

Symbolic Execution with Angr

RPISEC

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```
static int prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            delta = size_limit;
        } else {
            delta = 0;
        }
    } else {
        delta = 0;
    }

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if (((mods[i] + delta) % primes[i]) == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i]) == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```

Overview

- ▶ What is Symbolic Execution? What techniques does it compete with?
- ▶ How symbolic execution works (theory)
- ▶ How symbolic execution works (Angr commands)
- ▶ Solving MBE lab1A with Angr

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        /* avoid undefined behavior. */
        size_limit = (((BN_ULONG)0) - get_word(rnd));
    } else {
        size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
    }
    if (size_limit < maxdelta) {
        maxdelta = size_limit;
    }
    delta = 0;

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if ((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i]) == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```

Background - What it is and what is the problem space?

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) !=
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = ((BN_ULONG)0) - get_word(rnd);
        } else {
            size_limit = (BN_ULONG)0 - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if (((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```

What is Symbolic Execution?

- ▶ Executes a program with symbolic data (usually input)
- ▶ Essentially runs a program on "all possible inputs" at once
- ▶ Instead of having concrete data in each variable/address, variables/addresses store trees of what to do with the input

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) &
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
        delta = 0;
    }
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if ((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i]) == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```

What problems does Symbolic Execution solve?

- ▶ What input to provide to reach/avoid a specific line of code?
- ▶ How is a value deep in the program affected by some specific input?
- ▶ Do any inputs lead to any crash?
- ▶ On a crashing input, what registers are controlled by the input?

```
static inline prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    clear_is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) < 0)
        return 0;

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits < BN_BITS2) {
            /* avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = ((BN_ULONG)1) << bits - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;
    BN_ULONG rnd_word = get_word(rnd);

    /* In the case that the candidate prime is a single word then
     * we check that:
     * 1) It's greater than primes[i] because we shouldn't reject
     *    3 as being a prime number because it's a multiple of
     *    three.
     * 2) That it's not a multiple of a known prime. We don't
     *    check that rnd-1 is also coprime to all the known
     *    primes because there aren't many small primes where
     *    that's true. */
    for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
        if ((mods[i] + delta) % primes[i] == 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
} else {
    for (i = 1; i < NUMPRIMES; i++) {
        /* check that rnd is not a prime and also
         * that gcd(rnd-1, primes) = 1 (except for 2) */
        if (((mods[i] + delta) % primes[i]) == 0) ||
            ((i > 1) && (rnd_word % primes[i]) == 0)) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
}
```

Symbolic Execution vs Fuzzing

Symbolic Execution

- + Explores all inputs
- + Very detailed output
- Uses more memory/time

Fuzzing

- Only explores random inputs
- Only learn crash vs non-crash
- + Uses around as much memory/time as target program

- ▶ Symbolic execution can the path `if(input == 0xdeadbeefdeadbeef) { ... }`
- ▶ Even coverage-guided fuzzing will only find it $\frac{1}{2^{64}}$ of the time¹

¹Unless the compare is digit-by-digit

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (bits == BN_BITS2) {
        /* Avoid undefined behavior. */
        BN_ULONG mod = BN_mod_word(rnd, BN_MASK2 - get_word(rnd));
    } else {
        size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        if (size_limit > maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;
loop:
    if (is_single_word) {
        BN_ULONG mod = BN_mod_word(rnd, BN_MASK2 - get_word(rnd));
    }
    /* In the case that the candidate prime is a single word then
     * we check that:
     * 1) It's greater than primes[i] because we shouldn't reject
     *    3 as being a prime number because it's a multiple of
     *    three.
     * 2) That it's not a multiple of a known prime. We don't
     *    check that rnd-1 is also coprime to all the known
     *    primes because there aren't many small primes where
     *    that's true. */
    for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
        if ((mods[i] + delta) % primes[i] == 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
} else {
    for (i = 1; i < NUMPRIMES; i++) {
        /* check that rnd is not a prime and also
         * that gcd(rnd-1, primes) = 1 (except for 2) */
        if (((mods[i] + delta) % primes[i]) <= 1) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
        }
    }
}
```


Setting up a state for symbolic execution

- ▶

