# Interprocedural Information Flow Analysis of XML Processors

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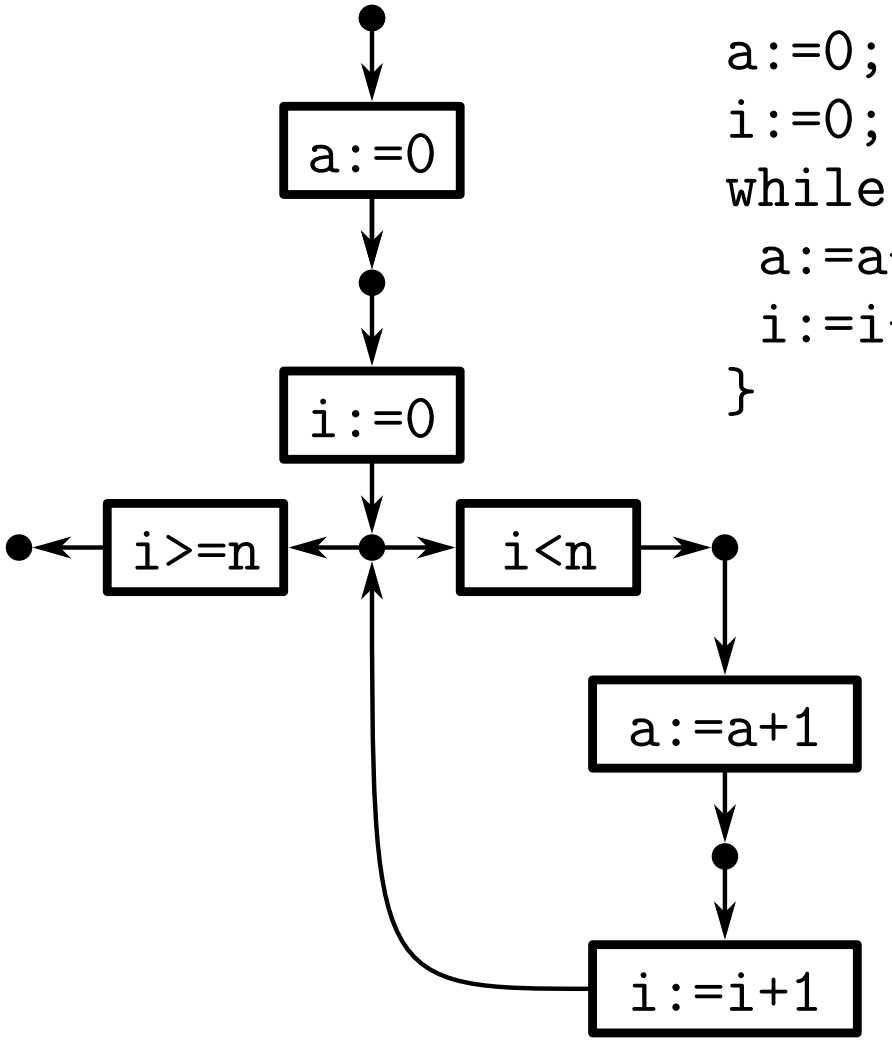
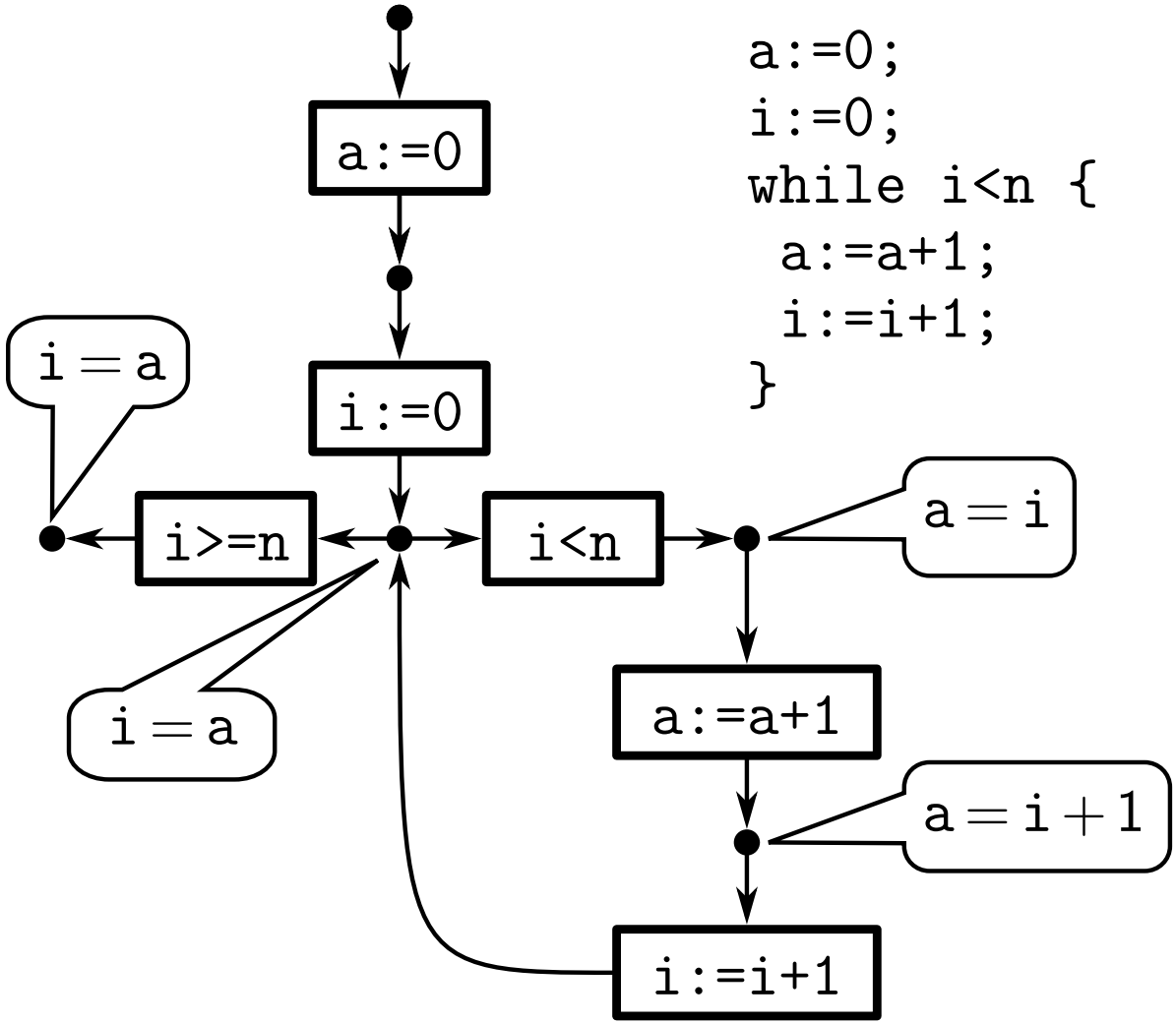
# Program Verification




```
a:=0;
i:=0;
while i<n {
 a:=a+1;
 i:=i+1;
}
```

