# ULTIMATE Automizer

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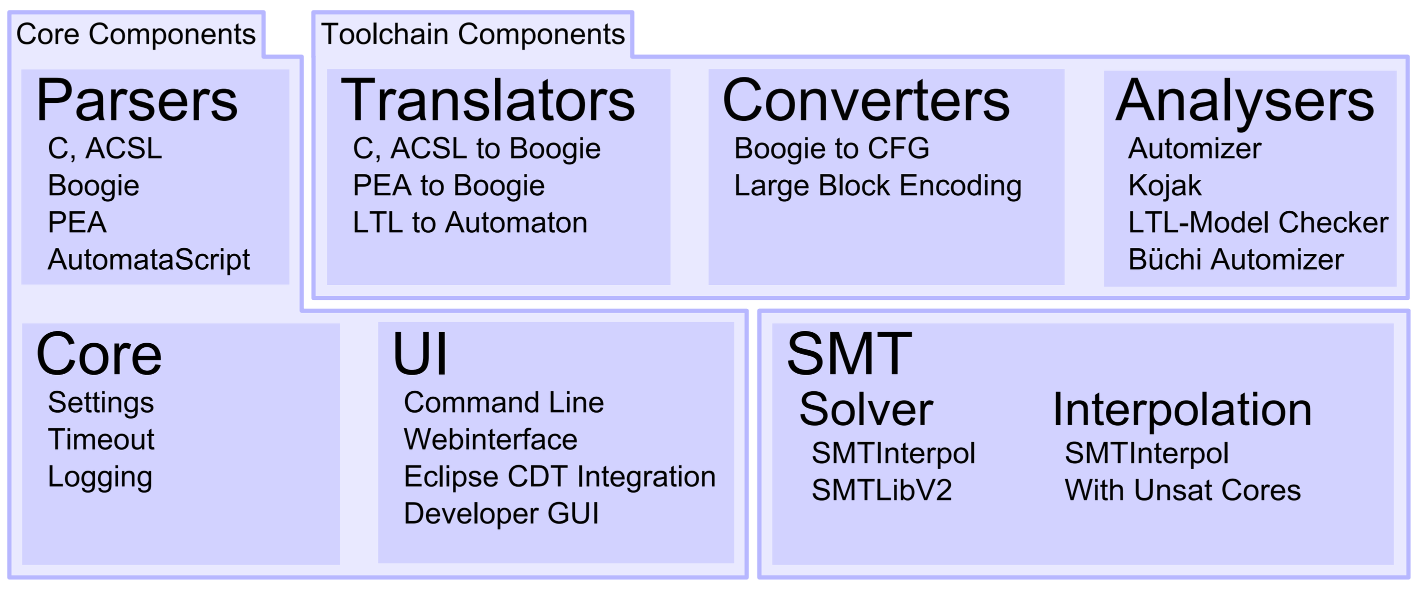
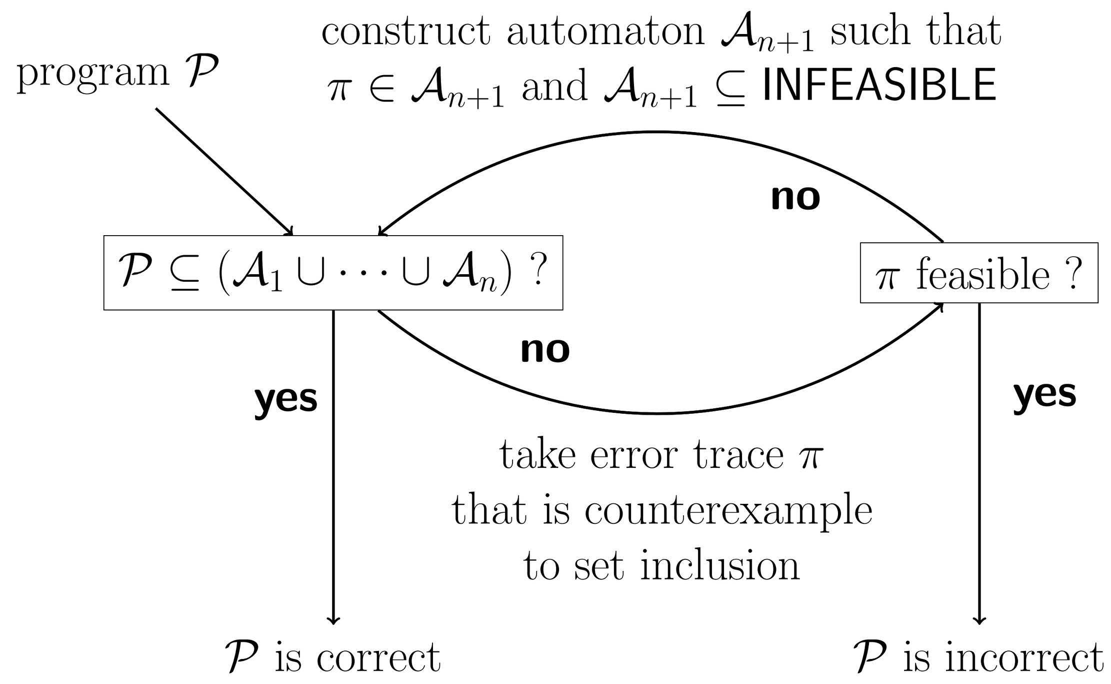
## Ultimate program analysis framework



