# Information Flow Control by Program Analysis

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# Context

Work in progress from a joint project with Gregor Snelting (KIT)

Information flow control for mobile components based on precise analysis of parallel programs

Part of priority programme 1496

Reliably Secure Software Systems ($RS^3$)

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# What This Talk is About

Theme:

How can program analysis technology be used for information flow analysis?

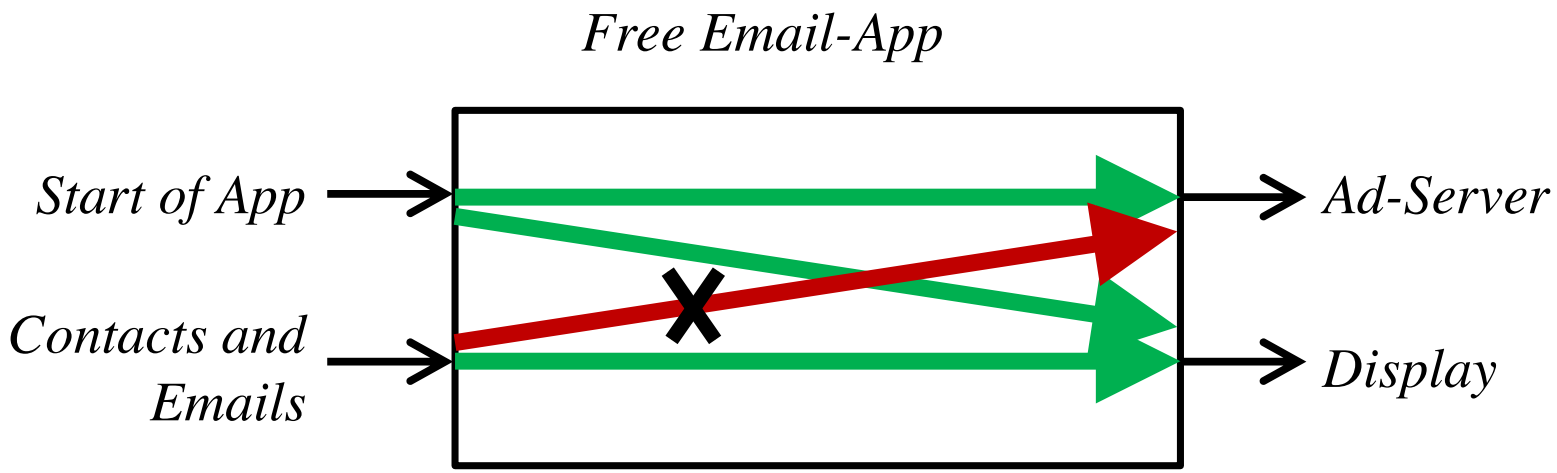
Program analysis:

data-flow analysis, abstract interpretation, invariant generation, software model checking, ...

Information flow analysis:

see next slide

# Information Flow: Example




Reference scenarios of SPP RS$^3$:

- Certifying app store for Android
- E-Voting systems
- Software security for mobile devices

# Non-Interference

For simplicity: transformational terminating programs only

Semantic setup:

| | |
|---|---|
| Variables: | $Var = Low \dot{\cup} High$ |
| States: | $\Sigma = \{ \sigma \mid \sigma : Var \rightarrow Val \}$ |
| Program semantics: | $[\![ \pi ]\!] : \Sigma \rightarrow \Sigma$ |

Low-equivalence of states:

$$\sigma \sim_L \sigma' \quad :\Leftrightarrow \quad \sigma|_{Low} = \sigma'|_{Low}$$

Program $\pi$ is called *non-interferent* iff f.a. $\sigma,\sigma' \in \Sigma$:

$$\sigma \sim_L \sigma' \quad \Rightarrow \quad [\![ \pi ]\!](\sigma) \sim_L [\![ \pi ]\!](\sigma')$$

# Possibilistic Non-Interference

Semantics of non-deterministic programs:

$$[\![ \pi ]\!] : \Sigma \to 2^{\Sigma}$$

Refinement:

$$\pi \sqsubseteq \pi' \quad :\Leftrightarrow \qquad \forall \sigma: \quad [\![ \pi ]\!](\sigma) \subseteq [\![ \pi' ]\!](\sigma)$$

Program $\pi$ is called *non-interferent* iff f.a. $\sigma,\sigma' \in \Sigma$:

$$\sigma \sim_L \sigma' \implies \forall \rho \in [\![ \pi ]\!](\sigma) : \exists \rho' \in [\![ \pi ]\!](\sigma') : \rho \sim_L \rho'$$

Refinement Paradox: Non-interference is not preserved by refinement.

