Task 0

```
$ wget hexgolems.com/smt/img.ova
```

setup VM (with Virtualbox)

```
$ ssh smtworkshop@127.0.0.1 -p 2222
```

password: smtlogin

SMT-Solver

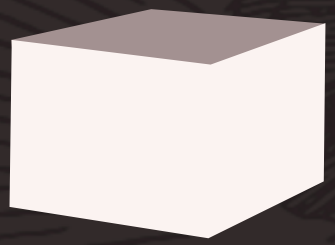
for reversing

About me

coco@hexgolems.de

PHD student from Ruhr-Universität Bochum

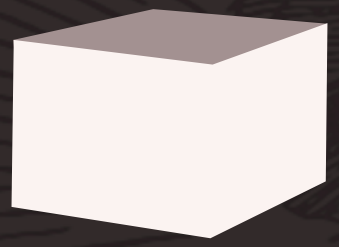
RE, security, theory and bouldering



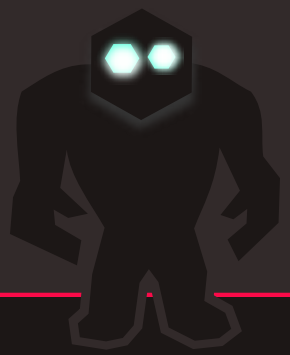
SMT Solver

x < 5
x+3 >= 4
x*2 < 3
x > 0

Constraints

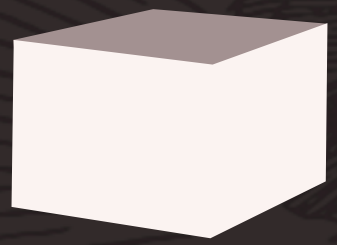


SMT Solver



$x < 5$
$x+3 >= 4$
$x*2 < 3$
$x > 0$

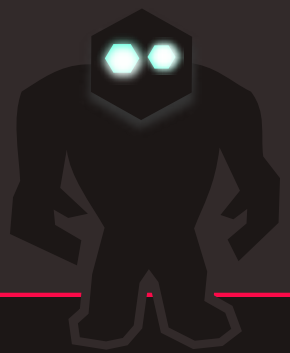
Constraints



SMT Solver

$x = 1$

Solution



x < 5
x+3 >= 4
x*2 < 3
x > 0

Constraints

Magic

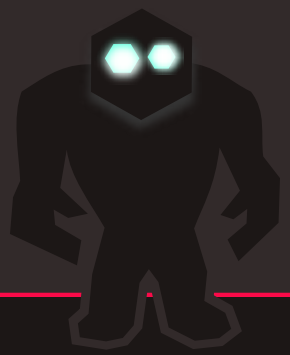
x = 1

Solution

Why bother?

Why bother?

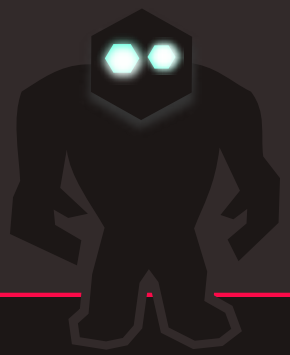
```
ENC("secret...", k) == "13b7c9...."
```



Why bother?

```
ENC("secret...", k) == "13b7c9...."
```

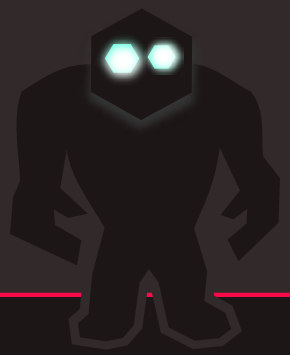
(Happened to Petya)



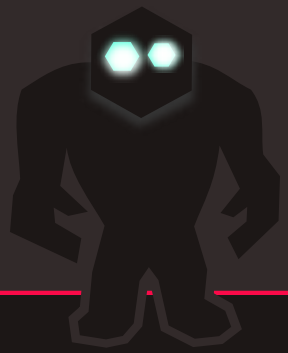
Why bother?

ENC("secret...", k) == "13b7c9...."

