SLAM III: Discovering Predicates

V&T

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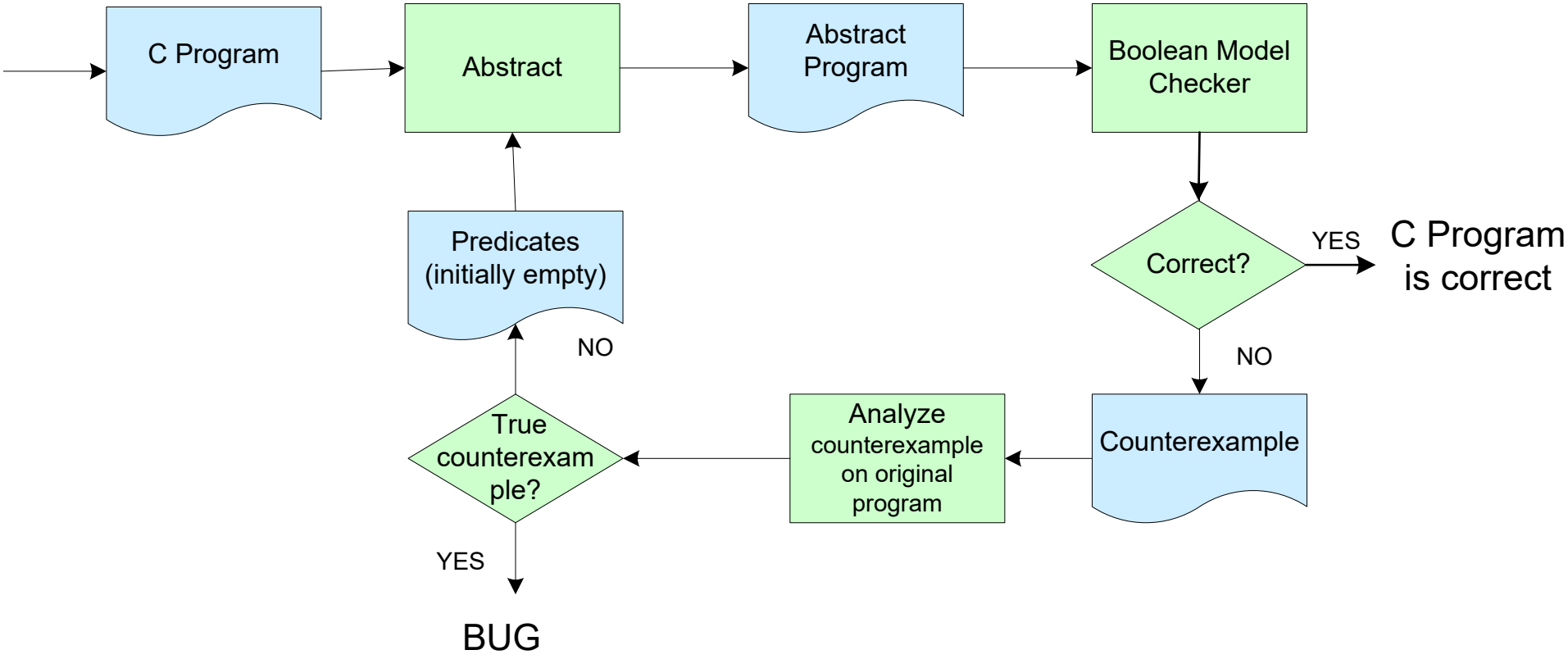
The Approach



Today's Problem

- Figuring out that a counterexample is infeasible
- Finding new predicates

First, recapitulate example

Program

```
1.  void example(){
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.     }// if req
21.   } while(nPackets != nPacketsOld);
22.   release();
23. }
```

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. }
```

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. }
```

```
1.  void example(){
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.       }
17.       smartDevFreeBlock(req);
18.       IoCompleteRequest(irp);
19.       nPackets++;
20.     }// if req
21.   } while(nPackets != nPacketsOld);
22.   release();
23. }
```

Counterexample in C

```
1.  void example(){
2.    {
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.       }
14.
15.
16.
17.       smartDevFreeBlock(req);
18.       IoCompleteRequest(irp);
19.       nPackets++;
20.     }
21.   } assume(nPackets == nPacketsOld);
22.   release();
23. }
```

How do we show this counterexample is infeasible?

