CONSTRAINING PICTURES WITH PICTURES

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This paper presents a visual language called Miró for specifying and restricting operating system
security configurations. A Miró *picture* specifies exactly what rights users have on files. A Miró
constraint, also stated visually, restricts the set of Miró pictures that are considered legal. Such
constraints on pictures give an exact specification of security policies and a practical method for
alerting users to potential security holes. The language is easy to use and succinct.

1 Introduction

Miró is a visual language for specifying security configura-
tions. By "visual language," we mean a language whose en-
tities are graphical, such as boxes and arrows. By "specify-
ing," we mean stating independently of any implementation
the required and/or desired properties of a system. Finally,
by "security," we mean security for operating systems: en-
suring that files are protected from unauthorized access and
granting privileges to perhaps some users, but not others.

1.1 Motivation
Why visual specifications?   Pictures, diagrams, graphs,
charts and the like are commonly used to aid one's under-
standing of control information, data structures, computer
organization, and overall system behavior. With the advent
of new display technology they have become more popular as
a means of communicating ideas in general. Visual concepts
have even infected our terminology; for example, the basic
unit of security in Multics is a "ring."

Our work differs from other work in visual languages in
three important ways: First, unlike many languages based
on diagrams where boxes and lines may fail to have a pre-
cise meaning, or worse, have multiple interpretations, we are
careful to provide a completely formal semantics for our vi-
sual language. Second, in contrast to visual programming
languages, we are interested in specifications, not executable
programs. Third, we do not use visualization just for the sake
of drawing pretty pictures; instead, we address a domain, se-
curity, that lends itself naturally to a two-dimensional repre-
sentation.

Why security?   Computer security is a central problem in
the practical use of operating systems. Security has always
been a concern of traditional operating systems, but with
the proliferation of large, distributed systems, the problem
of guaranteeing security to users is even more critical. In
order to provide security in any one system, it is important
to clearly specify the appropriate security policy (those for a
university would be different from those for a bank) and then
to enforce that policy. Here we address the first of these two
issues by providing a way to express these policies succinctly,
precisely, and visually.

As opposed to previous approaches to specifying security
which use simple, fixed policies [2,9], our emphasis is on pro-
viding the users at a site with the ability to tailor a security
policy to their needs and to support the use of that policy in
a working file system. Moreover, we are interested in helping
users navigate through a specification as a means of under-
standing a specific system's security configuration.

Security lends itself naturally to visualization because the
domains of interest are best expressed in terms of relations on
sets, easily depicted as Venn diagrams, and the connections
among objects in these domains are best expressed as rela-
tions (e.g., access rights), easily depicted as edges in a graph
(where the nodes are Venn diagrams). The Miró picture and
constraint languages extend Harel's work on higraphs [4], an
elegant formalism that shows relations on Venn diagrams.

1.2 Model of Security
The semantics of Miró are defined in terms of an underlying
security model. The basis for this model is the Lampson
access matrix [6], in which one axis is labeled with the names
of users and a second axis is labeled with file names. An
entry in the matrix for a certain user and file describes all
the modes by which the user may access the file. An example
of an access type is "the user has the right to read the file."
The range of modes of access may vary from one operating
system to another.

The access matrix provides the ability to represent all pos-
sible security situations. A major challenge for a security
specification scheme is to restrict the set of possible situations
to only those that are *realizable* and *acceptable*. Since the op-
erating system can only support certain configurations, some
access matrices must be disallowed. (E.g., in Unix a situation
where one group of users has permission to read a file, and a
second group of users has permission to write that file can-
not be *realized* [10]). Specific security policies may make some
situations unacceptable (e.g., in the military Bell-LaPadula
security model [1,3], users and files are assigned linear se-
curity levels (i.e., top secret, secret, not secret); it is only
acceptable for users to write to files at their security level or
higher, and to read files at their level or lower.) Another way
to restrict the set of *acceptable* situations would be to es-
tablish guidelines for the default protection of newly-created
files and users. The specification of these default protections
is of tremendous practical importance; the failure of previ-
ous systems to address this issue fully has been the source of
numerous security problems in the past.

For us as specifiers the challenge is two-fold: first to be able
to describe any access matrix in a straightforward and simply
understood way, and second to be able to describe the set of
realizable and acceptable access matrices. Section 2 gives a
brief overview of the basic Miró picture language which is rich
enough to represent any static access matrix [12]. Its com-
plete description and formal semantics can be found in [7].
Section 3 gives details of the Miró constraint language which

can restrict the set of Miró pictures to those that are realizable and acceptable. This constraint language is the most novel and significant contribution of this paper. Section 4 enumerates the Miró software tools.