Or any function



CONSTRAINTS

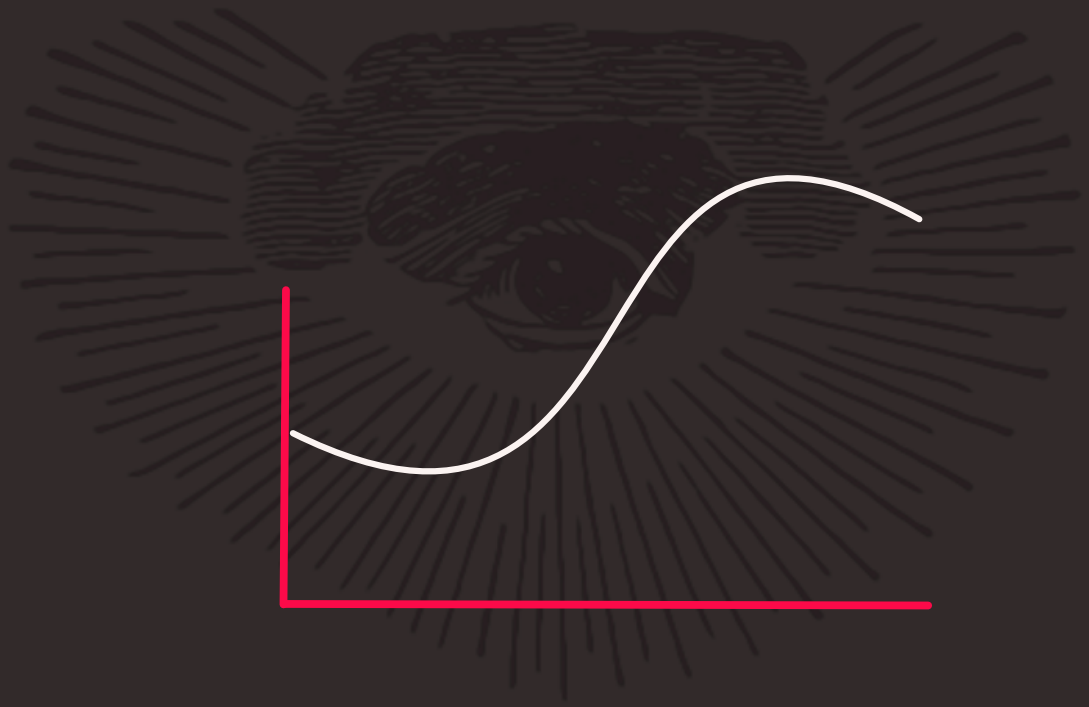


Linear Constraints

$x+y==z$

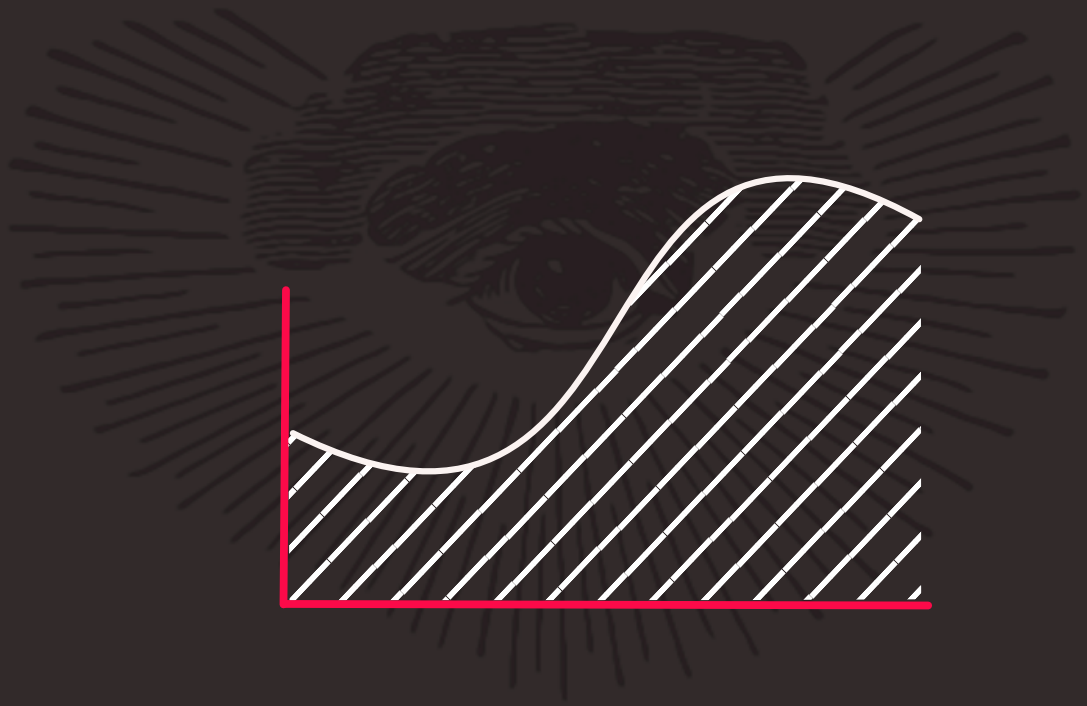
Non-Linear Constraints

x*y==z



Inequalities

x*y <= z



Logical Ops

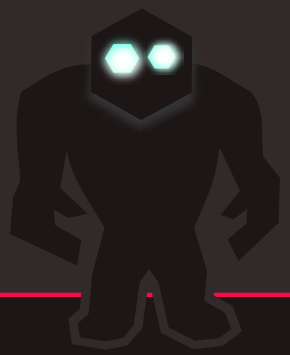
```
(x*y<=z) || x<4
```

Binary Ops

x&y <= z

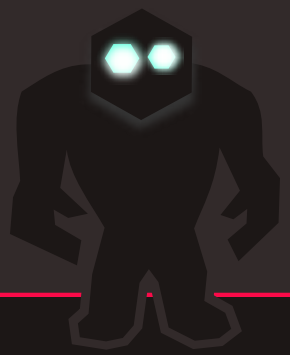
Whatever goes here

$$\texttt{if}(\overbrace{\ldots\ldots}) \{ \ldots \}$$



We can use as constraint*

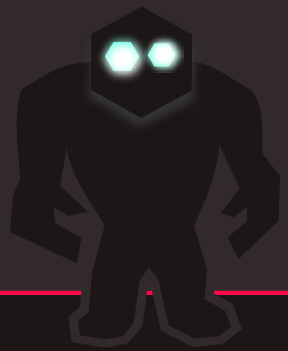
Assert(.....)



*Standard Terms & Conditions Apply

(u)int ✓

x*2 == 4



Overflows ✓

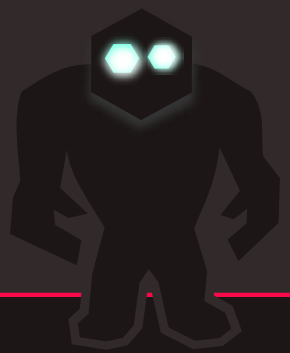
$$x-1 > 5 \;\&\&\; x < 5$$

Weird Ops

x%y^3

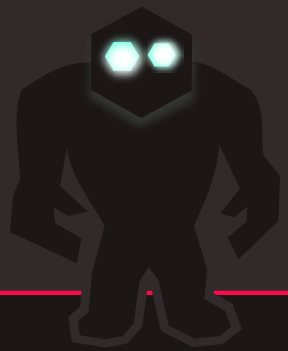
float

```
x*x == 2
```



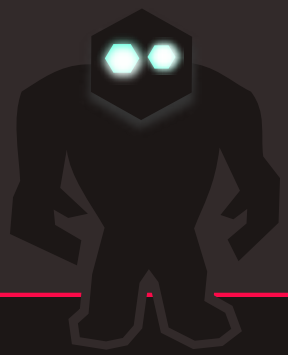
~~float~~

~~x*x == 2~~

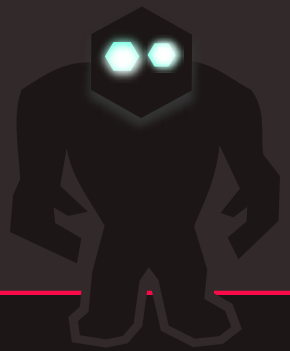


int[] ✓

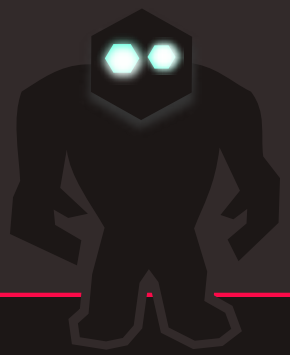
x[y] + y



CODE

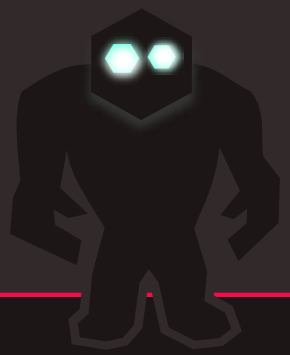


```
Assert( x*20 == 100 )
Assert(   x <= 100     )
```



```
Assert( x*20 == 100 )
Assert(   x <= 100     )
```

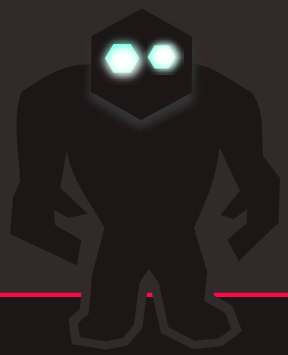
What is x?



```
x =   Var(64, "x")
  Assert( x*20 == 100 )
  Assert(   x <= 100      )
```

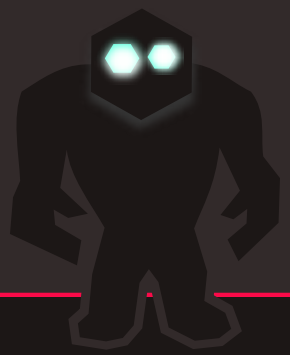
Unique

```
x =   Var(64, "x")
  Assert( x*20 == 100 )
  Assert(   x <= 100      )
```



```
x =   Var(64, "x")
  Assert( x*20 == 100 )
  Assert(   x <= 100     )
```

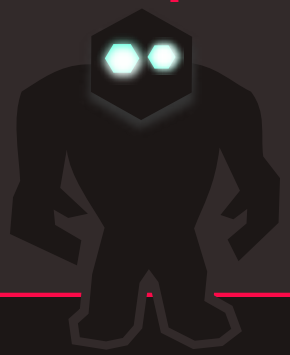
Signedness?



```
x =   Var(64, "x")
  Assert( x*20 == 100 )
  Assert(    Ulte(x, 100) )
```

```
b = Boolector()
x = b.Var(64, "x")
b.Assert( x*20 == 100 )
b.Assert( b.Ulte(x, 100) )
```

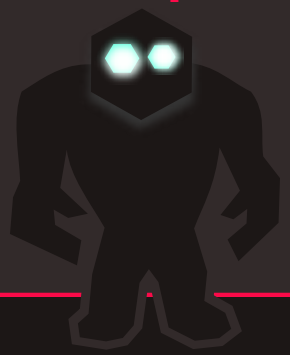
```python
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```



Import

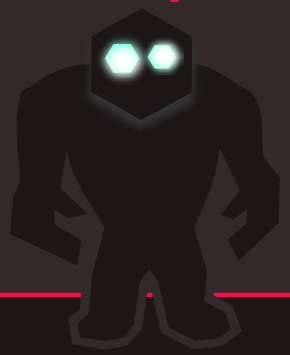
```
from boolector import Boolector
```

```
b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```



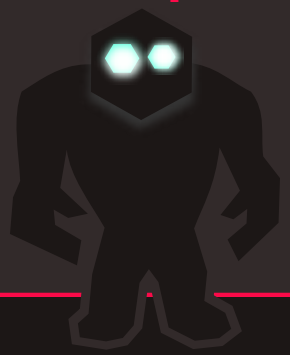
```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

We want the solution



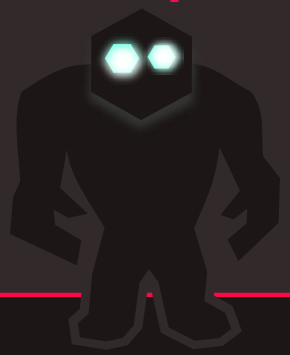
```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