Example: l := ? is non-interferent, its refinement l := h is not

Reason: Non-interference is a „hyper-property“

# A Fundamental Problem

- Abstraction is inherent to program analysis
- However, as just observed (Refinement Paradox):

  Non-interference does not transfer from abstractions
- Consequence:

  Program analysis cannot be applied directly to non-interference

# Program Dependence Graphs (PDGs)

- A structure known from program slicing
- Nodes correspond to statements and conditions;
  we add artificial nodes for initial and final value of program variables
- Edges capture data dependences and control dependences
- PDGs can be applied for non-interference analysis

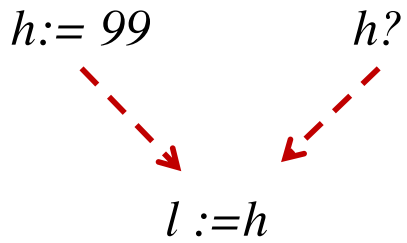
  Analysis principle:

  If there is no path in PDG from high input to low output
  then the program is non-interferent

# Direct and Indirect Flows

Direct flows:

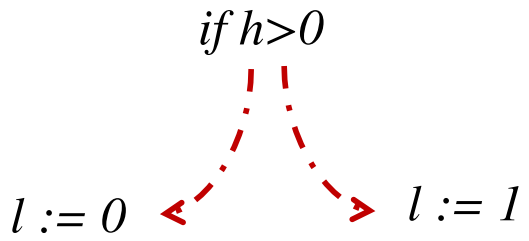
l := h




captured by data dependence edges in PDG

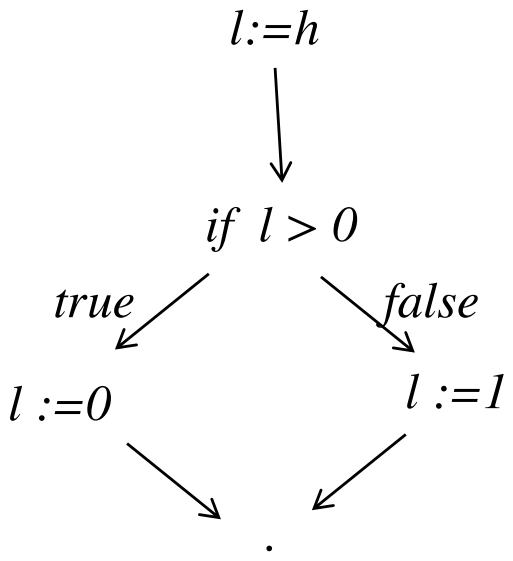
Indirect flows:

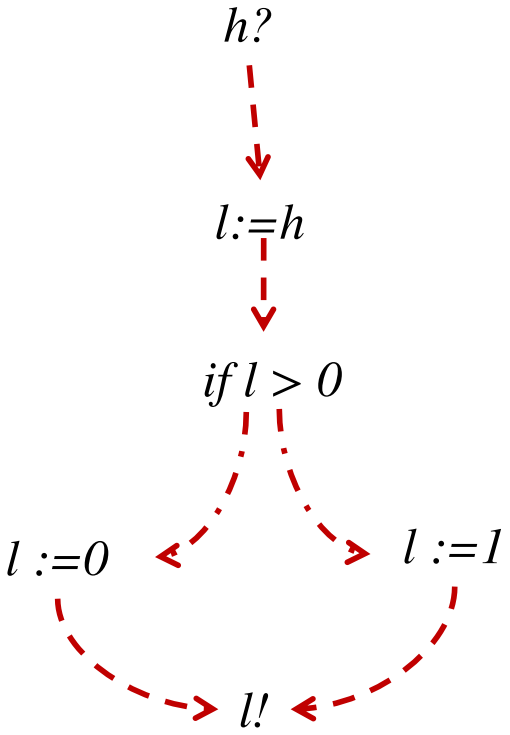
if h>0 then l := 0 else l := 1




captured by control dependence edges in PDG

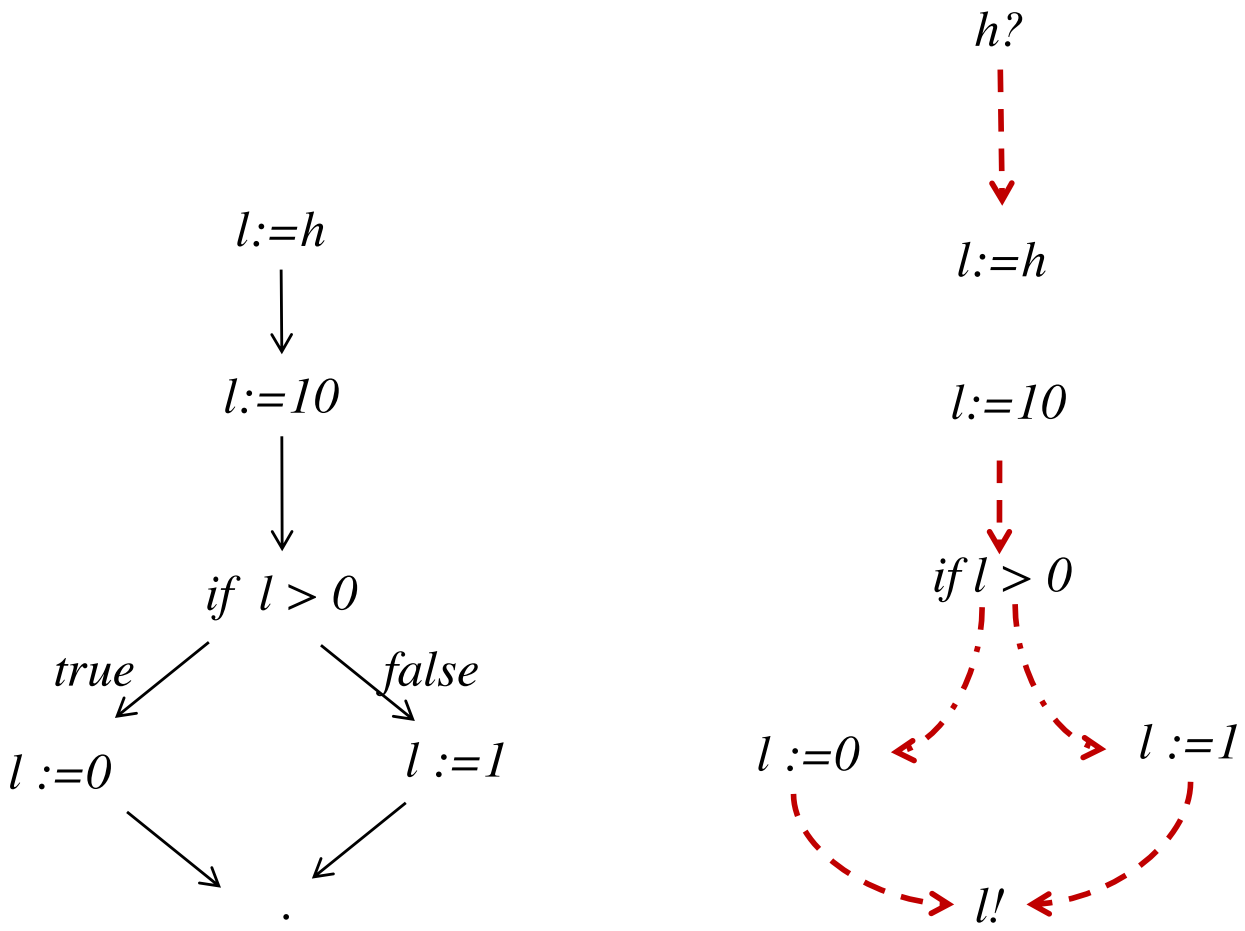
# Example 1




There is a path from h? to l!. Hence: Program may be interferent

# Example 2




There is no path from h? to l!. Hence: Program is non-interferent

