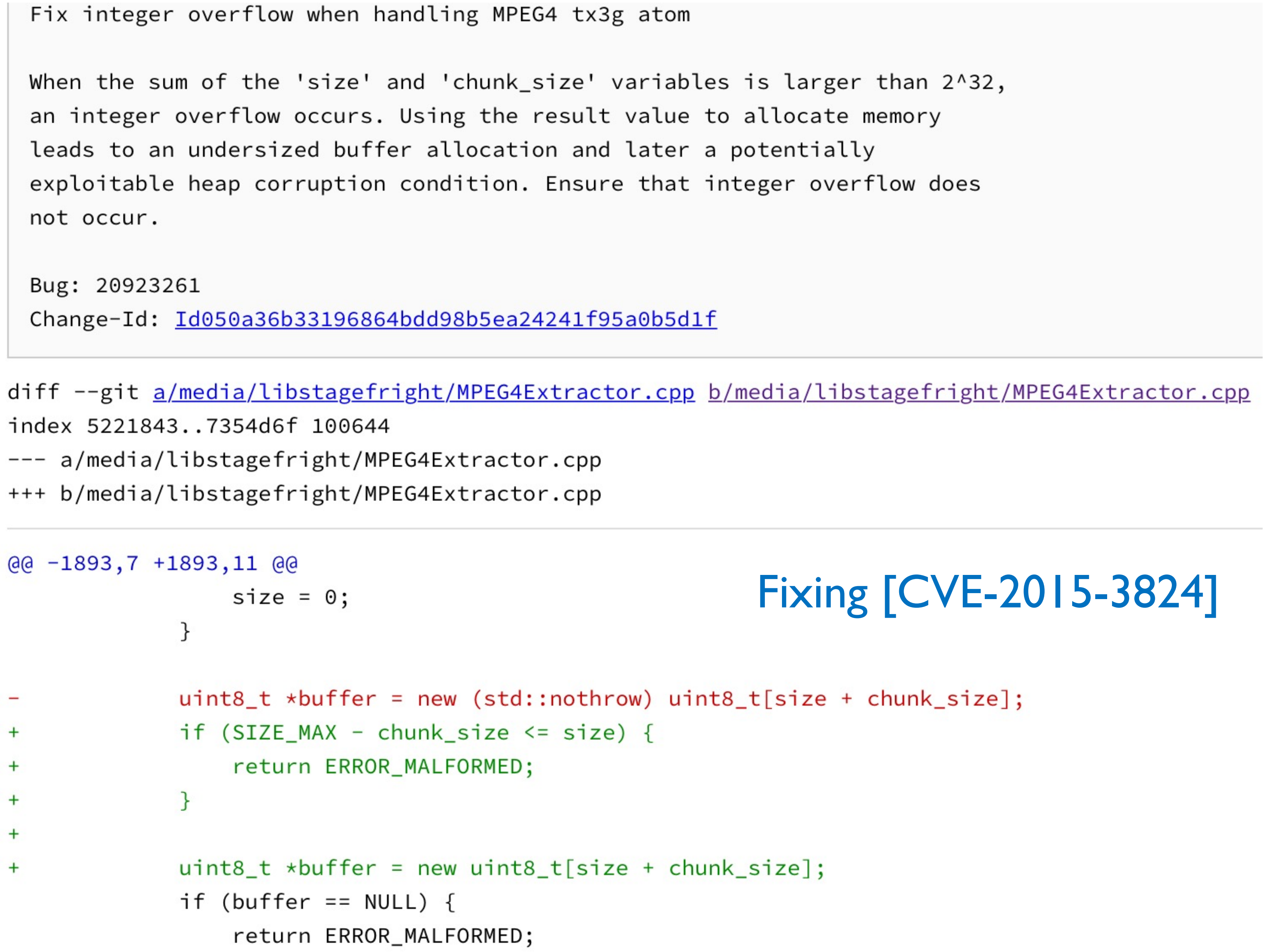
```
case FOURCC('t', 'x', '3', 'g'):
{
    uint32_t type;
    const void *data;
    size_t size = 0;
    if (!mLastTrack->meta->findData(
            kKeyTextFormatData, &type, &data, &size)) {
        size = 0;
    }

    uint8_t *buffer = new (std::nothrow) uint8_t[size + chunk_size];
    if (buffer == NULL) {
        return ERROR_MALFORMED;
    }

    if (size > 0) {
        memcpy(buffer, data, size);
    }

    if ((size_t)(mDataSource->readAt(*offset, buffer + size, chunk_size))
```

http://drippler.com/drip/stagefright-explained-exploit-changed-android

Integer Overflow [CVE-2015-3824]