We can use constants



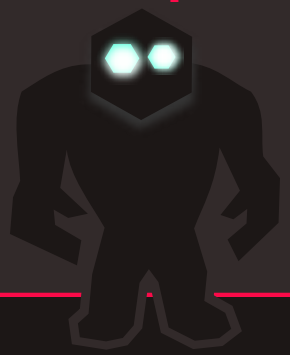
```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

With given value



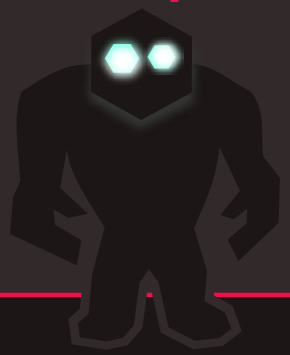
```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

... and bit width



```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

Try to solve



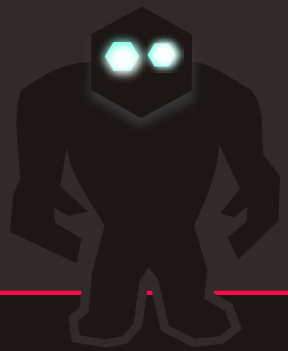
```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

Print Solution

```
from boolector import Boolector

b = Boolector()
b.Set_opt("model_gen", 1)

const   = b.Const(133713378, 64)
x       = b.Var(64, "x")

b.Assert(x*20 == 100)
b.Assert(b.Ult(x, 100))

res = b.Sat()

if res == b.SAT:
    print("{} {}".format(x.symbol, int(x.assignment, 2)))
else:
    print("unsat")
```

:-(

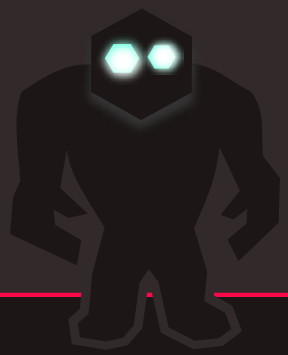
TASK



Find x (int64_t) such that:

x < 0

x*133713378 == 13372



Task 1

Find x (int64_t) such that:

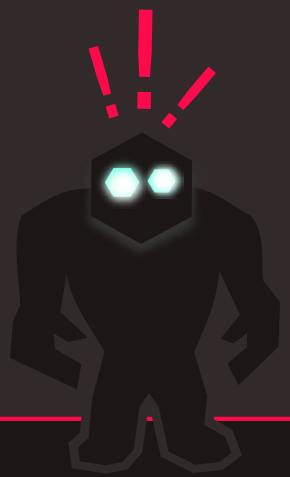
x < 0
x*133713378 == 13372

code in: ~/smt/task_1.py

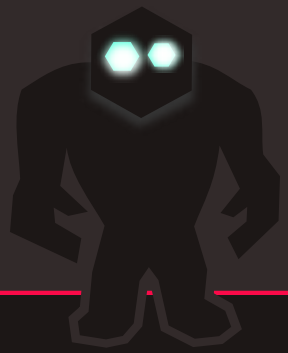
b.Slt(x,y) //Signed less than

Hint: There is a solution

Tips



Universality



So far: "Find x,y,z such that ψ becomes true"

Variables

So far: "Find x,y,z such that ψ becomes true"

Any formula

So far: "Find x,y,z such that ψ becomes true"

Now: "is ψ always true?"

Now: "is ψ always true?"

$$\Longleftrightarrow$$

not(ψ) has no solution

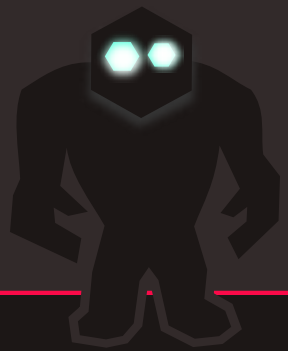
Now: "is ψ always true?"

$$\Longleftrightarrow$$

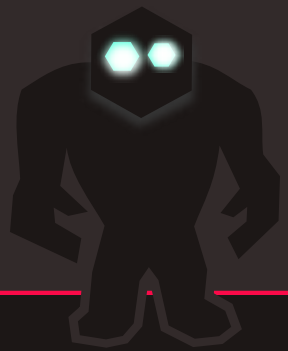
not(ψ) has no solution

ask Solver!

TASK



```
((x | y) & ~(x & y)) + 2*(x&y)
```



```
x      y      ((x | y) & ~(x & y)) + 2*(x&y)
```

x	y	((x | y) & ~(x & y)) + 2*(x&y)
1	1	2

x	y	((x | y) & ~(x & y)) + 2*(x&y)
1	1	2
5	1	6

x	y	((x | y) & ~(x & y)) + 2*(x&y)
1	1	2
5	1	6
2	5	7

$$((x \mid y) \,\&\, \sim(x \,\&\, y)) + 2*(x\&y)$$

$$\stackrel{?}{=}$$

$$x+y$$

Task 2

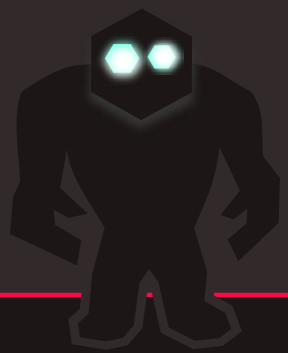
Are

```
((x | y) & ~(x & y)) + 2*(x&y)
```

and

```
x+y
```

always the same?



Task 2

Are

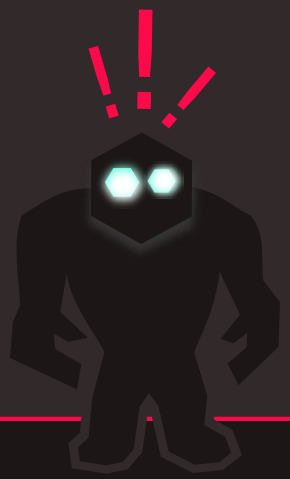
((x | y) & ~(x & y)) + 2*(x&y)

and

x+y

always the same?

Tips

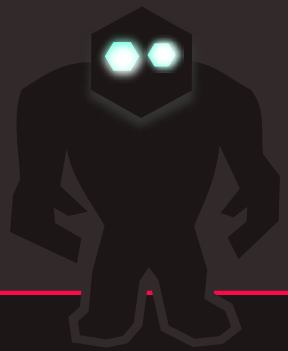


code in: ~/smt/task_2.py

~x //Binary negation

Bonus Task

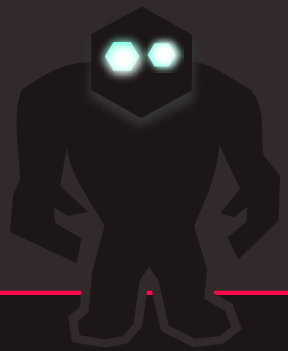
```
if((x*x+x)%2 == 0){
    //[...]
}else{
    //[...]
}
```



Bonus Task

WTF?

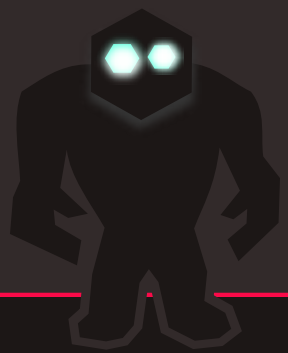
```
if((x*x+x)%2 == 0){
    //[...]
}else{
    //[...]
}
```



Bonus Task

```
if((x*x+x)%2 == 0){
    //[...]
}else{
    //[...]
}
```

Can we get here?

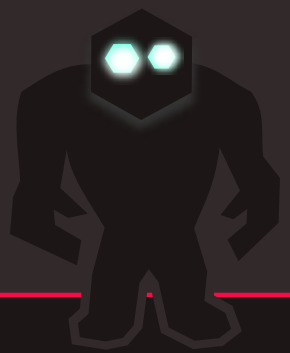


Bonus Task

```
if((x*x+x)%2 == 0){
    //[...]
}else{
    //[...]
}
```

Can we get here?

(Yes x = 0)



Bonus Task

```
if((x*x+x)%2 == 0){
    //[...]
}else{
    //[...]
}
```

Can we get here?

Workflow

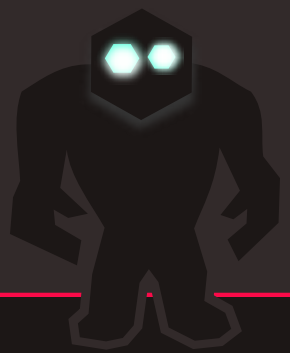
?