# Path Conditions

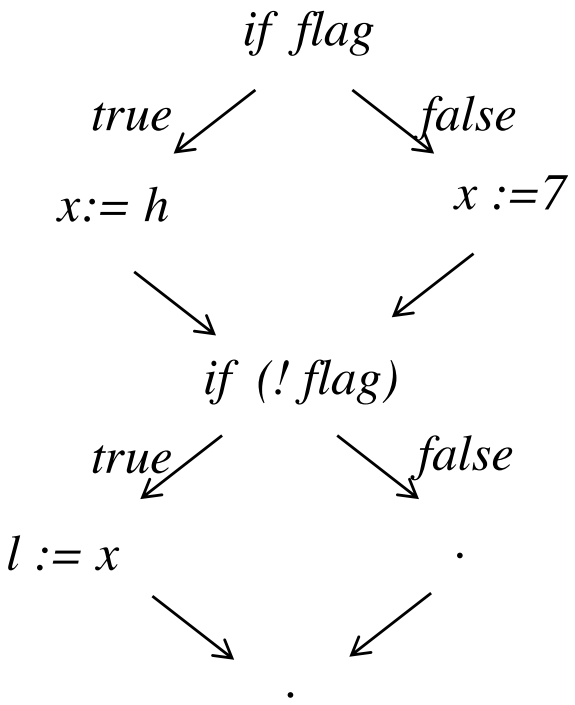
[Snelting]

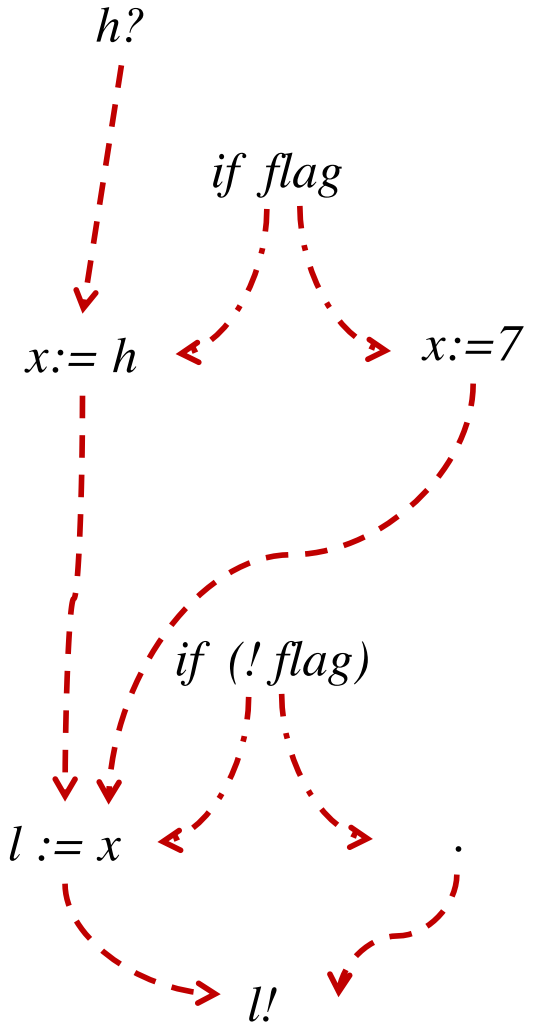
Goal: Improve precision of PDG-based dependence analysis

Idea: For each path in the PDG indicating critical flow, read off a necessary condition for flow from the guards. If all these conditinos are unsatisfiable, there is no flow.

