CFlow

A Demo with a Pinch of Theory

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Outline

Introduction

Goal

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- Simplify (and not enforce) programming of *distributed* and *secured* softwares
- Source language: simple sequential language
  - globally shared memory
    - accessible from any host
  - annotations for code distribution
    - where to execute every statement
  - security level given to every global variable
    - specifies who can read and/or write
- Target language: real world language (F♯)
  - communication between hosts through TCP/IP
  - encryptions and signatures to protect globals

Security in the source

- Accessibility based on security lattices
- IF label $\in$ (confidentiality lattice $\times$ integrity lattice)
  - $l_1 \rightsquigarrow l_2 \;\Leftrightarrow\; (l_1 \leq_C l_2 \wedge l_2 \leq_I l_1)$
  - x := y *iff* $y \rightsquigarrow x$
  - A can read x *iff* $x \rightsquigarrow_C A$
  - A can write x *iff* $A \rightsquigarrow_I x$
- Security lattices are compiler plugins (2 already coded)
  - HL: 2 $\times$ flat lattice with top and bottom
    - $\{L <_C [\hat{}HL] <_C H\} \times \{L <_I [\hat{}HL] <_I H\}$
  - ReadersWriters: 1 set of readers and 1 set of writers (R, W)
    - $R_1 <_C R_2 \;\Leftrightarrow\; R_2 \subset R_1$
    - $W_1 <_I W_2 \;\Leftrightarrow\; W_2 \subset W_1$

Source Language

Program header

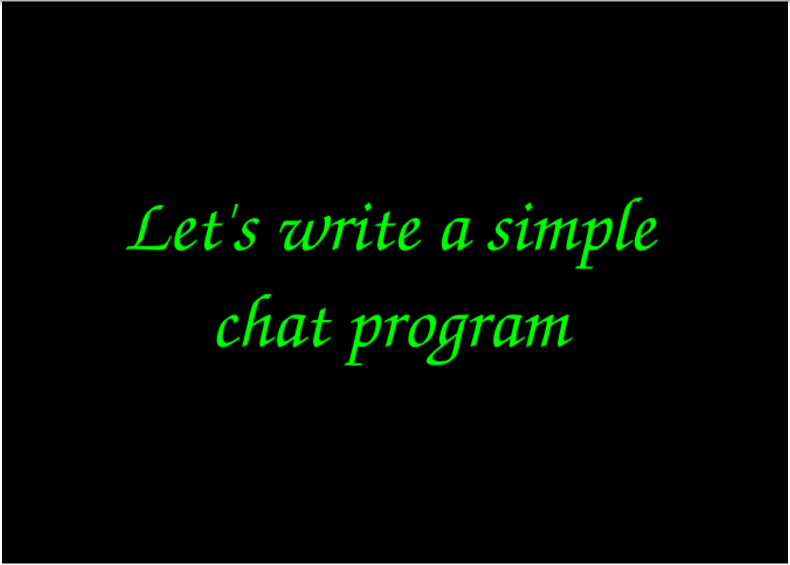
- Define the security lattice used: `SLattice` HL;
  - the compiler loads the appropriate plugin to manipulate strings corresponding to security labels
- Define the roles: `Role` #HH# *A*;
  - all roles in the execution environment
    - A, B: secured line or VPN between A and B
    - A, B, others: any network with "outsiders" connected
  - compiler protects against the attacker level, either:
    - `Role` #LL# *attacker* ;
    - stronger weakest than all roles
- Define globals: `global string`(64) #HH# *message*;

Program body

$$
\begin{array}{lcl}
e & ::= & x \mid op(e_1, \ldots, e_n) \\
S & ::= & \mathbf{skip} \mid x \mathrel{\mathbf{:=}} e \mid S \;;\; S \\
 & \mid & \mathbf{if}\ e\ \mathbf{then}\ S\ \mathbf{else}\ S\ \mathbf{end} \mid \mathbf{while}\ e\ \mathbf{do}\ S\ \mathbf{done} \\
 & \mid & A : [S]
\end{array}
$$