Workflow

?

```
x < 5
x+3 >= 4
x*2 < 3
x > 0
```

Translate



Workflow

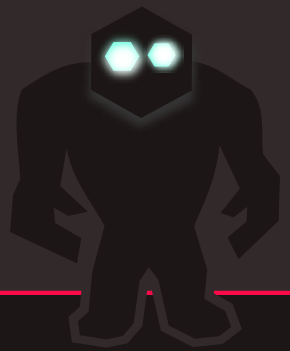
?

$x < 5$
$x+3 >= 4$
$x*2 < 3$
$x > 0$

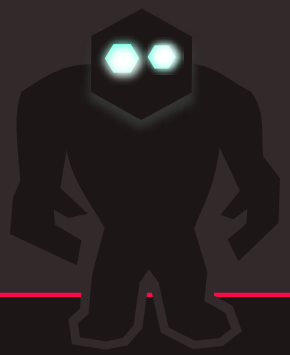
$x = 1$

Translate

SMT



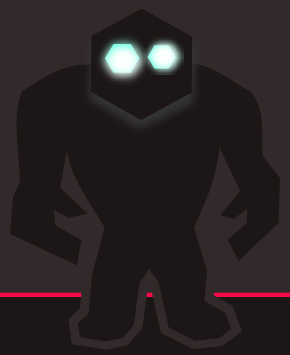
INPUT CRAFTING



$y = P(x)$

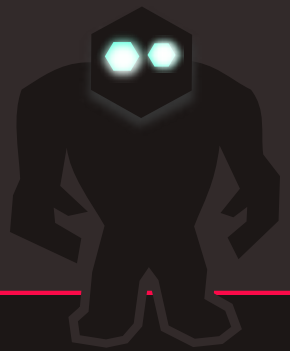
$$y = P(x)$$

Inputs



$y = P(x)$

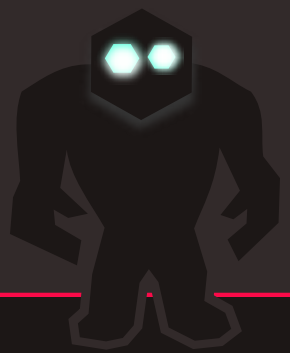
State after $P(x)$



$y = P(x)$

State after $P(x)$

(Variables / Registers
Memory)



$y = P(x)$

Is there x such that $\psi(y)$?

$y = P(x)$

Is there x such that $\psi(y)$?

Translate

(Formula that "runs" P) && $\psi(y)$

$y = P(x)$

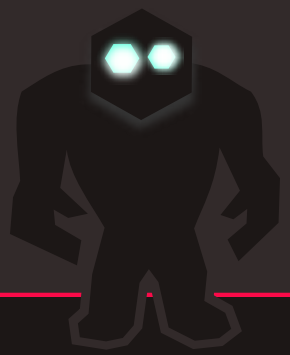
Is there x such that $\psi(y)$?

Translate

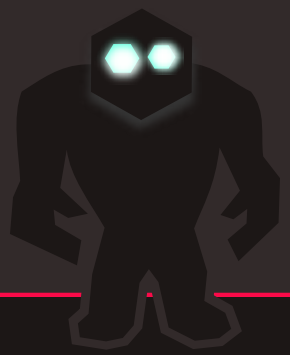
(Formula that "runs" P) && $\psi(y)$

Solver finds x

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
uint64_t c = a + b;
```

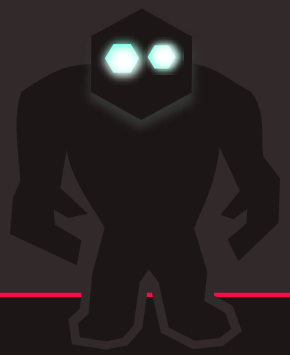


```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
uint64_t c = a + b;
// c == 0x1
```



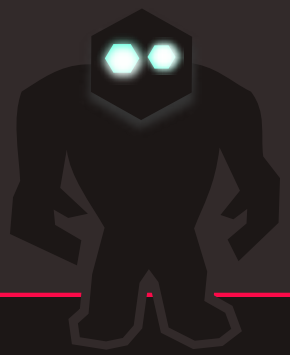
Translate

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
uint64_t c = a + b;
// c == 0x1
```



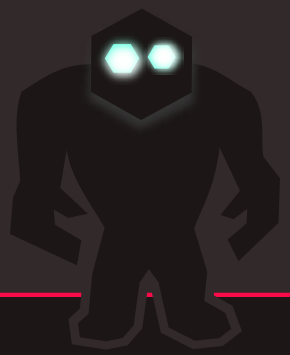
Translate

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
uint64_t c = a + b;
Assert(c == 0x1)
```



Translate

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
Assert(c == a + b)
Assert(c == 0x1)
```



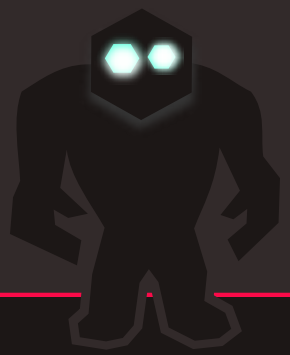
Translate

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
uint64_t b = x * 0x94d941135c908617;
Assert(c == a + b)
Assert(c == 0x1)
```

Assert, not Assign

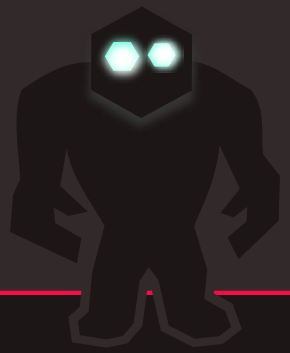
Translate

```
uint64_t x = read_uint();
uint64_t a = x ^ 0xd701ecf9bd67d788;
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```



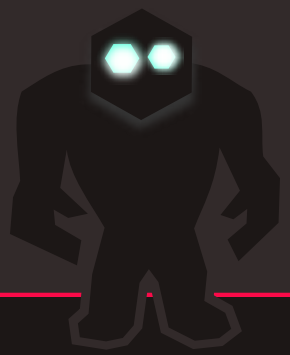
Translate

```
uint64_t x = read_uint();
Assert(a == x ^ 0xd701ecf9bd67d788)
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```



Translate

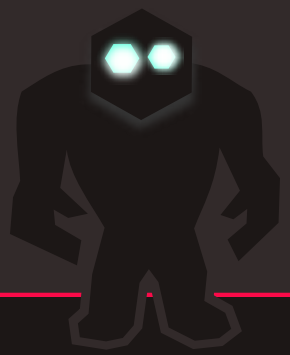
```
x = Var(64, "x")
Assert(a == x ^ 0xd701ecf9bd67d788)
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```



Translate

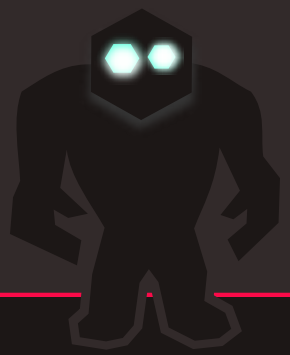
Craft Input

```
x = Var(64, "x")
Assert(a == x ^ 0xd701ecf9bd67d788)
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```



Translate

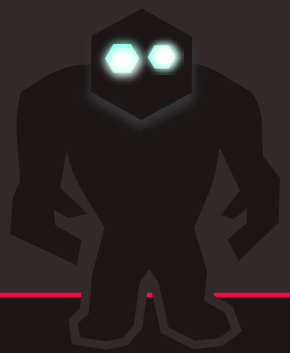
```
a = Var(64, "a")
b = Var(64, "b")
c = Var(64, "c")
x = Var(64, "x")
Assert(a == x ^ 0xd701ecf9bd67d788)
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```



Translate

Necessary Evil

```
a = Var(64, "a")
b = Var(64, "b")
c = Var(64, "c")
x = Var(64, "x")
Assert(a == x ^ 0xd701ecf9bd67d788)
Assert(b == x * 0x94d941135c908617)
Assert(c == a + b)
Assert(c == 0x1)
```

