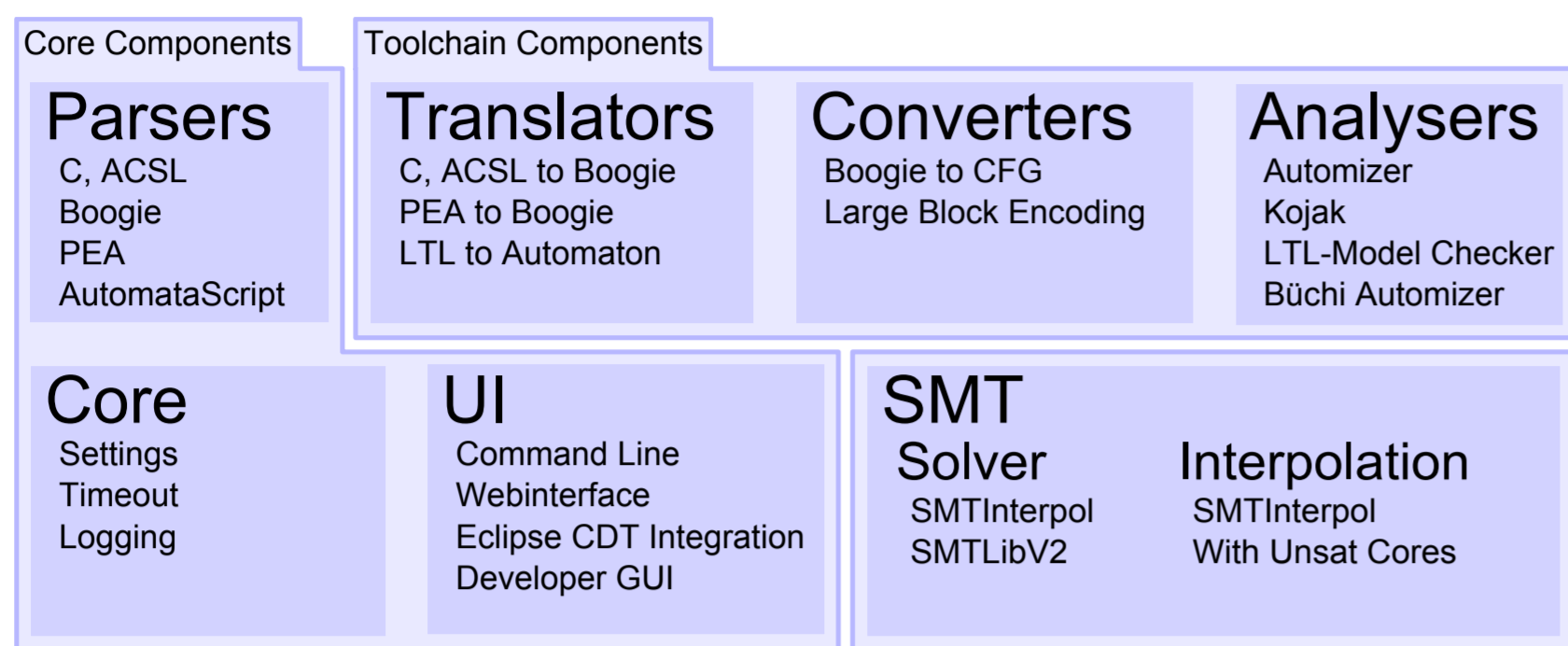


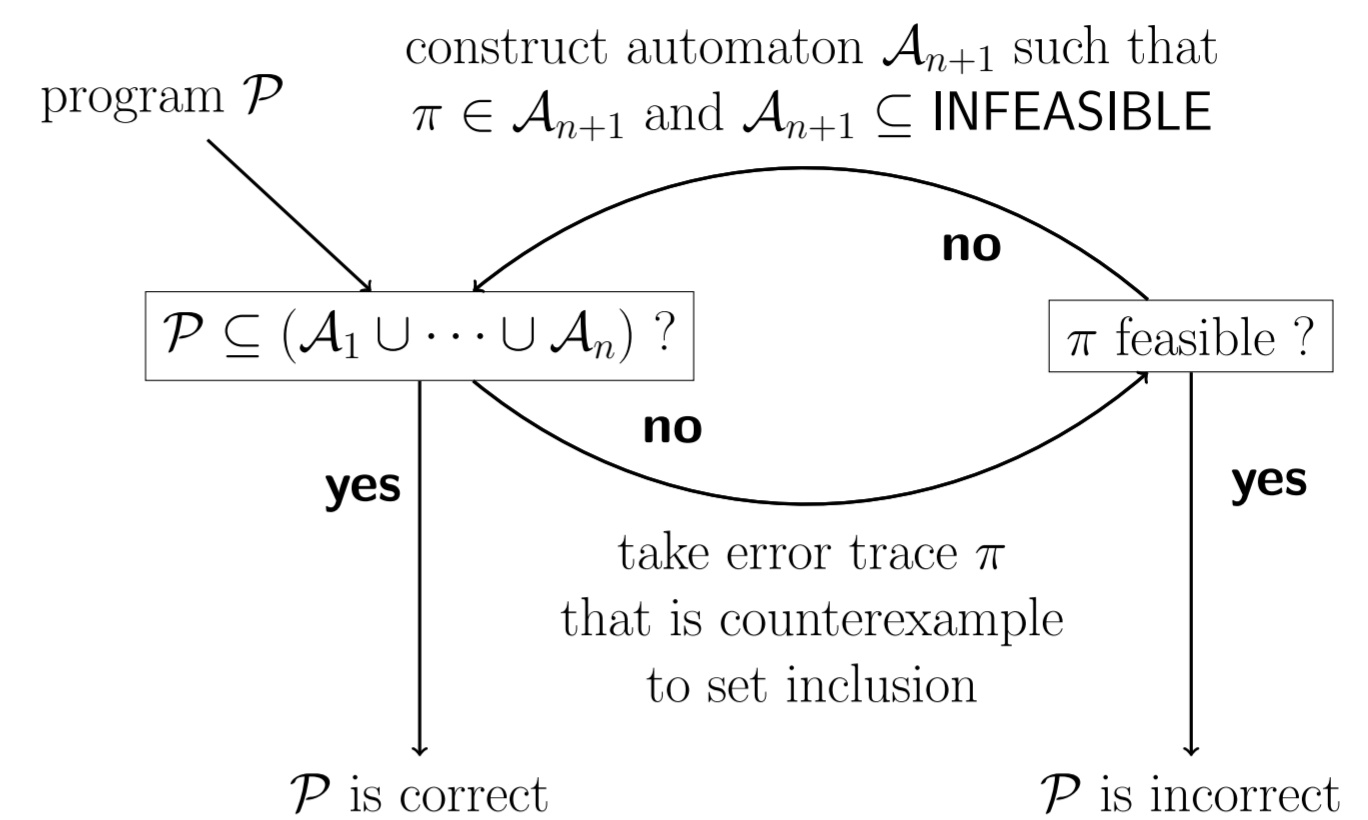
ULTIMATE Automizer

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Ultimate program analysis framework