# Program Verification



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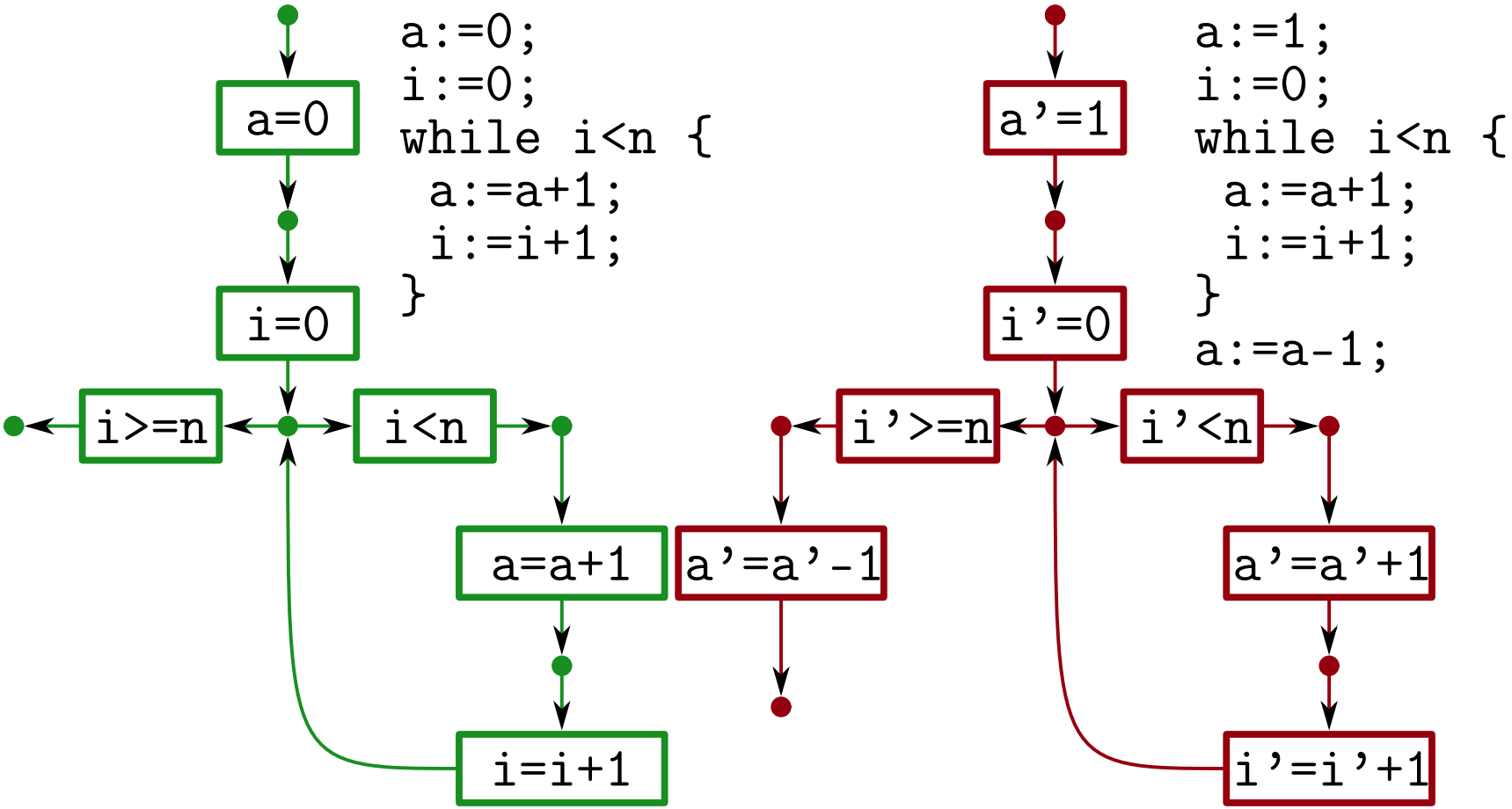
- In general undecidable
- Abstract interpretation provides computable over-approximation

# Program Equivalence



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Program equivalence $\Longleftrightarrow$ 2-Hypersafety property

// (modulo termination)

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- Required: computable approximation?

## Applications

- translation validation
- correctness of program transformation, e.g., for improvement, refactoring, ...

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- information flow security

# Information Flow

Secret 

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Adversary 

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Observations 

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Question **Can the adversary learn about the secret?**

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$$[\![p]\!]\, s_1 \stackrel{?}{=}_{\mathtt{x}} [\![p]\!]\, s_2$$

Can adversary distinguish between two secret values?

# Related Work on IF

- A lattice model for secure information flow — Denning 1976
- A sound type system — Volpano et al. 1996

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- Program dependence graphs — Hammer, Snelting 2009
- Self-composition — Barthe et al. 2004, 2011, 2013; Banerjee 2011; Kovacs et al. 2013

# Outline of the Talk

- Our approach
- Aligning of programs
- Relational abstract interpretation
- Procedures
- Structured data and tree automata