- A: [S]
  - statement localization
  - means: role A executes S
  - can be nested

Coding a chat program



How it works

A 4-steps process

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- Slicing: cut into uniquely localized threads
- Control Flow Protocol: prevent thread reordering
  - check *pc* set by previous "visible" threads
- Variable Replication: compute with thread locals
- Encrypting & Signing: enforce security labels of globals

A 4-steps process

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  - *do:* SSA-like: each local assigned by unique thread

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  - *need:* a unique tag to sign and verify

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  - *ensure:* static previous call graph until same host
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  - *do:* assigned globals transfer at merge points
- Encrypting & Signing: enforce security labels of globals
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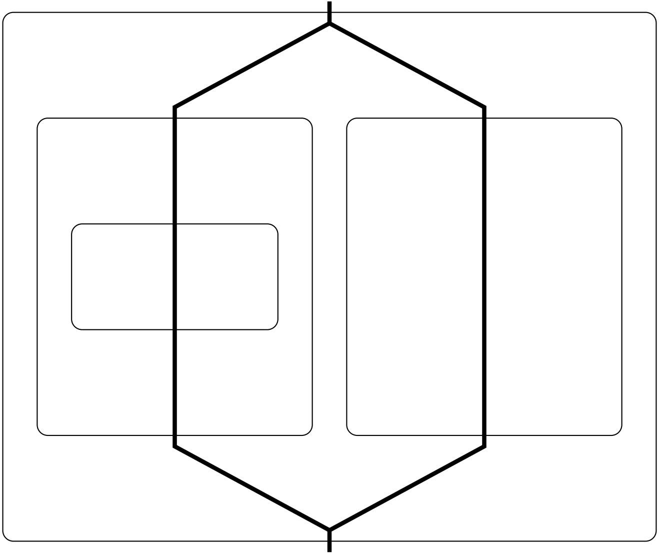
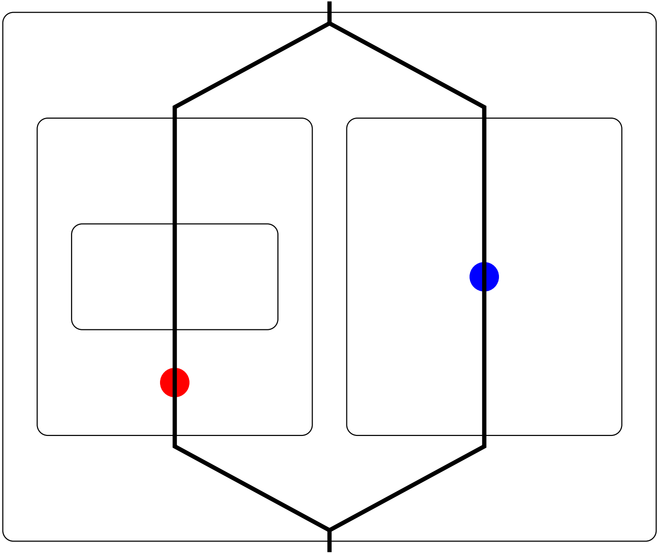
Slicing



Slicing



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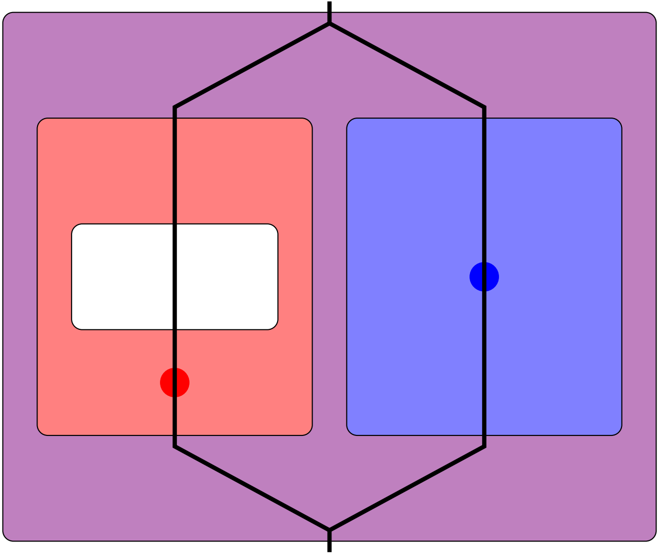