Caveat: Requires SSA-form of programs

# Path conditions improve precision of PDGs



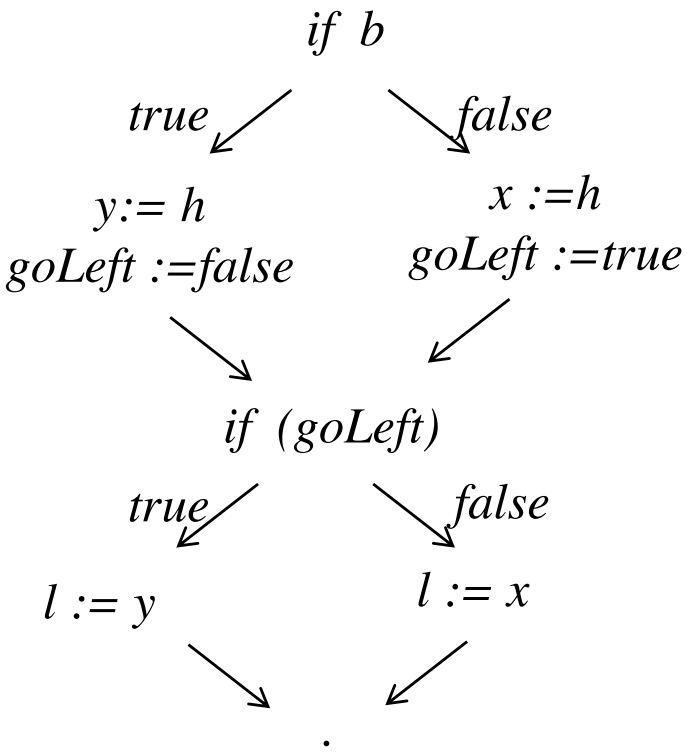



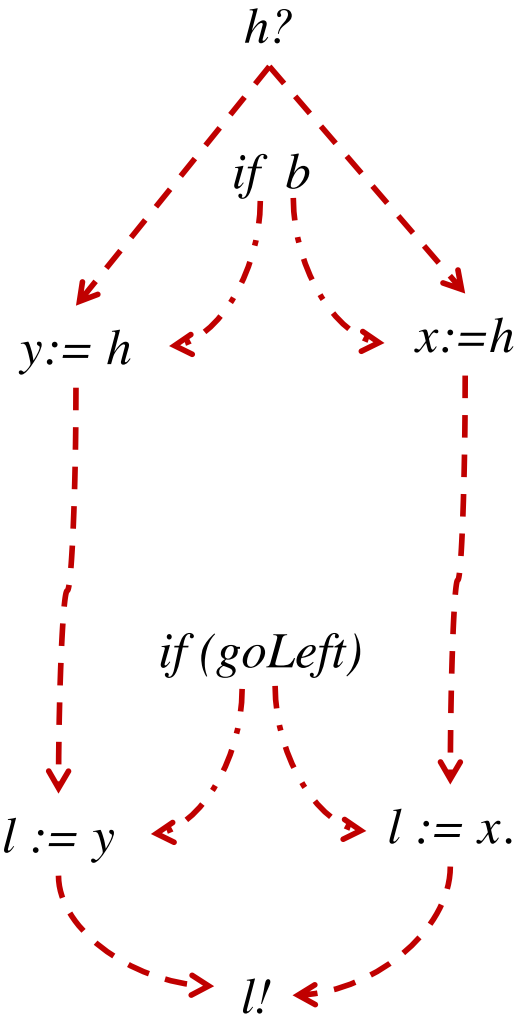

PDG alone: false alarm

+ path conditions: OK

*flag ∧ ! flag*

# Further Improvements by Data Analysis Desirable



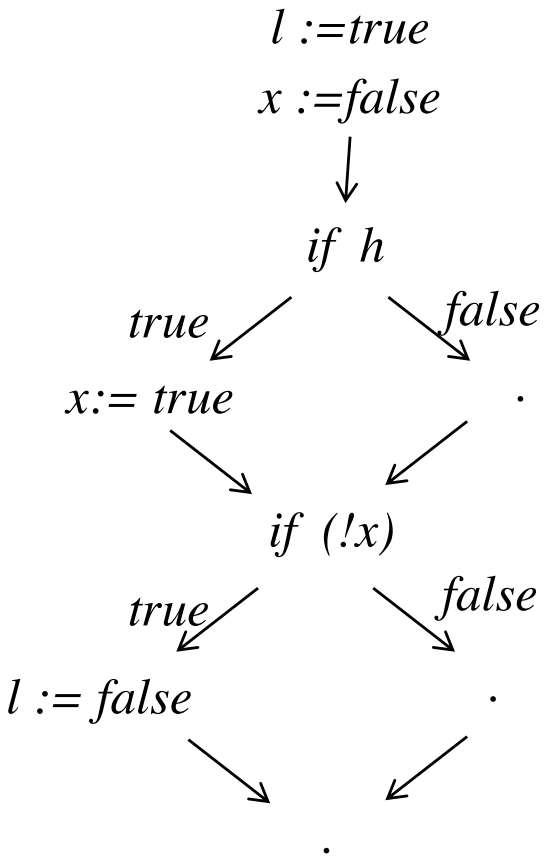

PDG + path conditions: false alarm

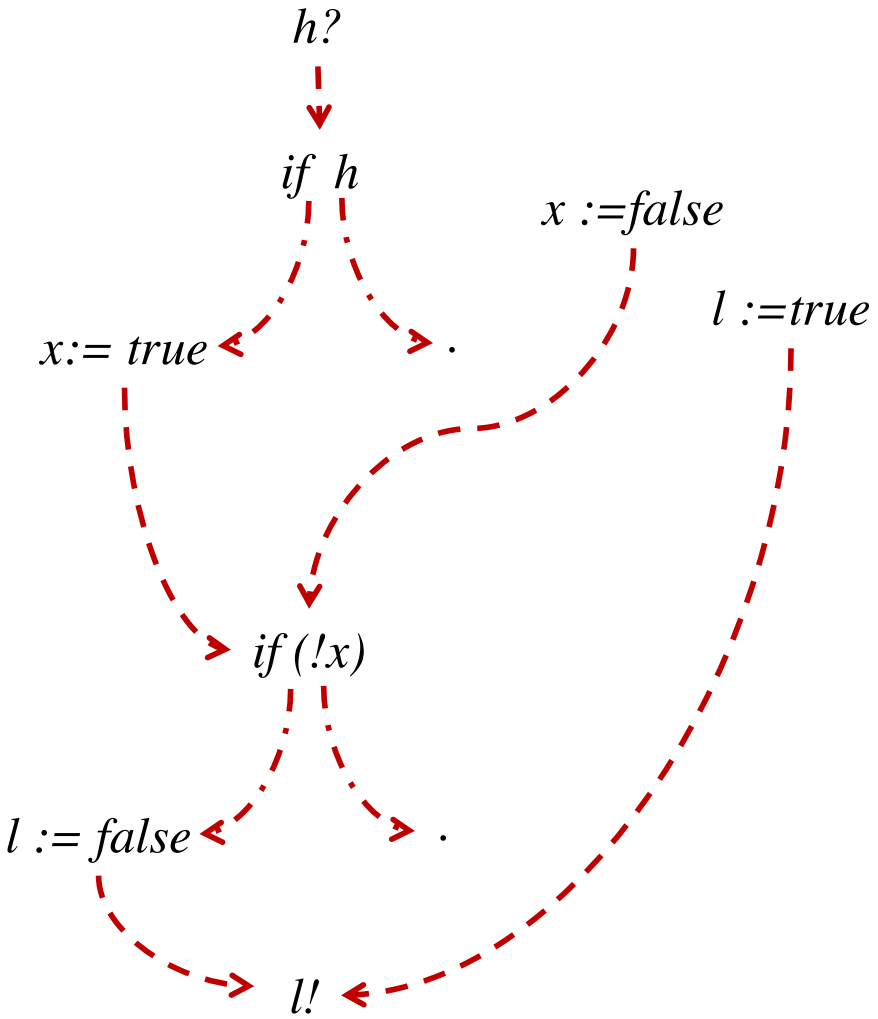
+ invariant: OK

*For left path:* $b \wedge goLeft \wedge goLeft = !\, b$