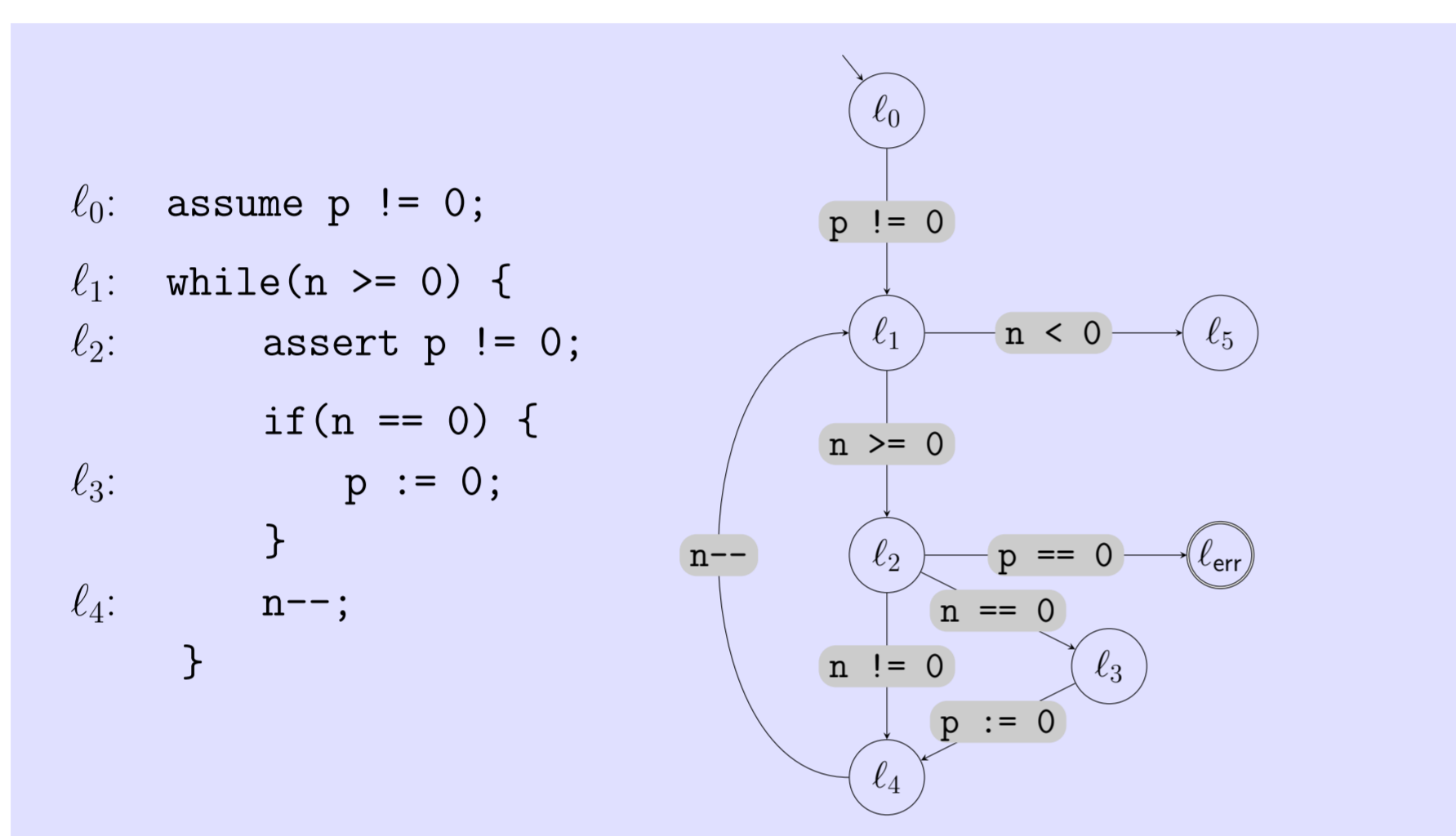


Automizer algorithm

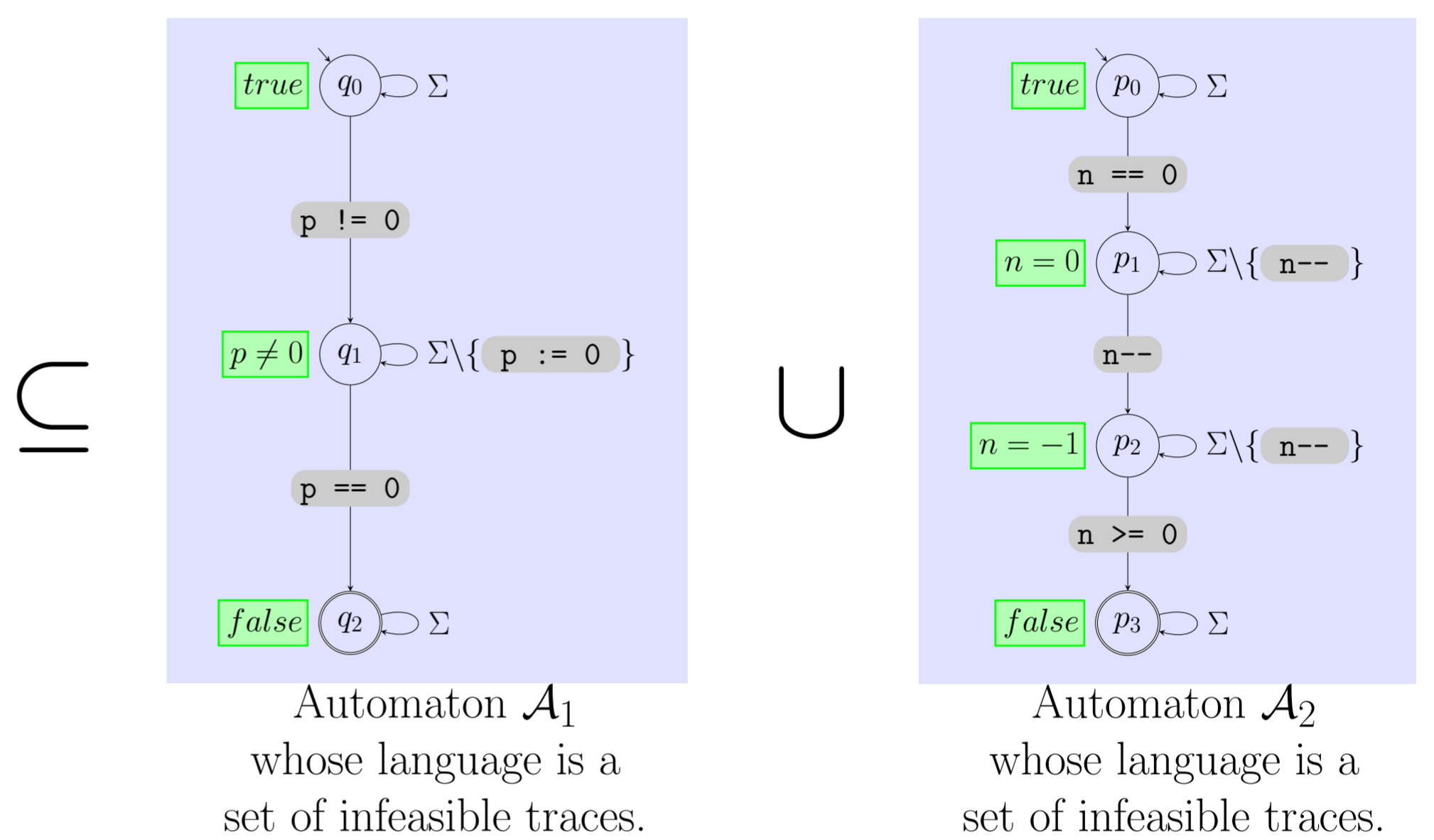


Automata-theoretic proof of program correctness

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.



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



- Alphabet: set of program statements

$\Sigma = \{ p \neq 0, n < 0, n \geq 0, p == 0, n == 0, n != 0, p := 0, n -- \}$

- The language of \mathcal{P} is the set of error traces.

- In the first iteration, we analyze feasibility of the error trace $\pi_1 = p \neq 0 \ n \geq 0 \ p == 0$. π_1 is infeasible. Via interpolation, we obtain the following Hoare triples.