# Our Approach

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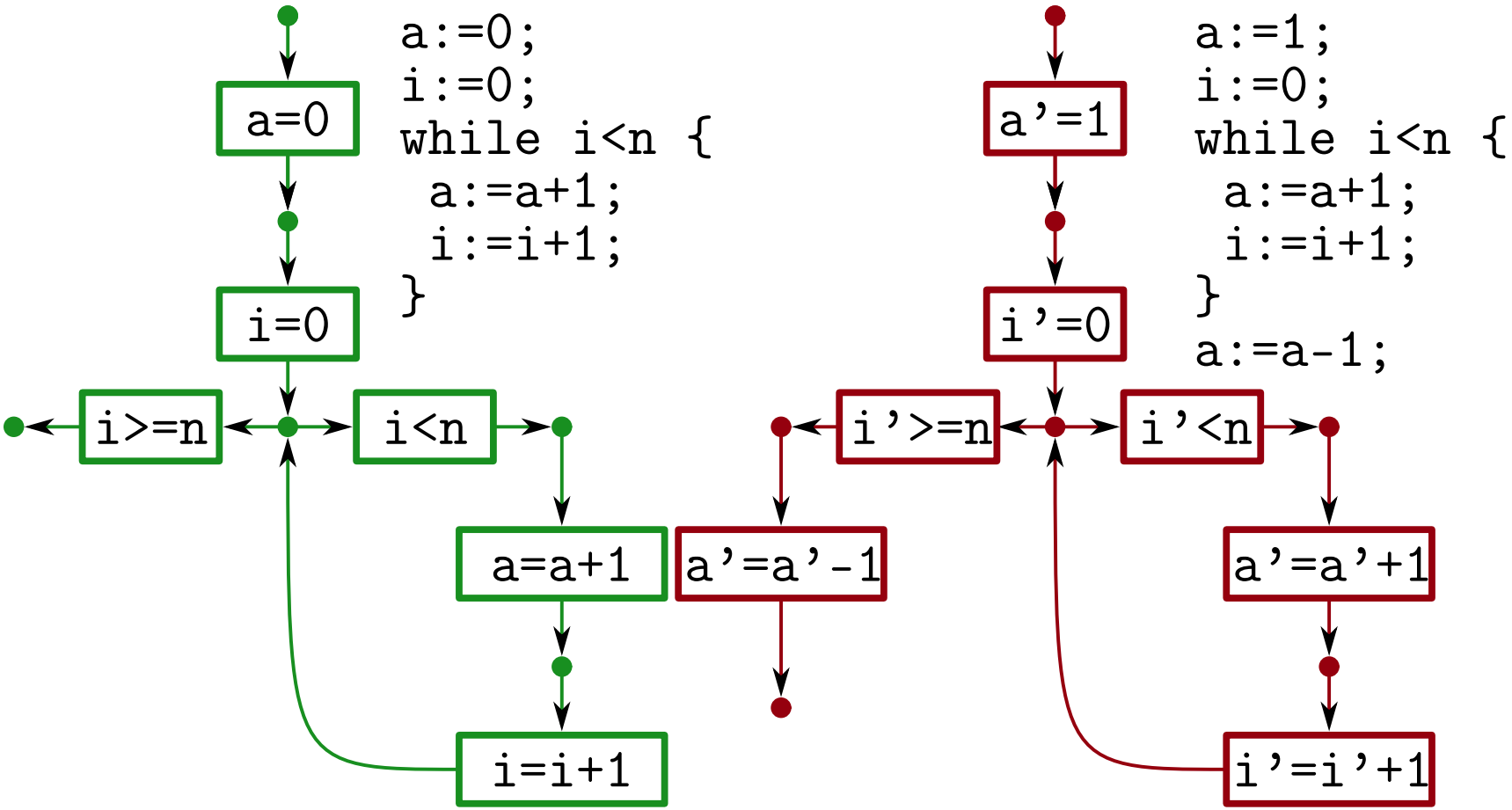
  Relate program structure
  $\Longrightarrow$ syntactical

  Relate program states at corresponding program points
  $\Longrightarrow$ semantical

# Our Approach



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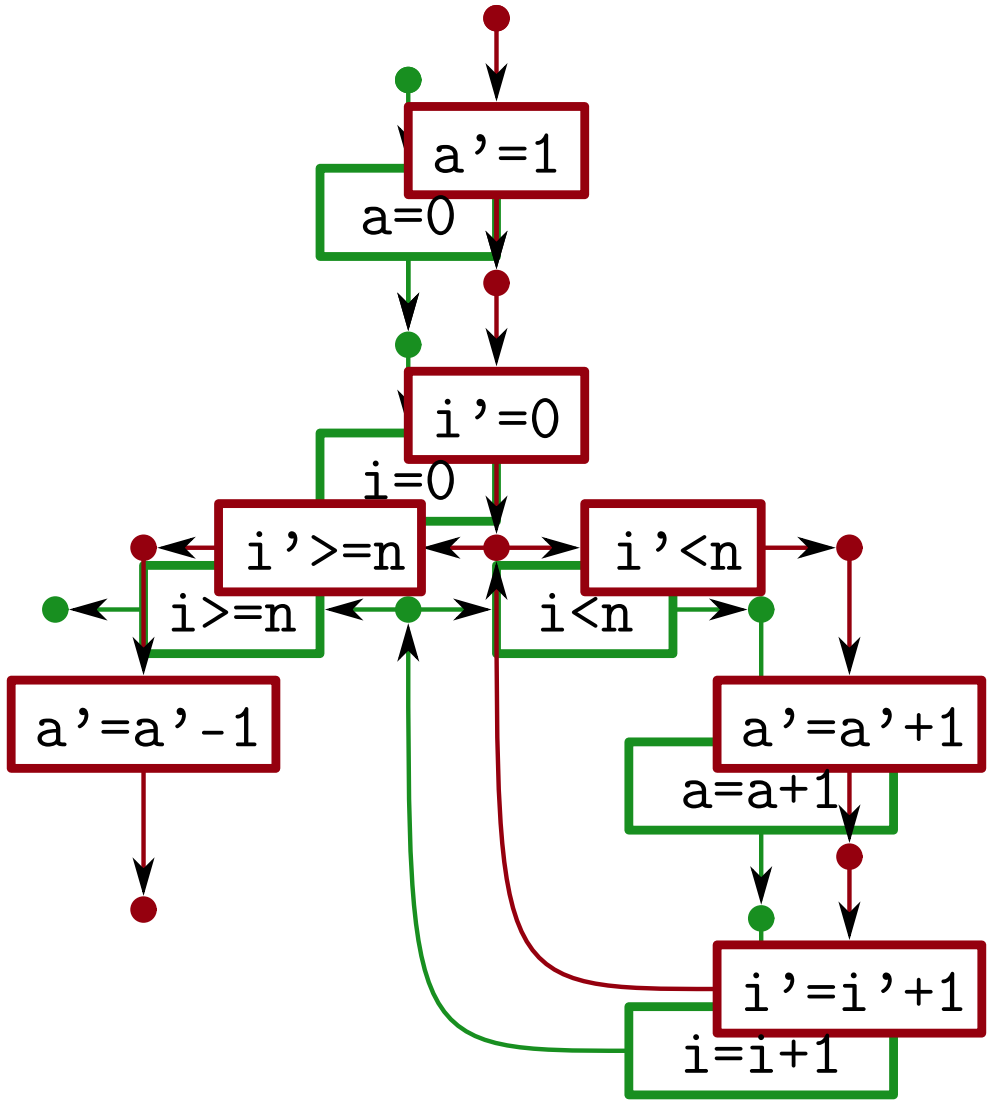

