Soundness and completeness considered harmful

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Vision

Sound: catch all errors

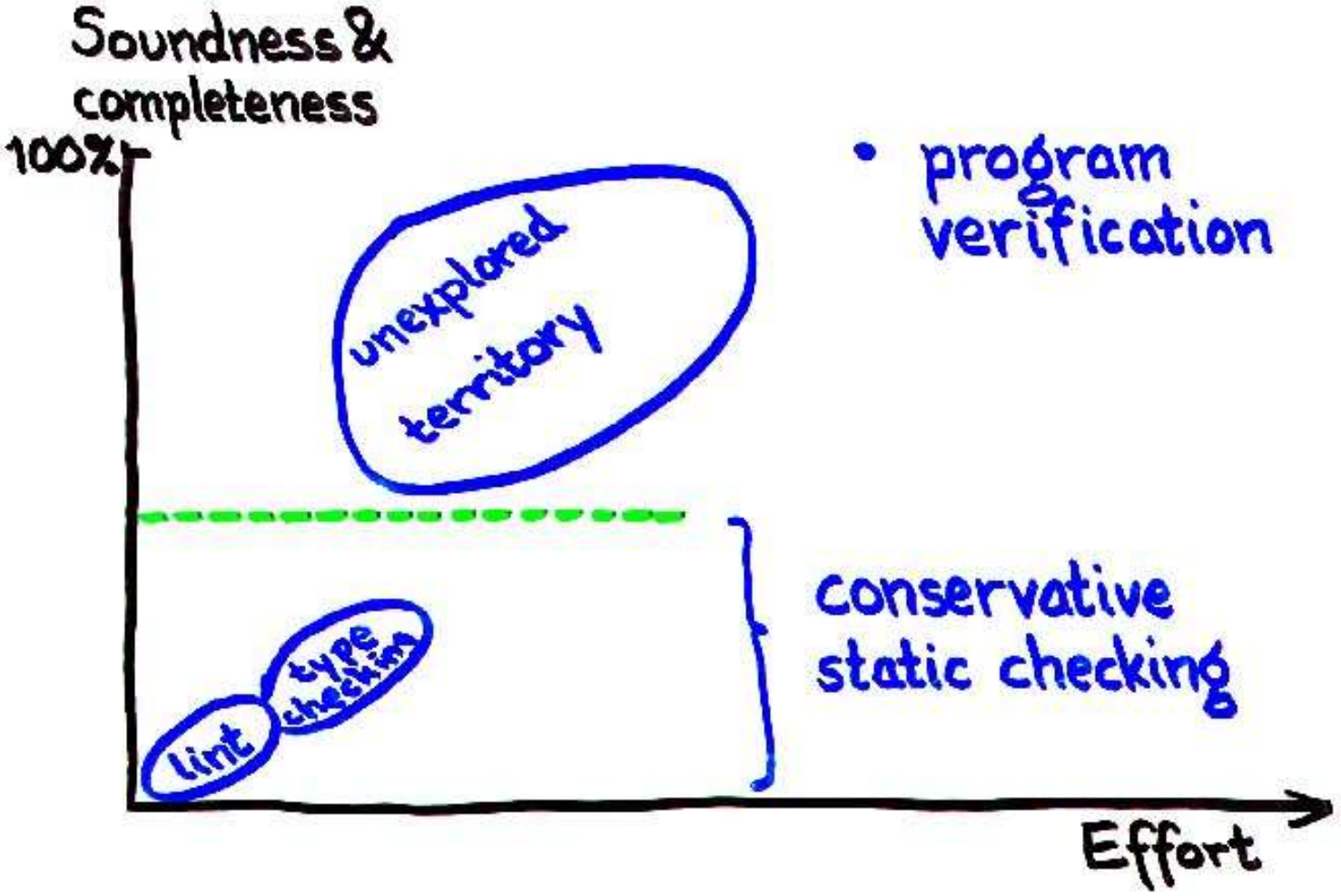
