SLAM
Motivation & Example

Verification & Testing

Roderick Bloem

This week: SLAM

Automatically verify properties of drivers

Part of MS Windows Driver Kit (called the *Static Driver Verifier*)

Key: automatic abstraction

Based on: Ball & Rajamani, Automatically Validating Temporal Safety Properties of Interfaces, SPIN Workshop on Software Model Checking, 2001

Why Drivers?

Drivers are…

…critical

- Run in kernel space, can wreak havoc

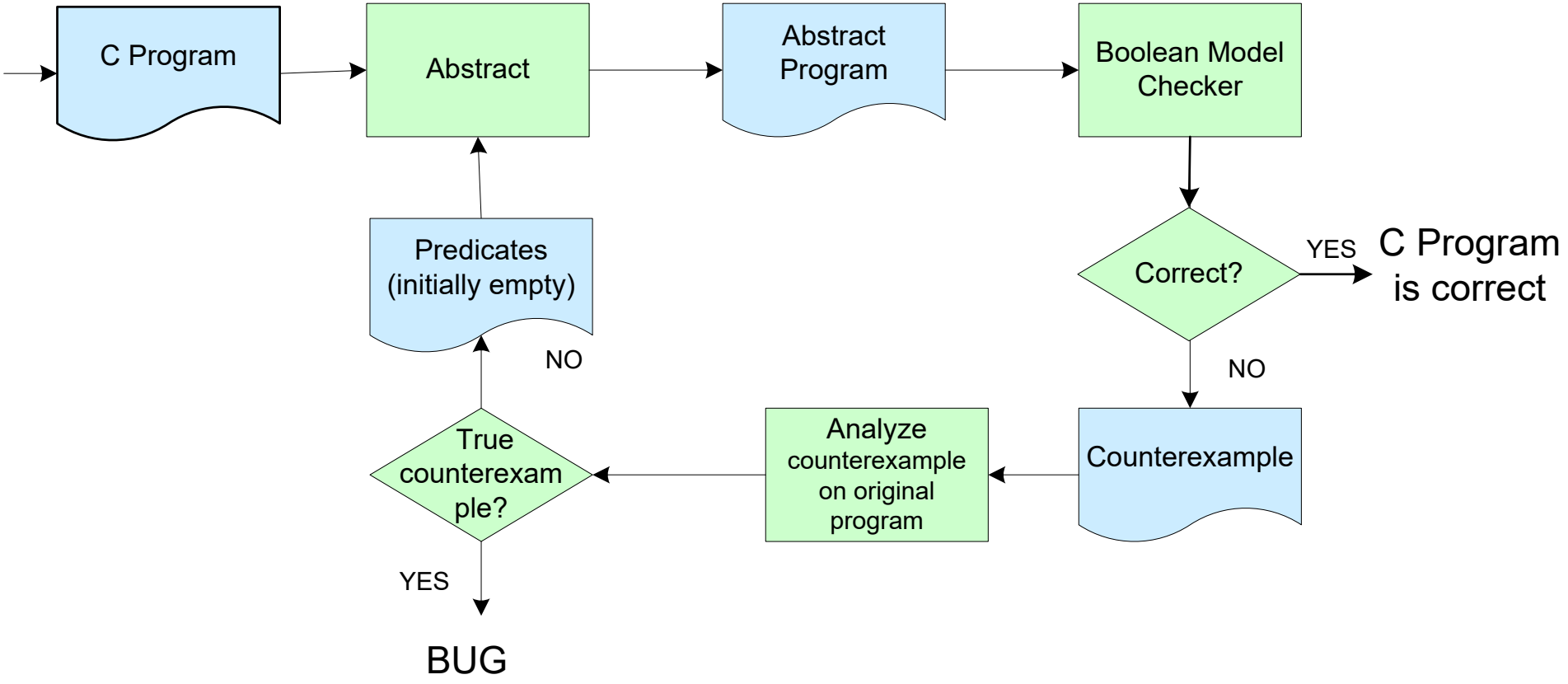
…not under MS control

- Developed by hardware companies (limited understanding of Windows)
- Cannot: verify correctness, impose coding standards, educate designers, …

…simple

- Small code base
- Important properties: locking protocol, …
- Correctness may not depend on implementation details