- Allocating memory of size: `size + chunk_size`
- Can overflow if the sum is big (larger than `2^32`)
- End up with far too little memory allocated in the array
- Potentially lead to exploitable heap corruption condition

Fixing [CVE-2015-3824]



```
Fix integer overflow when handling MPEG4 tx3g atom

When the sum of the 'size' and 'chunk_size' variables is larger than 2^32,
an integer overflow occurs. Using the result value to allocate memory
leads to an undersized buffer allocation and later a potentially
exploitable heap corruption condition. Ensure that integer overflow does
not occur.

Bug: 20923261
Change-Id: Id050a36b33196864bdd98b5ea24241f95a0b5d1f
```

```
diff --git a/media/libstagefright/MPEG4Extractor.cpp b/media/libstagefright/MPEG4Extractor.cpp
index 5221843..7354d6f 100644
--- a/media/libstagefright/MPEG4Extractor.cpp
+++ b/media/libstagefright/MPEG4Extractor.cpp
```

```
@@ -1893,7 +1893,11 @@
                 size = 0;
             }
 
-            uint8_t *buffer = new (std::nothrow) uint8_t[size + chunk_size];
+            if (SIZE_MAX - chunk_size <= size) {
+                return ERROR_MALFORMED;
+            }
+
+            uint8_t *buffer = new uint8_t[size + chunk_size];
             if (buffer == NULL) {
                 return ERROR_MALFORMED;
```

https://android.googlesource.com/platform/frameworks/av/+/463a6f807e187828442949d1924e143cf07778c6 https://www.usenix.org/sites/default/files/conference/protected-files/woot16_slides_drake.pdf

[CVE-2015-3864] Fixing Fixes …

- "When I made my patch for CVE-2015-3824, I missed that **`chunk_size`** is 64-bit and can be above 2^{32}"
- With such a value, the check could be bypassed:

```
if (SIZE_MAX - chunk_size <= size)
{
    return ERROR_MALFORMED;
}
```

- Know your units of measurement!

https://nvd.nist.gov/vuln/detail/CVE-2015-3864 https://www.blackhat.com/docs/us-15/materials/us-15-Drake-Stagefright-Scary-Code-In-The-Heart-Of-Android.pdf

Stagefright – Size Check

```
mTimeToSampleCount = U32_AT(&header[4]);

uint64_t allocSize = mTimeToSampleCount * 2 *
sizeof(uint32_t);
if (allocSize > SIZE_MAX) {
    return ERROR_OUT_OF_RANGE;
}

mTimeToSample = new uint32_t[mTimeToSampleCount * 2];

size_t size = sizeof(uint32_t) * mTimeToSampleCount *
2;
```

32-bit Integer Arithmetic

- In C, the product of two 32-bit integers is a 32-bit integer; the upper 32 bits of the result are lost
  - All factors in the calculation of `allocSize` are of type `uint32_t`
  - `SIZE_MAX` = 2^{32}
- Buffer overflows would not be detected!
- Flawed check makes memory corruption in the heap possible; send malformed MP4 video to overwrite memory locations that give control to the attacker

Stagefright – Summary

- A very powerful set of attacks
  - Large number of devices affected
  - No user interaction needed
  - Attacker just sends an MMS to a phone
- Root cause of the attacks: flaws in integer operations
  - Further technical details need to be explored to turn this vulnerability into an exploit
- Mitigation: ASLR makes this attack more difficult
- Pointer ahead in the course: search for vulnerabilities was conducted with fuzzing

Format String Demo

Read Secret using Format String

```
void vuln(char *user_input){
  char buf[128];

  strcpy(buf, user_input);
  printf(buf);
  printf("\n");
}

int main(int argc, char **argv) {
  char *secret = (char *) malloc(5);
  strcpy(secret, "4067");
  printf("secret is at: %p\n", secret);

  vuln(argv[1]);
}
```

- Disable ASLR (on Linux)
  - `echo 0 | sudo tee /proc/sys/kernel/randomize_va_space`
- Locate constant string on the stack
  - `./format “AAAA$(python -c 'print “%08x ”*20')”`
- Print secret
  - `./format $(python -c 'print “\x60\x81\x55\x56” + “%4$s”')`

Take Aways

- Dangers of abstraction: one may slip up when using 32-bit and 64-bit integers at the same time
  - Programming with a 32-bit language on a 64-bit machine?
- Predictable memory allocation is bad for security
- Next lecture / tutorial: what to leave behind in freed memory?