CSE 374: Programming Concepts and Tools

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Spring 2017
Lecture 25: Undefined Behavior

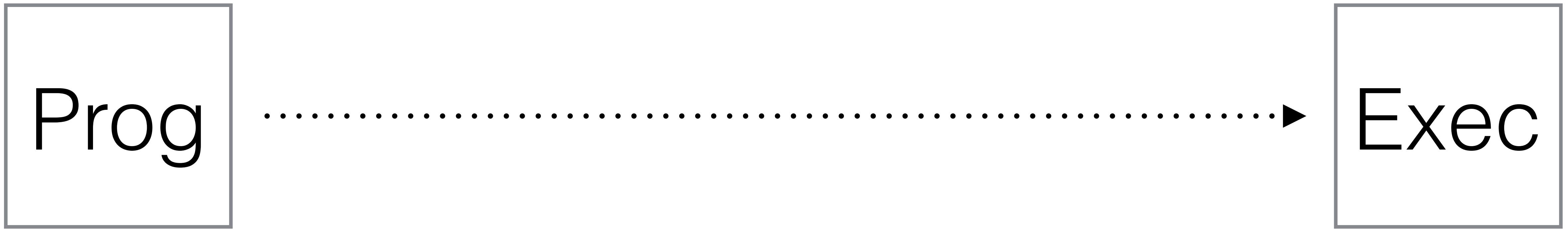
It’s my Birthday!

- I’m super excited to tell you about one of my favorite topics today
- I brought you brownies, eat them
  - Contains: flour, sugar, eggs, vanilla, chocolate, butter, pecans (in some)

Administrivia

- HW6 turned in last night, or using late days
- HW7 out today (demo at end of class)
- HW5 grading is almost done, we'll grade HW6 as fast as we can
- Final review session 2-4pm on Tues, June 6 in CSE 403

Compilation



- In the beginning, the compiler was just a simple, straightforward translator

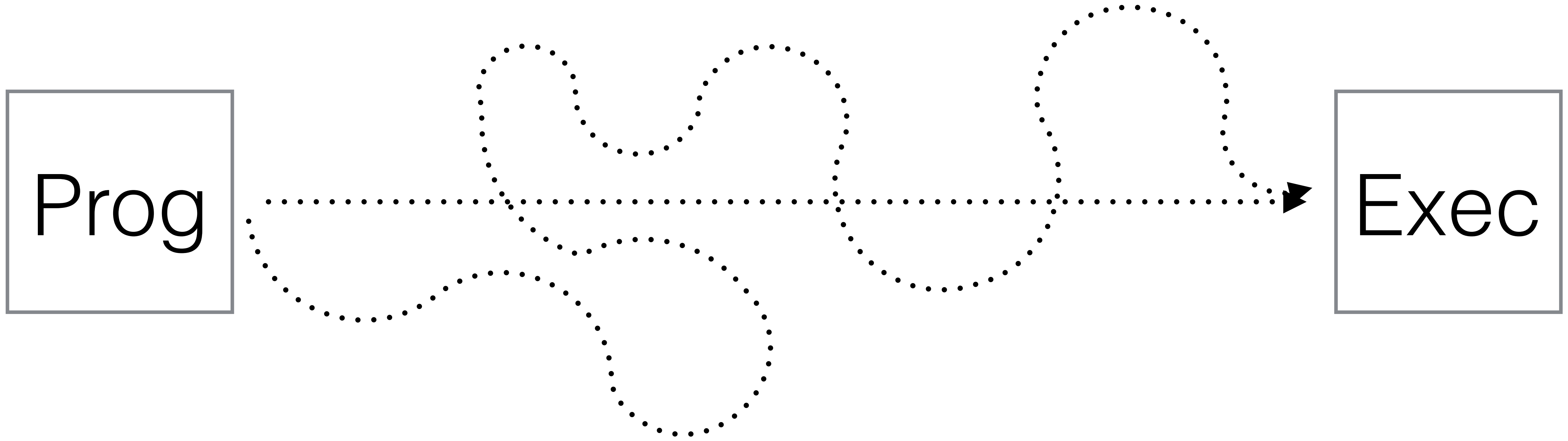
- As the age old story goes, we wanted our code to run faster