The Approach



Approach

Construct abstraction of program

- Abstraction is conservative: every bug in original program exists in abstraction
- Abstraction adds behavior: may have spurious counterexample that is impossible on real program

Make abstraction more precise until

- The abstraction contains no counterexamples OR
- We find a real bug

We use predicate abstraction

- Result of the abstraction is Boolean Program

Approach

1. Keep a set of predicates. First set is empty
2. Use predicates to construct Boolean Program
   - First approximation has only data flow, no variables
3. Run model checker for Boolean program
   - No counterexample? C program is correct! Stop.
4. Analyze counterexample
   - If real: found a real bug. Stop
   - If not, add predicates to make abstraction more precise. Go to 2.

This loop may run forever, but if it stops, you have an answer

Boolean Programs

- Functions with parameters, recursion
- Global and local Variables

- No mallocs and frees
- Only Boolean (one-bit) variables; no integers
- Nondeterminism: *
- assert , assume

Theory: Boolean programs are pushdown automata

  – Checking Boolean programs is not hard (algorithm next week)

Some Syntax

- **`assert(e)`**
  - dump core unless `e` is true
- **`assume(e)`**
  - executions with `e` false are irrelevant.
- **`*:`** function that evaluates to 0 or 1 nondeterministically
  - example: `if(*) b = 1; else b=2;` evaluates to `b=1` or `b=2`, but never to `b=3`.
  - `*` is a function, not a value (After `b = *, b` equals `0` or `1`, `b` cannot equal `*`)

Choose

SLAM papers use choose function:
choose(f, g) is the same as
f ? true : (g? false: *);

i.e.,

- If f is true then true,
- if g is true then false,
- if neither are true then nondeterministic
- Both are true should be impossible

Example: Specification

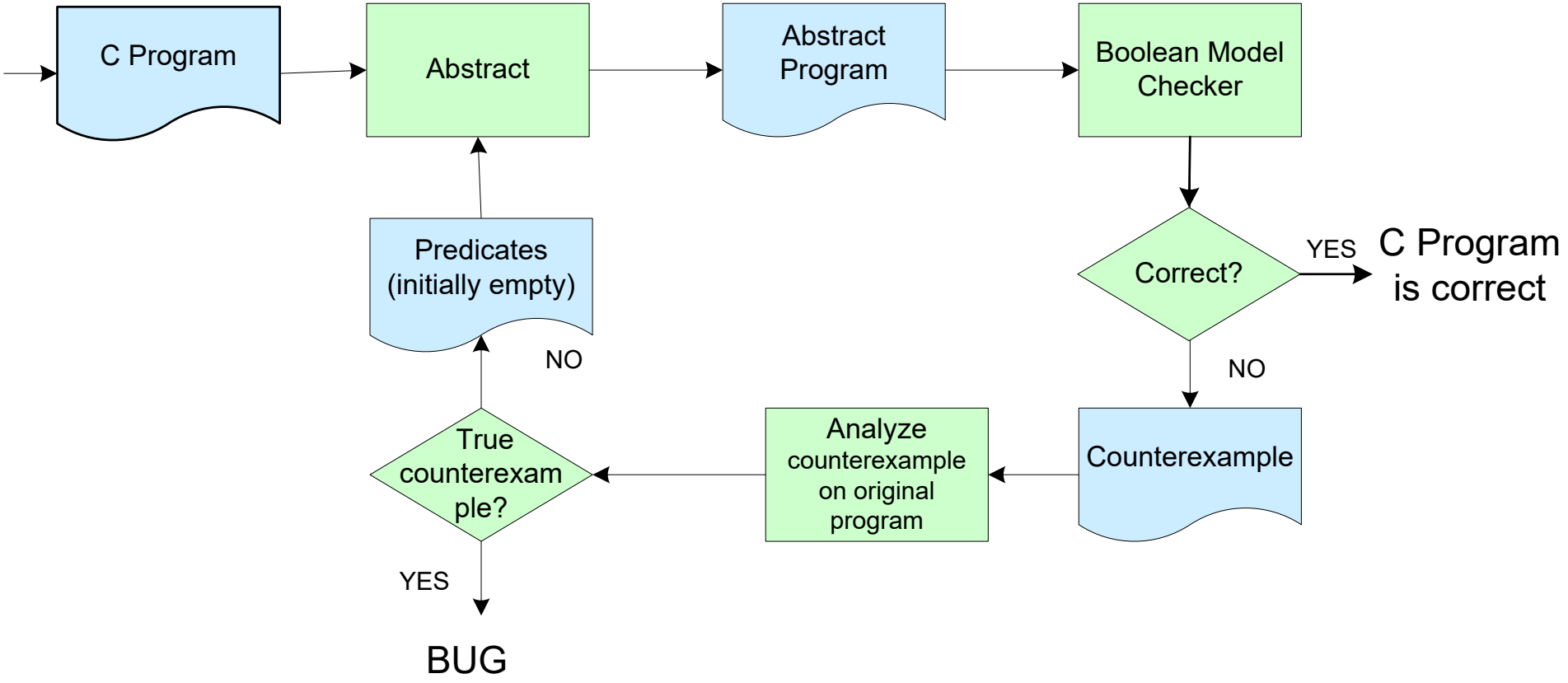
```
bool isLocked = false;

void lock(){
  assert(!isLocked);
  isLocked = true;
}

void release(){
  assert(isLocked);
  isLocked = false;
}
```

```
2   do{
3     lock();
4     nPacketsOld = nPackets;
5     req = devExt->WLHV;
6     if(req && req-> status){
7       devExt->WLHV = req->next;
8       release();
9       irp = req->irp;
10      if(req->status > 0){
11        irp->IoS.status = SUCCESS;
12        irp->IoS.Info = req->Stat;
13      } else {
14        irp->IoS.status = FAIL;
15        irp->IoS.Info = req->Stat;
16      }
17      smartDevFreeBlock(req);
18      IoCompleteRequest(irp);
19      nPackets++;
20    }
21  } while(nPackets != nPacketsOld);
22  release();
```