2 Miró Pictures and Types

2.1 Miró Pictures

A Miró **picture** is formed from a set of objects, each of which is either a **box** or an **arrow**, each optionally labeled. Boxes represent individual processes and files or collections of processes or files; arrows represent access rights. A box that represents a single process or file is **atomic**. Arrows can be **positive** or **negative**, representing the granting or denial of access rights. Well-formedness conditions restrict the domain of syntactically legal pictures; one condition is that arrows be attached at both ends.

Figure 1 shows a Miró security specification that reflects some aspects of the Unix file protection scheme. The outermost left-hand box depicts a world, World, of users, two groups, Group1, and Group2, and two users, Alice and Bob. The containment and overlap relationships between the world, groups, and users indicate that all users are in the world, and that some users are members of more than one group. The right-hand box denotes the set of files in Alice's mail directory. The arrows indicate that Alice, and no other user, has read access to her mail files. She is granted read permission because the direct positive arrow from Alice overrides (i.e., is more tightly nested than) the negative arrow from World.
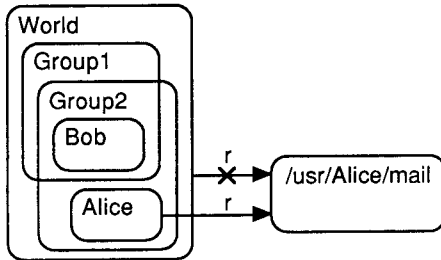

Figure 1: A Sample Miró Picture

The presence of negative arrows introduces some nontriviality to our semantics. For example, in Figure 2, it is not clear whether Bob has read access to the file /usr/admin because one arrow is more tightly nested at the tail and a second arrow is more tightly nested at the head. We call such pictures *ambiguous* (a formal definition appears in [7]). Informally, a picture is not ambiguous if, for each pair (u, f), where u is an atomic user box and f is an atomic file box, there is a *single* arrow (positive or negative) that is more tightly nested on both ends than all other arrows and therefore governs whether u has access to f.
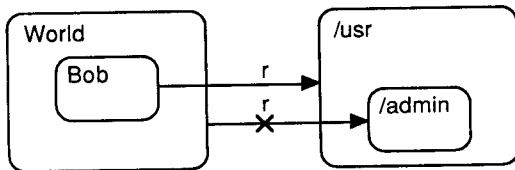

Figure 2: An Ambiguous Miró Picture

2.2 Types

Each arrow or box object has a *type*. The type of an arrow is an element of a user-specified finite set *Any* of access permissions (e.g., *Any* = {read, write, execute}). A box's type is a *name* plus a (possibly empty) set of *attributes*.

The box type definition provides a subtyping mechanism. A subtype inherits all of the attributes of its parent type, and can add additional attributes of its own. In the examples that follow, there are two main box types: Entity and Sysobj. There are three subtypes of Entity (World, Group, and User) and two subtypes of Sysobj (Dir and File). Type information can be used to express restrictions such as "there must be exactly one instance of type World." The constraint language outlined in the next section provides a means for restricting pictures based on the values of type attributes.

In this paper we assume that all Miró pictures are well-formed, non-ambiguous, and type-consistent.

3 Constraints

Miró is expressive enough to specify security configurations for any operating system. However, the kinds of pictures users can draw will vary depending on the particular system they are specifying. In particular, the system architecture will impose constraints on what should be considered a "legal" (realizable and acceptable) picture for that system. For example, a legal picture for Multics may be illegal for Unix.

Constraints themselves are specified by pictures drawn in a visual language similar to the Miró picture language described in Section 2. We make the distinction, therefore, between *Miró pictures* and *Miró constraints*. Each constraint specifies a "pattern," which is a template for many different Miró pictures. If a particular Miró picture is an instance of the pattern, we say that picture *matches* the pattern.

Constraints are typically statements in which the occurrence of some situation will imply that some further condition should hold. Therefore, constraints are divided into two parts: the antecedent (or *trigger*) and the consequent (or *requirement*). For example, we may wish to specify the constraint that any time a user has write access to a file, he should also have read access to it. In this case, the existence of write privilege is the "trigger" of the read privilege "requirement." Both parts are expressed together in a single constraint. We describe shortly how these constraints are depicted and give a description of their semantics.