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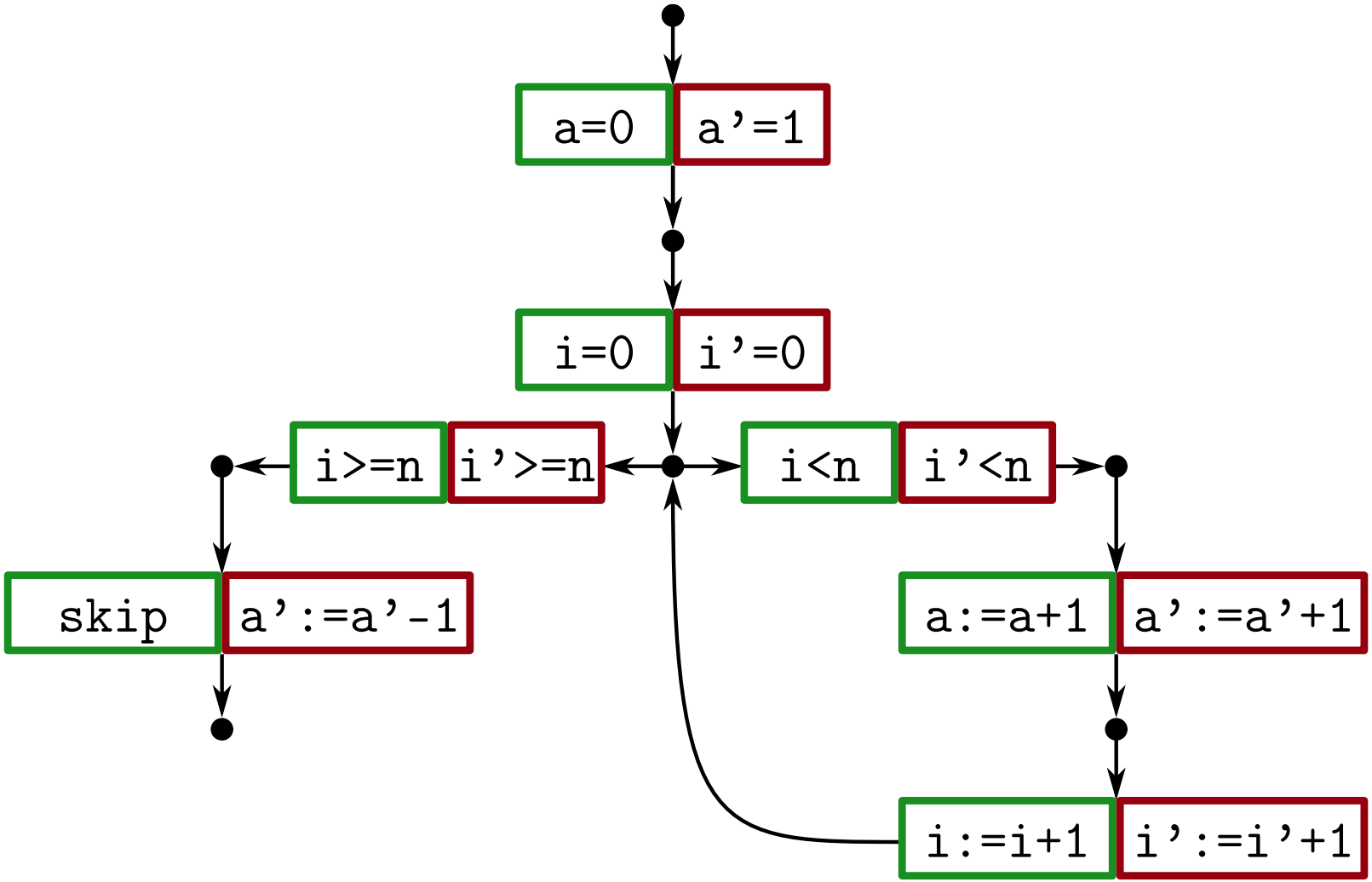

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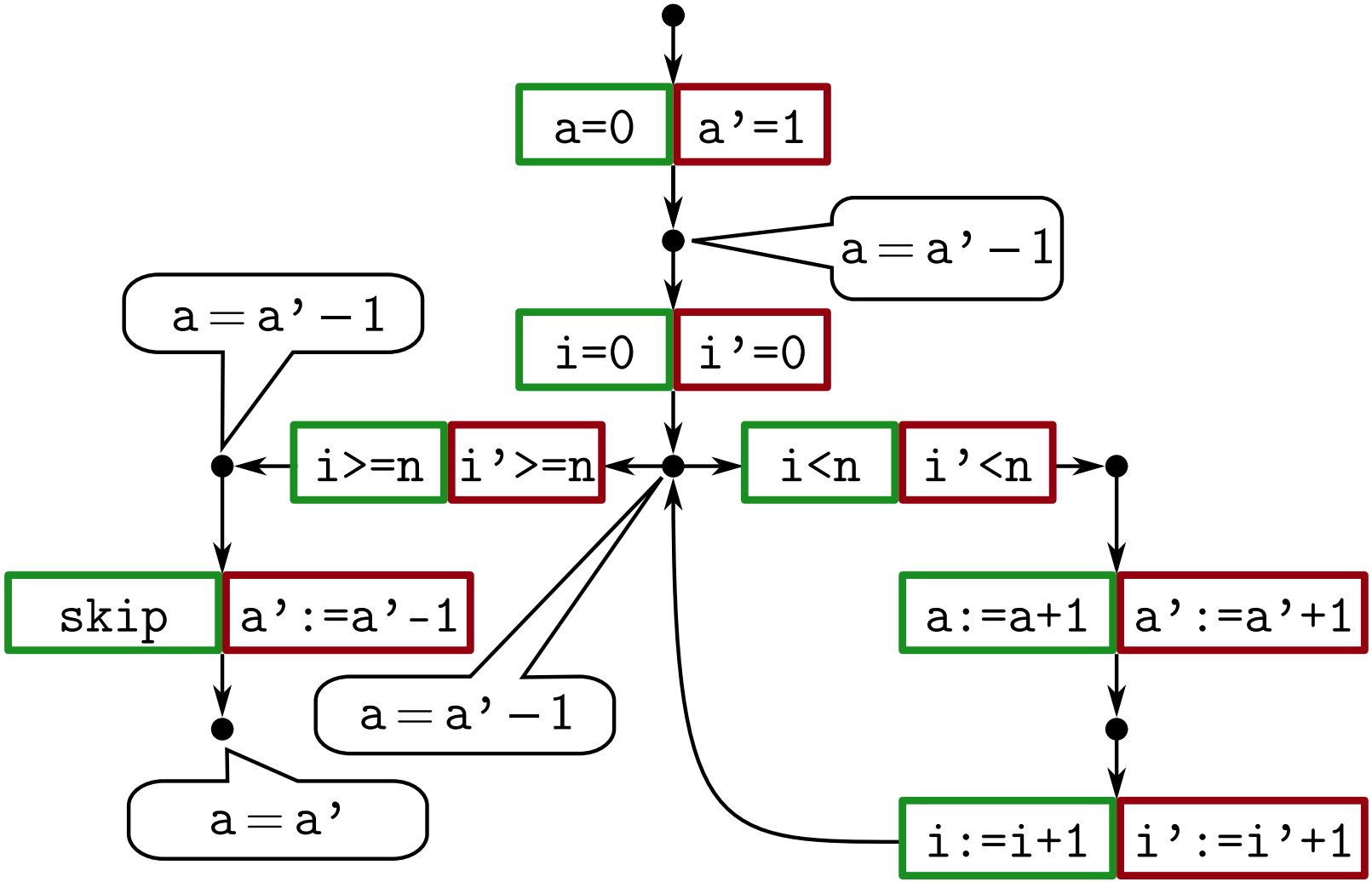