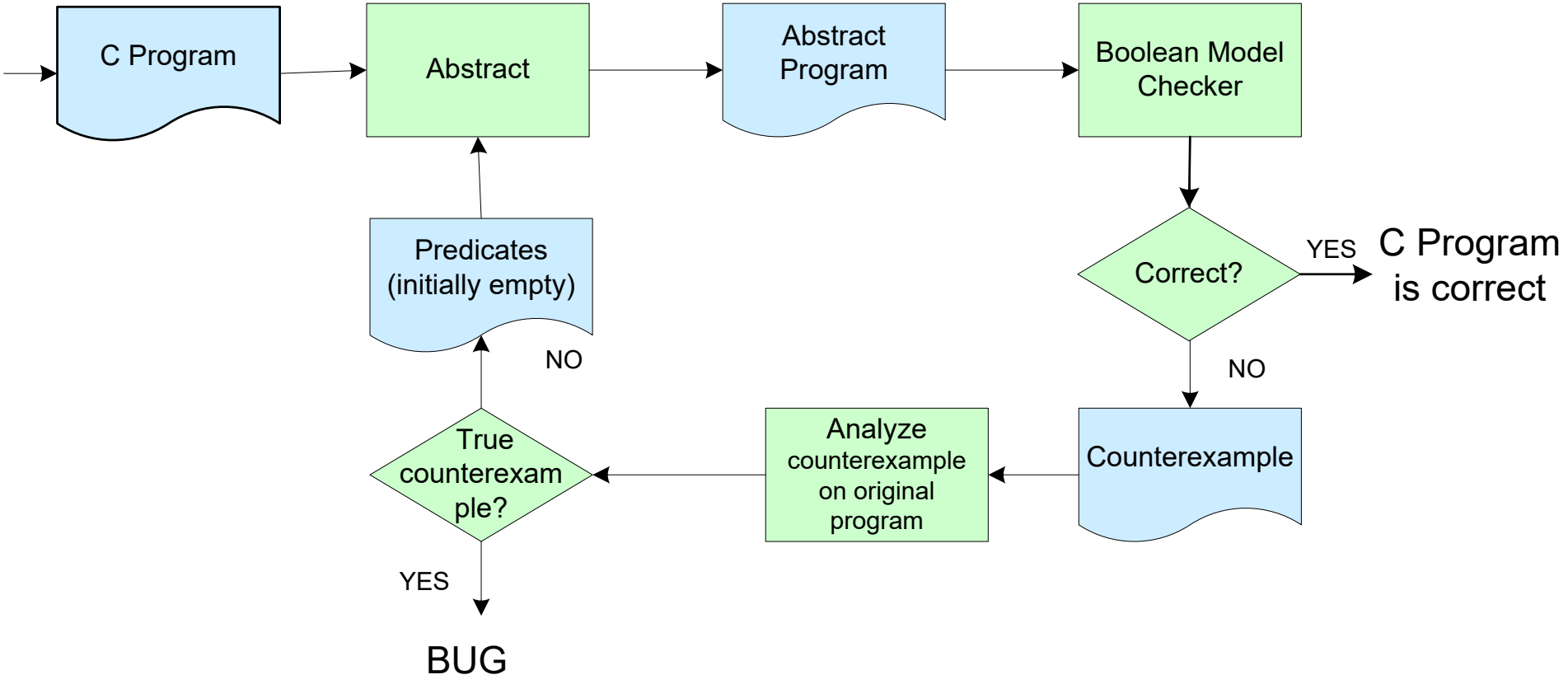
The Approach



First Boolean Program

```
1.  void example(){
2.    do{
3.      lock();
4.      skip;
5.      skip;
6.      if(*){
7.        skip;
8.        release();
9.        skip;
10.       if(*){
11.         skip;
12.         skip;
13.       } else {
14.         skip;
15.         skip;
16.       }
17.       skip;
18.       skip;
19.       skip;
20.     }// if
21.   } while(*);
22.   release();
23. }
```