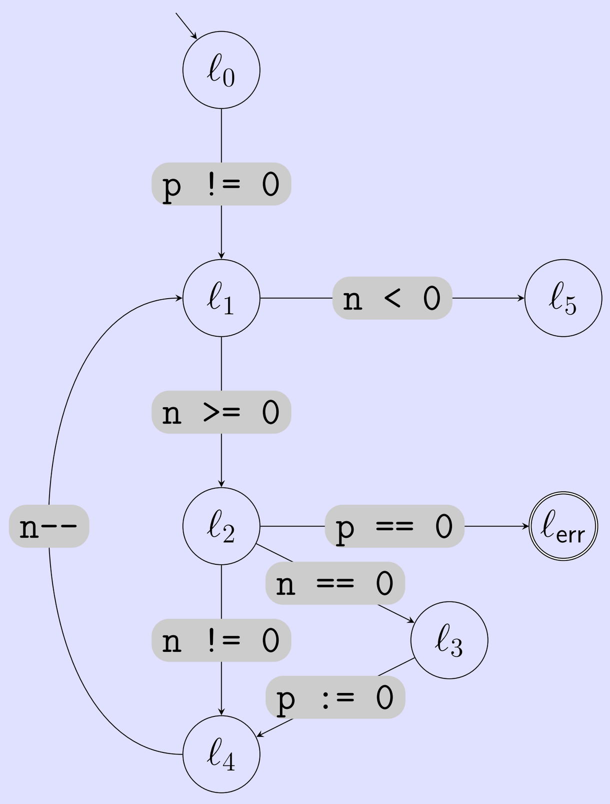

## Automizer algorithm




## Automata-theoretic proof of program correctness

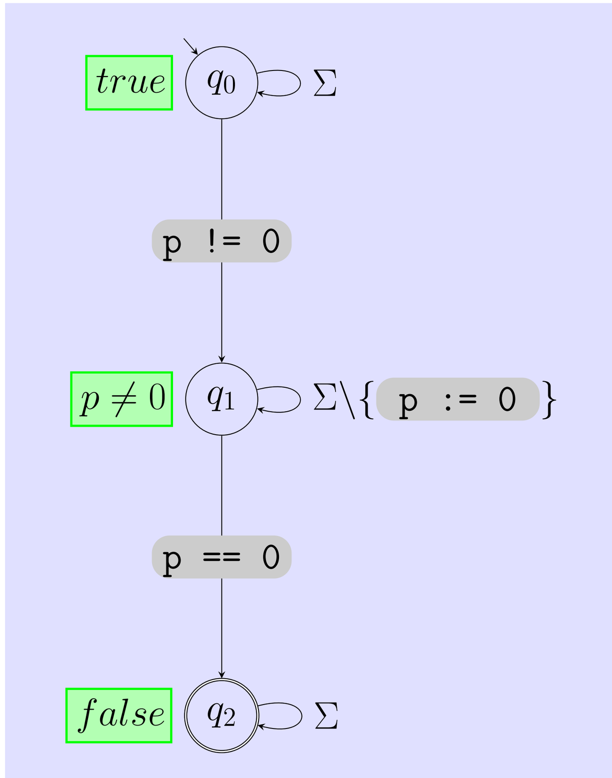
Program $\mathcal{P}$ is correct because each error trace is infeasible, i.e. the inclusion $\mathcal{P} \subseteq \mathcal{A}_1 \cup \mathcal{A}_2$ holds.

```
ℓ0:  assume p != 0;
ℓ1:  while(n >= 0) {
ℓ2:      assert p != 0;
         if(n == 0) {
ℓ3:          p := 0;
         }
ℓ4:      n--;
     }
```