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Intput: programs $p_1, p_2$

Output: 2-program $[p_1, p_2]$

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- Each pair of finite runs of $p_1, p_2$ corresponds to some finite run of $[p_1, p_2]$;

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## Idea

- Each pair of finite runs of $p_1, p_2$ corresponds to some finite run of $[p_1, p_2]$;
- The two programs are executed as synchronously as possible!

$\Longrightarrow$ Similar statements are preferably aligned ...

# Grammar of 2-Programs

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 & & \ \} \\
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# Grammar of 2-Programs (cont.)

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# Aligning Two Programs

**Programs** $p_1 = \mathtt{c};\mathtt{d}$ $p_2 = \mathtt{e};\mathtt{f}$

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$p_1 = \mathtt{c}\,;\mathtt{d}$ $\quad$ $p_2 = \mathtt{e}\,;\mathtt{f}$

## Some alignments

$$[c, \mathtt{skip}]\,;[d, \mathtt{skip}]\,;[\mathtt{skip}, e]\,;[\mathtt{skip}, f],$$
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$$[\mathtt{skip}, e]\,;[c, f]\,;[d, \mathtt{skip}],$$
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$$[\mathtt{skip}, e];[\mathtt{skip}, f];[c, \mathtt{skip}];[d, \mathtt{skip}]$$

**Idea** Minimize tree distance!

# Aligning Two Programs (cont.)

Robust Tree Edit Distance — Pawlik, Augsten 2011

$\Longrightarrow$ minimal number of insertions, deletions, renamings

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Aligning sequences $c_1, ..., c_k$ and $d_1, ..., d_l$

- Compute the sequence of pairs with minimal distances
- Then, compute the composition of each aligned pair $[c_i, d_j]$ ...

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Aligning sequences $c_1, ..., c_k$ and $d_1, ..., d_l$

- Compute the sequence of pairs with minimal distances
- Then, compute the composition of each aligned pair $[c_i, d_j]$ ...
  - If roots of ASTs are identical, proceed recursively.
  - Otherwise, align $c_i$ and $d_j$ with `skip`.

# Aligning Two Programs (cont.)

## Example

`z:=42; x:=y+1` `z:=3*z+6; x:=y+1`

are aligned to:

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`[z:=42,skip]; [skip,z:=3*z+6];[x:=y+1,x:=y+1]`

# Aligning Two Programs (cont.)

**The program**

```
x := 0;
if (secret>0) {x := 1;};
```

**is self-aligned to**

```
[x := 0,x := 0];
if [secret>0,secret>0] [x := 1,x := 1];
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# Aligning Two Programs (cont.)

**The program**

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x := 0;
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**is self-aligned to**

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[x := 0,x := 0];
if [secret>0,secret>0] [x := 1,x := 1];

else if [¬secret>0,secret>0]
        [skip,x := 1];
else if [secret>0,¬secret>0]
        [x := 1,skip];
```
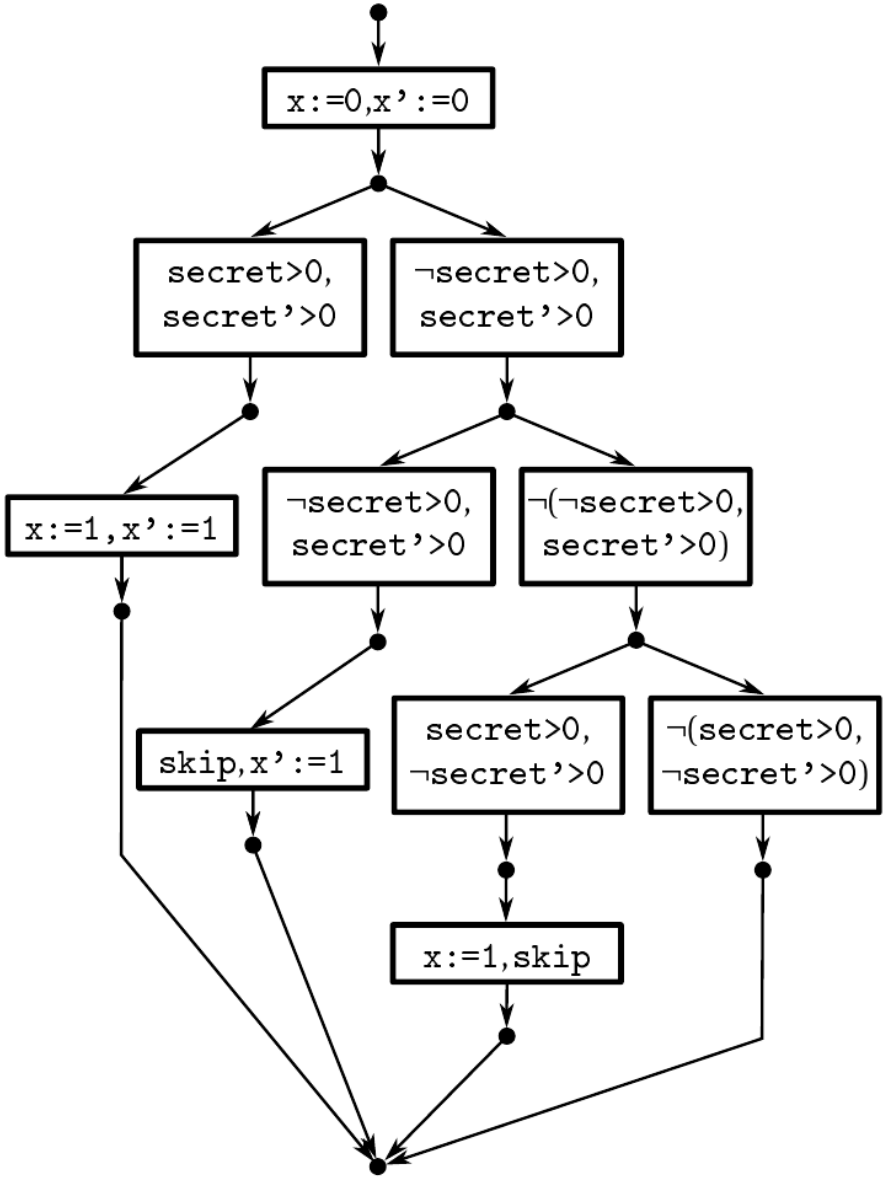

# The CFG of the Example



# Relating Program States of 2-Programs

## Goal

Compute invariants of pairs of program states!