*For right path:* $!\, b \wedge !\, goLeft \wedge goLeft = !\, b$

# The Show Stopper




PDG + path conditions

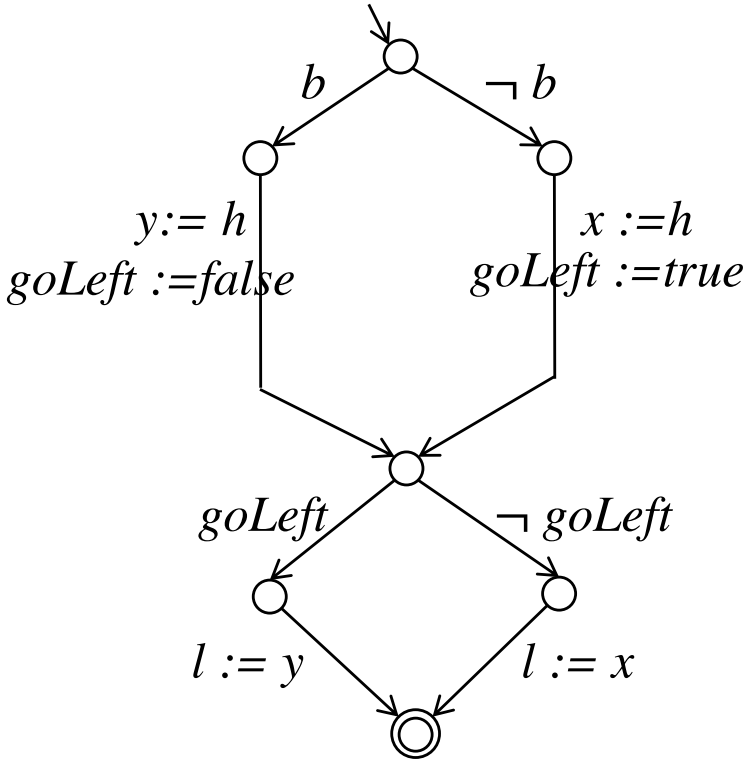
+ invariant: unsound

$h \wedge !x \ \wedge \ x = h$

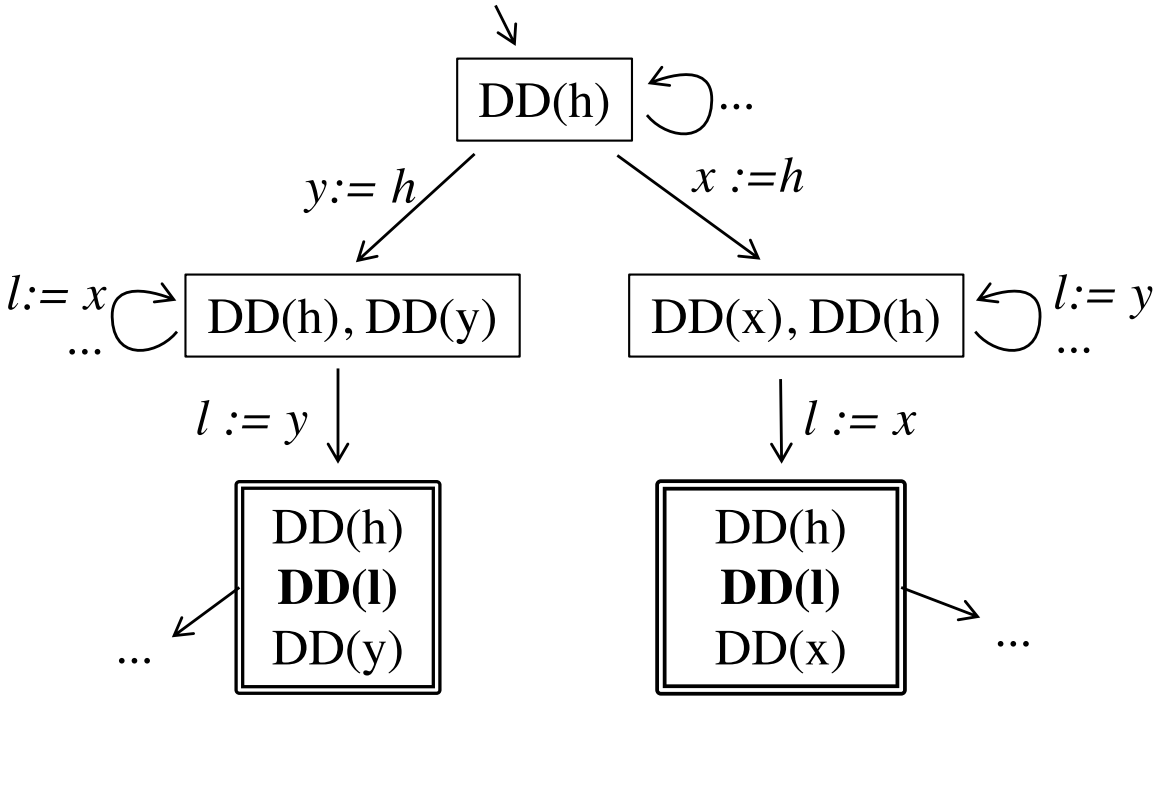
# A Glimpse on Data Flow Slicing

- Guiding intuition: flow happens along PDG paths only
- Add new type of dependencies (data control dependencies) to avoid soundness problem
- Define a notion of critical executions based on data-, control-, and data-control-dependencies