```
import z3
registers = ['eax', 'ebx', 'ecx', 'edx', 'ebp', 'esp'] # and so on
symstate = {reg: z3.BitVec(reg, 32) for reg in registers}
symstate['memory'] = z3.Array('memory', z3.BitVecSort(32), z3.BitVecSort(8))
```
- ▶ Note that the z3 variable `eax` in the model will be the starting value of `eax`
- ▶ `symstate['eax']` will be mutated throughout the computation, and will contain an expression corresponding to the ending value of `eax`

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (bits <= BN_BITS2) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)-1);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        size_limit = ((BN_ULONG)0) + get_word(rnd);
        else {
            size_limit = ((BN_ULONG)0) + bits - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }

loop:
    /* In the case that the candidate prime is a single word then
     * we check that:
     * 1) It's greater than primes[i] because we shouldn't reject
     *    3 as being a prime number because it's a multiple of
     *    three.
     * 2) That it's not a multiple of a known prime. We don't
     *    check that rnd-1 is also coprime to all the known
     *    primes because there aren't many small primes where
     *    that's true. */
    for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
        if ((mods[i] + delta) % primes[i] == 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
} else {
    for (i = 1; i < NUMPRIMES; i++) {
        /* check that rnd is not a prime and also
         * that gcd(rnd-1, primes) = 1 (except for 2) */
        if (((mods[i] + delta) % primes[i]) == 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
}
```


z3.Array vs dict of z3.BitVec for representing memory

- ▶ `memory = z3.Array('memory', z3.BitVecSort(32), z3.BitVecSort(8))` symbolically represents an array of 2^{32} bytes (around 4GB)
- ▶ `z3.Store(memory, index, value)` represents a modified memory (with value written to index), even with *symbolic* index and value
- ▶ `memory[index]` represents a read from memory, even if index is symbolic
- ▶ `memory = {i: z3.BitVec('mem[{i}]'.format(i=i), 8) for i in idxs}` only allows concrete indices, while still allowing symbolic values, and is more efficient when we know we won't have symbolic-indexed reads/writes

```
static prime(BIGNUM *rnd, int bits) {
    int i;
    BN_ULONG mod;
    BN_ULONG mask2 = BN_MASK2 - primes[NUMPRIMES - 1];
    int is_single_word = bits <= BN_BITS2;

again:
    if (BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        /* If bits is so small that it fits into a single word then we
         * can only don't want to exceed that many bits. */
        BN_ULONG size_limit =
            is_single_word ? (BN_ULONG)-1 :
            /* odd-numbered behavior */
            ((BN_ULONG)1) << bits;
        if (BN_ULONG mod < size_limit) {
            /* is the case that the candidate prime is a single word then
             * 1) it is a prime because we shouldn't reject
             * 2) as being a prime number because it's a multiple of
             * 3) a multiple of a known prime. We don't
             * check that rnd-1 is also coprime to all the known
             * primes because there aren't many small primes where
             * that's true. */
            for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
                if ((mod[i] + delta) % primes[i] == 0) {
                    delta += 2;
                    if (delta > maxdelta) {
                        goto again;
                    }
                    goto loop;
                }
            }
        } else {
            for (i = 1; i < NUMPRIMES; i++) {
                /* check that rnd-1 is not a prime and also
                 * that god(rnd-1) = 1 (except for 2) */
                if (((mod[i] + delta) % primes[i]) == 0) {
                    delta += 2;
                    if (delta > maxdelta) {
                        goto again;
                    }
                    goto loop;
                }
            }
        }
    }
}
```