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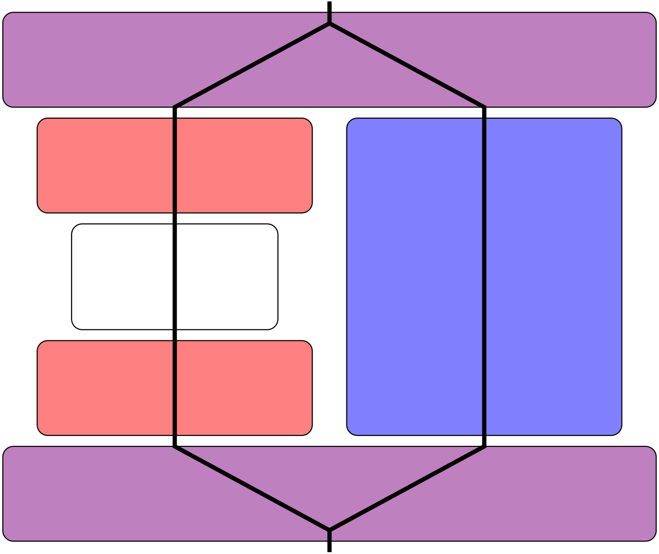

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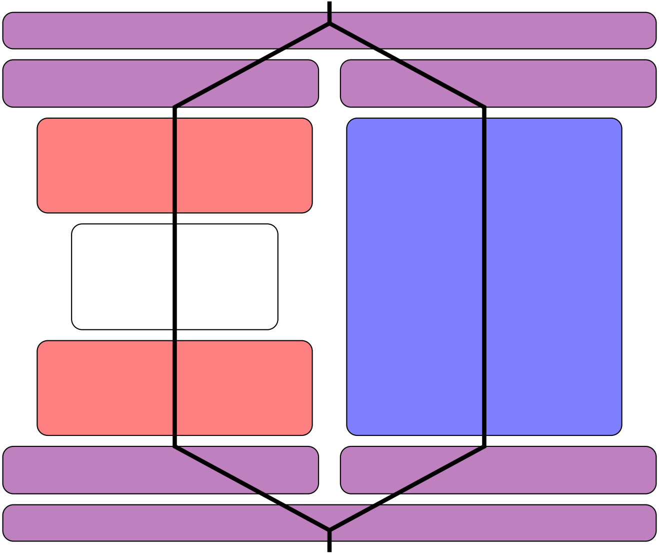

Control Flow Protocol

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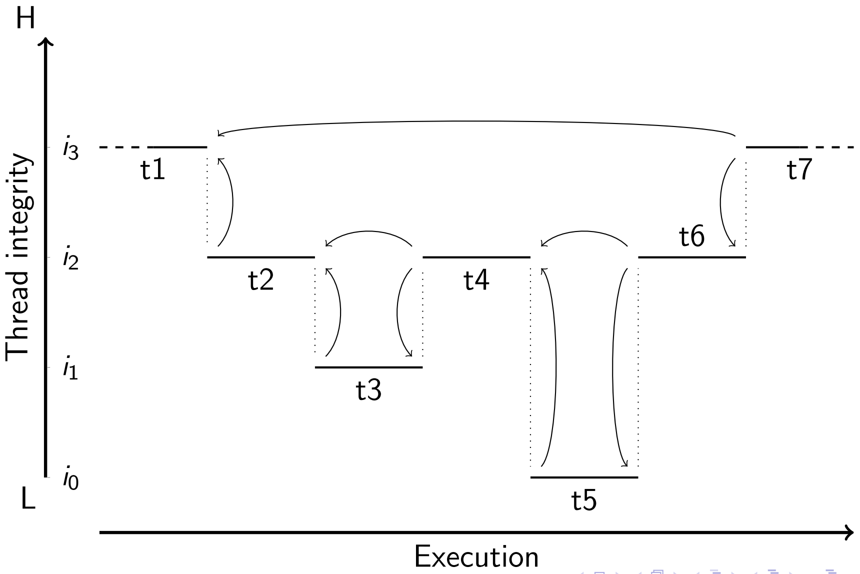