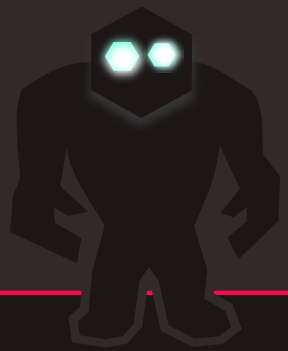


```
x = x + 1
a = x + 2
```

Translate

```
x = x + 1
a = x + 2
```

```
Assert(x == x + 1)
Assert(a == x + 2)
```

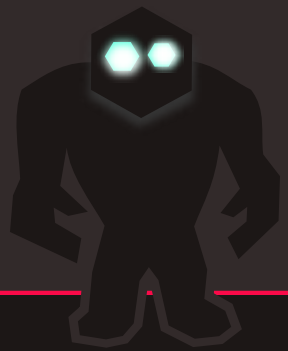


Unsat

Translate

```
x = x + 1
a = x + 2
```

```
Assert(x == x + 1)
Assert(a == x + 2)
```

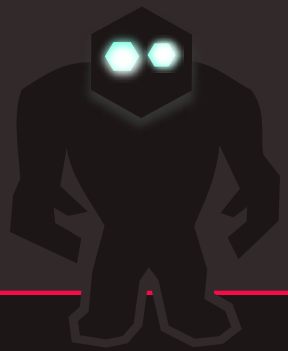


Unsat

Translate

```
x = x + 1
a = x + 2
```

~~Assert(x == x + 1)~~
~~Assert(a == x + 2)~~



SSA

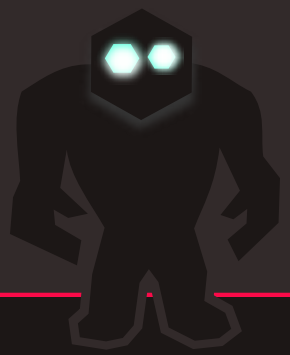
⋮

sets x

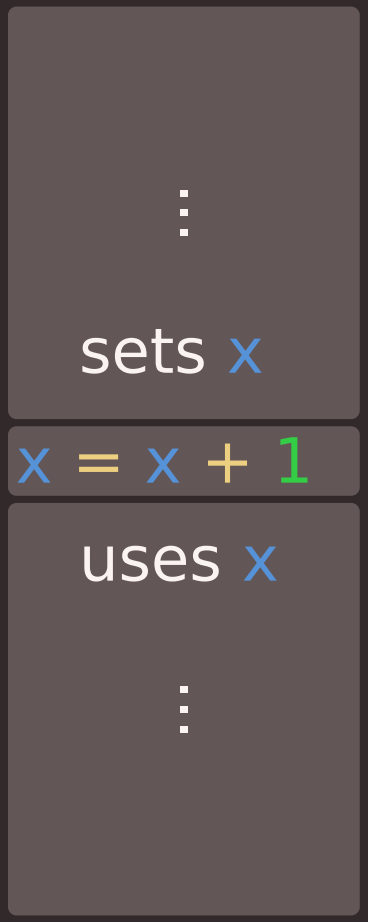
x = x + 1

uses x

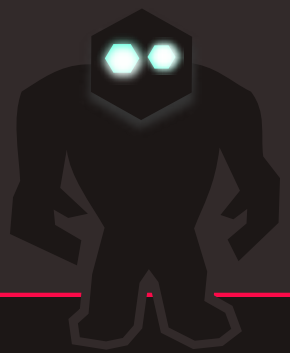
⋮



SSA



code where x is assigned



SSA

⋮

sets x

x = x + 1

uses x

⋮

x assigned second time

SSA

⋮

sets x

x = x + 1

uses x

⋮

x is used/set some more

SSA

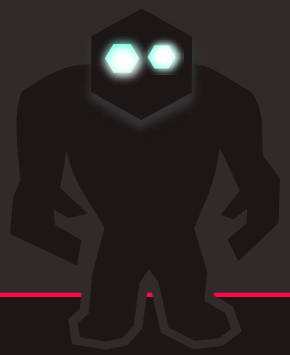
⋮

sets x

x1 = x + 1

uses x1

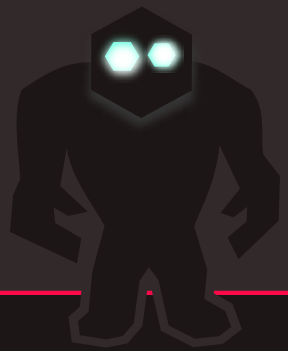
⋮



Translate

```
x = x + 1
a = x + 2
```

~~Assert(x == x + 1)~~
~~Assert(a == x + 2)~~



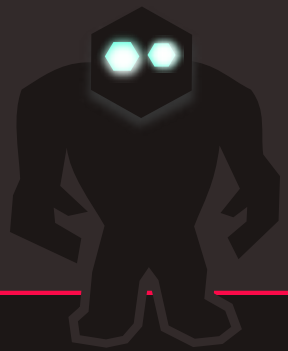
Translate

```
x = x + 1
a = x + 2
```

~~Assert(x == x + 1)~~
~~Assert(a == x + 2)~~

SSA

```
x1 = x  + 1
 a = x1 + 2
```



Translate

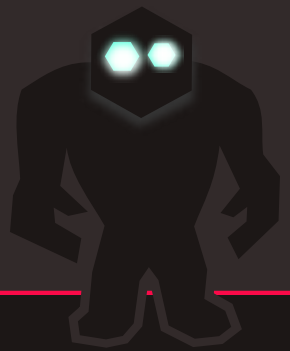
```
x = x + 1
a = x + 2
```

~~Assert(x == x + 1)~~
~~Assert(a == x + 2)~~

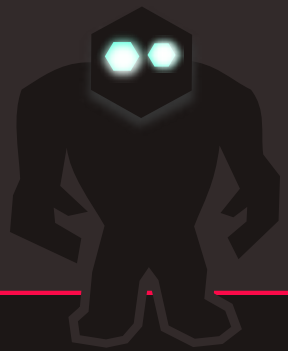
SSA

```
x1 = x  + 1
 a = x1 + 2
```

Assert(x1 == x + 1)
Assert(a == x1 + 2)



TASK



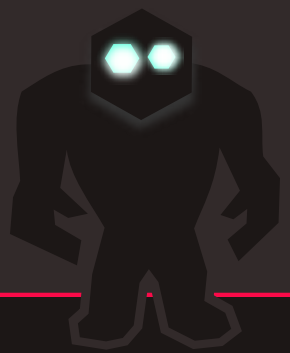
Task 3

find input x

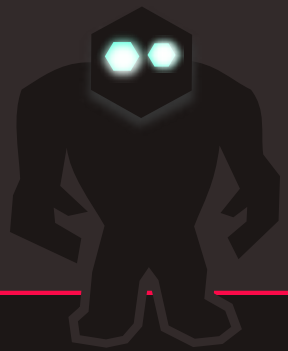
```
int main(){
  uint64_t x = read_uint();
  uint64_t a = 0;

  a += x;
  x = x ^ 0xd701ecf9bd67d788;
  a += x;
  x = x * 0x94d941135c908617;
  a += x;
  return a;
}
```

xor

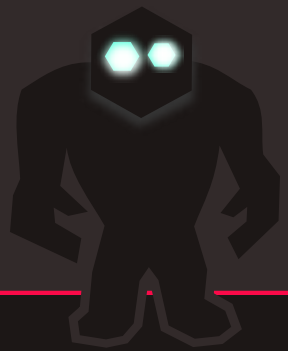
to return 1



CONTROL FLOW



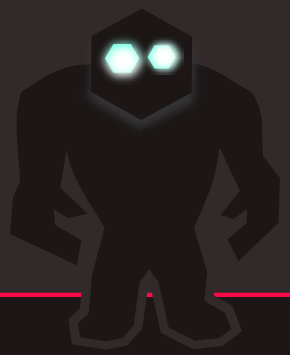
```
if(i == 0) {
    x = x + 5;
} else {
    x = x + 3;
}
y = x;
```



```
if(i == 0) {
   x = x + 5;
} else {
   x = x + 3;
}
y = x;
```

SSA →

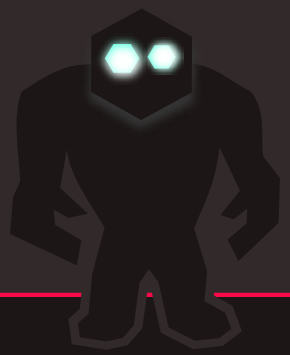
```
if(i == 0) {
   x1 = x + 5;
} else {
   x2 = x + 3;
}
y = x???;
```



```
if(i == 0) {
   x = x + 5;
} else {
   x = x + 3;
}
y = x;
```