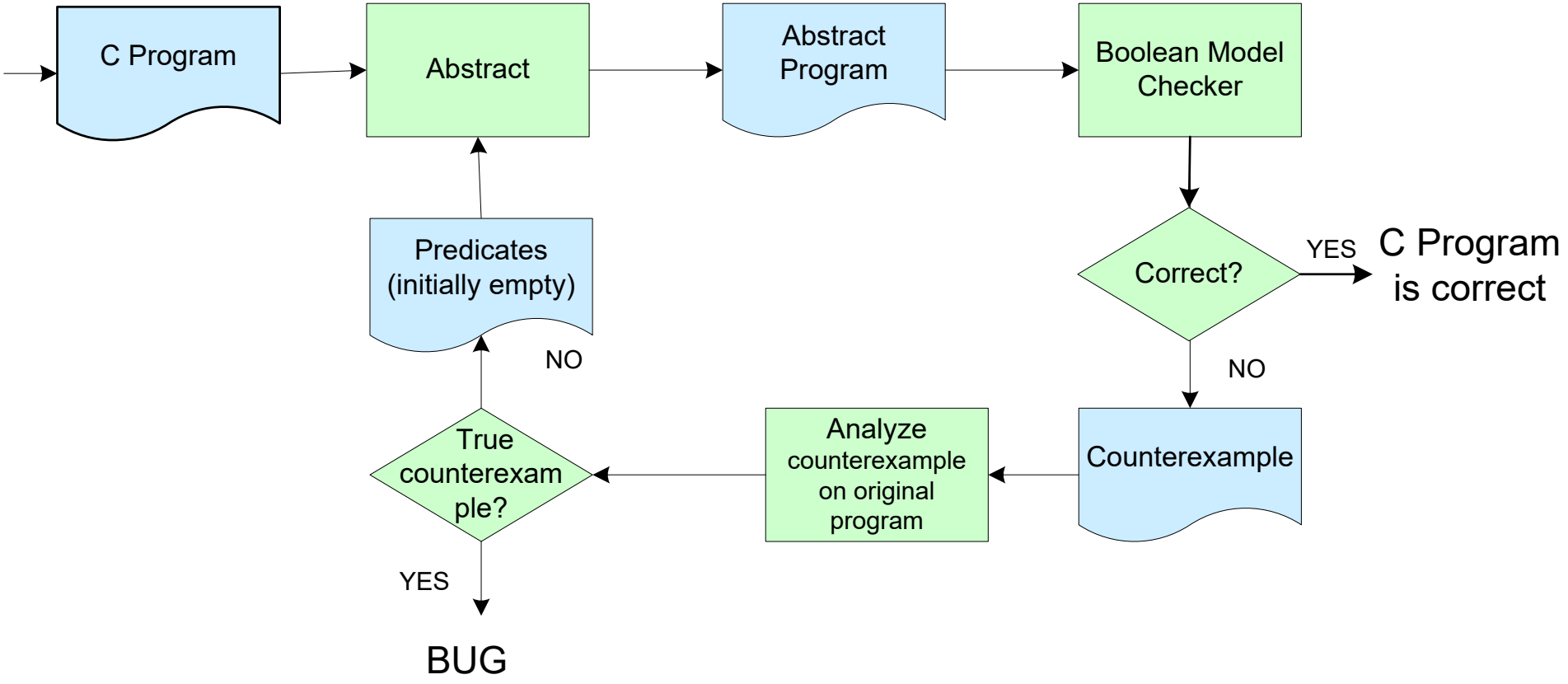
The Approach



Boolean Counterexample

```
1.  void example(){
2.    {
3.      lock();
4.      skip;
5.      skip;
6.      {
7.        skip;
8.        release();
9.        skip;
10.       {
11.         skip;
12.         skip;
13.       }
14.
15.
16.
17.     skip;
18.     skip;
19.     skip;
20.     }
21.   }
22.   release();
23. }
```

The Approach



```
2   do{
3     lock();
4     nPacketsOld = nPackets;
5     req = devExt->WLHV;
6     if(req && req-> status){
7       devExt->WLHV = req->next;
8       release();
9       irp = req->irp;
10      if(req->status > 0){
11        irp->IoS.status = SUCCESS;
12        irp->IoS.Info = req->Stat;
13      } else {
14        irp->IoS.status = FAIL;
15        irp->IoS.Info = req->Stat;
16      }
17      smartDevFreeBlock(req);
18      IoCompleteRequest(irp);
19      nPackets++;
20    }
21  } while(nPackets != nPacketsOld);
22  release();
```

```
2   do{                                   do{
3     lock();                               lock();
4     nPacketsOld = nPackets;               nPacketsOld = nPackets;
5     req = devExt->WLHV;                   req = devExt->WLHV;
6     if(req && req-> status){              assume(req && req-> status){
7       devExt->WLHV = req->next;             devExt->WLHV = req->next;
8       release();                            release();
9       irp = req->irp;                       irp = req->irp;
10      if(req->status > 0){                  assume(req->status > 0){
11        irp->IoS.status = SUCCESS;            irp->IoS.status = SUCCESS;
12        irp->IoS.Info = req->Stat;            irp->IoS.Info = req->Stat;
13      } else {                              } else {
14        irp->IoS.status = FAIL;               irp->IoS.status = FAIL;
15        irp->IoS.Info = req->Stat;            irp->IoS.Info = req->Stat;
16      }                                     }
17      smartDevFreeBlock(req);               smartDevFreeBlock(req);
18      IoCompleteRequest(irp);               IoCompleteRequest(irp);
19      nPackets++;                           nPackets++;
20    }                                     }
21  } while(nPackets != nPacketsOld);     } assume(nPackets == nPacketsOld);
22  release();                            release();
```

