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
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  - \- But only transforms vulnerability into program crash
  - \- Run-time overhead

Key Idea: Use Program Synthesis

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Example:

```
if(???)  {R} else { /* handle error */}
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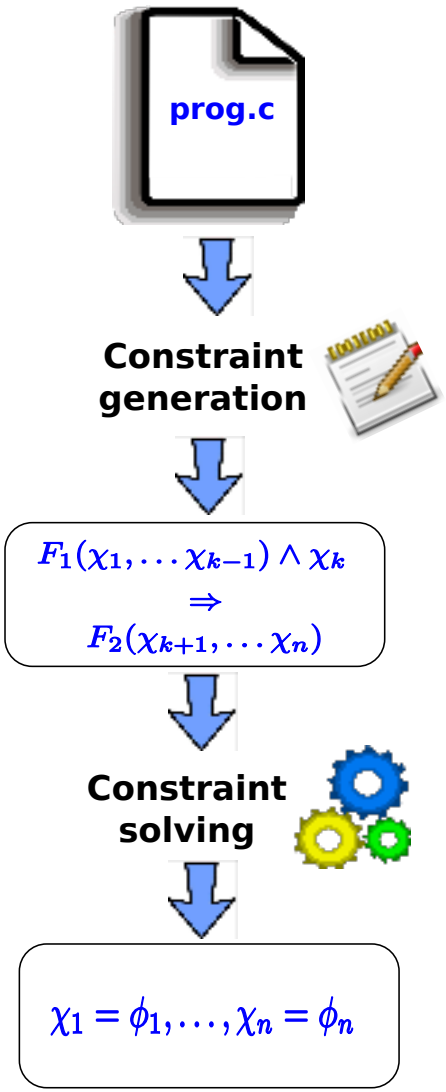
Key Idea: Program synthesis to guarantee memory safety

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:

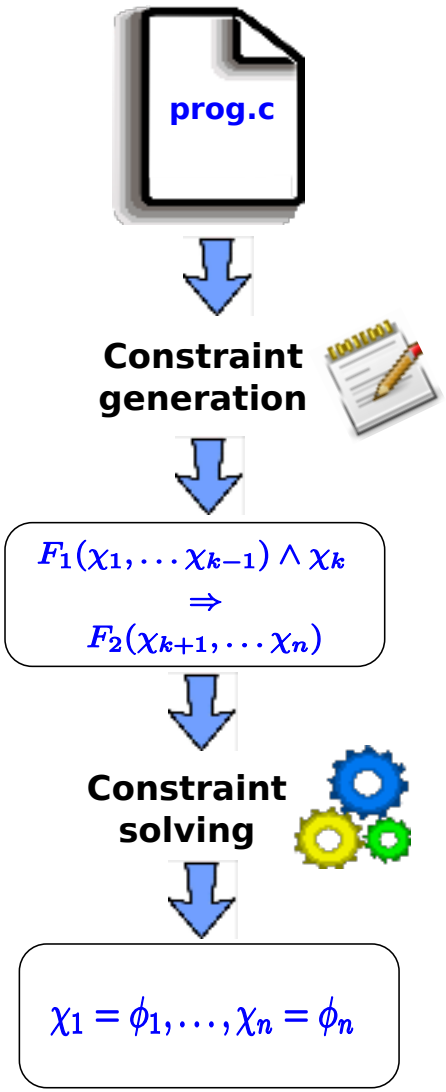
```
if(???)  {R} else { /* handle error */}
```

Solution Overview



1. Constraint Generation:

Solution Overview



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   - Represent unknown guards using placeholders

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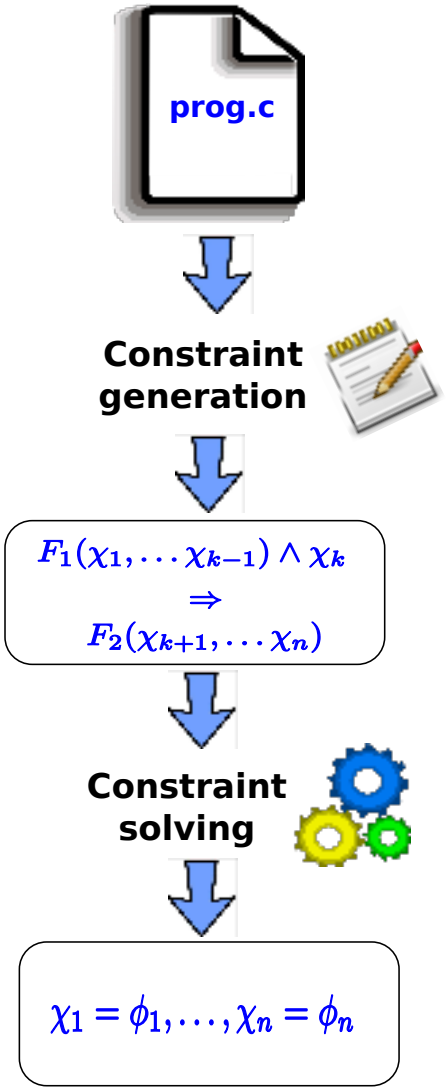

1. Constraint Generation:
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   - Perform dual forward and backward analysis to generate constraint for each unknown

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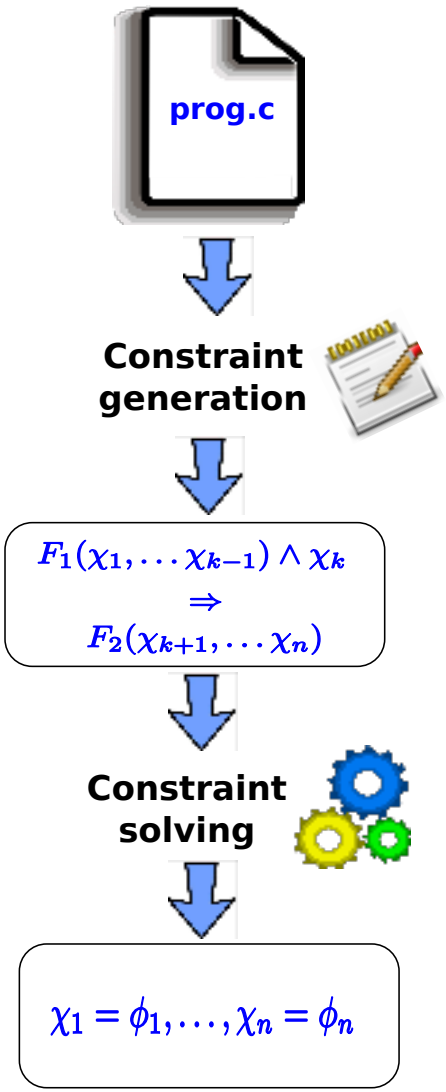

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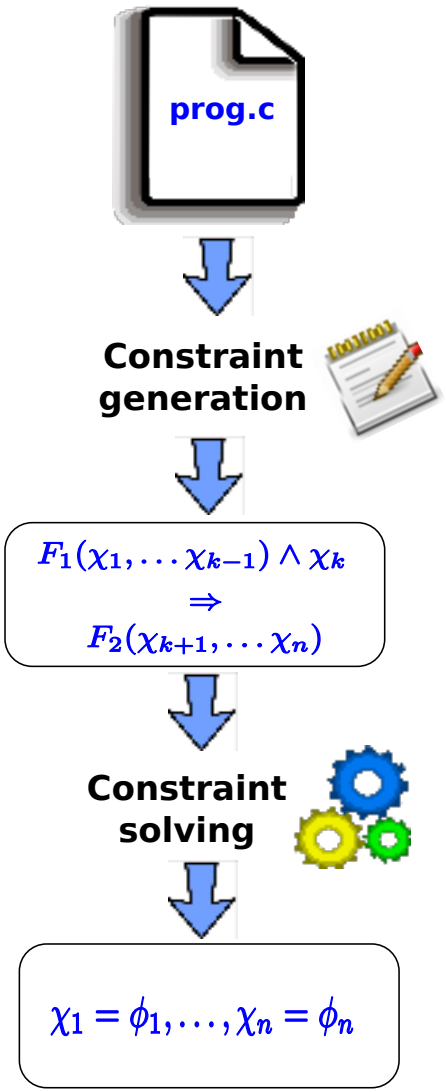

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   - An extended abduction algorithm for solving constraint system with multiple unknowns

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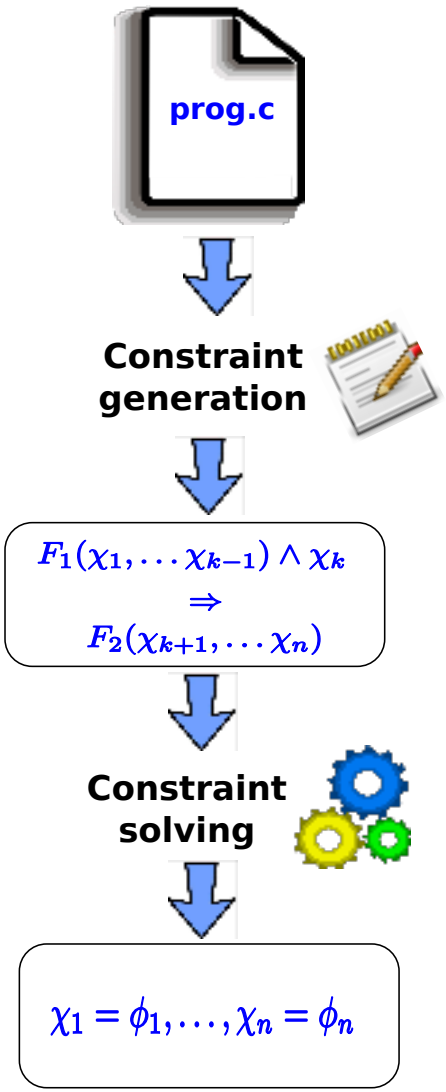

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   - Represent unknown guards using placeholders
   - Perform dual forward and backward analysis to generate constraint for each unknown
2. Constraint Solving:
   - An extended abduction algorithm for solving constraint system with multiple unknowns
   - Guarantees Pareto-optimality

Constraint Generation Overview

ϕ

```
{
    ...
}
```

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