SSA →

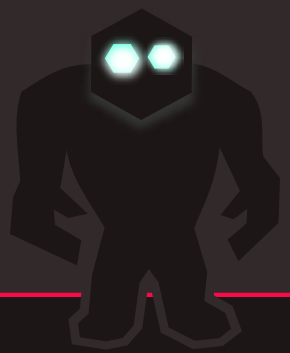
```
if(i == 0) {
   x1 = x + 5;
} else {
   x2 = x + 3;
}
y = (i==0)? x1 : x2;
```



```
if(i == 0) {
   x = x + 5;
} else {
   x = x + 3;
}
y = x;
```

SSA →

```
x1 = x + 5;
x2 = x + 3;
y = (i==0)? x1 : x2;
```



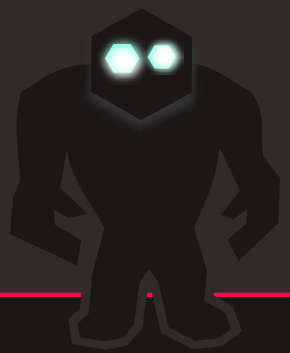
```
if(i == 0) {
   x = x + 5;
} else {
   x = x + 3;
}
y = x;
```

SSA

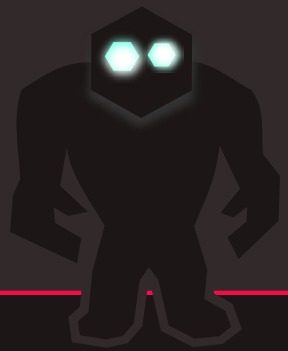
```
x1 = x + 5;
x2 = x + 3;
y = (i==0)? x1 : x2;
```

Translate

```
Assert(x1 == x + 5)
Assert(x2 == x + 3)
Assert(y == Cond( i==0, x1, x2 ) )
```



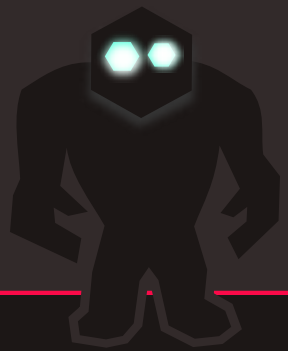
TASK



Task 4

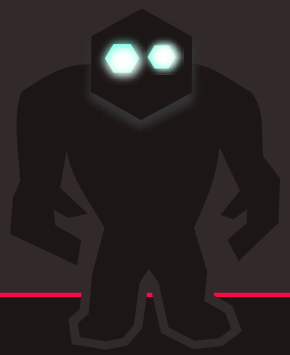
Translate:

```
int32_t v = read_int();
char c = read_char();
if( c == '-' ){
    v-=1;
else{
    v*=2;
}
// v == -1 && c > 'A'
```



Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

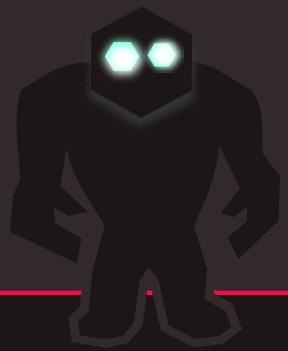


Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
```

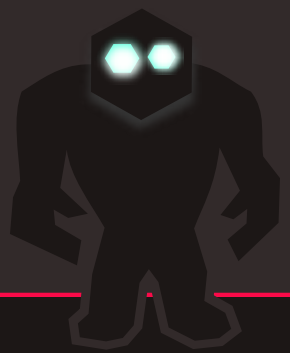


Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
Assert( i<n );
body(i);
i++;
```

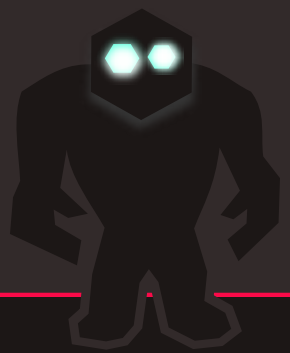


Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
Assert( i<n );
body(i);
i++;
Assert( i<n );
body(i);
i++;
```

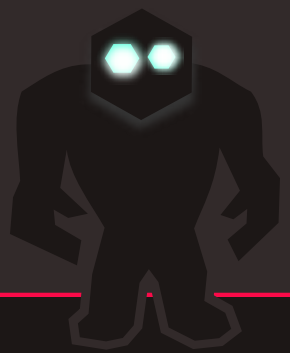


Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
Assert( i<n );
body(i);
i++;
Assert( i<n );
body(i);
i++;
[...]
```

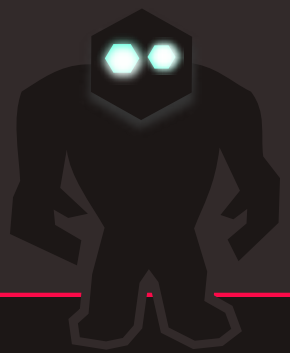


Loops

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
Assert( i<n );
body(i);
i++;
Assert( i<n );
body(i);
i++;
[...]
Assert( !(i<n) );
```



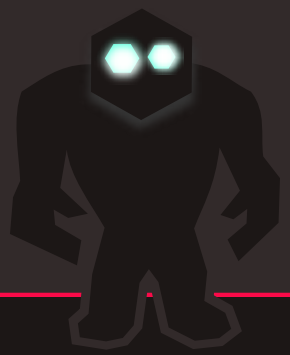
Exact number of Iterations needed

Exact number of Iterations needed

BAD

(but for now we can live with it)

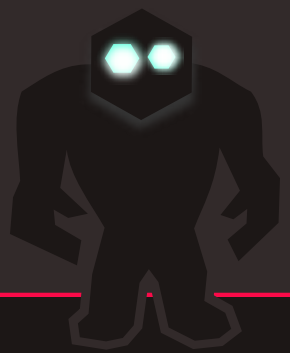
TASK



Task 5

Translate:

```
uint32_t v = read_uint();
uint32_t r = v;
for(int i = 0; i<32; i++){
    r = r ^ (v<<i)*(v+r);
}
// r == 2016
```

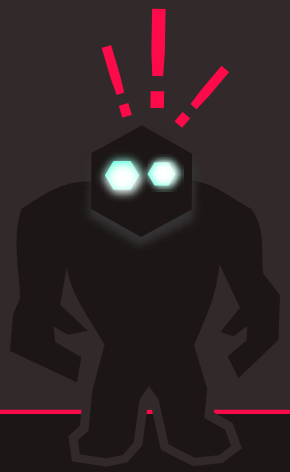


Task 5

Translate:

```
uint32_t v = read_uint();
uint32_t r = v;
for(int i = 0; i<32; i++){
    r = r ^ (v<<i)*(v+r);
}
// r == 2016
```

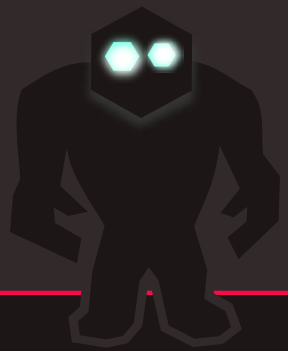
Tips



Unroll:

```
for i in range(32):
    r_next = Var(32,"r"+str(i))
    Assert( r_next == r^... )
    r = r_next
```

TASK



Task 6

Translate:

```
int check( char* str, int len ){
  uint64_t v = 0;
  for( int i = 0; i < len; i++ ){
    if( str[i] == '-' ){
      v -=1;
    } else {
      v*=2;
    }
  }
  return v == 0xffffffffbadc0de0;
}
```

CRYPTO

Task 7

```
def hash_func(inputstr):
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc

def bitstring(str): [...]
```

Task 7

```
def hash_func(inputstr):    "100010001"
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc

def bitstring(str): [...]
```

Task 7

```
def hash_func(inputstr):
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc

def bitstring(str): [...]
```

Iterate input Bit by Bit

Task 7

```
def hash_func(inputstr):
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc
```

Update crc based on bit