- Set of critical executions is regular for a given program
- Prove: if program has no critical execution, then program is non-interferent (Isabelle!)
- Check absence of critical executions using data analyses (e.g. using CPAChecker [Beyer et al.])
- Note: Approach allows to check non-interference by safety analysis!

# A Glimpse on Data Flow Slicing: Example

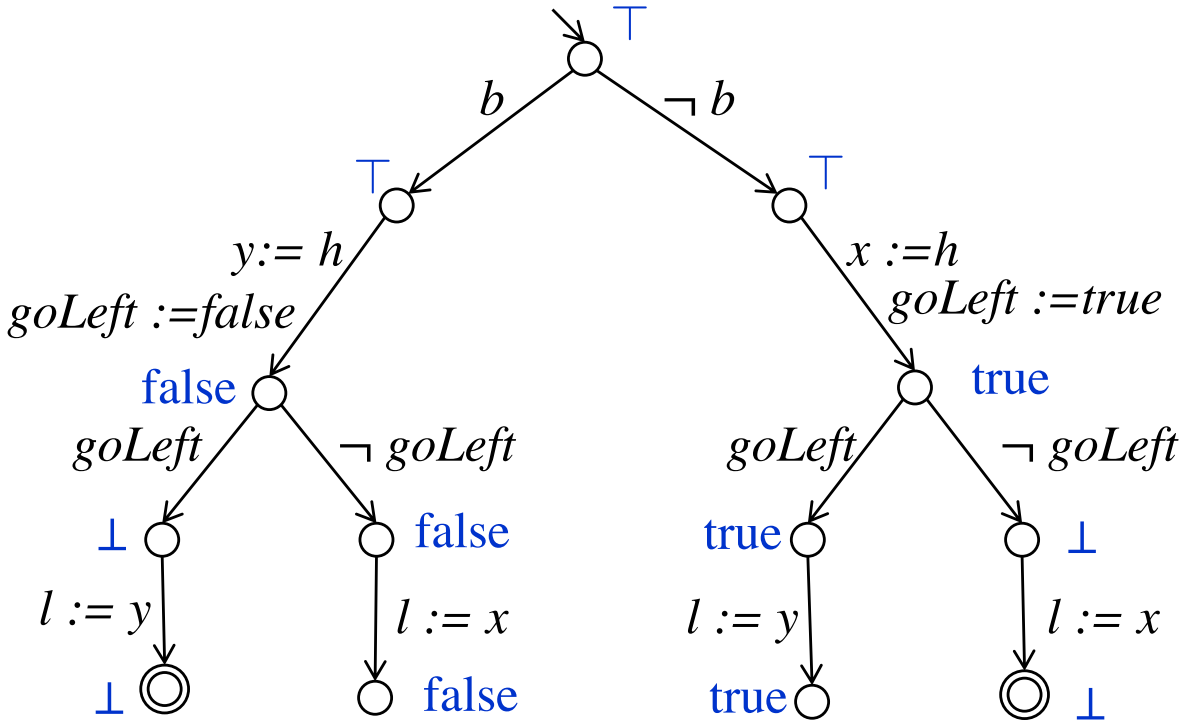



Program




Critical executions automaton

# A Glimpse on Data Flow Slicing: Example




Product of program and automaton

Constant propagation on product proves absence of critical information flow

# Discussion

Approach for non-interference analysis by classic program analysis

Alternative approaches:

- Self-composition
- Hyper-logics

Further work in our project:

- Use DPNs to help PDG-based non-interference analysis of parallel programs based on LSOD
- Use DPNs to help type-based non-interference analysis of parallel programs