Decentralized control for secrecy

joint work with

E. Badouel B. Caillaud
Inria-Rennes

M. Bednarczyk A. Borzyszkowski
Ipipan-Gdansk

February 2007

Works in the field of Security

- Many aspects (access control, encryption, authentification, trust, intrusion detection, leaks of information ...)
- Static Verification (Cryptographic Protocols) with rewriting techniques, model checking, information theory...
- Run time Verification (User Requests in Web Services) using type and effect systems, automata...
- Any contribution of SCT?

This presentation

- A first attempt in this direction
- Partial results, toy applications

Thesis

Supervisory Control Theory may help enforcing Security

Supervisory Control

Usual Game

Control Objective : Safety / Liveness

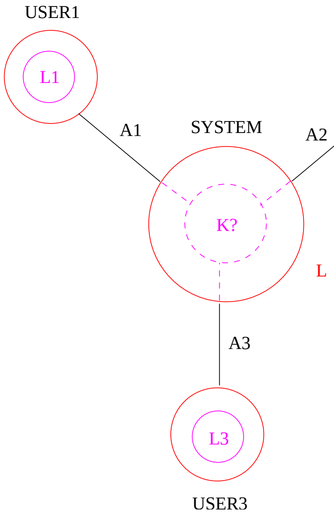
Observers: on the side of the Controller

Other Game

Control Objective : Secrecy

Observers: on the side of the Opponent

Example 1



SECRETS

Li IN Ai *

UNCONTROLLED BEHAVIOUR

L INCLUDED IN (A1+A2+A3) *

FIND MAXIMAL PERMISSIVE CONTROL

K INCLUDED IN L SUCH THAT

USERS i +1 AND i + 2 MAY NEVER KNOW

THAT USER i HAS PERFORMED wi IN Li

EVEN THOUGH THEY TALK TO EACH OTHER

Formalization

SECRET SET

$S_1 = L_1 \parallel (A_2 + A_3)^* \cap L$

$S_2 = L_2 \parallel (A_1 + A_3)^* \cap L$

$S_3 = L_3 \parallel (A_1 + A_2)^* \cap L$

OPPONENT'S ALPHABET

$\Sigma_1 = A_2 \cup A_3$

$\Sigma_2 = A_1 \cup A_3$

$\Sigma_3 = A_1 \cup A_2$

$\mathcal{S} = \{(S_1, \Sigma_1), (S_2, \Sigma_2), (S_3, \Sigma_3)\}$ is a CONCURRENT SECRET

Definition

$\mathcal{S}$ is opaque if $\forall w \in L \;\; \forall i$

$w \in S_i \;\; \Rightarrow \;\; \Pi_{\Sigma_i}(w) = \Pi_{\Sigma_i}(w')$ for some $w' \in L \setminus S_i$

opacity is the opposite of normality when $(\forall i) S_i = \overline{S_i}$

S_i is normal if $\Pi_{\Sigma_i}(w) = \Pi_{\Sigma_i}(w') \Rightarrow w \in \overline{S_i}$ iff $w' \in \overline{S_i}$

An earlier definition of opacity

Bryans, Koutny, Mazare, Ryan

Definition

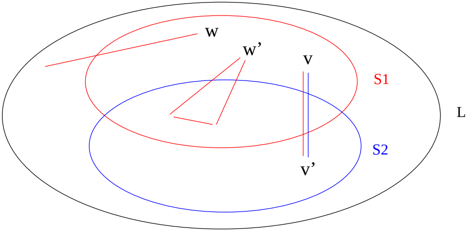
A predicate ϕ over runs ρ of the system is opaque w.r.t. the observation function *obs* if, for every run $\rho \in \phi$, there is a run $\rho' \notin \phi$ such that $obs(\rho) = obs(\rho')$

single observer
arbitrary observation function (states may be observable)
opacity is in general not decidable

opacity is asymmetric
Concurrent opacity is needed in order that the observer neither knows ϕ, nor he knows not ϕ

Safe Kernels

If L is prefix closed and all secrets S_i are regular, one can decide whether the concurrent secret $\mathcal{S}$ is opaque w.r.t. L. If not, one can compute the safe kernel $K(L, \mathcal{S})$ of L.



w in K(L,S)

w' not in K(L,S)

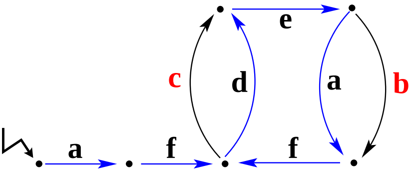
v,v' in K(L,S)

Definition

The *safe kernel* $K(L, \mathcal{S})$ of L is the subset of all words $w \in L$ such that for every prefix u of w and for every i $\Pi_{\Sigma_i}(u) = \Pi_{\Sigma_i}(u')$ for some $u' \in L \setminus S_i$

Example 2

But using $K(L, \mathcal{S})$ as a controller does not solve our problem ...
because users know the system and the controller!



