Overview

- Safety Question
- HRU Model
- Take-Grant Protection Model
- SPM, ESPM
  – Multiparent joint creation
- Expressive power
- Typed Access Matrix Model

What Is "Secure"?

- Adding a generic right *r* where there was not one is "leaking"
- If a system *S*, beginning in initial state s_0, cannot leak right *r*, it is *safe with respect to the right r*.

Safety Question

- Does there exist an algorithm for determining whether a protection system *S* with initial state s_0 is safe with respect to a generic right *r*?
  - Here, "safe" = "secure" for an abstract model

Mono-Operational Commands

- Answer: *yes*
- Sketch of proof:

  Consider minimal sequence of commands $c_1, \ldots, c_k$ to leak the right.

  –Can omit **delete**, **destroy**

  –Can merge all **create**s into one

  Worst case: insert every right into every entry; with *s* subjects and *o* objects initially, and *n* rights, upper bound is $k \leq n(s+1)(o+1)$

General Case

- Answer: *no*
- Sketch of proof:

  Reduce halting problem to safety problem

  Turing Machine review:

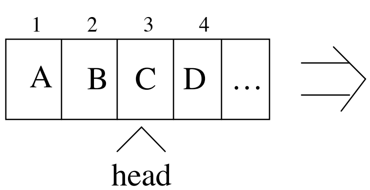
  – Infinite tape in one direction

  – States K, symbols M; distinguished blank b

  – Transition function $\delta(k, m) = (k', m', \text{L})$ means in state k, symbol m on tape location replaced by symbol m', head moves to left one square, and enters state k'

  – Halting state is q_f; TM halts when it enters this state

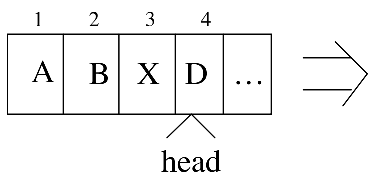
Mapping



Current state is k

	s_1	s_2	s_3	s_4	
s_1	A	*own*			
s_2		B	*own*		
s_3			C k	*own*	
s_4				D end	

Mapping



	s_1	s_2	s_3	s_4	
s_1	A	*own*			
s_2		B	*own*		
s_3			X	*own*	
s_4				D k_1 end	

After $\delta(k, \text{C}) = (k_1, \text{X}, \text{R})$ where k is the current state and k_1 the next state

Command Mapping

$\delta(k, \text{C}) = (k_1, \text{X}, \text{R})$ at intermediate becomes

```
command c_{k,C}(s3, s4)
if own in A[s3, s4] and k in A[s3, s3]
     and C in A[s3, s3]
then
  delete k from A[s3, s3];
  delete C from A[s3, s3];
  enter X into A[s3, s3];
  enter k1 into A[s4, s4];
end
```

Mapping

1	2	3	4	5
A	B	X	Y	*b*

head

	s_1	s_2	s_3	s_4	s_5
s_1	A	*own*			
s_2		B	*own*		
s_3			X	*own*	
s_4				Y	*own*
s_5					*b* k_2 end

After $\delta(k_1, \text{D}) = (k_2, \text{Y}, \text{R})$ where k_1 is the current state and k_2 the next state

Command Mapping

$\delta(k_1, \text{D}) = (k_2, \text{Y}, \text{R})$ at end becomes

command crightmost$_{k,c}$(s_4, s_5)
if *end* **in** $A[s_4, s_4]$ **and** k_1 **in** $A[s_4, s_4]$
    and D **in** $A[s_4, s_4]$
then
  delete *end* **from** $A[s_4, s_4]$;
  create subject s_5;
  enter *own* **into** $A[s_4, s_5]$;
  enter *end* **into** $A[s_5, s_5]$;
  delete k_1 **from** $A[s_4, s_4]$;
  delete D **from** $A[s_4, s_4]$;
  enter Y **into** $A[s_4, s_4]$;
  enter k_2 **into** $A[s_5, s_5]$;
end

Rest of Proof

- Protection system exactly simulates a TM
  - Exactly 1 *end* right in ACM
  - 1 right in entries corresponds to state
  - Thus, at most 1 applicable command
- If TM enters state q_f, then right has leaked
- If safety question decidable, then represent TM as above and determine if q_f leaks
  - Implies halting problem decidable
- Conclusion: safety question undecidable

Other Results

- Set of unsafe systems is recursively enumerable
- Delete **create** primitive; then safety question is complete in **P-SPACE**
- Delete **destroy**, **delete** primitives; then safety question is undecidable
  - Systems are monotonic
- Safety question for monoconditional, monotonic protection systems is decidable
- Safety question for monoconditional protection systems with **create**, **enter**, **delete** (and no **destroy**) is decidable.