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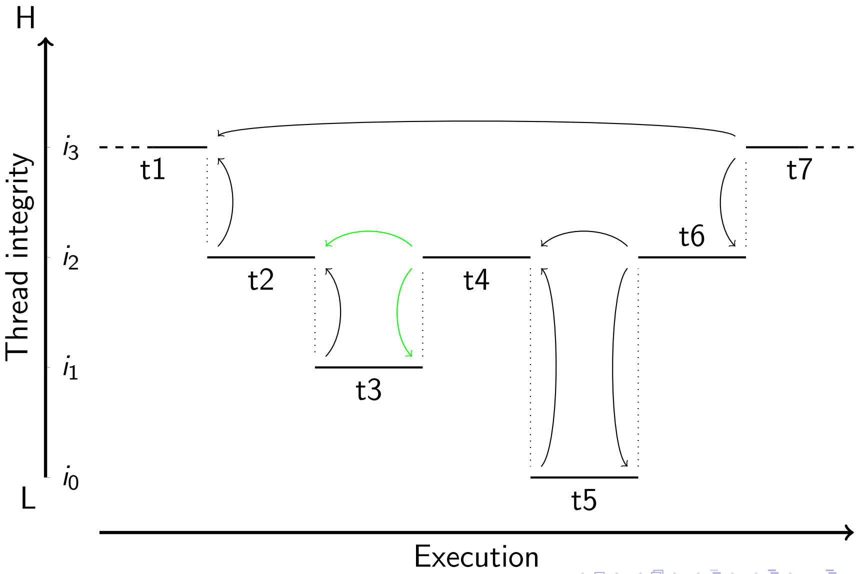

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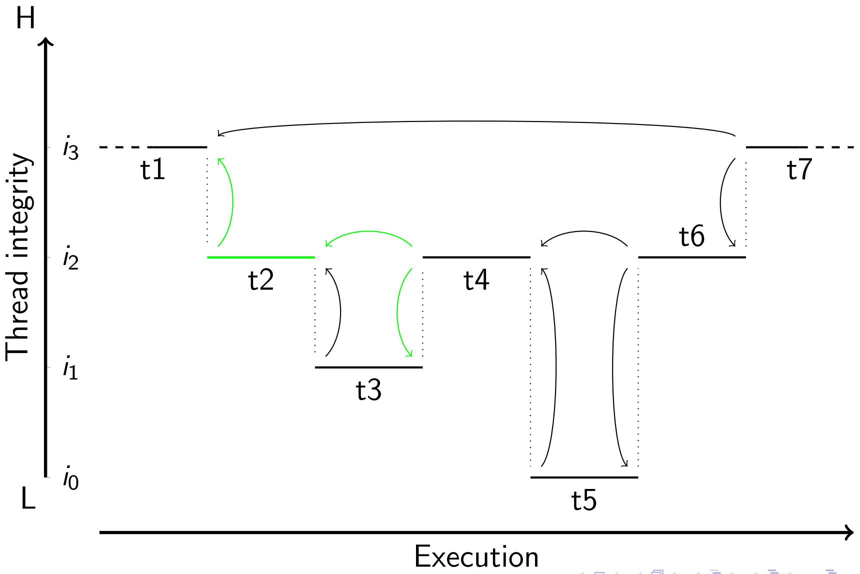