Associated with each box in a Miró picture is information concerning its type (and thus its attributes), which arrows are drawn to or from it, its corresponding entries in the access matrix, and the boxes it contains and is contained in. We would like our constraint language to be able to place restrictions on all this information. In particular, we want to express constraints on these aspects of a Miró picture:

- Which arrows may be drawn (e.g., "there can be at most 20 arrows leading to any box of type top-secret"). Such constraints specify certain *syntactic relations* among boxes because they depend solely on the syntax of the Miró picture, and not on its meaning.

- Entries in the associated access matrix (e.g., "if a user has **write** access to a file, he should also have **read** access to it"). These constraints specify *semantic relations* among boxes because they depend on the meaning of the Miró picture.

- Box *containment relations* (e.g., "every user in the Miró group should have a sub-directory contained in his home directory called miro").

3.1 Syntax and Semantics

Like Miró pictures, Miró constraints contain boxes and arrows, but with restrictions and extensions to the picture syntax. We now present an informal version of the syntax and semantics in an incremental fashion. The constraint language does have a formal semantics, which we have omitted for the sake of brevity.

Keep in mind that the meaning of a constraint picture is exactly the set of Miró pictures that legally match it. Therefore, at each step in the presentation we give examples of constraints (constructed from the syntax as described up to that point) and Miró pictures, and explain why a particular Miró picture does or does not match a particular constraint.

3.1.1 Box Patterns

Each constraint provides a pattern against which a particular Miró picture is matched. At the lowest level of the pattern are **box patterns** against which individual boxes are matched. A box pattern is a standard Miró box containing a *box predicate* taken from the *box predicate language*. A particular box in a Miró picture **matches** the box pattern if the values of its attributes make the predicate true.

The box predicate is basically a Boolean expression (where "&," "|," and "!" denote "and," "or," and "not") of relations involving constants and attribute names associated with some box type. We use $\subseteq$ and $\subset$ as relations on box types to denote subtype and strict subtype, respectively. We use **variables** to force attribute values of two or more boxes to match. A variable name is distinguished from other identifiers by preceding it with a "$". Each variable $X in a constraint must appear in at least one predicate containing the expression "*attribute* = $X." The semantics of each variable name in a constraint is as follows: Pick any box pattern in which the variable is compared to an attribute for equality and set the value of the variable to the value of the attribute of the box matching the rest of that box pattern. Then, for each other use of the variable, substitute the assigned value for the variable name; that substituted value must make each of the box predicates in those boxes true.

The boxes shown in Figure 3 illustrate the basics of the box predicate language. The predicates match: (a) all **Users** named **jones**, (b) all **Groups** other than those named **miro** or **theory**, and (c) all **Files** created in January 1988.

type = User &
name = "jones"

type = Group &
! (name ∈ { "miro","theory" })

(a)   (b)

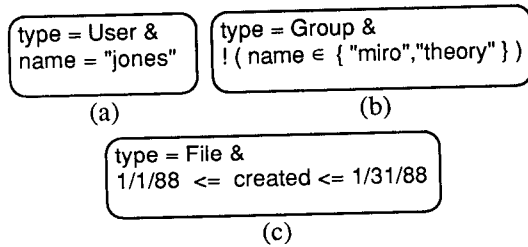type = File &
1/1/88 <= created <= 1/31/88

(c)

Figure 3: Three Box Patterns

For the remainder of the paper, we will adopt the shorthand that upper-case letters denote box predicates matched *only* by the box instance in the Miró picture named with the same lower-case letter (i.e., *a* matches *A* only, *b* matches *B* only, etc.).

3.1.2 Arrows

There are three kinds of constraint arrows, one for each type of relationship between boxes (syntactic, semantic, or containment) we wish to constrain. We call the arrows associated with these relationships *syntax arrows*, *semantics arrows*, and *containment arrows*, respectively. Both the head and tail of a syntax or semantics arrow lie directly on the boundary of the boxes to which they are connected, whereas the head of a containment arrow lies inside its connected box. Syntax and semantics arrows are visually distinguished by drawing them with solid and dashed lines, respectively. We also adopt the convention that syntax and semantics arrows are horizontal, while containment arrows are vertical. Examples of these arrows are shown in Figure 4.