Complete: no spurious warnings

Benefit vs. cost

+ Find errors early

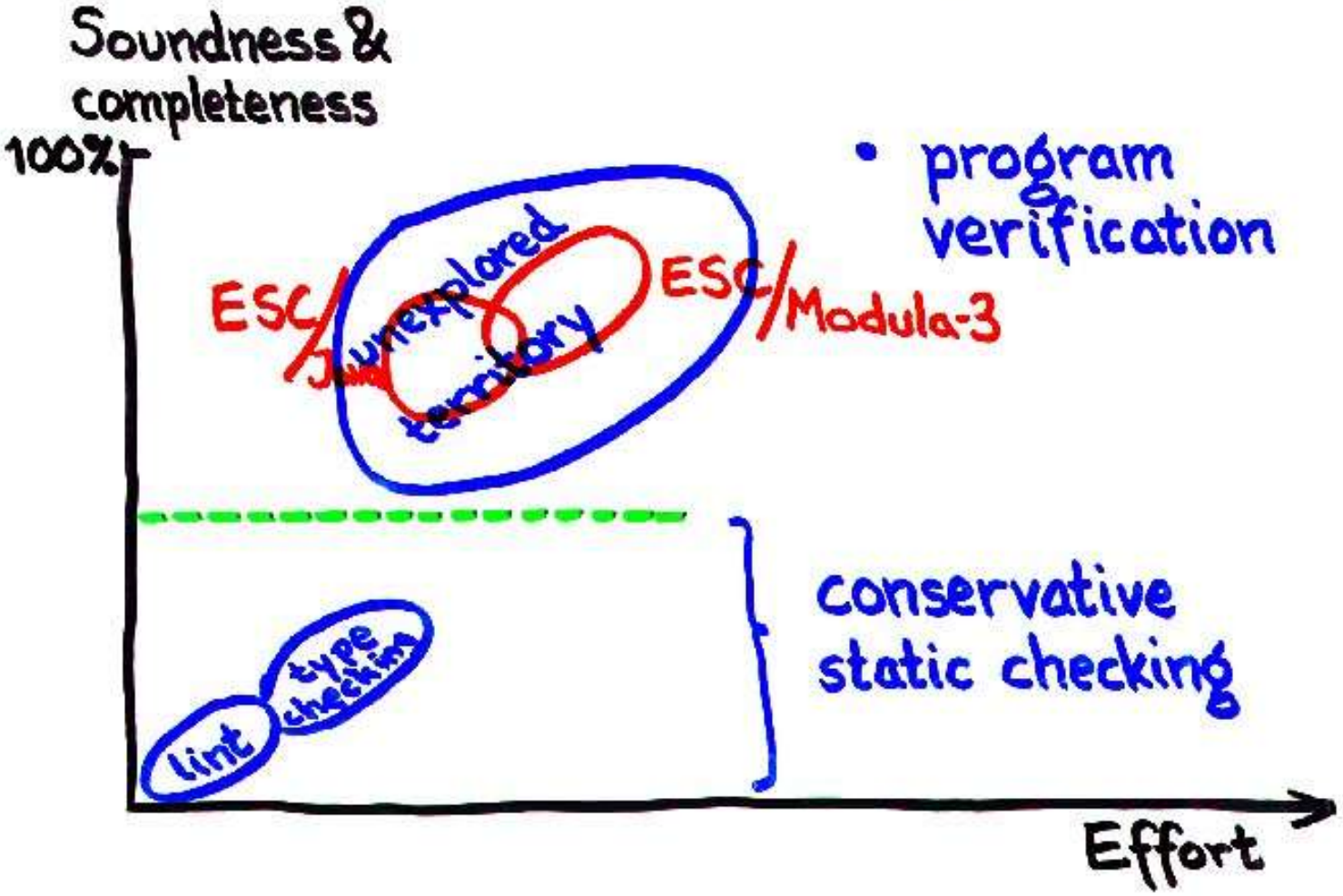
- Annotating the program
- Running the tool
- Analyzing the output