```
def bitstring(str): [...]
```

Task 7

```
def hash_func(inputstr):
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc

def bitstring(str): [...]
```

32 Bit Words

Task 7

```
def hash_func(inputstr):
    crc = 0
    for bit in inputstr:
        if int(bit) == most_signficant_bit(crc):
            crc = (crc << 1)&0xffffffff
        else:
            crc = ((crc << 1)^0x04C11DB7)&0xffffffff
    return crc
```

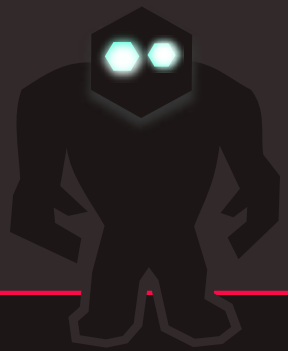
```
def bitstring(str): [...]
```

String to Bit-String

Task 7

Find input such that:

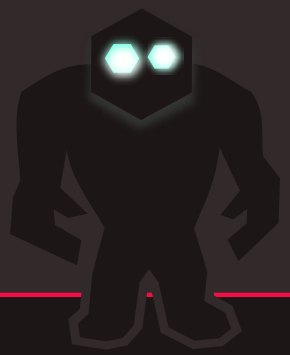
- hash(bitstring(input)) == 0



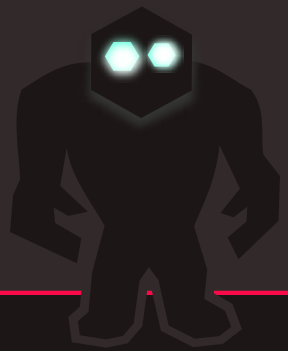
Task 7

Find input such that:

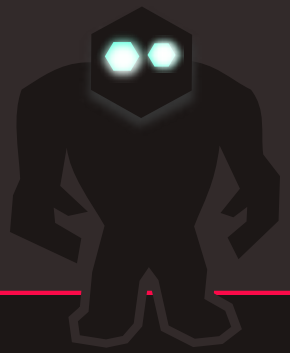
- hash(bitstring(input)) == 0
- input contains only "+-<>;␣"




DIY



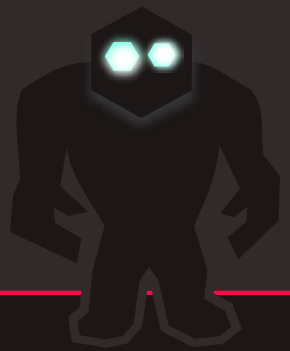
Active
Python
Runs on Binary



github.com/angr

Miasm

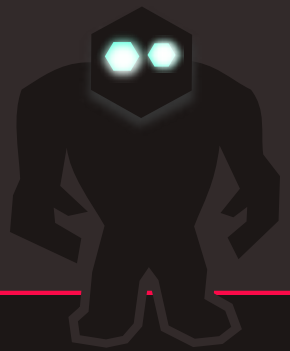
Active
Python
Runs on Binary



github.com/cea-sec/miasm

TRITON

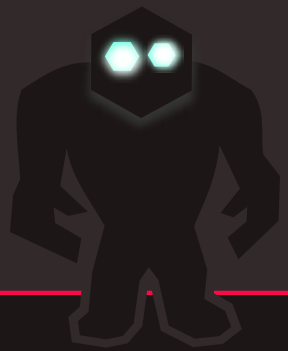
Active
C++/Python
Runs on Binary



triton.quarkslab.com

BAP

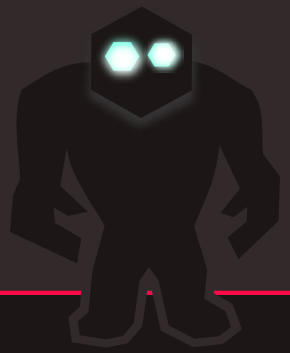
Active
Ocaml/(Python)
Runs on Binary

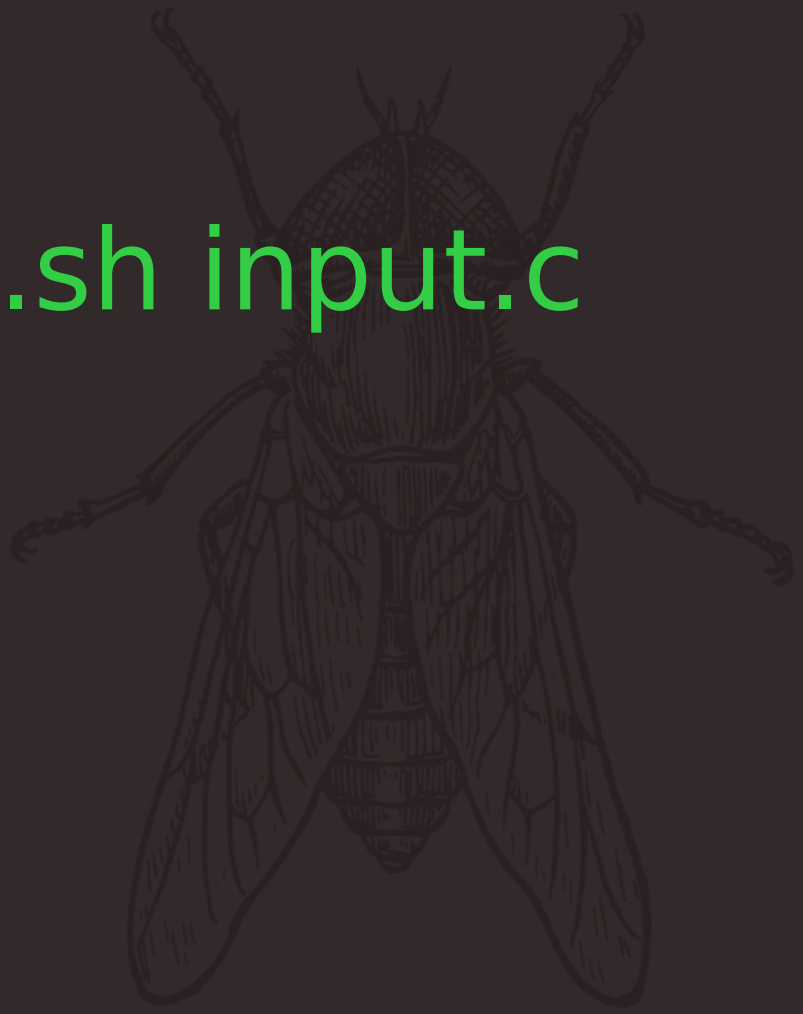


github.com/BinaryAnalysisPlatform/bap

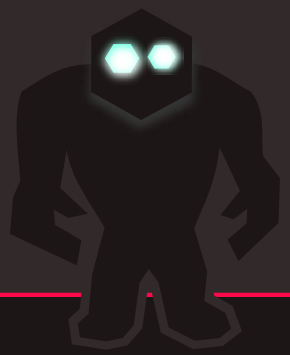
Inactive
Not OS
Runs on C
Standalone

llbmc.org





```
$ sh run_llbmc.sh input.c
```



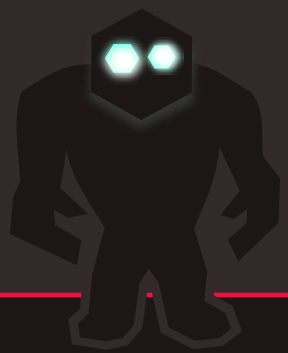
$ sh run_llbmc.sh input.c

(add parameters to llbmc in run_llbmc.sh)

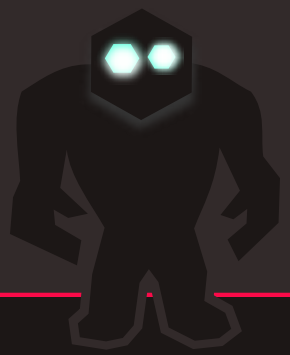
```
$ sh run_llbmc.sh input.c
```

```
#include "llbmc.h"
```

Does LLBMC know what we want?



Define Inputs?



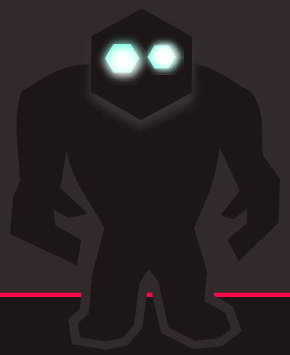
Define Inputs?