Symbolically executing branch-free code

- Translate arithmetic, indexing, etc into SMT constraints
- Angr internally uses VEX for this instead of translating x86 directly

```
mov eax, ebx
```

```
symstate['eax'] = symstate['ebx']
```

```
add ecx, edx
```

```
symstate['ecx'] += symstate['edx']
```

```
mov byte [esp+0x10], al
```

```
esp_10 = symstate['esp']+0x10  
al = z3.Extract(7, 0, symstate['eax'])  
symstate['memory'] = z3.Store(symstate['memory'], esp_10, al)
```

```
movsx eax, byte [eax]
```

```
star_eax = z3.Select(symstate['memory'], eax)  
symstate['eax'] = z3.SignExt(24, star_eax)
```

```
static int probable_prime(BIGNUM *rnd, int bits) {  
    int i;  
    uint16_t mods[NUMPRIMES];  
    BN_ULONG delta;  
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];  
    char is_single_word = bits <= BN_BITS2;  
  
again:  
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {  
        return 0;  
    }  
  
    /* we now have a random number 'rnd' to test. */  
    for (i = 1; i < NUMPRIMES; i++) {  
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);  
        if (mod == (BN_ULONG)-1) {  
            return 0;  
        }  
        mods[i] = (uint16_t)mod;  
    }  
    /* If bits is so small that it fits into a single word then we  
    * should not have to exceed that many bits. */  
    BN_ULONG size_limit;  
    if (bits == BN_BITS2) {  
        /* Avoid undefined behavior. */  
        size_limit = (((BN_ULONG)0) - get_word(rnd));  
    } else {  
        size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;  
    }  
    if (size_limit < maxdelta) {  
        delta = size_limit;  
    } else {  
        delta = 0;  
    }  
    loop:  
    if (is_single_word) {  
        BN_ULONG rnd_word = get_word(rnd);  
        /* If bits is small enough to fit into a single word then  
        * we don't have to worry about overflowing. */  
        /* If bits is greater than primes[i] because we shouldn't reject  
        * 3 as being a prime number because it's a multiple of  
        * 2. If it is a multiple of a known prime, we don't  
        * check that rnd-1 is also coprime to all the known  
        * primes because there aren't many small primes where  
        * that's true. */  
        for (i = 1; i < NUMPRIMES; i++) {  
            if ((mod[i] + delta) % primes[i] == 0) {  
                if (delta > maxdelta) {  
                    goto again;  
                }  
                goto loop;  
            }  
        }  
    } else {  
        for (i = 1; i < NUMPRIMES; i++) {  
            /* check that rnd-1 is not a prime and also  
            * that gcd(rnd-1, primes) = 1 (except for 2) */  
            if (((mod[i] + delta) % primes[i]) != 1) {  
                if (delta > maxdelta) {  
                    goto again;  
                }  
                goto loop;  
            }  
        }  
    }  
    return 1;  
}
```

Handling symbolic reads with `z3.Array` vs `z3.BitVec`

C.

```
tmp = username[i];
tmp ^= serial;
```

Assembly:

```
0x08048aee    mov edx, dword [local_14h]
0x08048af1    mov eax, dword [arg_8h]
0x08048af4    add eax, edx
0x08048af6    movzx eax, byte [eax]
0x08048af9    movsx eax, al
0x08048afc    xor eax, dword [local_10h]
```

List of z3.BitVec:

```
eax = z3.SignExt(24, sym_username[local_14h])
eax ^= local_10h
```

z3.Array:

```
local_14 = symstate['esp']+0x14 # &i
symstate['edx'] = symstate['memory'][local_14]
arg_8 = symstate['ebp']+0x8 # &username
symstate['eax'] = symstate['memory'][arg_8]
symstate['eax'] += symstate['edx']
symstate['eax'] = z3.ZeroExt(24, symstate['eax'])
al = z3.Extract(7, 0, symstate['eax'])
symstate['eax'] = z3.SignExt(24, al)
local_10 = symstate['esp']+0x10 # &serial
symstate['eax'] ^= symstate['memory'][local_10]
```

[illegible]

Symbolically executing branches - Graphically

```
int f(int x, int y) {
    if (x > 3) {
        x += 1;
    } else {
        y = 2*y+3;
    }
    if(y != 0) {
        x /= y;
    } else {
        x *= 2;
    }
    return x + y;
}
```

$x = x_0, y = y_0$

$x > 3$

$x = x_0 + 1, y = y_0$

$y \neq 0$

$x = \frac{x_0+1}{y_0}$
 $y = y_0$

$y = 0$

$x = 2 * (x_0 + 1)$
 $y = 0$

$y \neq 0$

$x = \frac{x_0}{2*y_0+3}$
 $y = 2*y_0+3$

$y = 0$

$x = 2 * x_0$
 $y = 0$

```
static_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    clear_is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) < 0)
        return 0;

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod <= (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (clear_is_single_word) {
        BN_ULONG size_limit = BN_MASK2;
        if (bits < BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = ((BN_ULONG)0) - get_word(rnd);
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    /* In the case of the candidate prime being a single word then
     * we check that:
     * 1) It's greater than primes[i] because we shouldn't reject
     *    3) It's not a prime number because it's a multiple of
     *    2) That it's not a multiple of a known prime. We don't
     *    check that rnd-1 is also coprime to all the known
     *    primes because that's a much more complicated problem
     *    that's true. */
    for (i = 1; i < NUMPRIMES; i++) {
        if ((mods[i] + delta) % primes[i] == 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
} else {
    for (i = 1; i < NUMPRIMES; i++) {
        /* check that rnd is not a prime and also
         * that gcd(rnd-1, primes) = 1 (except for 2) */
        if (((mods[i] + delta) % primes[i]) <= 0) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
}
```