$\Longrightarrow$ relational abstract interpretation

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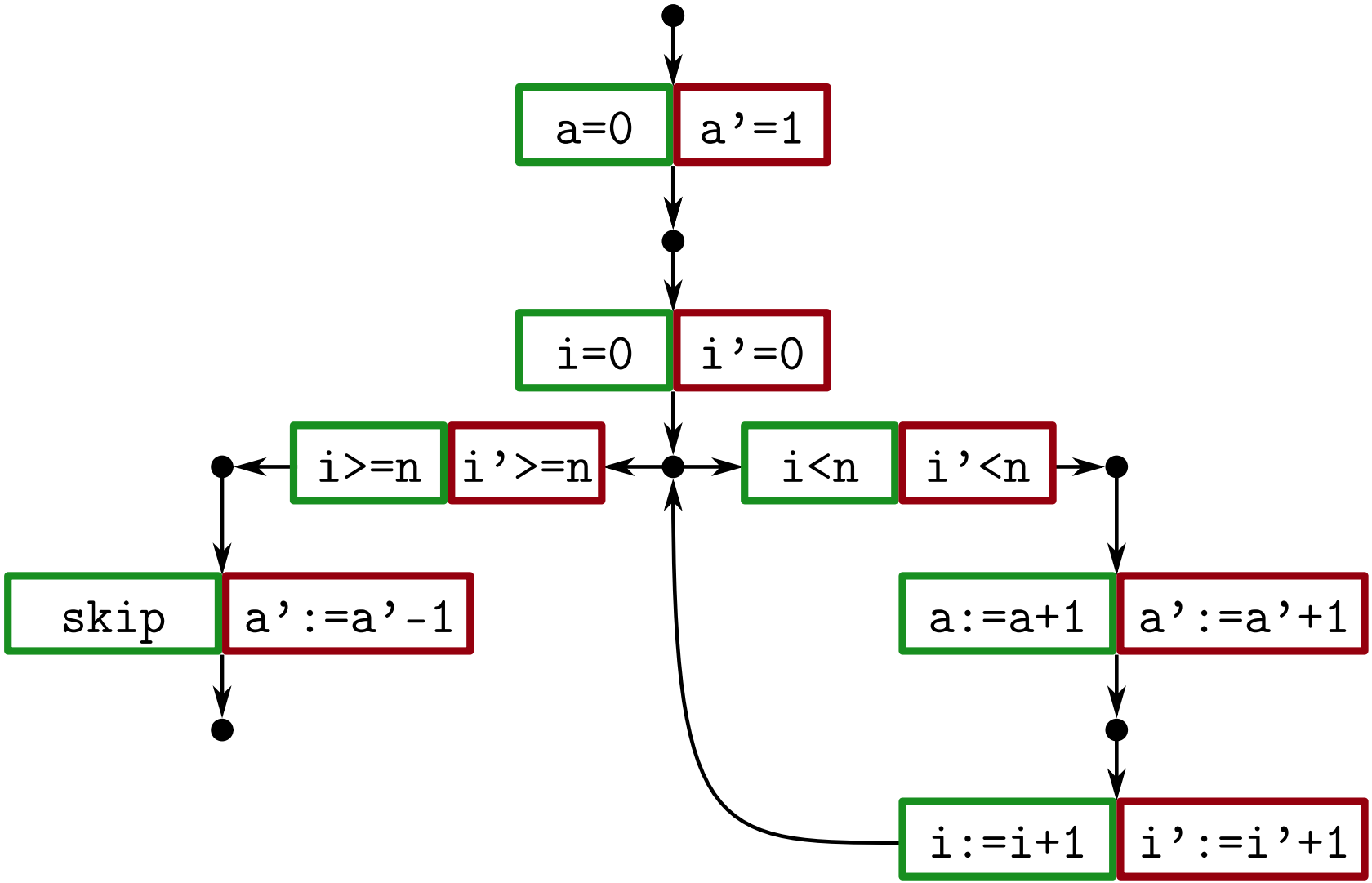
## Example