A ─S→ B   A ─S─> B   B
                                    ↑
                                    A

(a) Syntax   (b) Semantics   (c) Containment
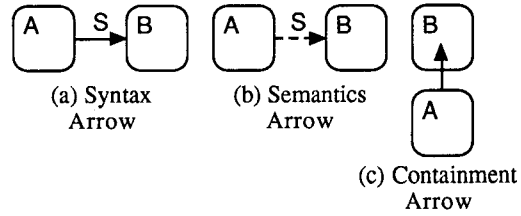   Arrow   Arrow   Arrow

Figure 4: The Three Constraint Arrows Types

Syntax and semantics arrows are labeled, but containment arrows are not. The label in the former two cases serves to further specify which type of relationship exists between A and B. Recall that Any is the set of allowed access types. In general, the label specifies some non-empty set $S \subseteq Any$. If S is a singleton, we write it simply as s instead of $\{ s \}$.

We now describe what it means for boxes a and b to match patterns A and B with respect to each type of arrow.

(a) Syntax Arrow: If there is a syntax arrow from A to B labeled S, then there must exist an arrow in the Miró picture from a to b of some type $s \in S$.

(b) Semantics Arrow: If there is a semantics arrow from A to B labeled S, then the access matrix associated with the Miró picture must specify that a has some permission s on b, where $s \in S$. Furthermore, since the access matrix is only defined on atomic boxes, any box pattern having a semantics arrow incident on it can be matched only by an atomic box.

(c) Containment Arrow: If there is a containment arrow from A to B, then box a must be directly contained in box b in the Miró picture.

Miro Picture

a b   r   e   f
c d   w
                  w
                  ✗
                  r   g

Constraints

D ─w→ G   A   A
                 ↑   ↑
(a) Matched

D ─w→ G   B   D
                 ↑   ↑
(b) Not Matched (c) Matched (d) Not Matched

A ─{ r,w }→ E   D ─r→ F | G
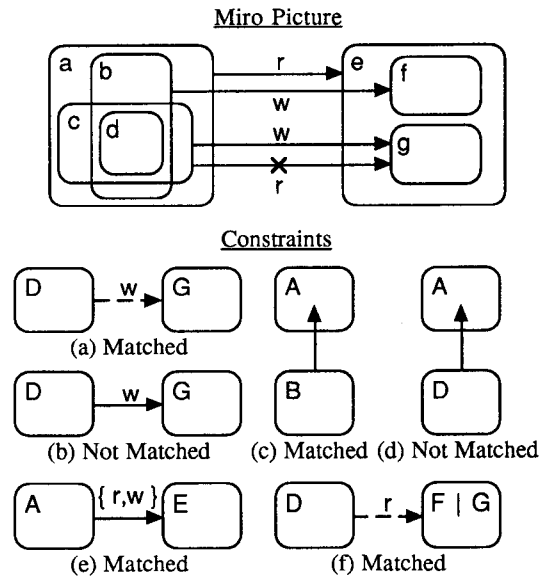
(e) Matched   (f) Matched

Figure 5: Constraint Arrow Examples

Consider the Miró picture and six different constraints shown in Figure 5. Along with each constraint is an indication of whether or not the Miró picture matches that constraint. We now explain each of these results:

(a) and (b): Constraint (a) is matched because d does have write access to g; constraint (b) is not matched because there is not a write arrow connecting d to g in the picture.

(c) and (d): Constraint (c) is matched because b is directly contained in a; constraint (d) is not matched because d is contained in a, but not directly so.

(e): Constraint (e) is matched because there is a read arrow from a to e in the picture. This constraint points out the "or" nature of the set label on syntax and semantics arrows: constraint (e) would have been matched if there had been either a read or a write arrow (or both) from a to e.

(f): Constraint (f) is matched since d has read access to f.

3.1.3 Containment and Starred Containment

In Miró pictures, we already have a powerful visual representation for containment, and we allow this representation in constraints as well. Drawing one box inside another is a shorthand for drawing a containment arrow between two non-intersecting boxes. Figure 6a shows the equivalence of these two representations. We will see later that containment arrows (the left-hand side of the equality) provide more expressiveness than the box-inside-a-box representation (the right-hand side of the equality).

The constraint syntax also provides a means for specifying that a box is contained in another box *at some level*, as opposed to being contained directly. A containment arrow with a star at its tip denotes this more general *starred containment* relation. Again, there is an equivalent graphical representation for starred containment in which one starred box is drawn inside another (Figure 6b).

