
# Optimal Guard Synthesis for Memory Safety

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# Memory Safety Errors

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- In C and C++ perennial source of security vulnerabilities
- In Java, C# program crashes due to exceptions

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- Dynamic approaches to memory safety
  - \+ Widely used in managed languages
  - \- But only transforms vulnerability into program crash
  - \- Run-time overhead

# Key Idea: Use Program Synthesis

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Example:

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if(???)  {R} else { /* handle error */}
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# Key Idea: Use Program Synthesis

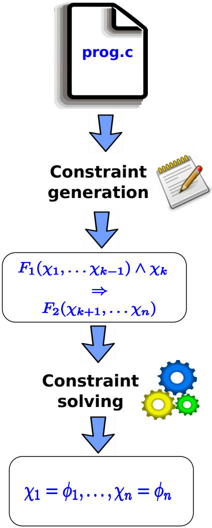
**Key Idea: Program synthesis to guarantee memory safety**

1. Programmer specifies which parts of the program should be guarded
2. Our technique synthesizes correct and optimal guards that guarantee memory safety
   - Optimal means as weak and as simple as possible

Example:

```
if(???)  {R} else { /* handle error */}
```

# Solution Overview




1. Constraint Generation:

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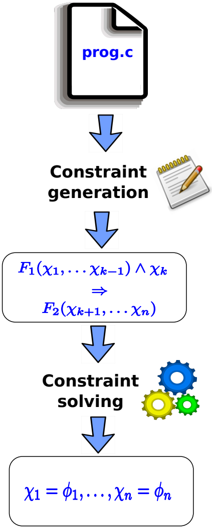


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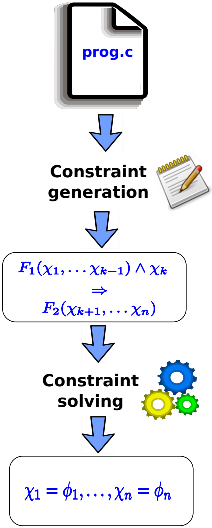


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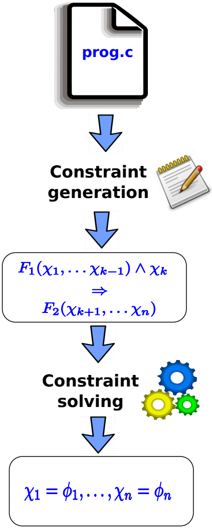


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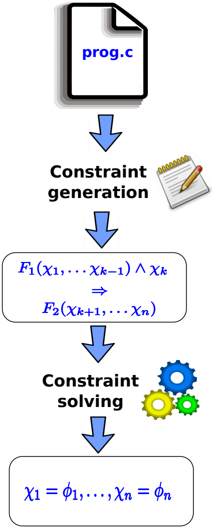


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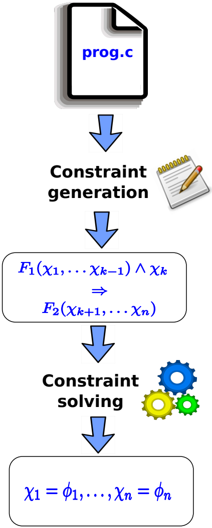


1. Constraint Generation:
   - Represent unknown guards using placeholders
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2. Constraint Solving:
   - An extended abduction algorithm for solving constraint system with multiple unknowns
   - Guarantees Pareto-optimality

# Constraint Generation Overview

$\phi$

```
{
    ...
}

if(??)
{
    ...
}
```

- At synthesis point, compute postcondition $\phi$ of code above ??

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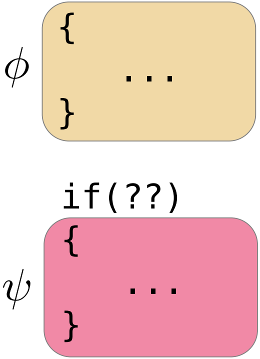


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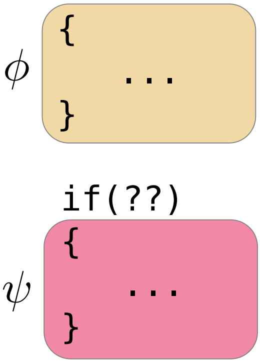


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- Condition to guarantee memory safery:

$$\phi \wedge ?? \models \psi$$

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- $O \equiv$ memory safety precondition $\psi$
- $E \equiv$ Solution for ??