$\{true\}$	$p \neq 0$	$\{p \neq 0\}$
$\{p \neq 0\}$	$n \geq 0$	$\{p \neq 0\}$
$\{p \neq 0\}$	$p == 0$	$\{false\}$

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

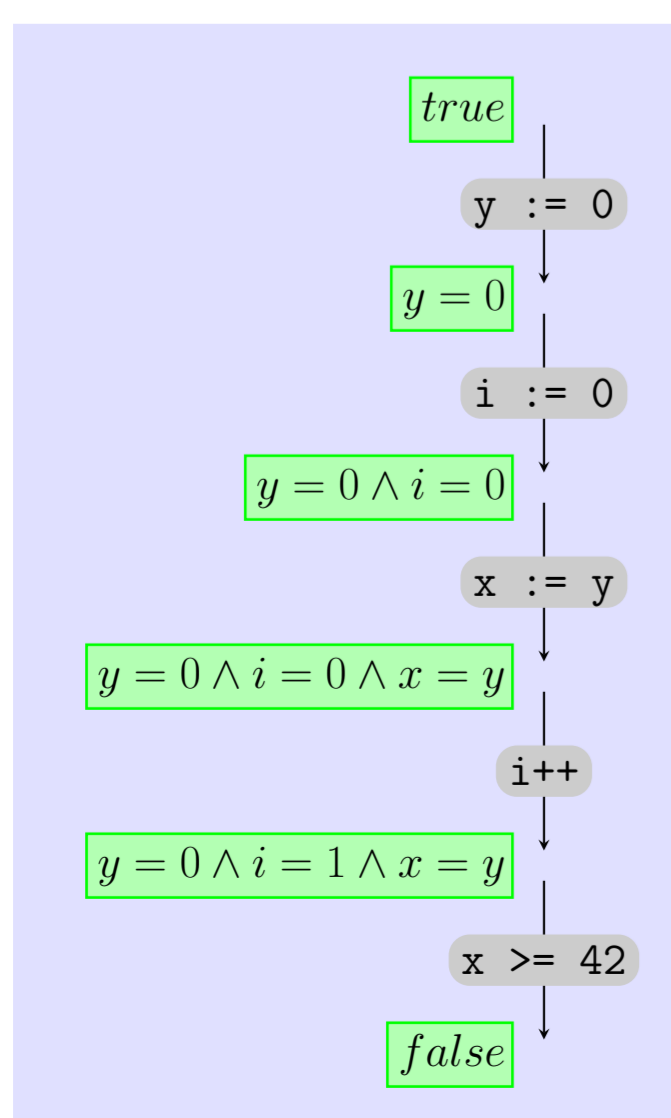
$(q, \mathcal{A}, q') \in \delta \implies \{\varphi_q\} \mathcal{A} \{\varphi_{q'}\}$ is a valid Hoare triple
 $q = q_{init} \implies \varphi_q = true$
 $q \in Q_{final} \implies \varphi_q = false$

