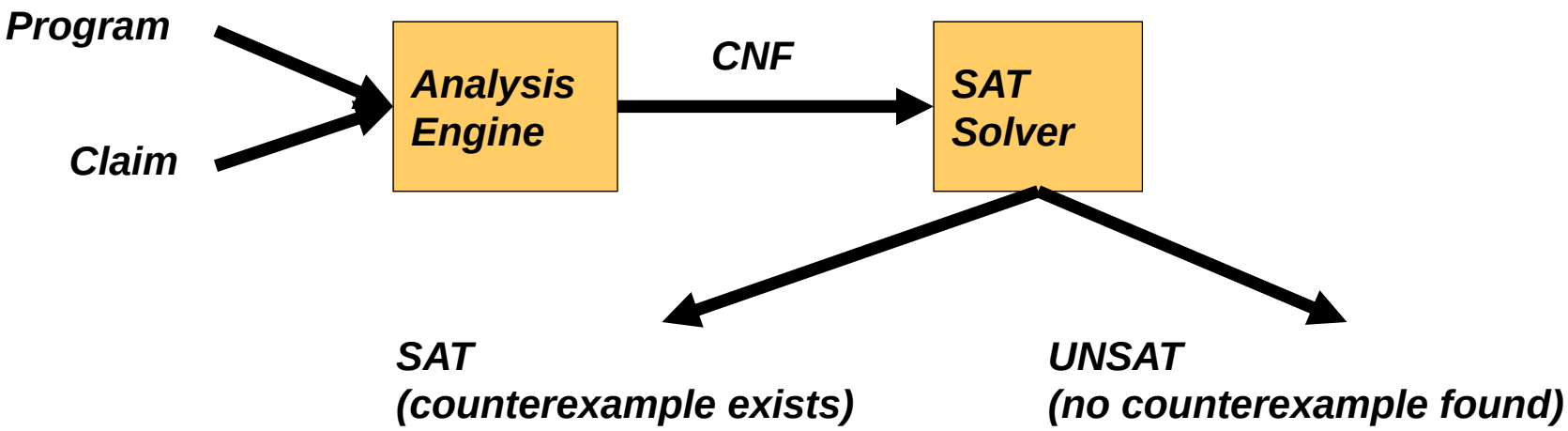
CBMC

Bug Catching with SAT-Solvers

- **Main Idea: Given a program and a claim use a SAT-solver to find whether there exists an execution that violates the claim.**



Programs and Claims

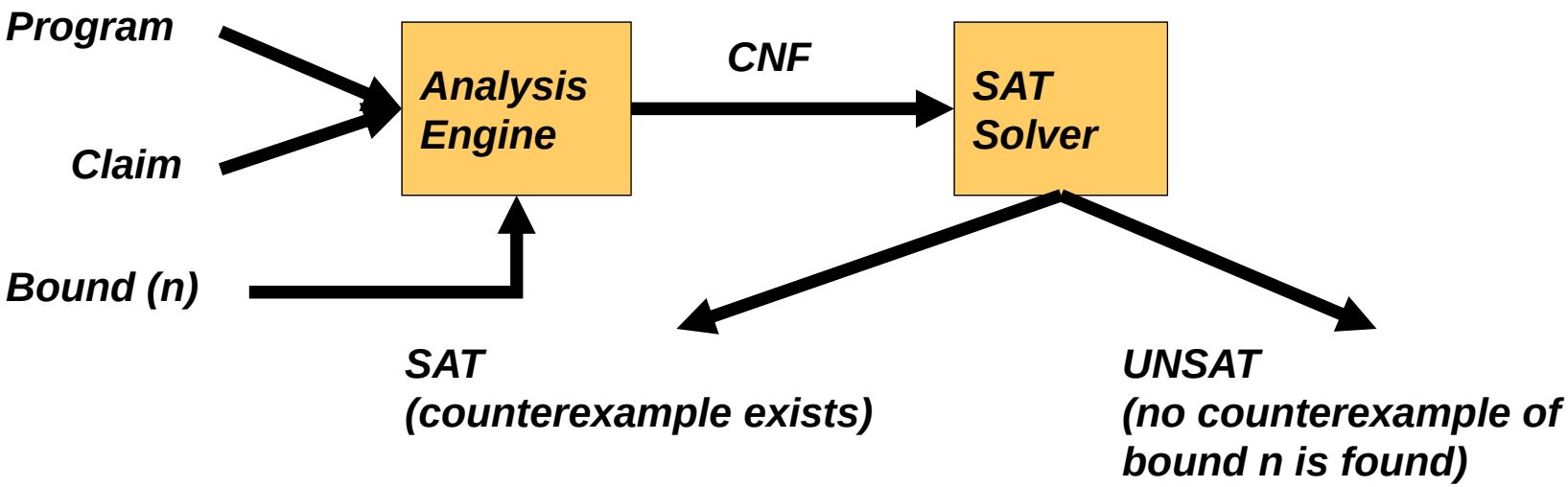
- **Arbitrary ANSI-C programs**
  - **With bitvector arithmetic, dynamic memory, pointers, …**
- **Simple Safety Claims**
  - **Array bound checks (i.e., buffer overflow)**
  - **Division by zero**
  - **Pointer checks (i.e., NULL pointer dereference)**
  - **Arithmetic overflow**
  - **User supplied assertions (i.e., `assert (i > j)`)**
  - **etc**

Why use a SAT Solver?