Static Checking



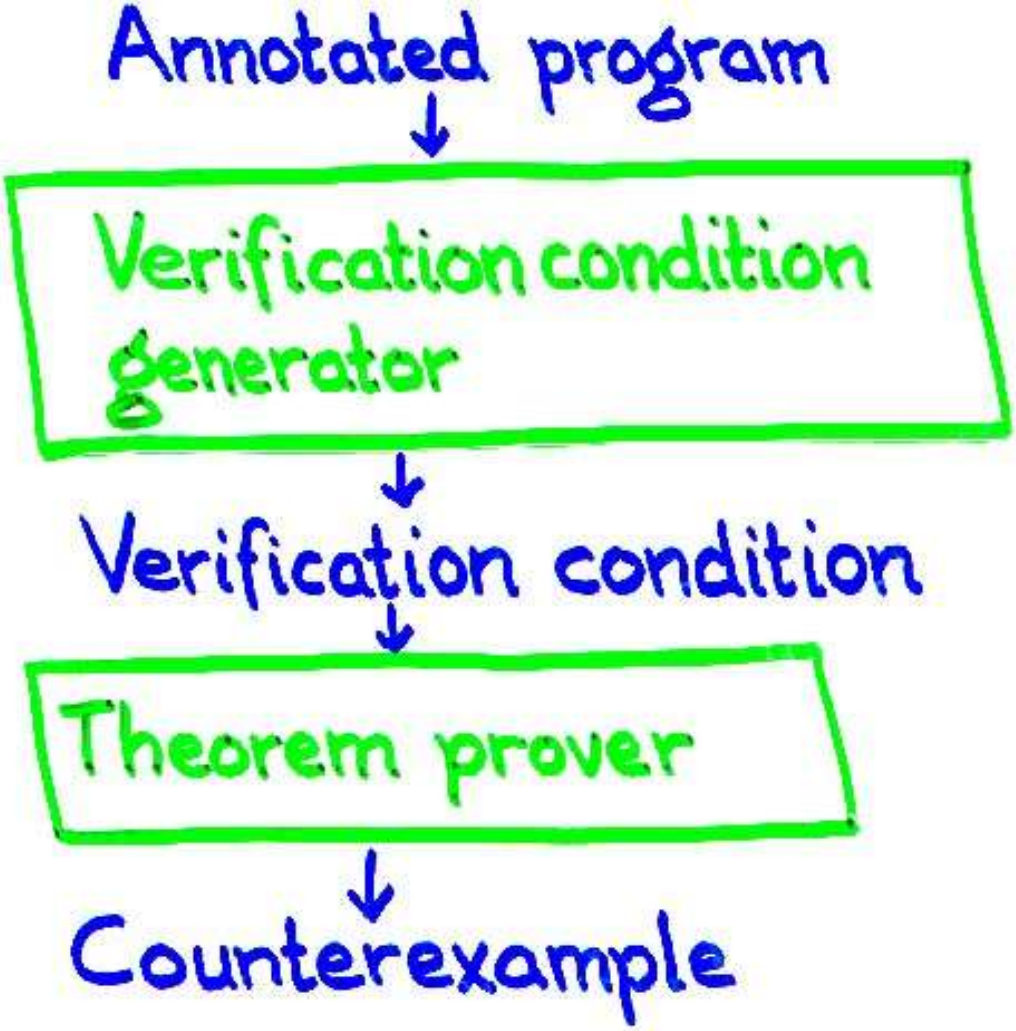
Note: Illustration not to scale

Static Checking

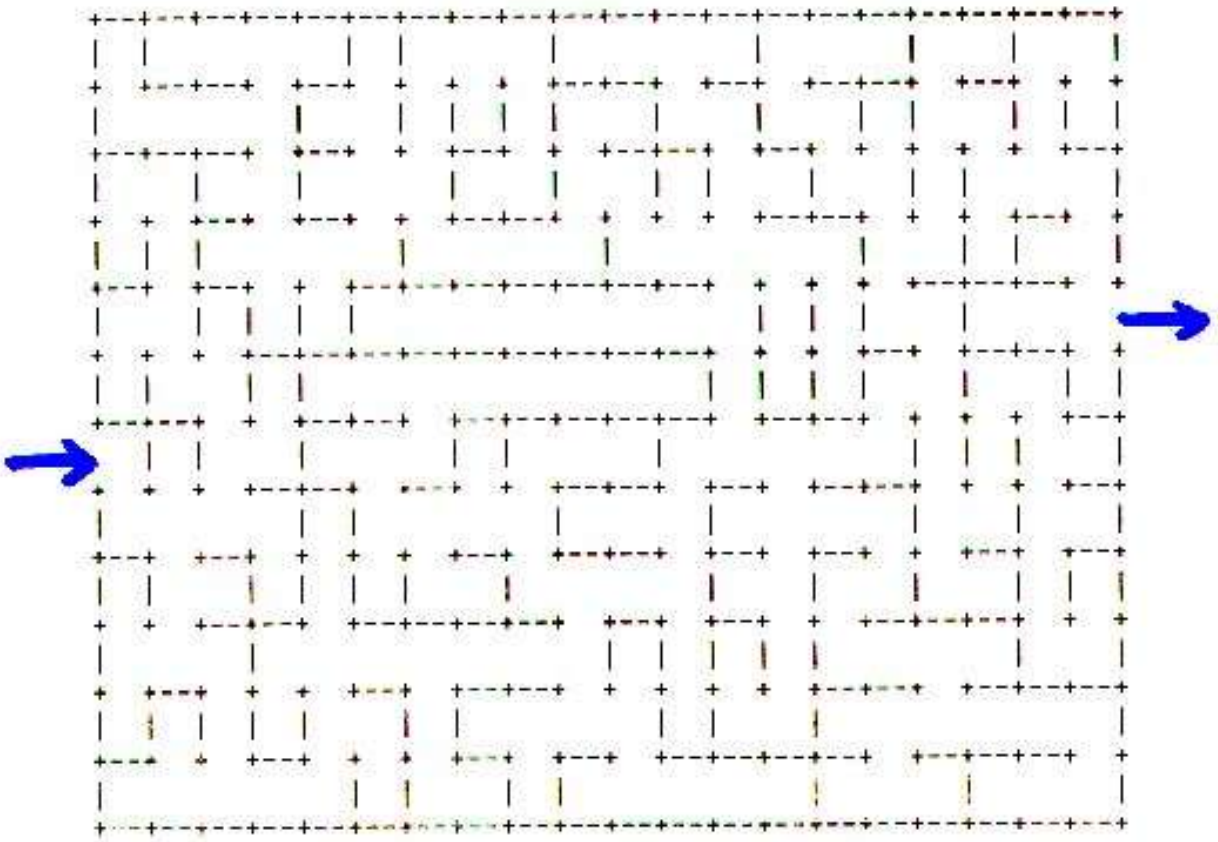


Note: Illustration not to scale

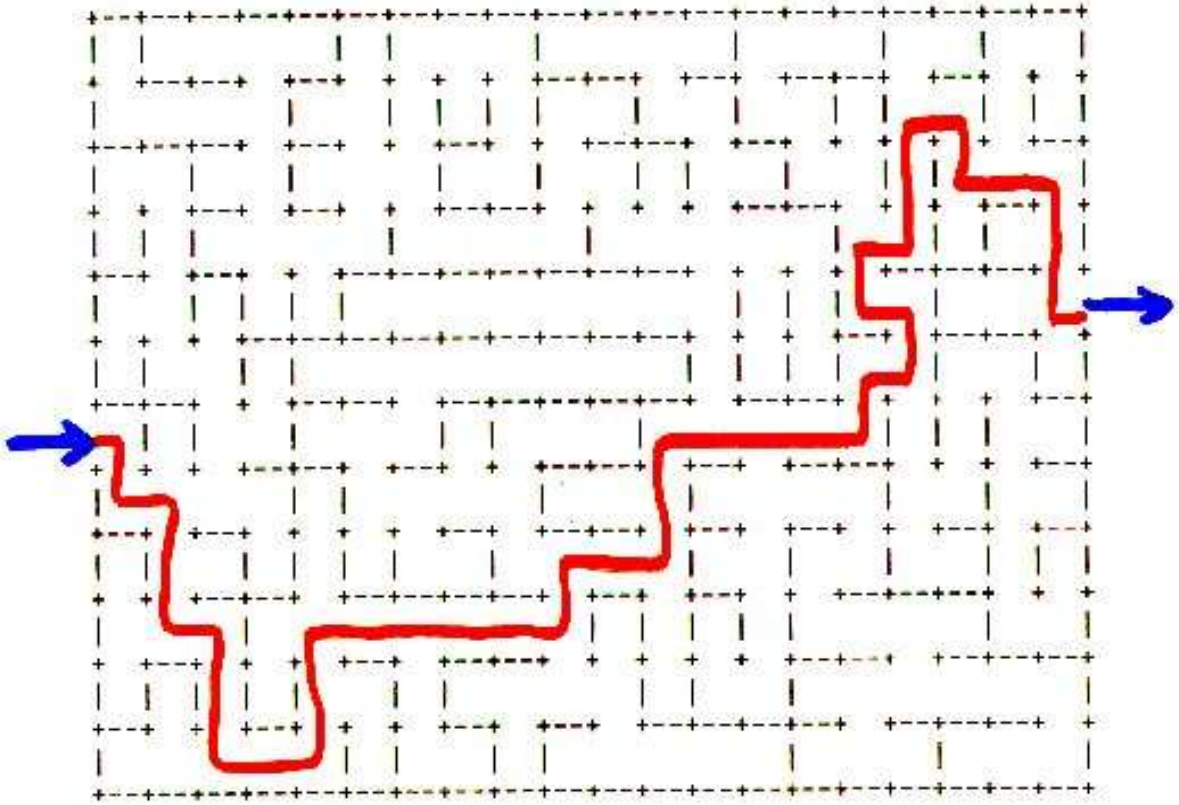
How ESC works



Generating mazes



Generating mazes



Creating a maze

```
uf := new UnionFind;
uf.Init(...);
while ( uf.NumberOfClasses() ≠ 1) {
    pick a new door d that joins rooms p,q;
    if( uf.Find(p) ≠ uf.Find(q)) {
        open door d;
        uf.Union(p,q);
} }
```

```
class UnionFind {

    abstract var valid: bool ;
    abstract var size: nat ;
    abstract var state: any ;

    proc Init( uf: UnionFind; n: nat );
        requires uf ≠ null ;
        modifies uf.valid, uf.size, uf.state;
        ensures uf.valid ∧ uf.size = n ;

    ⋮
```

```
:
proc Find( uf: UnionFind; p:nat ): nat ;
    requires uf≠null ∧ uf.valid ∧ p<uf.size;
    modifies uf.state ;
    ensures  result < uf.size;

proc Union( uf: UnionFind; p,q: nat ) ;
    requires uf≠null ∧ uf.valid ∧ p<uf.size∧q<uf.size;