- At synthesis point, compute postcondition ϕ of code above ??

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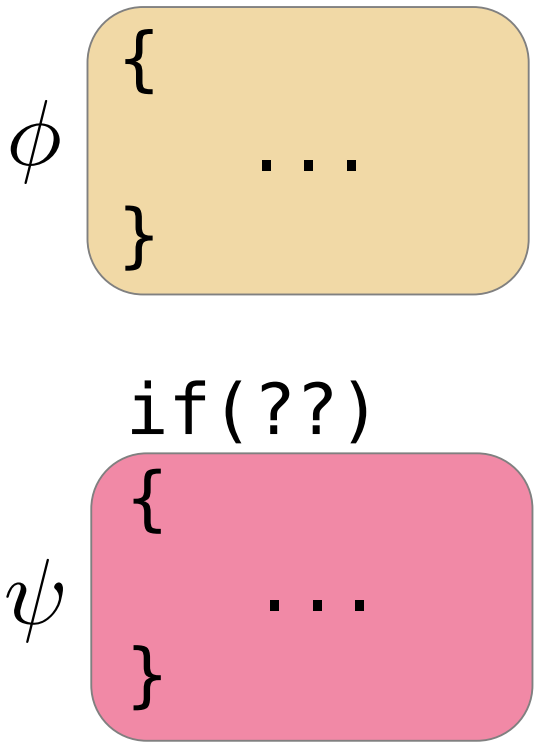

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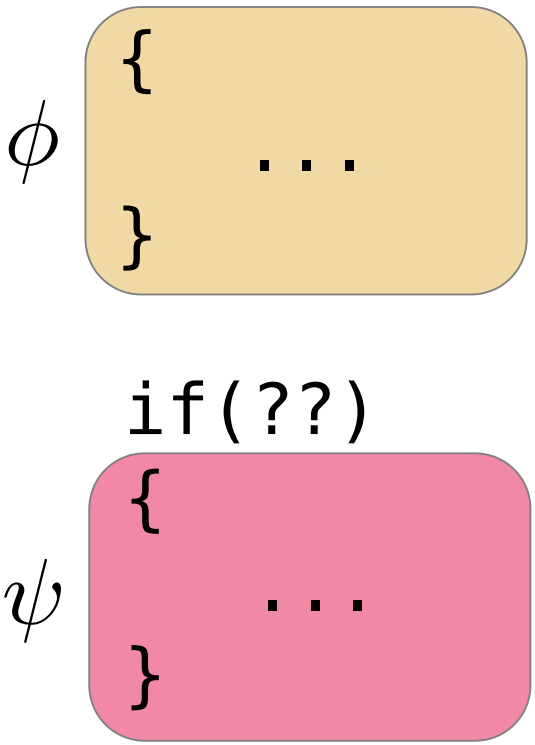

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- Compute precondition ψ that ensures memory safety of code guarded by ??
- Condition to guarantee memory safery:

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

Key Insight: Abduction

Solution: **Abductive inference**

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- $F \equiv$ postcondition ϕ before ??
- $O \equiv$ memory safety precondition ψ
- $E \equiv$ 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++;
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  if(??) {
    argv[optind+1]=...;
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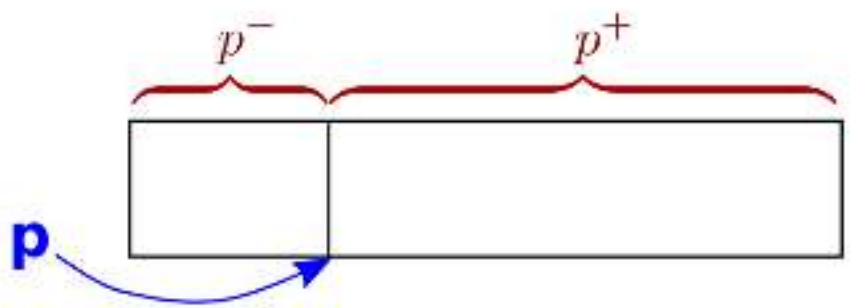


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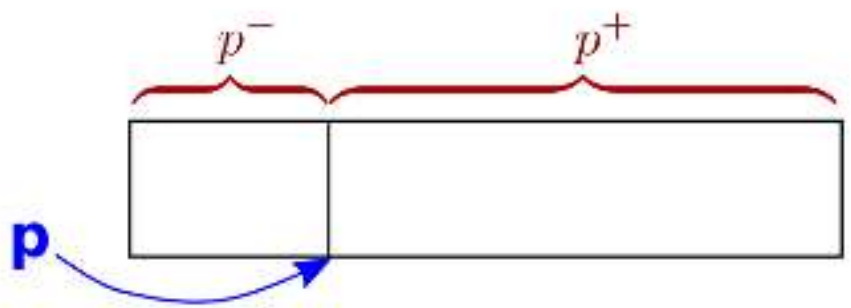
- Code snippet from Unix Coreutils with protected memory access
- Convention: For pointer p:
  - p^+ represents distance to end of memory block
  - p^- represents distance from beginning of memory block

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Example Cont.

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

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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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- Buffer access:

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

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- Solve abduction problem
  $\phi \wedge ?? \models \psi$ where

$$\phi: \quad \begin{array}{c} argv^+ = argc \wedge \\ argv^- \geq 1 \ \wedge \ optind \geq 0 \end{array}$$

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- Solution: $argc - optind > 1$

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- 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?