$S_1 = \Sigma^* afc(\Sigma \setminus \{c\})^*$ (last c follows af), $\Sigma_1 = \{c, f\}$,
$S_2 = \Sigma^* deb(\Sigma \setminus \{b\})^*$ (last b follows de), $\Sigma_2 = \{b, e\}$

$K(L, \mathcal{S}) = L \setminus afc\Sigma^*$
$K(K(L, \mathcal{S}), \mathcal{S}) = K(L, \mathcal{S}) \setminus afdeb\Sigma^*$

What remains in the end is $(afde)^*$

Supremal Safe Sublanguage

$SupK(\bullet, \mathcal{S})$ is monotone in first argument

Definition

Let $SupK(L, \mathcal{S})$ be the greatest fixpoint of the operator $K(\bullet, \mathcal{S})$ included in L

Theorem

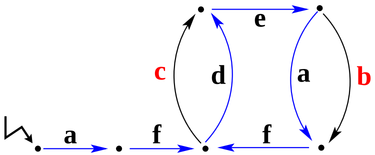
$SupK(L, \mathcal{S})$ is the union of all controls enforcing the opacity of concurrent secret $\mathcal{S}$

Sufficient conditions under which $SupK(L, \mathcal{S})$ is regular and computable ?

Two sources of problems

- The closure ordinal of $K(\bullet, \mathcal{S})$ may be transfinite
- $SupK(\bullet, \mathcal{S})$ may be not regular

$K(\bullet, \mathcal{S})$ has a transfinite closure ordinal



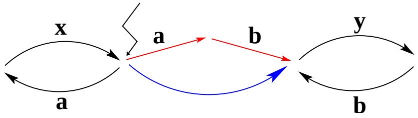
$S_1 = \Sigma^* afc(\Sigma \setminus \{c\})^*$ (last c follows af), $\Sigma_1 = \{c, f\}$,
$S_2 = \Sigma^* deb(\Sigma \setminus \{b\})^*$ (last b follows de), $\Sigma_2 = \{b, e\}$
$S_3 = L \setminus (\Sigma^* c \Sigma^*)$ (there is no c)
S_3 safe w.r.t. any $L' \subseteq L$ with at least one word with c

$lim_{i \to \omega} K^i(L, \mathcal{S}) = Pref((afde)^\omega)$

$K^{\omega+1}(L, \mathcal{S}) = \emptyset$

$SupK(\bullet, \mathcal{S})$ is not regular

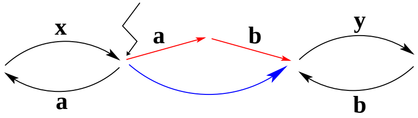
$\Sigma = \{a, b, x, y\}$ $\quad L = Pref((ax)^*(\varepsilon + ab)(yb)^*)$



$$\Sigma_1 = \{a, b\}, \quad \complement S_1 = \varepsilon + (ax)^* ab(yb)^* + \{a, x, y\}^*$$
$$\Sigma_2 = \{x, y\}, \quad \complement S_2 = (ax)^*(yb)^*$$
$$\Sigma_3 = \{a, b, x, y\}, \quad \complement S_3 = \varepsilon + a\Sigma^*$$

$$S_1 = \rightarrow$$
$$S_2 = \rightarrow\rightarrow$$

$$SupK(L, \mathcal{S}) = Pref\left(\cup_{n\in\mathbb{N}} (ax)^n (\varepsilon + ab)(yb)^n\right)$$



$$(ax)^n\,(\varepsilon)\,(yb)^m$$
$$\downarrow_{\{a,b\}}$$
$$(ax)^{n-1}\,(ab)\,(yb)^{m-1}$$
$$\downarrow_{\{x,y\}}$$
$$(ax)^{n-1}\,(\varepsilon)\,(yb)^{m-1}$$
$$\downarrow_{\{a,b\}}$$
$$(ax)^{n-2}\,(ab)\,(yb)^{m-2}$$
$$\ldots$$

hence $n = m$

Some sufficient conditions

language theoretic conditions (i) and (ii)

i) system language L closed under prefix

ii) secrets closed under suffix ($S_i\Sigma^* \subseteq S_i$)

structural conditions (iii) or (iv) or (v)

iii) $\Sigma_1 \subseteq \Sigma_2 \ldots \subseteq \Sigma_n$ — chain of alphabets