Take-Grant Protection Model

- A specific (not generic) system
  - Set of rules for state transitions
- Safety decidable, and in time linear with the size of the system
- Goal: find conditions under which rights can be transferred from one entity to another in the system

System

○ objects (files, …)
● subjects (users, processes, …)
⊗ don't care (either a subject or an object)

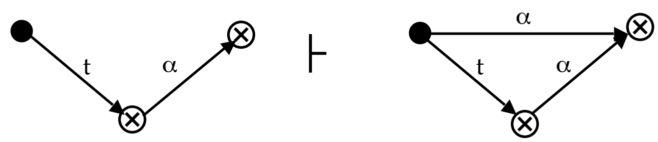
$G \vdash_x G'$ apply a rewriting rule x (witness) to G to get G'

$G \vdash^* G'$ apply a sequence of rewriting rules (witness) to G to get G'

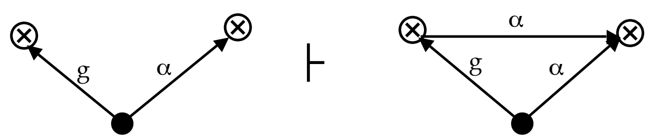
R = { t, g, r, w, … } set of rights

Rules

take



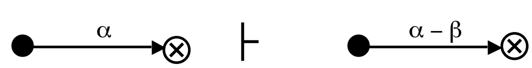
grant



More Rules

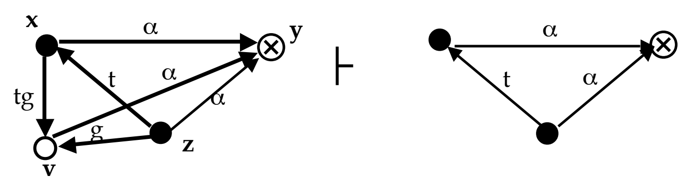
create

remove



These four rules are called the *de jure* rules

Symmetry



1. **x** creates (*tg* to new) **v**
2. **z** takes (*g* to **v**) from **x**
3. **z** grants (α to **y**) to **v**
4. **x** takes (α to **y**) from **v**

Similar result for grant

Islands

- *tg*-path: path of distinct vertices connected by edges labeled *t* or *g*
  - Call them “tg-connected”
- island: maximal *tg*-connected subject-only subgraph
  - Any right one vertex has can be shared with any other vertex

Initial, Terminal Spans

- initial span from **x** to **y**: **x** subject, *tg*-path between **x**, **y** with word in { $\overrightarrow{t}^*\overrightarrow{g}$ } ∪ { ν }
  - **x** can give rights it has to **y**
- terminal span from **x** to **y**: **x** subject, *tg*-path between **x**, **y** with word in { $\overrightarrow{t}^*$ } ∪ { ν }
  - **x** can acquire any rights **y** has

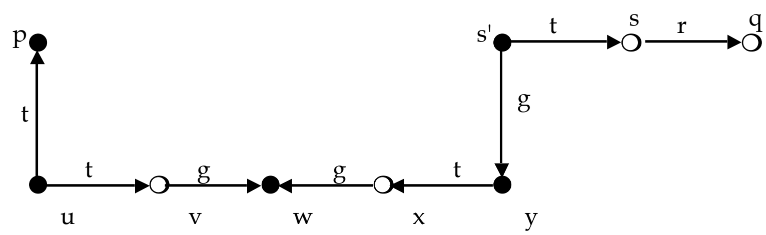
Bridges

- bridge: *tg*-path between subjects **x**, **y**, with associated word in

$$\{ \overrightarrow{t}^*, \overleftarrow{t}^*, \overrightarrow{t}^*\overleftarrow{g}\overleftarrow{t}^*, \overrightarrow{t}^*\overrightarrow{g}\overleftarrow{t}^* \}$$