Control Flow Protocol

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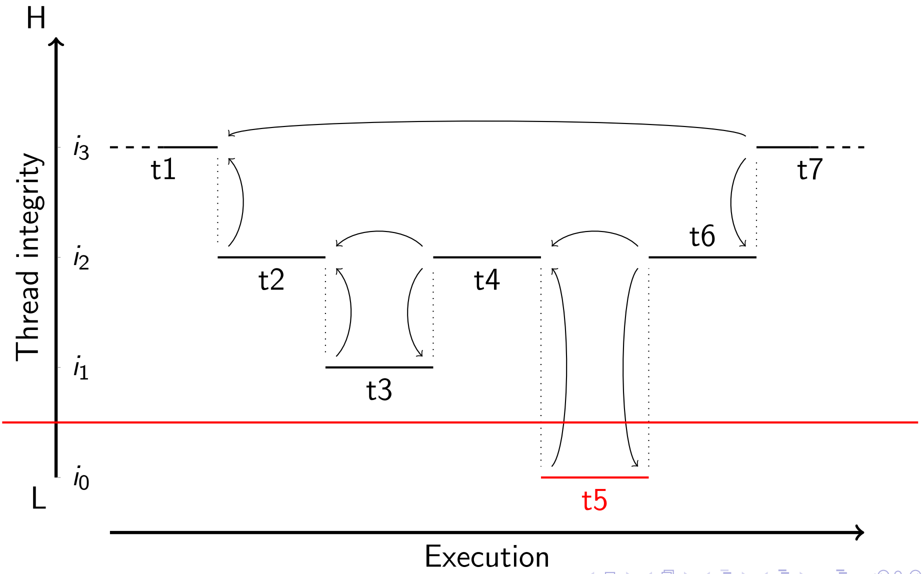

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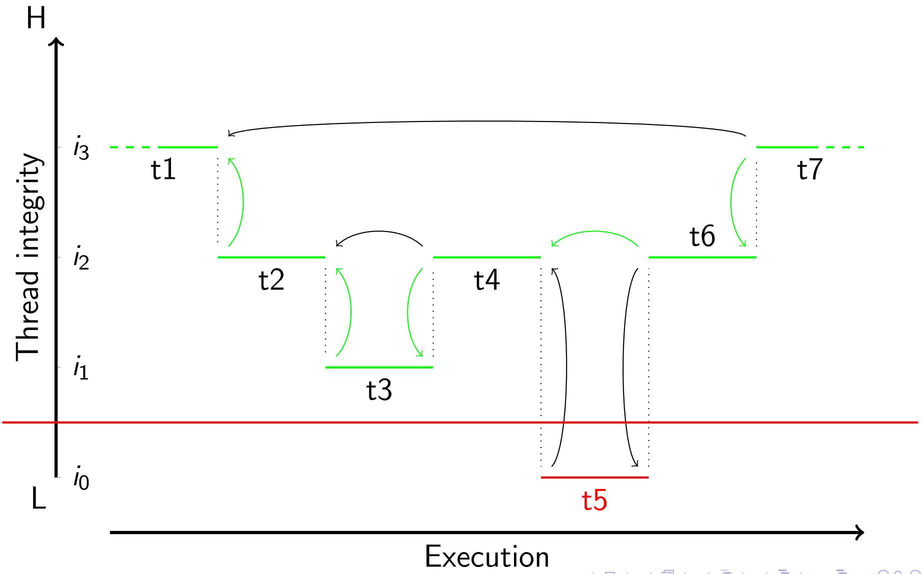

Static Single Remote Assigner

- goal: statically know assigning thread if remote assignment
- single remote last assignment
- SSA-like transformation
- trick: merging threads write in merger locals

```
check (a8 i j.pc1) ≅ ("a8", [i; j]) do {
 b5 i j.pc2 := ("b5", [i; j]);
 if ((a8 i j.y) mod 2) = 1
 then {b5 i j.x := (a1 i j.x) + 9}
 else {skip; b5 i j.x := a1 i j.x};
 call(a4 i j) }
```