Example

```
if (0)
    { do_something(); }
int x=0;
printf(“%d\n”, x);
```

```
int x=0;
printf(“%d\n”, x);
```

Compiler Optimization



- Your code doesn’t take a straight trip down
- All sorts of manipulation on the way down
- Compiler must maintain meaning of the program

Compiler’s Promise

I solemnly swear that the meaning of the output program will match the meaning of the input program*

*As long as the input program has meaning

What if program is weird?

```
int x=0;
int y=0;
while (true) {
    y = x;
    x += 1;
    if (x <= y) {
        printf("weird");
    }
}
```

Overflow

1	1	1	1	1	1	1	1

+1

0	0	0	0	0	0	0	0

What if program is weird?

```
int x=0;
int y=0;
while (true) {
    y = x;
    x += 1;
    if (x <= y) {
        printf("weird");
    }
}
```

What if program is weird?

```
while (true) {
}
```

using clang on macOS, optimized with -O3

Undefined Behavior

- Compiler doesn’t have to maintain meaning if code doesn’t have meaning
- How to get faster code: declare all sorts of things to not have meaning, then allowed to do anything to them
- C may have taken this too far

Undefined Behavior

```
int y = x/0;
```

$\xrightarrow{?}$

```
A. int y = 0;

B. int y = 5;

C. int y = -1;

D. format_drive();

E. launch_missiles();
```

Compiler’s Promise

I solemnly swear that the meaning of the output program will match the meaning of the input program*

If the input has no meaning, the compiler can do anything!

*As long as the input program has meaning

Does this happen in practice?

YES

Undefined Behavior:
What Happened to My Code?
Wang et. al, APSys ‘12

Signed Overflow

- Signed overflow is undefined in C
    - When you have the largest signed number, and you add more to it, the result is undefined according to the C language specification
- This allows for a lot of cool loop optimizations, but also puts us in awkward situations

How to test for overflow?

- Suppose `x` ≥ 0 and `y` > 0
- If `x+y` is negative, then overflow occurred
- This is problematic…

Example

```
int do_fallocate(…,loff_t offset, loff_t len)
{
    struct inode *inode = ...;
    if (offset < 0 || len <= 0)
        return -EINVAL;
    /* Check for wrap through zero too */
    if ((offset + len > inode->i_sb-
>s_maxbytes) || (offset + len < 0))
        return -EFBIG;
    ...
}
```

fs/open.c
Linux Kernel

Example

```
int do_fallocate(…,loff_t offset, loff_t len)
{
    struct inode *inode = ...;
    if (offset < 0 || len <= 0)
        return -EINVAL;
    /* Check for wrap through zero too */
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>s_maxbytes) || (offset + len < 0))
        return -EFBIG;
    ...
}
```

fs/open.c
Linux Kernel

Division by 0

- division by 0 in C is undefined behavior
- If division by 0 ever occurs, entire program has no meaning, and can be transformed into anything
- In practice compilers generate nothing whenever they can

Example

```
if (msize == 0)
   msize = 1 / msize; /* provoke a signal */
```

Result: Entire check removed

from the Linux Kernel:
lib/mpi/mpi-pow.c

Uninitialized Read

- In C, you can make up a variable without putting something in it
- This variable is called “uninitialized”
- If you read from it, that is undefined behavior

Uninitialized Read

- Thought: if there's nothing well defined in there, maybe it's just "kinda random"

- We could use that, with some other stuff, to seed our random number generator

Example

```
struct timeval tv;
unsigned long junk; /* XXX left uninitialized
  on purpose */

gettimeofday(&tv, NULL);
srandom((getpid() << 16) ^ tv.tv_sec ^
  tv.tv_usec ^ junk);
```

lib/libc/stdlib/rand.c in FreeBSD libc

Example

```
struct timeval tv;
unsigned long junk; /* XXX left uninitialized
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gettimeofday(&tv, NULL);
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```

lib/libc/stdlib/rand.c in FreeBSD libc

How to solve?

- we have bandaids not cures
- many different compiler flags to disable optimizations (`-fwrapv` gives meaning to signed overflow)
- flags not complete, even if they were wouldn't be satisfying
- we need something better