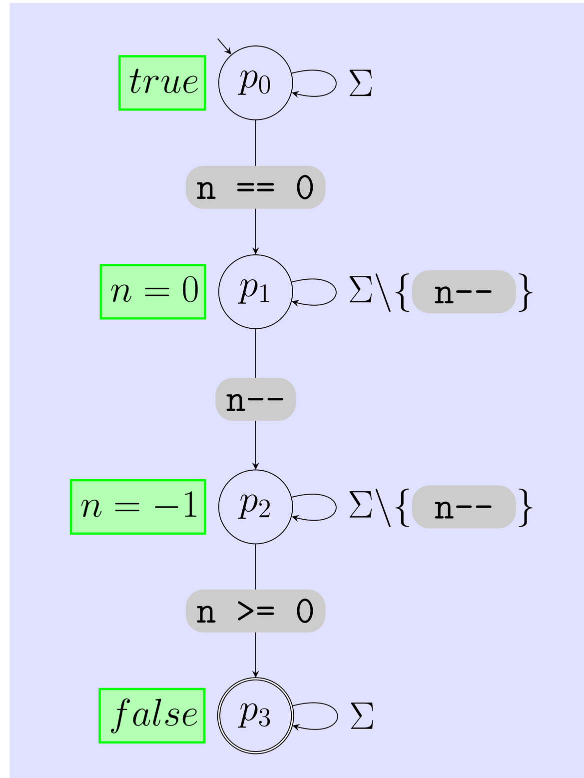

Program / automaton $\mathcal{P}$ whose language is the set of error traces.

$\subseteq$




Automaton $\mathcal{A}_1$ whose language is a set of infeasible traces.

$\cup$




Automaton $\mathcal{A}_2$ whose language is a set of infeasible traces.

- Alphabet: set of program statements
  $\Sigma = \{$ `p != 0`, `n < 0`, `n >= 0`, `p == 0`, `n == 0`, `n != 0`, `p := 0`, `n --` $\}$
- The language of $\mathcal{P}$ is the set of error traces.
- In the first iteration, we analyze feasibility of the error trace $\pi_1 =$ `p != 0` `n >= 0` `p == 0`. $\pi_1$ is infeasible. Via interpolation, we obtain the following Hoare triples.

  $\{true\}$ `p != 0` $\{p \neq 0\}$
  $\{p \neq 0\}$ `n >= 0` $\{p \neq 0\}$
  $\{p \neq 0\}$ `p == 0` $\{false\}$

  We construct the automaton $\mathcal{A}_1$ such that its language is the set of all traces whose infeasibility can be shown using the predicates $true$, $p \neq 0$, and $false$.
- Analogously, in the second iteration the automaton $\mathcal{A}_2$ is constructed.
- We check the inclusion $\mathcal{P} \subseteq \mathcal{A}_1 \cup \mathcal{A}_2$ and conclude that each error trace is infeasible and hence $\mathcal{P}$ is correct.

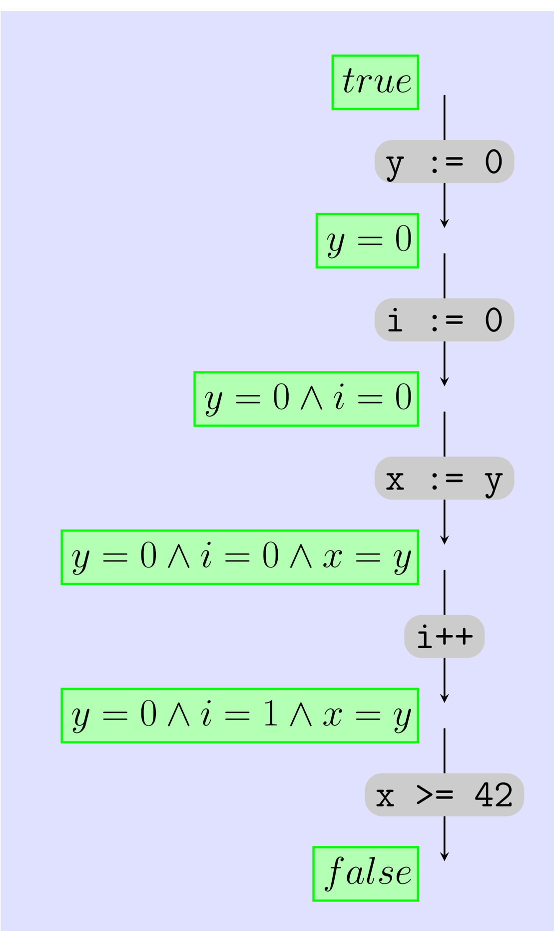
**Definition** Given an automaton $\mathcal{A} = (Q, \delta, q_{\mathsf{init}}, Q_{\mathsf{final}})$ over the alphabet of program statements, we call a mapping that assigns to each state $q \in Q$ a predicate $\varphi_q$ a *Floyd-Hoare annotation for automaton $\mathcal{A}$* if the following implications hold.