  - rights can be transferred between the two endpoints
  - *not* an island as intermediate vertices are objects

Example



- islands { p, u } { w } { y, s' }
- bridges u, v, w; w, x, y
- initial span p (associated word ν)
- terminal span s's (associated word t)

can•share Predicate

Definition:

- can•share(r, **x**, **y**, G_0) if, and only if, there is a sequence of protection graphs $G_0, \ldots, G_n$ such that $G_0 \vdash^* G_n$ using only *de jure* rules and in G_n there is an edge from **x** to **y** labeled r.

can•share Theorem

- can•share(r, **x**, **y**, G_0) if, and only if, there is an edge from **x** to **y** labeled r in G_0, or the following hold simultaneously:
  - There is an **s** in G_0 with an **s**-to-**y** edge labeled r
  - There is a subject **x′** = **x** or initially spans to **x**
  - There is a subject **s′** = **s** or terminally spans to **s**
  - There are islands $I_1, \ldots, I_k$ connected by bridges, and **x′** in I_1 and **s′** in I_k

Outline of Proof

- **s** has r rights over **y**
- **s′** acquires r rights over **y** from **s**
  - Definition of terminal span
- **x′** acquires r rights over **y** from **s′**
  - Repeated application of sharing among vertices in islands, passing rights along bridges
- **x′** gives r rights over **y** to **x**
  - Definition of initial span

Key Question

- Characterize class of models for which safety is decidable
  - Existence: Take-Grant Protection Model is a member of such a class
  - Universality: In general, question undecidable, so for some models it is not decidable
- What is the dividing line?

Schematic Protection Model

- Type-based model
  - Protection type: entity label determining how control rights affect the entity
    - Set at creation and cannot be changed
  - Ticket: description of a single right over an entity
    - Entity has sets of tickets (called a *domain*)
    - Ticket is **X**/*r*, where **X** is entity and *r* right
  - Functions determine rights transfer
    - Link: are source, target "connected"?
    - Filter: is transfer of ticket authorized?

Link Predicate

- Idea: $link_i(\mathbf{X}, \mathbf{Y})$ if **X** can assert some control right over **Y**
- Conjunction or disjunction of:
  - $\mathbf{X}/z \in dom(\mathbf{X})$
  - $\mathbf{X}/z \in dom(\mathbf{Y})$
  - $\mathbf{Y}/z \in dom(\mathbf{X})$
  - $\mathbf{Y}/z \in dom(\mathbf{Y})$
  - **true**

Examples

- Take-Grant:

  $link(\mathbf{X}, \mathbf{Y}) = \mathbf{Y}/g \in dom(\mathbf{X}) \lor \mathbf{X}/t \in dom(\mathbf{Y})$
- Broadcast:

  $link(\mathbf{X}, \mathbf{Y}) = \mathbf{X}/b \in dom(\mathbf{X})$
- Pull:

  $link(\mathbf{X}, \mathbf{Y}) = \mathbf{Y}/p \in dom(\mathbf{Y})$

Filter Function

- Range is set of copyable tickets
  - Entity type, right
- Domain is subject pairs
- Copy a ticket $\mathbf{X}/r{:}c$ from $dom(\mathbf{Y})$ to $dom(\mathbf{Z})$
  - $\mathbf{X}/rc \in dom(\mathbf{Y})$
  - $link_i(\mathbf{Y}, \mathbf{Z})$
  - $\tau(\mathbf{Y})/r{:}c \in f_i(\tau(\mathbf{Y}), \tau(\mathbf{Z}))$
- One filter function per link function

Example

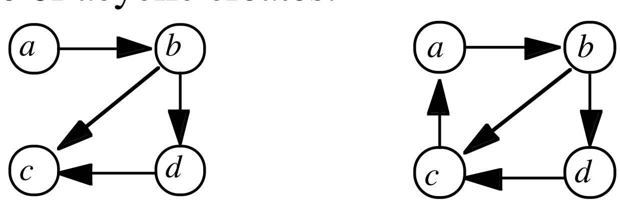
- $f(\tau(\mathbf{Y}), \tau(\mathbf{Z})) = T \times R$
  - Any ticket can be transferred (if other conditions met)
- $f(\tau(\mathbf{Y}), \tau(\mathbf{Z})) = T \times RI$
  - Only tickets with inert rights can be transferred (if other conditions met)
- $f(\tau(\mathbf{Y}), \tau(\mathbf{Z})) = \varnothing$
  - No tickets can be transferred