Cryptographic Protection

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- ensure IF policy
- encrypt and sign variables sent on the network
- select adequate keys
- use thread id as tag to compute MAC

```
check Verify(b.pc1_s, "a8."^i^"."^j^".pc1", b.pc1_mc, K^s_1HL) do {
 check Verify(b.y_s, "a8."^i^"."^j^".y", b.y_mc, K^s_1HL) do {
  b.x_mc := Decrypt(b.x_e, K^e_1HL);
  b.x := Unmarshal(b.x_mc);
  b.y := Unmarshal(b.y_mc);
  b.pc1 := Unmarshal(b.pc1_mc);
  check b.pc1 ≅ ("a8", [i; j]) do {
   b.pc2 := ("b5", [i; j]);
   if (b.y mod 2) = 1
   then {b.x := b.x + 9}
   else {b.x := b.x};
   b.x_mc := Marshal(b.x);
   b.pc2_mc := Marshal(b.pc2);
   b.x_e := Encrypt(b.x_mc, [K^e_1HL]);
```

What about security?

Integrity attack

Confidentiality attack

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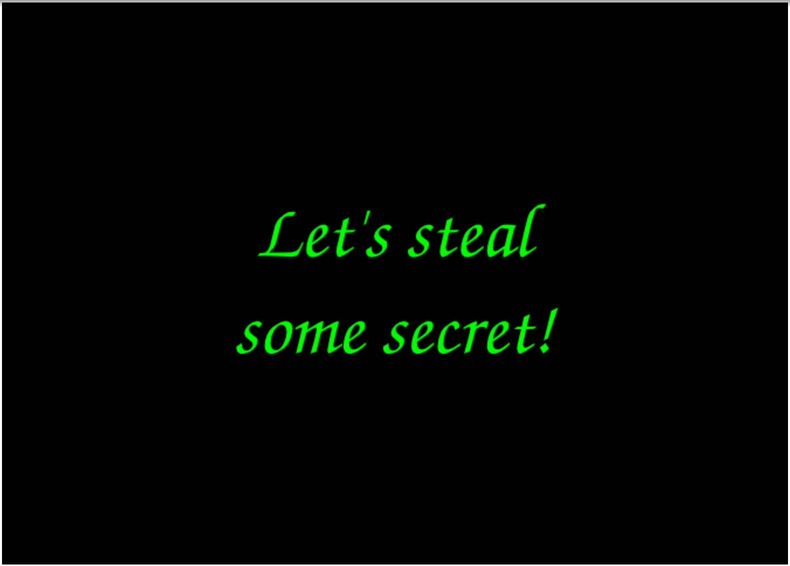

Conclusion

Experimental Results

Program	LOC		I/t		crypto		keys	Time (s)	
empty	2	102	1	(1+0)	0/0	0/0	0/0	1.59	1.63
running	18	464	3	(5+3)	2/2	4/4	1/2	1.58	1.71
rpc	11	321	2	(3+3)	2/2	4/4	1/1	1.63	2.58
guess	52	912	7	(13+3)	2/2	13/16	2/3	1.69	1.98
hospital	33	906	5	(9+0)	4/4	11/11	4/8	1.70	1.84
taxes	55	946	4	(7+2)	8/8	16/16	4/6	1.71	1.77

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RPC = 6000 symmetric-key cryptographic operations

Conclusion

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- Provide programming language for secured distributed programs
  - simple memory model: universally shared globals
  - simple security mechanism: label for access to globals
  - code size efficient
  - *but:* not flexible enough for now

Conclusion

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Theorem 1 (Main guarantee)

If an attack exists in the target semantics then it exists in the source semantics

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- Make security a piece of cake

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Theorem 1 (Main guarantee)

If an attack exists in the target semantics then it exists in the source semantics

- Make security a piece of cake
  - . . . Ok! . . . a wedding cake, but . . .
  - . . . handling security labels instead of keys, makes it easier to . . .
  - design the security policy at the source level
  - analyze the program security at the source level

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