Static Analysis:
The Good, The Bad and The Ugly

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It's all about theory, security, practice

...

and the rest.

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Static Program Analysis ?

Testing the code without running it.

- Mostly undecidable or semi-decidable !
- Specific properties can be tested
- Often hard and complex
- Can’t be both sound and complete

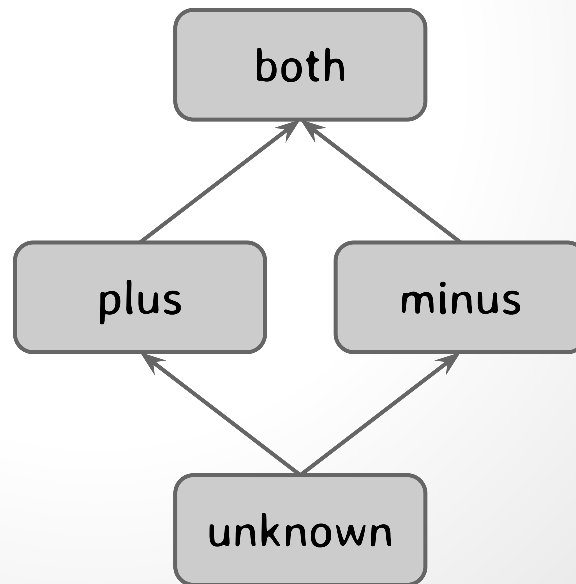
But we need it !

- Detecting corner case errors
- Verifying complex properties
- Get a proven formal verification
- compiler/optimization related stuff

Toy Example

Sign Analysis

- Decide sign of an arithmetical expression
- Use 4-way logic:
  - unknown
  - plus
  - minus
  - both



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Sign Analysis

```
type expr =
    | Int of int
    | Var of string
    | UMinus of expr
    | Add of expr * expr
    | Dif of expr * expr
    | Mul of expr * expr

type sign = UNKNOWN | PLUS | MINUS | BOTH

module Env = Map.Make(String)
```

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Sign Analysis

```
let rec sign env = function
    | Int i when i < 0      -> MINUS
    | Int i                 -> PLUS
    | Var x -> Env.find x env
    | UMinus e ->
      begin
        match sign env e with
         | PLUS              -> MINUS
         | MINUS             -> PLUS
         | _                 -> BOTH
      end
```

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Sign Analysis

```
| Add (e0, e1) ->
begin
  match (sign env e0, sign env e1) with
  | (PLUS, PLUS) -> PLUS
  | (MINUS, MINUS) -> MINUS
  | _ -> BOTH
end
```

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Sign Analysis

```
| Dif (e0, e1) ->
begin
  match (sign env e0, sign env e1) with
    | (PLUS, MINUS) -> PLUS
    | (MINUS, PLUS) -> MINUS
    | _ -> BOTH
end
```

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Sign Analysis

```
| Mul (e0, e1) ->
  begin
    match (sign env e0, sign env e1) with
    | (PLUS, PLUS)
    | (MINUS, MINUS) -> PLUS
    | (PLUS, MINUS)
    | (MINUS, PLUS) -> MINUS
    | _ -> BOTH
  end
```

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Sound or Complete ?

Analysis verifies a property

Sound Analysis:

identified cases really have the property

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Complete Analysis:

all cases are identified

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Sound Analysis provides safety

Complete Analysis tracks errors

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Analysis

- Model Checking
- Data flow Analysis
- Constraint Based Analysis
- Abstract Interpretation
- Type Systems
- *Handcrafted Analysis ;)*
- ...

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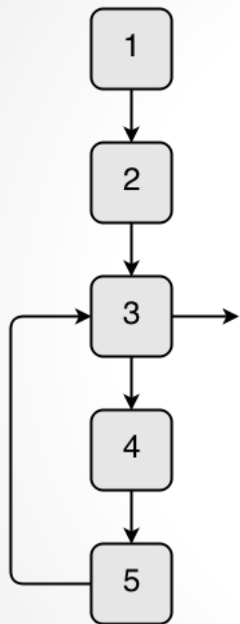
- Put label on code

```
[x ← a + b]¹
[y ← a * b]²
while [y > a + b]³ do
    [a ← a + 1]⁴
    [x ← a + b]⁵
done
```



- Build a flow graph

- Build equations and solve them

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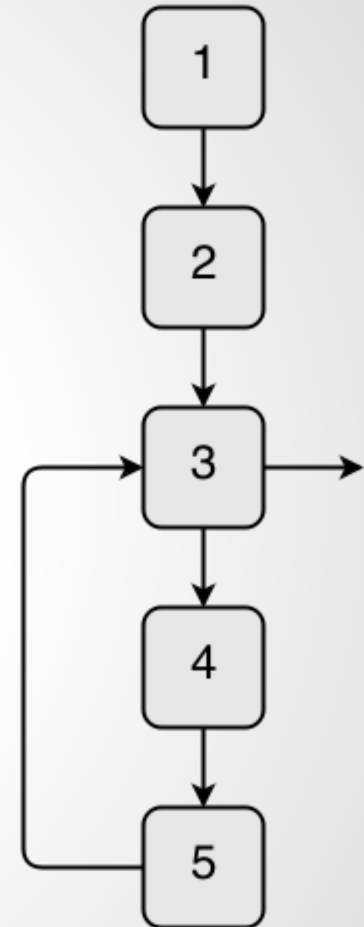
```
[x ← a + b]¹
[y ← a * b]²
while [y > a + b]³ do
   [a ← a + 1]⁴
   [x ← a + b]⁵
done
```