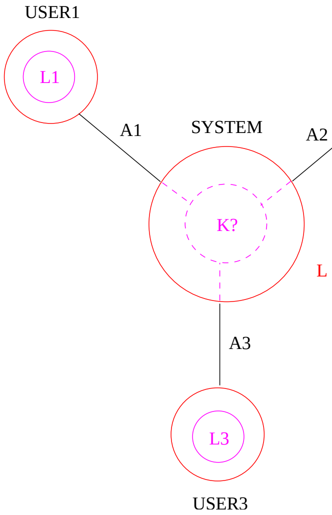
iv) $S_1 \subseteq S_2 \ldots \subseteq S_n$ — chain of secrets

v) $(\forall i \neq j)\ (\forall w, w' \in L)$ — observers $\perp$ secrets

$\Pi_{\Sigma_j}(w) = \Pi_{\Sigma_j}(w') \ \Rightarrow\ w \in S_i$ iff $w' \in S_i$ — true in Example 1

do not hold for Example 2!

Example 1



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Orthogonality in Example 1

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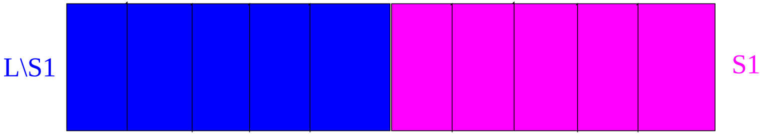
$S_2 = L_2 \parallel (A_1 + A_3)^* \cap L$	$\Sigma_2 = A_1 \cup A_3$
$S_3 = L_3 \parallel (A_1 + A_2)^* \cap L$	$\Sigma_3 = A_1 \cup A_2$

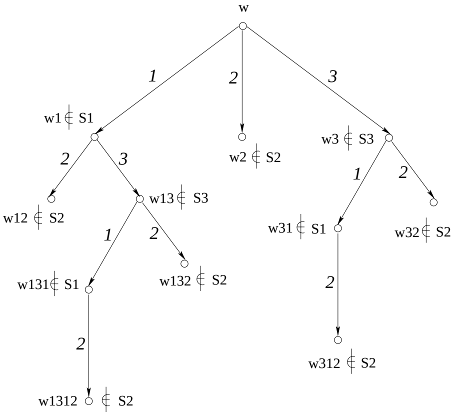
$L_1 \subseteq A_1^* \quad L_2 \subseteq A_2^* \quad L_3 \subseteq A_3^*$



Equivalence Classes w.r.t. Observer 3

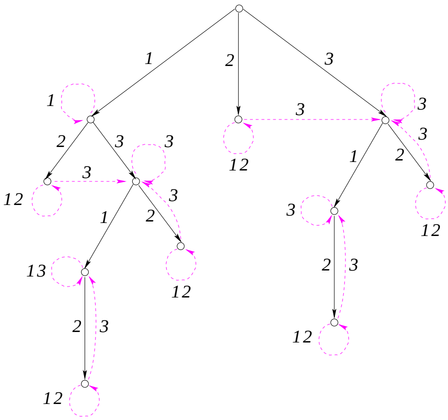
$\Pi_{\Sigma_3}(u) = \Pi_{\Sigma_3}(u') \;\Rightarrow\; \Pi_{A_1}(u) = \Pi_{A_1}(u')$
hence $u \in S_1$ if and only if $u' \in S_1$

$S_1 \subseteq S_2 \quad \Sigma_3 \subseteq \Sigma_2 \quad Obs_1 \perp S_3$ (a mixed case)



Finite pattern of proofs for $w \in SupK(L, \mathcal{S})$

$S_1 \subseteq S_2 \quad \Sigma_3 \subseteq \Sigma_2 \quad Obs_1 \perp S_3$

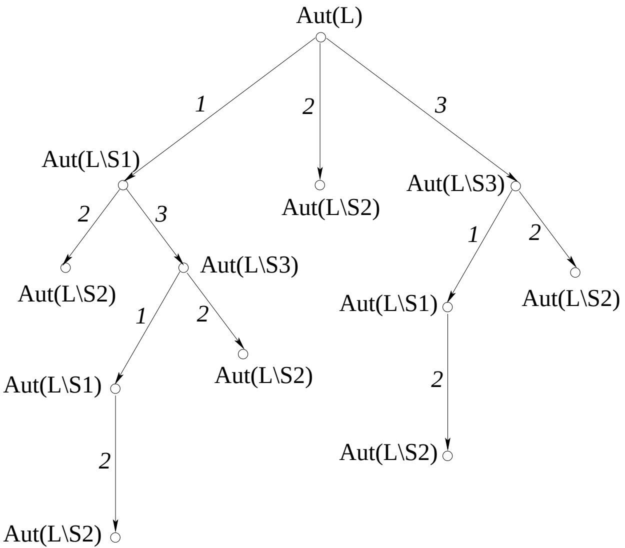


the missing edges

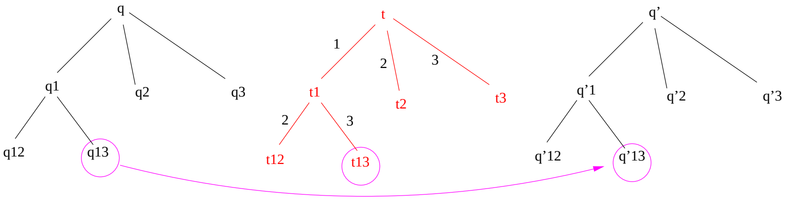
Theorem

If there exists a finite number of patterns of proof for all $w \in SupK(L, \mathcal{S})$, then $SupK(L, \mathcal{S})$ is a regular language