$$(q, st, q') \in \delta \implies \{\varphi_q\} st \{\varphi_{q'}\} \text{ is a valid Hoare triple}$$
$$q = q_{\mathsf{init}} \implies \varphi_q = true$$
$$q \in Q_{\mathsf{final}} \implies \varphi_q = false$$

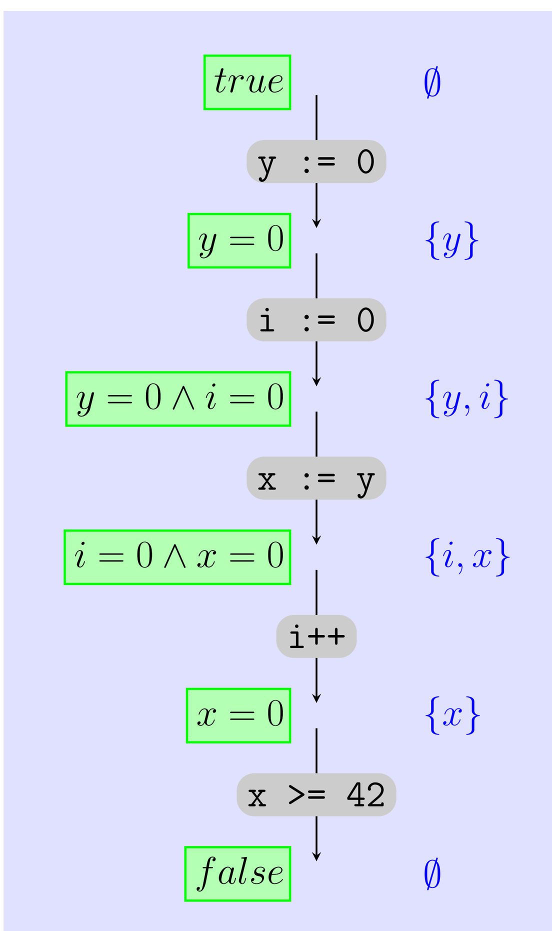
**Theorem** If an automaton $\mathcal{A}$ has a Floyd-Hoare annotation, then $\mathcal{A}$ recognizes a set of infeasible traces.

## Interpolation with unsatisfiable cores

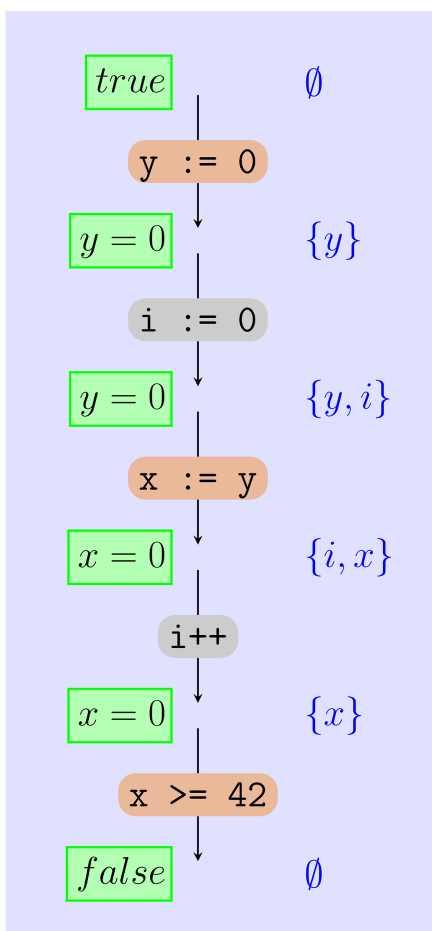
Level 1: "interpolation" via
- strongest post




Level 2: interpolation via
- strongest post
- live variable analysis




Level 3: interpolation via
- strongest post
- live variable analysis
- unsatisfiable cores




Algorithm (for level 3)
- Input: infeasible trace $st_1, \dots, st_n$ and unsatisfiable core $\mathsf{UC} \subseteq \{st_1, \dots, st_n\}$
- Replace each statement that does not occur in UC by a skip statement or a havoc statement.
  assume statement `ψ` ⇝ `skip`
  assignment statement `x:=t` ⇝ `havoc x`
- Compute sequence of predicates $\varphi_0, \dots, \varphi_n$ iteratively using the strongest post predicate transformer. $sp$
  $$\varphi_0 := true$$
  $$\varphi_{i+1} := sp(\varphi_i, st_{i+1})$$
- Eliminate each variable from predicate $\varphi_i$ that is not live at position i of the trace.
- Output: sequence of predicates $\varphi_0, \dots, \varphi_n$ which is a sequence of interpolants for the infeasible trace $st_1, \dots, st_n$