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	Kill	Gen
1	∅	{a+b}
2	∅	{a*b}
3	∅	{a+b}
4	{a+b, a*b, a+1}	∅
5	∅	{a+b}

	Entry	Exit
1	∅	{a+b}
2	{a+b}	{a+b, a*b}
3	{a+b}	{a+b}
4	{a+b}	∅
5	∅	{a+b}

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For real ?

Traditional code analysis requires:

- some language properties
- well founded semantics
- some execution model

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C doesn't fit this description !

C has the following drawbacks:

- no formal semantics
- the standard is sometimes *fuzzy*
- there’s still ambiguous syntactic aspects

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Are we doomed ?

We can still have:

- ➢ unsound, incomplete but useful analysis
- ➢ guidelines for other methods
- ➢ working analysis on very specific cases

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Buffer Overflow

```c
void ugly(char *src) {
  char              buf[8];
  strcpy(buf, src);
}

int main(int argc, char *argv[]) {
  if (argc > 1) {
    ugly(argv[1]);
  }
  return 0;
}
```

- Write outside of buffer boundaries
- Most common mistake
- Over the last 25 years:
  - 14% of security vulnerabilities
  - **23% of top severity vulnerabilities**
- Known for years (1972, 1988 …)

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What can be done ?

- ➢ track usage of risky functions (strcpy ;)
- ➢ check size constraints on function calls
- ➢ when constraints doesn't hold

  → **raise a warning**

- ➢ use code review/tests to confirm bug

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Statically Detecting Likely Buffer Overflow Vulnerabilities

David Larochelle and David Evans (Usenix 2001)

- Using LCLint (now splint)
- Annotate libc headers
- Verify constraints on buffer read/write

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```c
void ugly(char *src) {
  char          buf[8];
  strcpy(buf, src);
}

int main(int argc, char *argv[]) {
  if (argc > 1) {
    ugly(argv[1]);
  }
  return 0;
}
```

splint detects `strcpy(buf, src)`

```
Possible out-of-bounds store: strcpy(buf, src)
[...]
A memory write may write to an address beyond the allocated
buffer.
```

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```c
void mystrcpy(char *dst, char *src) {
  for (; *src != '\0'; src += 1, dst += 1)
    *dst = *src;
}

static
void ugly(char *src) {
  char          buf[8];
  mystrcpy(buf, src);
}

int main(int argc, char *argv[]) {
  if (argc > 1) {
    ugly(argv[1]);
  }
  return 0;
}
```

Detected !

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```c
static void ugly2(char *src) {
  char          *buf1 = malloc(8);
  char           buf2[8];
  strncpy(buf1, src, 8);
  strcpy(buf2, buf1);
  free(buf1);
}

int main(int argc, char *argv[]) {
  if (argc > 1)
    ugly2(argv[1]);
  return 0;
}
```

Detected !

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```c
static void ugly2(char *src) {
  char          *buf1 = malloc(8);
  char           buf2[8];
  strncpy(buf1, src, 8);
  buf1[7] = '\0';
  strcpy(buf2, buf1);
  free(buf1);
}

int main(int argc, char *argv[]) {
  if (argc > 1)
    ugly2(argv[1]);
  return 0;
}
```

False Warning !

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```c
static void ugly2(char *src) {
  char          *buf1 = malloc(8);
  char           buf2[8];
  strncpy(buf1, src, 7);
  strcpy(buf2, buf1);
  free(buf1);
}

int main(int argc, char *argv[]) {
  if (argc > 1)
    ugly2(argv[1]);
  return 0;
}
```

No warning !

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Clang Analyzer

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clang static analyzer:

- ➢ analysis during semantic pass
- ➢ Reusable C++ library
- ➢ you can implement your own checker

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- Complete C/C++/ObjC parser
- Full AST traversal
- Some checkers already available
- Still a little bit messy
- Out-of-the-box install doesn’t seem to detect simple buffer overflow

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Errors and Vulnerabilities

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- Static analysis detects possible code errors
- Code errors may be triggered by attackers
- Code errors may be exploitable

- Eliminating errors is important
- Any error may finally become a vulnerability
- Static analysis can help a lot
- Probably better during dev cycle

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- Specific analysis only identifies known flaws
- Too much spurious warning
- Quality is a matter of involvement
  - People don’t review their code, so why analyzing it
  - Beta testing will be done by users
  - As long as it works ...