Integer programs

# Relating Program States (cont.)



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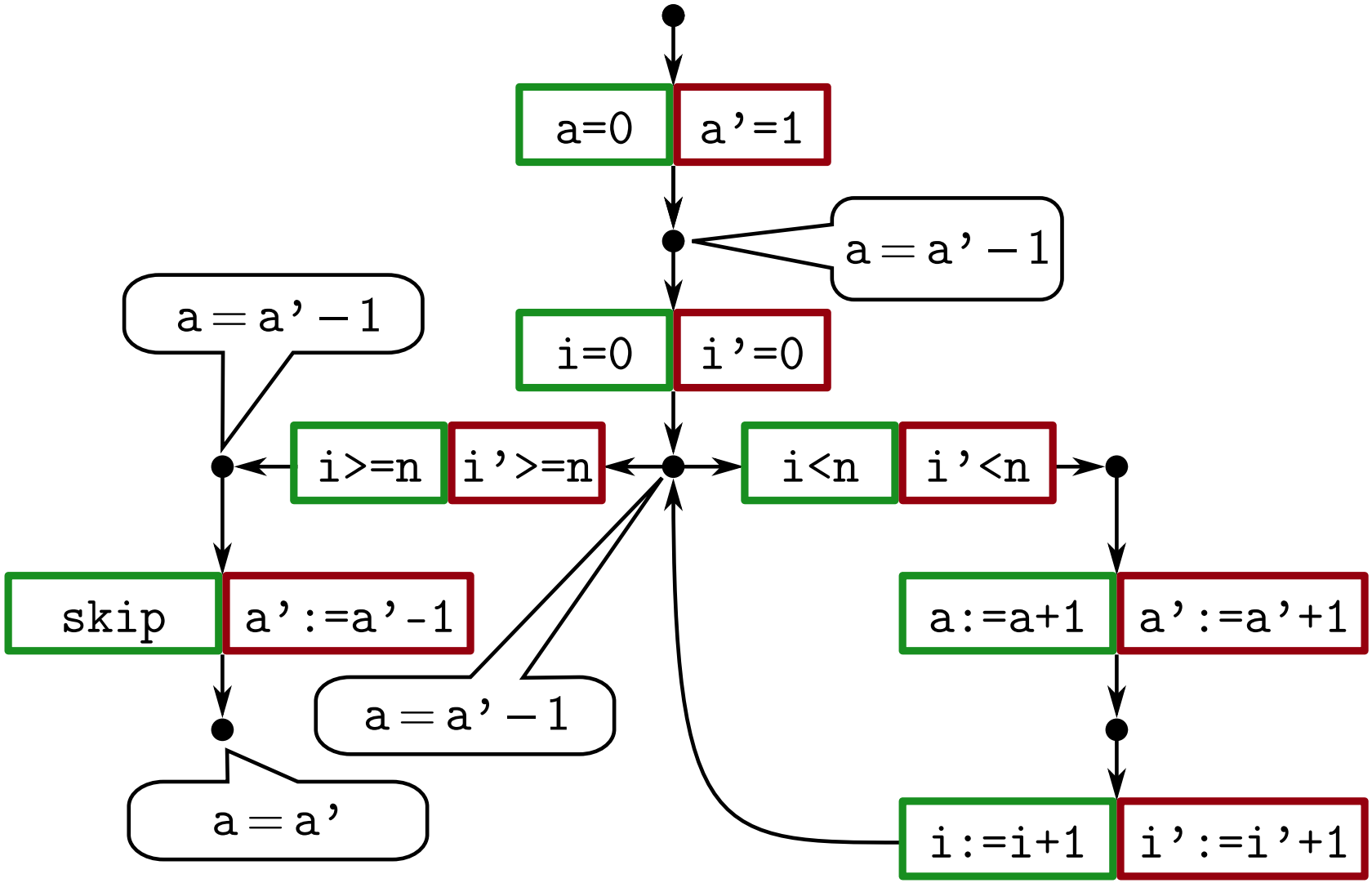

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$\Longrightarrow$ Occurring vector spaces cannot grow infinitely!

$\Longrightarrow$ Can be computed by fixpoint iteration!!

Karr 1976

Müller-Olm, S. 2004

# Interprocedural 2-Hypersafety Properties

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f() { b1 }
g() { b2 }
if (secret = 1) f(); else g();
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- The resulting 2-program has procedures

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  where the body of $[\mathtt{f},\mathtt{g}]$ is the alignment of `b1`, `b2`.

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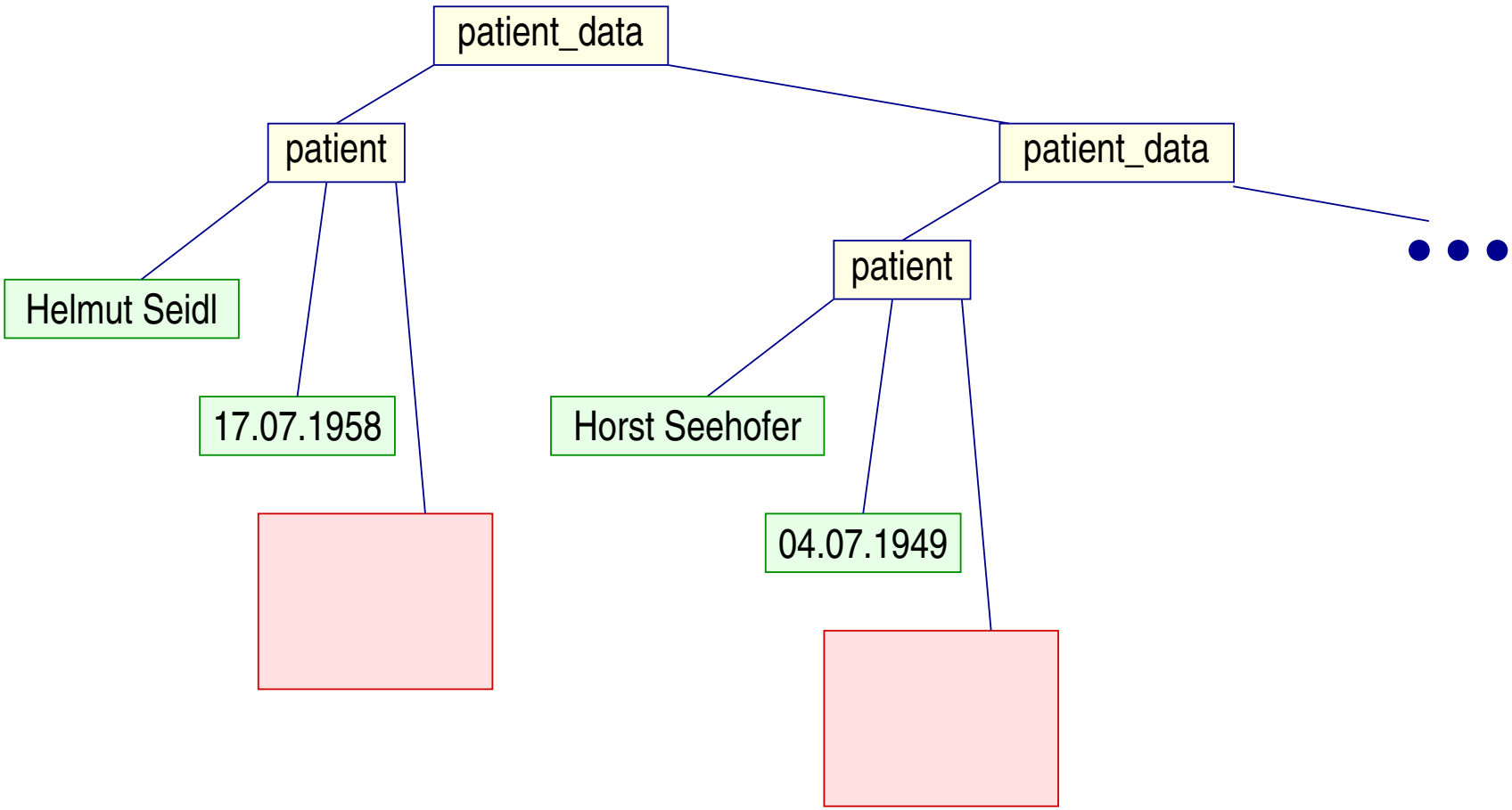
- Then apply standard interprocedural abstract interpretation!
  E.g., with affine equations Müller-Olm, S. 2003, 2005

