

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) {
            if (BN_mod_word(rnd, size_limit) < maxdelta) {
                delta = 0;
            } 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;
            }
        }
    }
}
```

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. */
        /* 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)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;
                }
            }
        }
    }
}
```

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) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
}
```

Symbolic Execution vs Fuzzing

Symbolic Execution

+ Explores all inputs

- Uses more memory/time

Fuzzing

- Only explores random inputs

+ Uses around as much memory/time as target program

TODO: more comparisons/columns? emphasize that "all inputs" means that symexec can find constant-time comparisons against a giant constant, unlike coverage-guided?

```
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) {
        size_limit =
            (bits <= BN_BITS2) ?
            /* Randomized behavior. */
            size_limit = ((BN_ULONG)1) << bits - get_word(rnd);
        else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        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]) <= 1) {
            delta += 2;
            if (delta > maxdelta) {
                goto again;
            }
            goto loop;
        }
    }
}
```


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 limit;
        if (bits == BN_BITS2) {
            /* Avoid undefined behavior. */
            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;
            }
        }
    }
}
```


Symbolically executing branch-free code

- Translate arithmetic, indexing, etc into SMT constraints

```
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
     * 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(end);
        } else {
            size_limit = (((BN_ULONG)1) << bits) - get_word(rnd) - 1;
        }
        if (size_limit < maxdelta) {
            maxdelta = size_limit;
        }
    }
    delta = 0;
    /* loop.
     * 1) That 'rnd' is not a multiple of any of the primes. We don't
     *    check that 'rnd-1' is also prime 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;
        }
    }
    /* check that 'rnd' is not a prime and also
     * that 'gcd(rnd-1, primes) == 1' (except for 2) */
    if (((mods[1] + delta) % primes[1]) != 1) {
        delta += 2;
    }
}
```

TODO: Avi

- ▶ symbolic branches
- ▶ symbolic loops
- ▶ symbolizing tainted memory (e.g. `sym_memory[(EBP+username+i)]` vs `sym_username[i]`)
- ▶ state explosion when looping on symbolic data

```
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;
                }
            }
        }
    }
}
```


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)) < 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;

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;
            }
        }
    }
}
```