```
__llbmc_nondef_unsigned_int();
__llbmc_nondef_uint8_t();
```

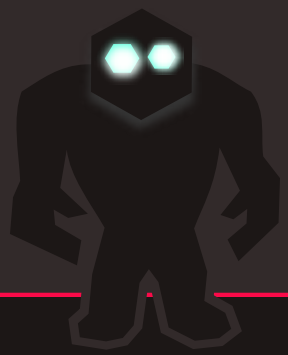
Define Inputs?

et al.

```
__llbmc_nondef_unsigned_int();
__llbmc_nondef_uint8_t();
```

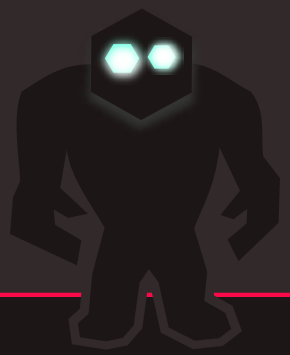


Additional Asserts?



Additional Asserts?

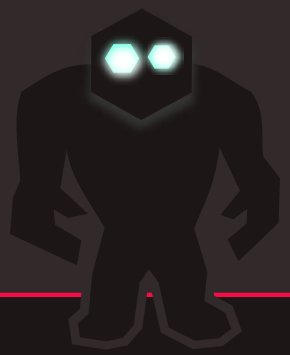
```
__llbmc_assert(q->x == 10);
```



Additional Asserts?

```
__llbmc_assert(q->x == 10);
__llbmc_assume(0 < s);
```

```
int main(){
  uint32_t alloc_len = __llbmc_nondef_uint32_t();
  __llbmc_assume(alloc_len > 0 && alloc_len < 1000);
  char* str = malloc(alloc_len);
  __llbmc_assume(str[alloc_len-1]==0);
  size_t len = strlength(str);
  __llbmc_assert(len < alloc_len);
  return 0;
}
```



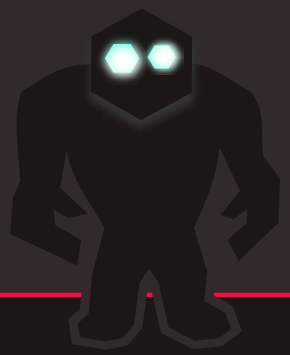
```
int main(){
  uint32_t alloc_len = __llbmc_nondef_uint32_t();
  __llbmc_assume(alloc_len > 0 && alloc_len < 1000);
  char* str = malloc(alloc_len);
  __llbmc_assume(str[alloc_len-1]==0);
  size_t len = strlength(str);
  __llbmc_assert(len < alloc_len);
  return 0;
}
```

Run function

Test Harness

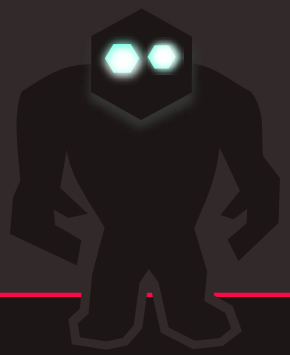
Create allocation

```
int main(){
  uint32_t alloc_len = __llbmc_nondef_uint32_t();
  __llbmc_assume(alloc_len > 0 && alloc_len < 1000);
  char* str = malloc(alloc_len);
  __llbmc_assume(str[alloc_len-1]==0);
  size_t len = strlength(str);
  __llbmc_assert(len < alloc_len);
  return 0;
}
```



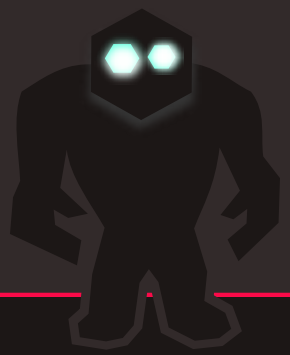
```
int main(){
  uint32_t alloc_len = __llbmc_nondef_uint32_t();
  __llbmc_assume(alloc_len > 0 && alloc_len < 1000);
  char* str = malloc(alloc_len);
  __llbmc_assume(str[alloc_len-1]==0);
  size_t len = strlength(str);
  __llbmc_assert(len < alloc_len);
  return 0;
}
```

It's a string

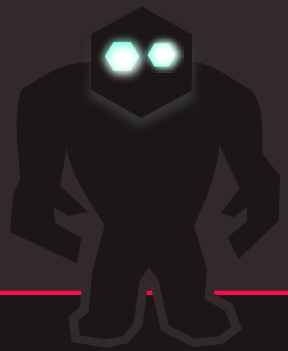


```
int main(){
  uint32_t alloc_len = __llbmc_nondef_uint32_t();
  __llbmc_assume(alloc_len > 0 && alloc_len < 1000);
  char* str = malloc(alloc_len);
  __llbmc_assume(str[alloc_len-1]==0);
  size_t len = strlength(str);
  __llbmc_assert(len < alloc_len);
  return 0;
}
```

Check some property



TASK



Task 8

Use LLBMC to solve Task 4
in ~/smt/task_8.c

TASK

Task 9

Use LLBMC to find bugs in ~/smt/task_9.c

```
#include "llbmc.h"
```

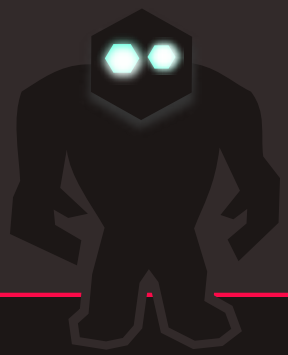
Define Inputs?

```
__llbmc_nondef_unsigned_int();
__llbmc_nondef_uint8_t();
```

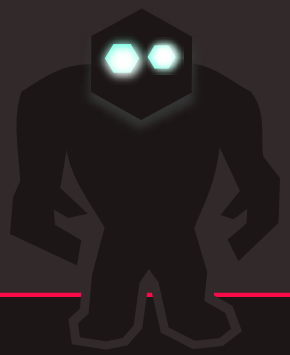
Additional Asserts?

```
__llbmc_assert(q->x == 10);
__llbmc_assume(0 < s);
```

```
$ sh run_llbmc.sh input.c
```

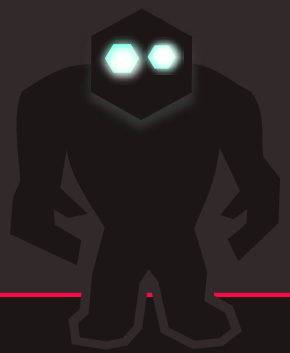


Thanks



Loops (cont'd)

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```



Loops (cont'd)

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
Assert( i<n );
body(i);
i++;
Assert( i<n );
body(i);
i++;
[...]
Assert( !(i<n) );
```

Loops (cont'd)

Exact number
of Iterations needed

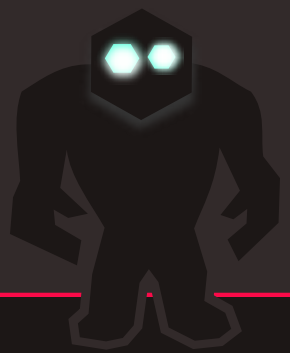
BAD

Loops (cont'd)

```
int i = 0;
```

Unroll

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

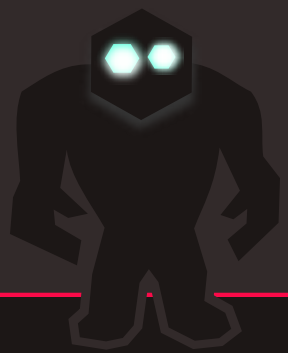


Loops (cont'd)

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
if(i<n){
    body(i);
    i++;

}
```

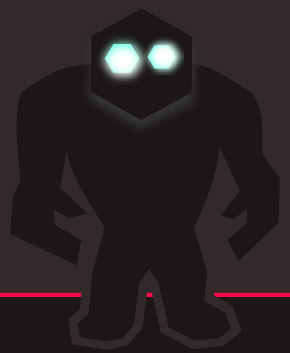


Loops (cont'd)

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
if(i<n){
    body(i);
    i++;
    if( i<n ){
        body(i);
        i++;
    }
}
```



Loops (cont'd)

```
for( int i = 0; i<n; i++ ){
    body(i);
}
```

Unroll

```
int i = 0;
if(i<n){
    body(i);
    i++;
    if( i<n ){
        body(i);
        i++;
    }
}
Assert( !(i<n) );
```