**Example** Tree-manipulating Programs

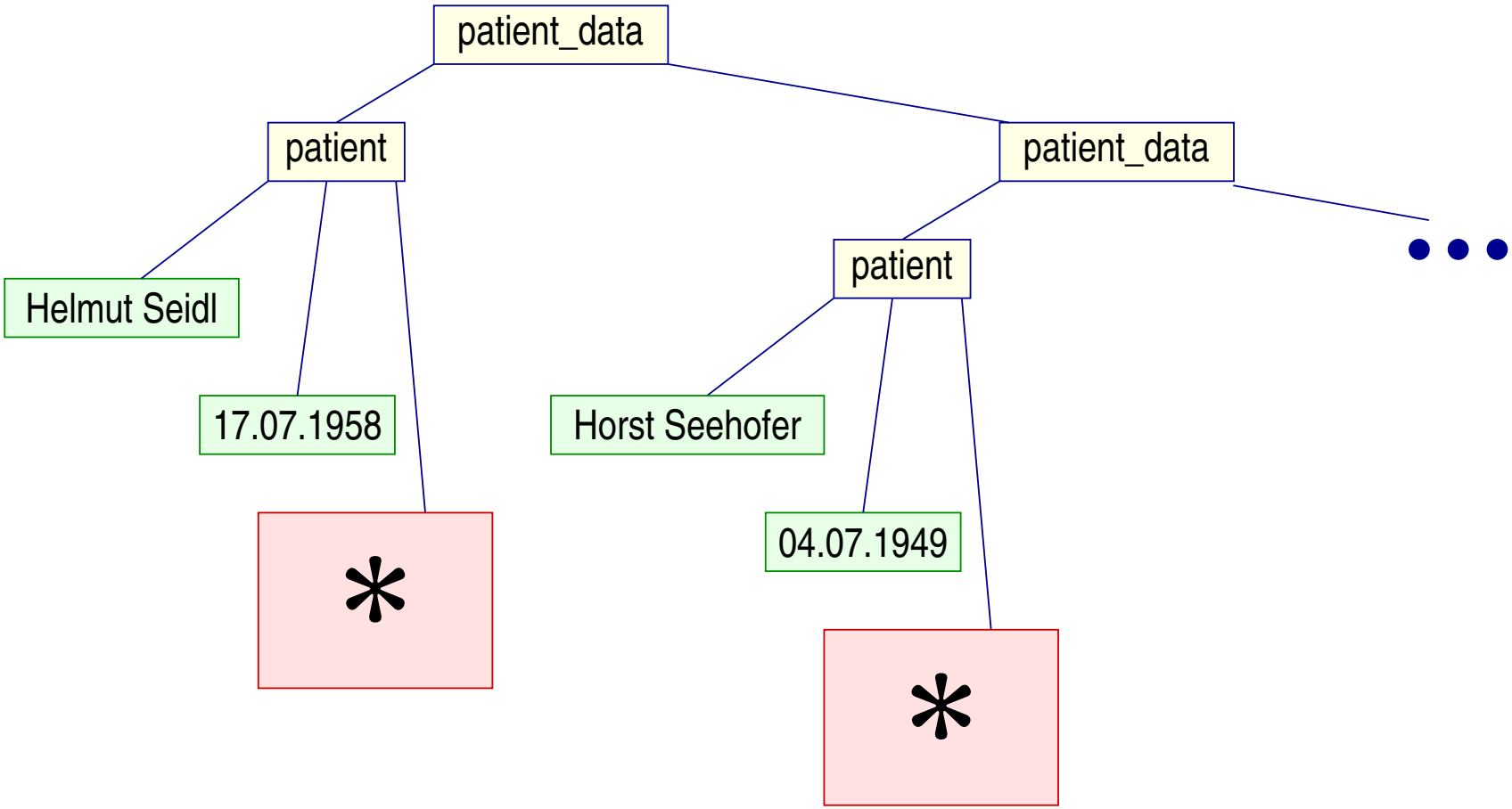
// Xml processors
// workflow languages

```
while (patient_data != []) {
  patient = patient_data.1;
  if (patient.1 = 'Helmut Seidl') {
    result = patient.2;
    patient_data = [];
  } else
    patient_data = patient_data.2;
}
```

# Tree Data Structure



# Relational Invariant



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## Goal

Compute for every program point of a 2-program all public views of variables!

# Analysis of Tree-Manipulating Programs

Unknowns $\langle u, x \rangle$

// $u$ 2-program point

// $x$ program variable

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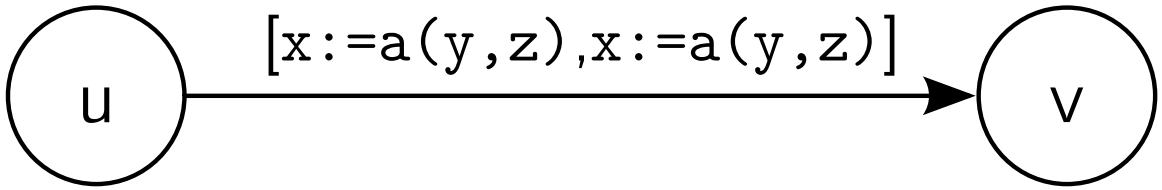


$$\langle v, \mathtt{x} \rangle(\mathtt{a}(H, T)) \Longleftarrow \langle u, \mathtt{y} \rangle(H), \langle u, \mathtt{z} \rangle(T)$$

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- In general, the least model cannot be computed.

- The Horn clauses required by the analysis, though, fall into the special class $\mathscr{H}_1$ ...

$\Longrightarrow$ the least model is regular

$\Longrightarrow$ and can be effectively computed!

Weidenbach 1999
Nielson, Nielson, S. 2002

## Format

$$\begin{aligned} p(a(X_1,\ldots,X_k)) &\Longleftarrow \text{any} \\ p(X) &\Longleftarrow \text{any} \end{aligned}$$

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- Simplified Horn clauses:

$$\begin{aligned} p(a(X_1,\ldots,X_k)) &\Longleftarrow q_1(X_{j_1}),\ldots,q_m(X_{j_m}) \\ p(X) &\Longleftarrow q_1(X),\ldots,q_r(X) \end{aligned}$$

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$$\Longrightarrow \quad \text{(alternating) tree automata}$$

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- 2-hypersafety properties can be analyzed by relational abstract interpretation of 2-programs.
- This approach even scales to programs with procedures.
- Tree language technology helps
  - to find good alignments
  - to analyze tree-manipulating programs