    modifies uf.state ;

proc NumberOfClasses( uf: UnionFind): nat ;
    requires uf≠null ∧ uf.valid ;
    modifies uf.state ;
    ensures  result ≤ uf.size ;
```

```
reveal class UnionFind {
    var r : nat[] ;
    var numClasses : nat ;

    rep valid ≡
          r≠null
        ∧ (∀i:nat :: i< r.length⇒r[i]<r.length)
        ∧ numClasses ≤ r.length ;

    rep size ≡ r.length ;

    depends state on numClasses, r[*] ;

:
```

```
proc Union( uf: UnionFind; p,q:nat) {
    var rp := uf.Find(p);
    var rq := uf.Find(q);
    if ( rp ≠ rq ) {
        if (...)
            uf.r[rp] := rq ;
        else
            uf.r[rq] := rp ;

        uf.numClasses-- ;
} }
```

```
proc Union( uf: UnionFind; p,q:nat) {
    var rp := uf.Find(p);
    var rq := uf.Find(q);
    if ( rp ≠ rq ) {
        if (...)
            uf.r[rp] := rq;
        else
            uf.r[rq] := rp;
        assume 0 < uf.numClasses;
        uf.numClasses--;
} }
```

On the design of ESC/Java

- Simplify annotation language
- Improve robustness and performance
- Enhance error reporting

Validity vs. object invariants

```
abstract var valid : bool ;
    ⋮
requires uf.valid ;
    ⋮
rep valid ≡  r ≠ null  ∧  ...
          ∧ numClasses ≤ r.length ;
  *       *       *
inv  r ≠ null ;
    ⋮
inv numClasses ≤ r.length ;
```

Problem with object invariants

```
proc P( a:A; b:B; c:C) {
        ⋮
      x.Q( y, z );
        ⋮
}
```

Specifying modifications

```
abstract var state: any;
    ⋮
modifies uf.state;
    ⋮
depends state on numClasses, ... ;
```

```
modifies uf.numClasses, ... ;
```

ESC/Java modifies checking

Callers: Use the specified modifies clause, except for what is not visible to caller

Implementation:

- Level 0: anything can be modified
- Level 1: fields of parameters subject to specified modifies clause

Conclusions

- Verification technology can find more errors than conservative methods
- Sound + complete ≠ useful
- Automate and find the right errors

www.research.digital.com/SRC/esc/Esc.html