Constructing an automaton from a pattern



Synchronized moves

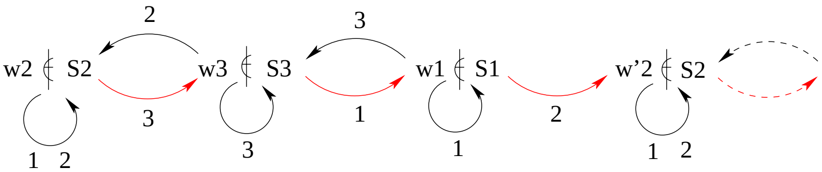


$t_{ij} \in (\Sigma_k)$ or $t_{ij} = \varepsilon$
$t_{ij} \in (\Sigma_k)$ and $t_{ijk} \in (\Sigma_k) \Rightarrow tt_{ij} = t_{ijk}$

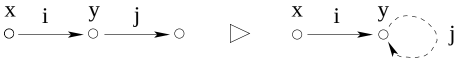
Compute the projection on topmost nodes

A case where finite patterns are not enough

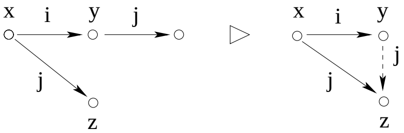
$$S_1 \subseteq S_2 \quad \Sigma_2 \subseteq \Sigma_3 \quad Obs_1 \perp S_3$$



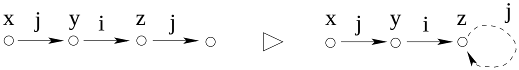
The four rules



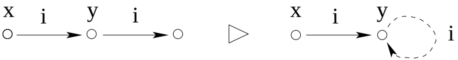
Secret j included in Secret i



Sigma j included in Sigma i



Observator i ortho Secret j



True

Theorem

If the complete n-ary tree rewrites to some finite graph, the spanning tree of this graph is a uniform pattern of proofs for all $w \in SupK(L, \mathcal{S})$

Theorem

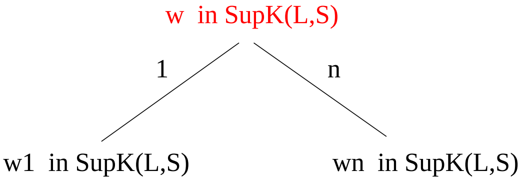
It is decidable whether some finite graph may be derived from the complete n-ary tree, and such graphs may be computed when they exist

One can then construct a finite automaton accepting $SupK(L, \mathcal{S})$

Decentralized control

Theorem

Let $w \in L$. If, for all $i \in \{1, \ldots, n\}$, $\pi_i(w) = \pi_i(w_i)$ for some $w_i \in SupK(L, \mathcal{S})$ then $w \in SupK(L, \mathcal{S})$

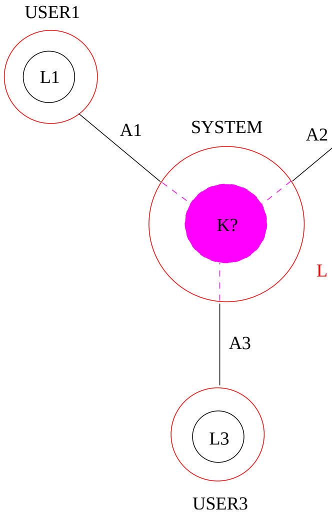


BY DEFINITION OF

THE

GREATEST FIXED POINT

Example 1



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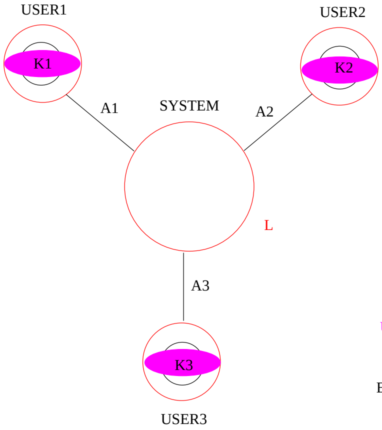
Example 1

$$K_i = \pi_i(SupK(L, \mathcal{S}))$$



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