- **SAT Solvers are very efficient**
- **Analysis is completely automated**
- **Analysis as good as the underlying SAT solver**
- **Allows support for many features of a programming language**
  - **bitwise operations, pointer arithmetic, dynamic memory, type casts**

What about loops?!

- **SAT Solver can only explore finite length executions!**
- **Loops must be bounded (i.e., the analysis is incomplete)**



CBMC: Supported Language Features

ANSI-C is a low level language, not meant for verification but for efficiency

Complex language features, such as

- ***Bit vector operators (shifting, and, or,…)***
- ***Pointers, pointer arithmetic***
- ***Dynamic memory allocation: malloc/free***
- ***Dynamic data types: `char s[n]`***
- ***Side effects***
- ***`float` / `double`***
- ***Non-determinism***

Using CBMC from Command Line

- To see the list of claims

```
cbmc --show-claims -I include file.c
```

- To check a single claim

```
cbmc --unwind n --claim x –I include file.c
```

- For help
  - cbmc --help

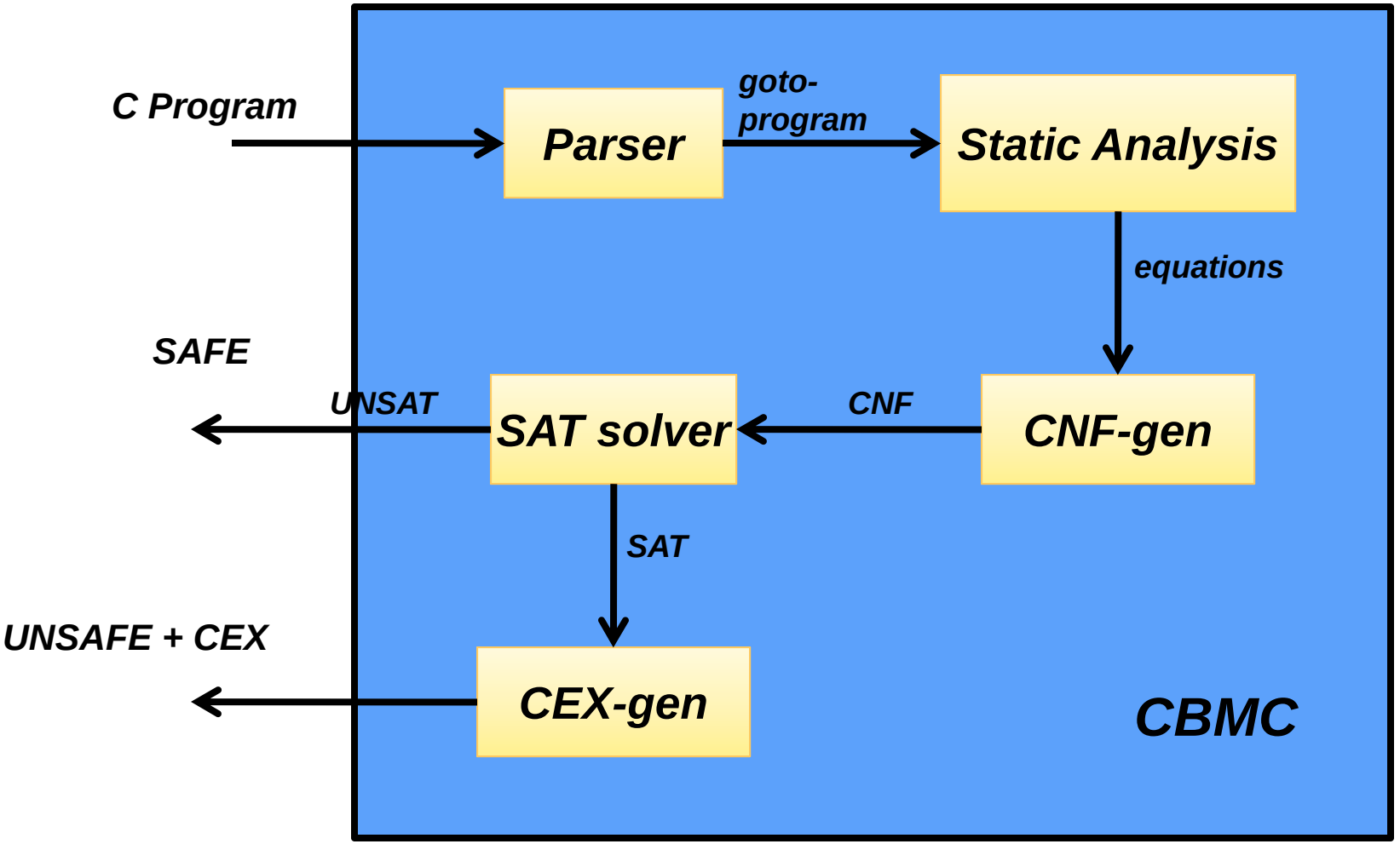
How does it work

- Transform a programs into a set of equations

1. Simplify control flow
2. Unwind all of the loops
3. Convert into Single Static Assignment (SSA)
4. Convert into equations
5. Solve with a SAT Solver
6. Convert SAT assignment into a counterexample

CBMC: Bounded Model Checker for C

A tool by D. Kroening/Oxford and Ed Clarke/CMU



Control Flow Simplifications

- ***All side effect are removed***
  - ***e.g., `j=i++` becomes `j=i;i=i+1`***
- ***Control Flow is made explicit***
  - ***`continue`, `break` replaced by `goto`***
- ***All loops are simplified into one form***
  - ***`for`, `do while` replaced by `while`***

Loop Unwinding

- ***All loops are unwound***
  - *can use different unwinding bounds for different loops*
  - *to check whether unwinding is sufficient special "unwinding assertion" claims are added*

- ***If a program satisfies all of its claims and all unwinding assertions then it is correct!***

- ***Same for backward `goto` jumps and recursive functions***

Loop Unwinding

```
void f(...) {
  ...
  while(cond) {
    Body;
  }
  Remainder;
}
```

while() loops are unwound iteratively

Break / continue replaced by goto

Loop Unwinding

```
void f(...) {