Discovering Infeasible Paths


```
lock();

npo = np;

req = devExt->WLHV;

assume(req && req->status)

devExt->WLHV = req->next;

release();

irp = req->irp;

assume(req->status > 0)
```

```
irp->IoS.status = SUCCESS;

irp->IoS.Info = req->Stat;

smartDevFreeBlock(req);

IoCompleteRequest(irp);

np = np + 1;

assume(np == npo)

release();
```

Computed from bottom to top
Note use of colors to track origin of predicates!
Assumption: function calls do not affect predicates

Discovering Infeasible Paths


```
lock();
% FALSE && devExt->WLHV->status>0
% && devExt->WLHV && devExt->WLHV->status
npo = np;
% np+1==npo && devExt->WLHV->status>0
% && devExt->WLHV && devExt->WLHV->status
req = devExt->WLHV;
% np+1==npo && req->status>0 &&
% req && req->status
assume(req && req->status)
% np+1==npo && req->status>0
devExt->WLHV = req->next;
% np+1==npo && req->status>0
release();
% np+1==npo && req->status>0
irp = req->irp;
% np+1==npo && req->status>0
assume(req->status > 0)
```

```
% np+1==npo
irp->IoS.status = SUCCESS;
% np+1==npo
irp->IoS.Info = req->Stat;
% np+1==npo
smartDevFreeBlock(req);
% np+1==npo
IoCompleteRequest(irp);
% np+1==npo
np = np + 1;
% np==npo
assume(np == npo)
%TRUE
release();
% TRUE
```

Computed from bottom to top
Note use of colors to track origin of predicates!
Assumption: function calls do not affect predicates

Adding Predicates

Blue and teal predicates do not lead to contradiction.

Red predicates lead to contradiction. If we add

- `{nPackets==nPacketsOld}` and
- `{nPackets+1==nPacketsOld}`

path is no longer possible in abstract program.

Note:

- Infeasibility is computed bottom-up,
- Functions (`smartDevFreeBlock`, etc.) must inlined or analyzed
- Path consists of
  - assignments (change the predicates)
  - assumes (derive from if, while, add a predicate)

New Predicates Make Path Impossible


```
lock();

nPacketsOld = nPackets;

req = devExt->WLHV;

assume(req && req->status)

devExt->WLHV = req->next;

release();

irp = req->irp;

assume(req->status > 0)
```

```
irp->IoS.status = SUCCESS;

irp->IoS.Info = req->Stat;

smartDevFreeBlock(req);

IoCompleteRequest(irp);

nPackets = nPackets + 1;

assume(nPackets == nPacketsOld)

release();
```

Dealing with asserts

1. Concrete program

```
1. x = 4;
2. if(x == 4){
3.   x = x + 1;
4. }
5. assert(x==5);
```

predicate `b:{x==5}`

3. Counterexample: 1, 2, 3, 4, 5:

2. abstract program:

Dealing with asserts

1. Concrete program

```
1. x = 4;
2. if(x == 4){
3.   x = x + 1;
4. }
5. assert(x==5);
```

predicate `b:{x==5}`

2. abstract program:

```
1. b = FALSE;
2. if(b? false : *){
3.   b = b? FALSE : *;
5. }
6. assert(b);
```

3. Counterexample: 1, 2, 3, 4, 5:

```
1. x = 4;
2. assume(x == 4)
3. x = x + 1;
4.
5. assume(x!=5);
```

Broken assertion becomes assumption that condition is false

```
x = 4;

assume(x == 4)

x = x + 1;

assume(x!=5);
```

New predicate:

Computing Infeasible Paths

```
In: a path P with l lines.
lp := l + 1                          // line pointer
condition[lp] := true;               // condition for line lp, a condition is a
                                        set of predicates
while(lp ≠ 0 && condition[lp] ≠ false){
  lp--
  if(statement(lp) = "assume(p)"){
    condition[lp] := "condition[lp+1] && p", use new color for p
  else if(statement(lp) = "x := e"){
    condition[lp] := condition[lp+1][x → e]
  }
  simplify condition
}

if(condition[lp]= … &&false&&…){
  report INFEASIBLE!
  add all predicates from all condition[i] with same color as false
} else {
  report FEASIBLE: BUG FOUND
}
```

Excluding paths

Guarantee: New predicates exclude the infeasible path

Hope: They also exclude other paths

How do you check whether expression equals FALSE?

- SLAM pretends that `int`s are integers and `float`s are real numbers, uses theorem prover.
  - Not precise (overflows, limited precision for floats)
  - Theorems over integers are undecidable
  - Theorem provers are relatively fast.
- Better: ints are bit vectors
  - SMT solvers are fast for bit vectors
  - Decidable, precise

Conclusion

You can find infeasible paths by repeated application of Hoare's axiom for assignment

You color each predicate that you find, if one predicate is transformed to false, add all predicates of that color.