Example

- Take-Grant Protection Model
  – *TS* = { subjects }, *TO* = { objects }
  – *RC* = { *tc*, *gc* }, *RI* = { *rc*, *wc* }
  – *link*(**p**, **q**) = **p**/*t* ∈ *dom*(**q**) ∨ **q**/*t* ∈ *dom*(**p**)
  – *f*(*subject*, *subject*) = { *subject*, *object* } × { *tc*, *gc*, *rc*, *wc* }

Create Operation

- Must handle type, tickets of new entity
- Relation can•create(*a*, *b*)
  – Subject of type *a* can create entity of type *b*
- Rule of acyclic creates:



Types

- $cr(a, b)$: tickets introduced when subject of type a creates entity of type b
- **B** object: $cr(a, b) \subseteq \{ b/r{:}c \in RI \}$
- **B** subject: $cr(a, b)$ has two parts
  - $cr_P(a, b)$ added to **A**, $cr_C(a, b)$ added to **B**
  - **A** gets **B**/$r{:}c$ if $b/r{:}c$ in $cr_P(a, b)$
  - **B** gets **A**/$r{:}c$ if $a/r{:}c$ in $cr_C(a, b)$

Non-Distinct Types

$cr(a, a)$: who gets what?

- $self/r{:}c$ are tickets for creator
- $a/r{:}c$ tickets for created

$cr(a, a) = \{ a/r{:}c, self/r{:}c \mid r{:}c \in R\}$

Attenuating Create Rule

$cr(a, b)$ attenuating if:

1. $cr_C(a, b) \subseteq cr_P(a, b)$ and
2. $a/r{:}c \in cr_P(a, b) \Rightarrow self/r{:}c \in cr_P(a, b)$

Safety Result

- If the scheme is acyclic and attenuating, the safety question is decidable

Expressive Power

- How do the sets of systems that models can describe compare?
  - If HRU equivalent to SPM, SPM provides more specific answer to safety question
  - If HRU describes more systems, SPM applies only to the systems it can describe

HRU *vs*. SPM

- SPM more abstract
  - Analyses focus on limits of model, not details of representation
- HRU allows revocation
  - SMP has no equivalent to delete, destroy
- HRU allows multiparent creates
  - SPM cannot express multiparent creates easily, and not at all if the parents are of different types because can•create allows for only one type of creator

Multiparent Create

- Solves mutual suspicion problem
  - Create proxy jointly, each gives it needed rights
- In HRU:

```
command multicreate(s0, s1, o)
if r in a[s0, s1] and r in a[s1, s0]
then
  create object o;
  enter r into a[s0, o];
  enter r into a[s1, o];
end
```


SPM and Multiparent Create

- can•create extended in obvious way
  - $cc \subseteq TS \times \ldots \times TS \times T$
- Symbols
  - $\mathbf{X}_1, \ldots, \mathbf{X}_n$ parents, $\mathbf{Y}$ created
  - $R_{1,i}, R_{2,i}, R_3, R_{4,i} \subseteq R$
- Rules
  - $cr_{P,i}(\tau(\mathbf{X}_1), \ldots, \tau(\mathbf{X}_n)) = \mathbf{Y}/R_{1,1} \cup \mathbf{X}_i/R_{2,i}$
  - $cr_C(\tau(\mathbf{X}_1), \ldots, \tau(\mathbf{X}_n)) = \mathbf{Y}/R_3 \cup \mathbf{X}_1/R_{4,1} \cup \ldots \cup \mathbf{X}_n/R_{4,n}$

Example

- Anna, Bill must do something cooperatively
  - But they don't trust each other
- Jointly create a proxy
  - Each gives proxy only necessary rights
- In ESPM:
  - Anna, Bill type a; proxy type p; right $x \in R$
  - $cc(a, a) = p$
  - $cr_{\text{Anna}}(a, a, p) = cr_{\text{Bill}}(a, a, p) = \varnothing$
  - $cr_{\text{proxy}}(a, a, p) = \{ \text{Anna}/x, \text{Bill}/x \}$