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

Interpolation with unsatisfiable cores

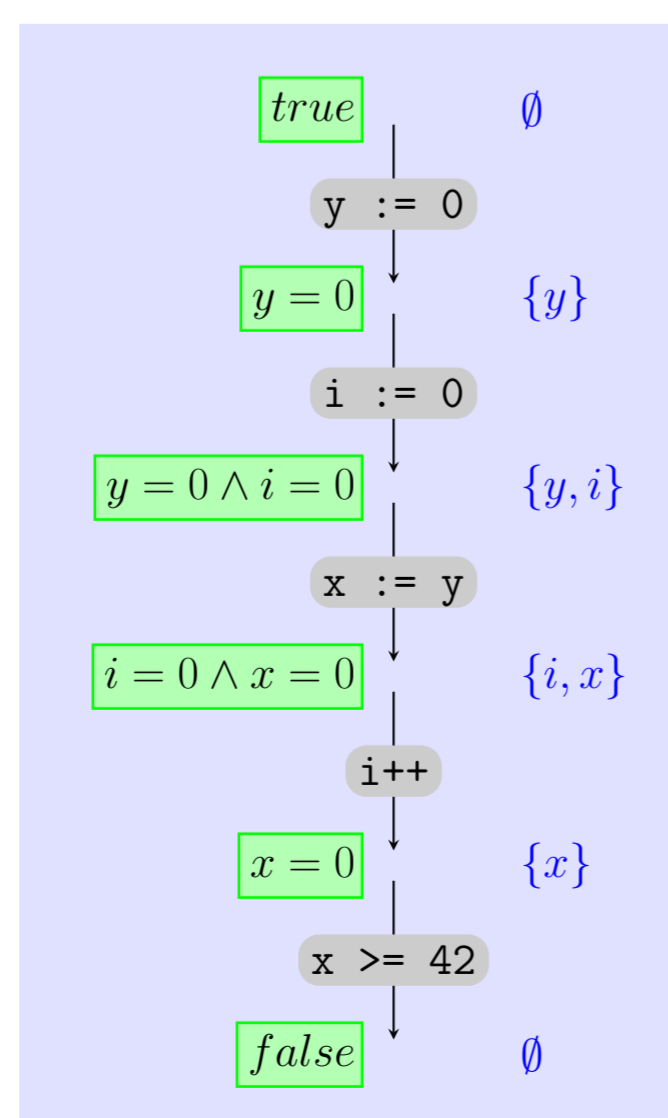
Level 1: “interpolation” via

- strongest post



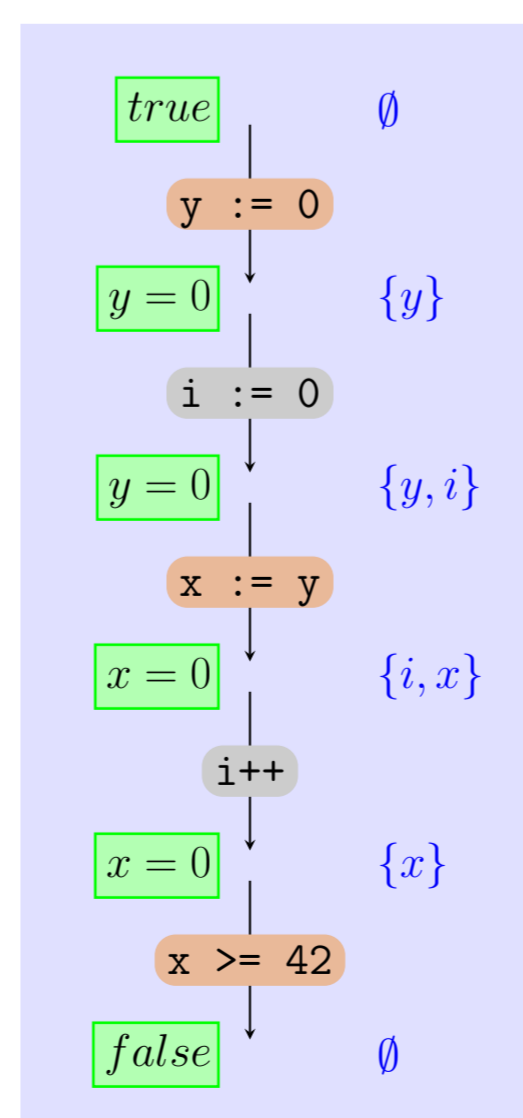
Level 2: interpolation via

- strongest post
- live variable analysis



Level 3: interpolation via

- strongest post
- live variable analysis
- unsatisfiable cores



Algorithm (for level 3)

- Input: infeasible trace $\mathcal{A}_1, \dots, \mathcal{A}_n$ and unsatisfiable core $UC \subseteq \{\mathcal{A}_1, \dots, \mathcal{A}_n\}$
- Replace each statement that does not occur in UC by a skip statement or a havoc statement.
 - assume statement $\psi \rightsquigarrow skip$
 - assignment statement $x := t \rightsquigarrow havoc\ x$
- Compute sequence of predicates $\varphi_0, \dots, \varphi_n$ iteratively using the strongest post predicate transformer. sp

$\varphi_0 := true$
 $\varphi_{i+1} := sp(\varphi_i, \mathcal{A}_{i+1})$

- Eliminate each variable from predicate φ_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 $\mathcal{A}_1, \dots, \mathcal{A}_n$