Symbolically executing branches - Programmatically

```
int f(int x, int y) {  
    if (x > 3) {  
        x += 1;  
    } else {  
        y = 2*y+3;  
    }  
    if(y != 0) {  
        x /= y;  
    } else {  
        x *= 2;  
    }  
    return x + y;  
}
```

```
import z3  
x0, y0 = z3.Ints('x0 y0')  
states, newstates = [(x0, y0, z3.Solver())], []  
for (x, y, s) in states:  
    t = s.__deepcopy__()  
    s.add(x > 3); newstates.append((x+1, y, s))  
    t.add(z3.Not(x > 3)); newstates.append((x, 2*y+3, t))  
states, newstates = newstates, []  
for (x, y, s) in states:  
    t = s.__deepcopy__()  
    s.add(y != 0); newstates.append((x/y, y, s))  
    t.add(z3.Not(y != 0)); newstates.append((2*x, y, t))  
for (x, y, s) in newstates:  
    print('x: %r; y: %r; s: %r; check: %r' % (x, y, s, s.check()))  
    if s.check() == z3.sat:  
        m = s.model()  
        print('m: %r; x: %r; y: %r' % (m, m.evaluate(x), m.evaluate(y)))  
        print('-'*5)
```

```
static int probable_prime(BIGNUM *rnd, int bits) {  
    int i;  
    uint16_t mods[NUMPRIMES];  
    int delta;  
    uint32_t maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];  
    bool is_single_word = bits <= BN_BITS2;  
  
again:  
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {  
        return 0;  
    }  
  
    /* we now have a random number 'rnd' to test. */  
    for (i = 1; i < NUMPRIMES; i++) {  
        BN_ULONG mod = BN_UWORD_mod_word(rnd, (BN_ULONG)primes[i]);  
        if (mod == 0) return 0;  
        mods[i] = (uint16_t)mod;  
    }  
    /* If bits is so small that it fits into a single word then we  
    * don't want to exceed that many bits. */  
    BN_ULONG size_limit = BN_UWORD; /* BN_ULONG */  
    /* Need to avoid overflow. */  
    size_limit = (((BN_ULONG)0) - get_word(rnd));  
    } else {  
        size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;  
    }  
    if (size_limit < maxdelta) {  
        maxdelta = size_limit;  
    }  
    delta = 0;  
  
    if (!is_single_word) {  
        BN_ULONG mod = BN_UWORD_mod_word(rnd);  
        /* In the case that the candidate prime is a single word then  
        * we check that:  
        * 1) It's greater than primes[i] because we shouldn't reject  
        * 3 as being a prime number because it's a multiple of  
        * three.  
        * 2) that it's not a multiple of a small prime. We don't  
        * know the size of the prime, so we check for all the known  
        * primes because there aren't many small primes where  
        * that's true. */  
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {  
            if ((mods[i] + delta) % primes[i] == 0) {  
                delta += 2;  
                if (delta > maxdelta) {  
                    goto loop;  
                }  
            }  
        }  
    } else {  
        for (i = 1; i < NUMPRIMES; i++) {  
            /* check that rnd is not a prime and also  
            * that get_word(rnd) == 1 (except for 2) */  
            if (((mod[i] + delta) % primes[i]) == 0) {  
                delta += 2;  
                if (delta > maxdelta) {  
                    goto loop;  
                }  
            }  
        }  
    }  
    return 1;  
}
```

Symbolically executing loops

```
void memcpy(  
    char *dest,  
    const char *src,  
    size_t n) {  
    for(size_t i=0; i<n; i++) {  
        dest[i] = src[i];  
    }  
}
```

$$i = 0$$

```
mem = mem0
```

$$i < n$$
$$i = 1$$
$$mem_1 = Store(mem_0, dst + 0, mem_0[src + 0])$$
$$i < n$$
 $i = 2$
$$mem_2 = Store(mem_1, dst + 1, mem_1[src + 1])$$
$$i < n$$