  ...
  if(cond) {
    Body;
    while(cond) {
      Body;
    }
  }
  Remainder;
}
```

while() loops are unwound iteratively

Break / continue replaced by goto

Loop Unwinding

```
void f(...) {
  ...
  if(cond) {
    Body;
    if(cond) {
      Body;
      while(cond) {
        Body;
      }
    }
  }
  Remainder;
}
```

while() loops are unwound iteratively

Break / continue replaced by goto

Unwinding assertion

```
void f(...) {
  ...
  if(cond) {
    Body;
    if(cond) {
      Body;
      if(cond) {
        Body;
        while(cond) {
          Body;
        }
      }
    }
  }
  Remainder;
}
```

- *while() loops are unwound iteratively*
- *Break / continue replaced by goto*
- *Assertion inserted after last iteration: violated if program runs longer than bound permits*

Unwinding assertion

```
void f(...) {
  ...
  if(cond) {
    Body;
    if(cond) {
      Body;
      if(cond) {
        Body;
        assert(!cond);
      }
    }
  }
  Remainder;
}
```

Unwinding assertion

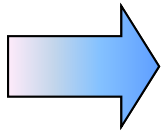
- *while() loops are unwound iteratively*
- *Break / continue replaced by goto*
- *Assertion inserted after last iteration: violated if program runs longer than bound permits*
- *Positive correctness result!*

Transforming Loop-Free Programs Into Equations (1)

- **Easy to transform when every variable is only assigned once!**

Program

```
x = a;
y = x + 1;
z = y – 1;
```



Constraints

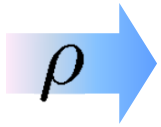
```
x = a &&
y = x + 1 &&
z = y – 1 &&
```

Transforming Loop-Free Programs Into Equations (2)

- **When a variable is assigned multiple times,**
- **use a new variable for the RHS of each assignment**

Program

```
x=x+y;
x=x*2;
a[i]=100;
```



SSA Program

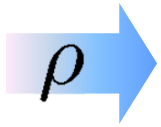
$x_1 = x_0 + y_0;$
$x_2 = x_1 * 2;$
$a_1[i_0] = 100;$

What about conditionals?

Program

```
if (v)
  x = y;
else
  x = z;

w = x;
```



SSA Program

```
if (v0)
  x0 = y0;
else
  x1 = z0;

w1 = x??;
```

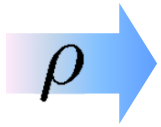
What should 'x' be?

What about conditionals?

Program

```
if (v)
  x = y;
else
  x = z;

w = x;
```



SSA Program

```
if (v0)
  x0 = y0;
else
  x1 = z0;
x2 = v0 ? x0 : x1;
w1 = x2
```

- **For each join point, add new variables with selectors**

Demo