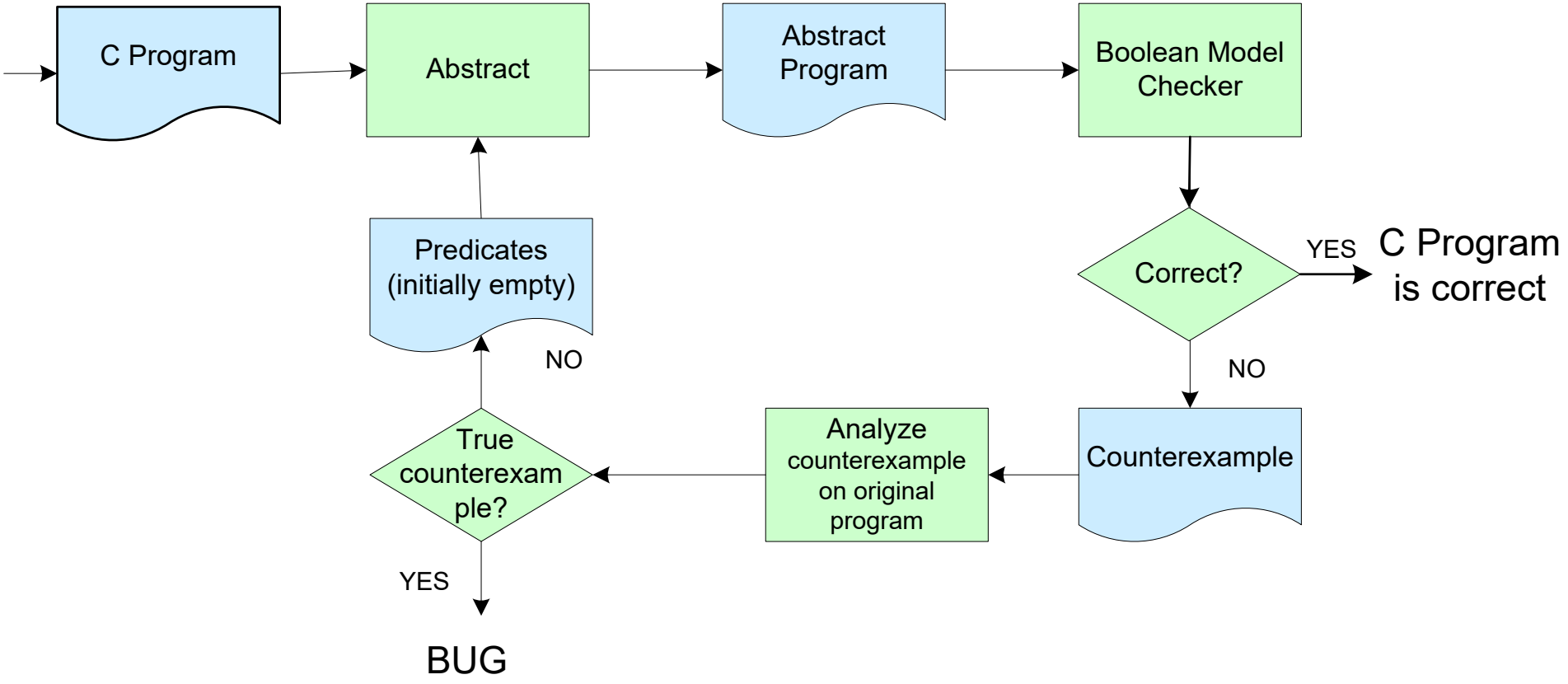
```
2   do{
3     lock();
4     nPacketsOld = nPackets;
5     req = devExt->WLHV;
6     assume(req && req-> status){
7       devExt->WLHV = req->next;
8       release();
9       irp = req->irp;
10      assume(req->status > 0){
11        irp->IoS.status = SUCCESS;
12        irp->IoS.Info = req->Stat;
13      } else {
14        irp->IoS.status = FAIL;
15        irp->IoS.Info = req->Stat;
16      }
17      smartDevFreeBlock(req);
18      IoCompleteRequest(irp);
19      nPackets++;
20    }
21  } assume(nPackets == nPacketsOld);
22  release();
```

Which Predicate can Prove Counterexample Infeasible?

Which Predicate can Prove Counterexample Infeasible?

{nPackets == nPacketsOld}

The Approach



b: nPackets == nPacketsOld

```
2   do{
3     lock();
4     nPacketsOld = nPackets;
5     req = devExt->WLHV;
6     if(req && req-> status){
7       devExt->WLHV = req->next;
8       release();
9       irp = req->irp;
10      if(req->status > 0){
11        irp->IoS.status = SUCCESS;
12        irp->IoS.Info = req->Stat;
13      } else {
14        irp->IoS.status = FAIL;
15        irp->IoS.Info = req->Stat;
16      }
17      smartDevFreeBlock(req);
18      IoCompleteRequest(irp);
19      nPackets++;
20    }
21  } while(nPackets != nPacketsOld);
22  release();
```

Second Boolean Program

```
1.  void example(){
2.    do{
3.      lock();
4.      b = true;
5.      skip;
6.      if(*){
7.        skip;
8.        release();
9.        skip;
10.       if(*){
11.         skip;
12.         skip;
13.       }  else {
14.         skip;
15.         skip;
16.       }
17.       skip;
18.       skip;
19.       b = b ? false: *;
20.     }// if
21.   } while(!b);
22.   release();
23. }
```

Second Boolean Program

Is correct – we are done.

The Approach