# Constraint Solving

$$F_1(\vec{\chi_1}) \wedge \chi_1 \Rightarrow F_1'(\vec{\chi_1'})$$
$$F_2(\vec{\chi_2}) \wedge \chi_2 \Rightarrow F_2'(\vec{\chi_2'})$$
$$\vdots$$
$$F_n(\vec{\chi_n}) \wedge \chi_n \Rightarrow F_n'(\vec{\chi_n'})$$

- Cannot directly use abduction because constraints have multiple unknowns

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- Cannot directly use abduction because constraints have multiple unknowns
- New iterative, stratification-based algorithm for solving constraint system
- Uses abduction as a helper procedure
- Resulting solution is Pareto-optimal
  - Cannot improve solution for one unknown without making others worse

# Example

- Code snippet from Unix Coreutils with protected memory access

```
int main(int argc,
   char** argv)
{
  if(argc<=1) return -1;
  argv++; argc--;

  optind=0;
  while(...) {
    optind++;
    if(*) {argv++;
           argc--;}
  }
  if(??) {
    argv[optind+1]=...;
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- Convention: For pointer $p$:

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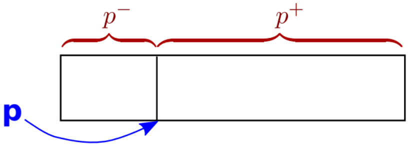


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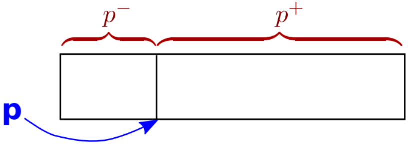
# Example

- Code snippet from Unix Coreutils with protected memory access
- Convention: For pointer $p$:
  - $p^+$ represents distance to end of memory block
  - $p^-$ represents distance from beginning of memory block

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# Example Cont.

- First Step: Compute what is known at ?? $\Rightarrow$ postcondition $\phi$

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$$argv^{+} = argc \wedge argv^{-} = 0$$

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  - From language semantics:

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  - From computing the strongest postcondition:

    $$argv^{+} = argc \wedge$$
    $$argv^{-} \geq 1 \wedge optind \geq 0$$

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- Second Step: Compute what needs to hold at ?? to ensure memory safety
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- Second Step: Compute what needs to hold at ?? to ensure memory safety
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- Buffer access:

$$optind + 1 < argv^{+} \wedge$$
$$optind + 1 \geq -argv^{-}$$

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  $\phi \wedge ?? \models \psi$ where

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- Solution: $argc - optind > 1$

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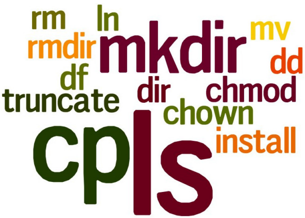
# Experiments

- Evaluated technique on the Unix Coreutils and parts of OpenSSH



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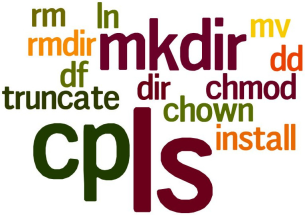

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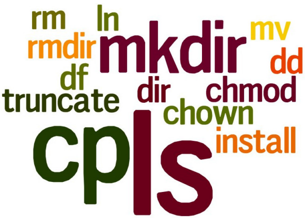
- Evaluated technique on the Unix Coreutils and parts of OpenSSH
- Removed conditionals used to prevent memory safety errors
- Used our new technique to synthesize the missing guards



# Experiments Cont.

| Program | Lines | # holes | Time (s) | Memory | Synthesis successful? | Bug? |
|---|---|---|---|---|---|---|
| Coreutils hostname | 160 | 1 | 0.15 | 10 MB | Yes | No |
| Coreutils tee | 223 | 1 | 0.84 | 10 MB | Yes | Yes |
| Coreutils runcon | 265 | 2 | 0.81 | 12 MB | Yes | No |
| Coreutils chroot | 279 | 2 | 0.53 | 23 MB | Yes | No |
| Coreutils remove | 710 | 2 | 1.38 | 66MB | Yes | No |
| Coreutils nl | 758 | 3 | 2.07 | 80 MB | Yes | No |
| SSH - sshconnect | 810 | 3 | 1.43 | 81 MB | Yes | No |
| Coreutils mv | 929 | 4 | 2.03 | 42 MB | Yes | No |
| SSH - do_authentication | 1,904 | 4 | 3.92 | 86 MB | Yes | Yes |
| SSH - ssh_session | 2,260 | 5 | 4.35 | 81 MB | Yes | No |

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- Two key ingredients:
  - Constraint generation: Generates VCs with placeholders using dual forward and backward reasoning
  - Constraint solving: New abduction-based algorithm for finding optimal solutions for placeholders representing unknown guards
- Experimental validation of our approach

# Questions?