`static int prime_prob(BIGNUM *rnd, int bits) {`

`int i;`

`uint16_t mods[NUMPRIMES];`

`BN_ULONG delta;`

`BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];`

`char is_single_word = bits <= BN_BITS2;`

`again:`

`if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) &&`

`return 0;`

`/* we now have a random number 'rnd' to test. */`

`for (i = 1; i < NUMPRIMES; i++) {`

`mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);`

`if ((BN_ULONG)-1) {`

`return 0;`

`mods[i] = (uint16_t)mod;`

`if bits is so small that it fits into a single word then we`

`* additionally don't want to exceed that many bits. */`

`if (!is_single_word) {`

`ULONG size_limit;`

`(bits == BN_BITS2) {`

`size_limit = (((BN_ULONG)0) - get_word(rnd));`

`/* Avoid undefined behavior. */`

`size_limit = ((BN_ULONG)-1) - get_word(rnd) - 1;`

`if (size_limit < maxdelta) {`

`maxdelta = size_limit;`

`delta = 0;`

`loop:`

`if (!is_single_word) {`

`BN_ULONG rnd_word = get_word(rnd);`

`In the case that the candidate prime is a single word then`

`* we check that:`

`* 1) It's greater than primes[i] because we shouldn't reject`

`* candidates that are multiples of primes[i] because it's a multiple of`

`* 2) that it's not a multiple of a known prime. We don't`

`* check that rnd-1 is also coprime to all the known`

`* primes because there aren't very small primes where`

`* that's true. */`

`for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {`

`if ((mods[i] + delta) % primes[i] == 0) {`

`delta += 2;`

`if (delta > maxdelta) {`

`goto again;`

`goto loop;`

`} else {`

`for (i = 1; i < NUMPRIMES; i++) {`

`/* check that rnd is not a prime and also`

`* that gcd(rnd-1, primes[i]) = 1 (except for 2). */`

`if (((mods[i] + delta) % primes[i]) != 1 ||`

`delta += 2;`

TODO: Luke

- ▶ loading binariess
- ▶ marking input as symbolic
- ▶ initiating the search/pruning the search space
- ▶ simprocedures for shortcutting syscalls?

```
static int prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) &
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if ((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i]) == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```


Example: MBE lab1A with Angr

```
static int probable_prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if ((BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) &
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if (((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
            }
        }
    }
}
```

Resources

- ▶ <https://github.com/angr/>
- ▶ <https://github.com/Z3Prover/z3/>
- ▶ <https://github.com/RPISEC/MBE>

```
static int prime(BIGNUM *rnd, int bits) {
    int i;
    uint16_t mods[NUMPRIMES];
    BN_ULONG delta;
    BN_ULONG maxdelta = BN_MASK2 - primes[NUMPRIMES - 1];
    char is_single_word = bits <= BN_BITS2;

again:
    if (!BN_rand(rnd, bits, BN_RAND_TOP_TWO, BN_RAND_BOTTOM_ODD)) {
        return 0;
    }

    /* we now have a random number 'rnd' to test. */
    for (i = 1; i < NUMPRIMES; i++) {
        BN_ULONG mod = BN_mod_word(rnd, (BN_ULONG)primes[i]);
        if (mod == (BN_ULONG)-1) {
            return 0;
        }
        mods[i] = (uint16_t)mod;
    }
    /* If bits is so small that it fits into a single word then we
     * additionally don't want to exceed that many bits. */
    if (is_single_word) {
        BN_ULONG size_limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            size_limit = (((BN_ULONG)0) - get_word(rnd));
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;

loop:
    if (is_single_word) {
        BN_ULONG rnd_word = get_word(rnd);

        /* In the case that the candidate prime is a single word then
         * we check that:
         * 1) It's greater than primes[i] because we shouldn't reject
         *    3 as being a prime number because it's a multiple of
         *    three.
         * 2) That it's not a multiple of a known prime. We don't
         *    check that rnd-1 is also coprime to all the known
         *    primes because there aren't many small primes where
         *    that's true. */
        for (i = 1; i < NUMPRIMES && primes[i] < rnd_word; i++) {
            if ((mods[i] + delta) % primes[i] == 0) {
                delta += 2;
                if (delta > maxdelta) {
                    goto again;
                }
                goto loop;
            }
        }
    } else {
        for (i = 1; i < NUMPRIMES; i++) {
            /* check that rnd is not a prime and also
             * that gcd(rnd-1, primes) = 1 (except for 2) */
            if (((mods[i] + delta) % primes[i]) != 0) {
                delta += 2;
            }
        }
    }
}
```