(a) Box Pattern A is Directly Contained in Box Pattern B
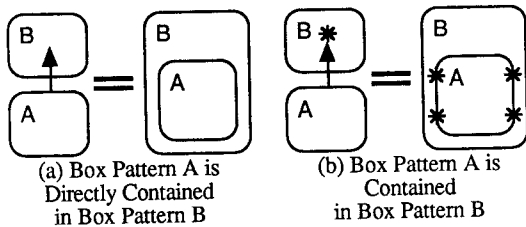
(b) Box Pattern A is Contained in Box Pattern B

Figure 6: Direct Containment (a) and Containment (b)

The semantics of a starred containment relation is straightforward. Boxes a and b will match the constraint shown in Figure 6b if and only if a is contained in b (one or more levels deep). For example, the Miró picture in Figure 5 would match constraint Figure 5d if the containment arrow were starred.

3.1.4 Negated Arrows

Each of the three kinds of constraint arrows may be negated like Miró arrows, but the semantics is different in each case. In general, a negated syntax arrow matches a negated *arrow* in the Miró picture, whereas a negated semantics arrow or containment arrow matches the negation of the *relation* that would be specified by the positive version of the arrow.

We now describe these semantics more formally by defining what it means for the boxes a and b to match the patterns A and B with respect to each type of negated arrow.

(a) Negated Syntax Arrow: If there is a negated syntax arrow from A to B labeled S, then there must exist a negative arrow in the Miró picture from a to b of some type $s \in S$.

(b) Negated Semantics Arrow: If there is a negative semantics arrow from A to B labeled S, then the access matrix associated with the Miró picture must specify that a has negative permission s on b, for some $s \in S$.

(c) Negated Containment Arrow: If there is a negative containment arrow (or negative starred containment arrow) from A to B, then box b must not be directly con-

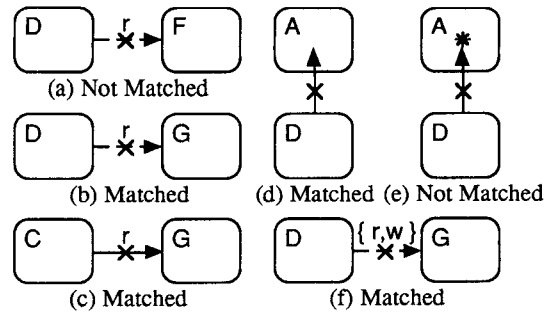tained in (or contained in at any level) box a in the Miró picture.

Figure 7: Constraints Using Negative Arrows

Figure 7 shows some simple constraints using negative arrows. As before, we indicate whether the Miró picture of Figure 5 matches each constraint. Most of these examples are straightforward, but constraint (f) deserves explanation. In the Miró picture, d has positive write access to g, but negative read access. Constraint (f) is matched because we only require the existence of a single access matrix entry which confirms either a negative read or a negative write relationship between d and g.

3.1.5 Thick and Thin

Recall that constraints in their general form are composed of both a trigger and a requirement, which must hold whenever the trigger is satisfied. We draw both parts of the constraint together and use *line thickness* to distinguish the two parts; the objects that form the trigger are thick, and the objects that form the requirement are thin (on a color display system, we might use two colors, such as red and blue, instead of line thickness). The loose meaning of a picture with both thick and thin objects is: "For each part of the Miró picture matching the thick part of the constraint, some additional part of the Miró picture must match the thin part of the constraint." To specify conditions that must always be true, the entire picture must be thin.
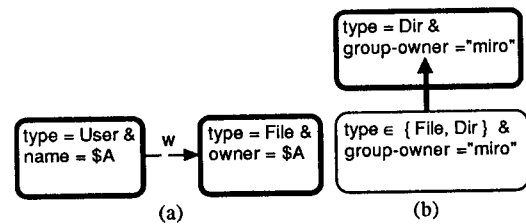

Figure 8: Two Thick and Thin Constraint Examples

The semantics of thick and thin constraints is spelled out more rigorously in section 3.1.6 below. For now, we present the simple examples of Figure 8 to introduce the meaning of such constraints. Constraint (a) says, "For every User box u and every File box f which is owned by that same user, u must have write access to f." Constraint (b) says, "For every Dir d owned by the group miro, all objects directly contained in d must either be Files or Dirs, and must also be owned by the group miro." Notice that this constraint will force its way down all Files and Dirs of any subtree rooted by a Dir owned by the miro group.

Constraint (b) illustrates a limitation of the shorthand representation for box containment — if we had represented this constraint using that shorthand, we could represent both

boxes, their thickness, and we could implicitly represent the containment arrow, but we could not represent the thickness of that arrow. Therefore, we need a rule defining which arrow thickness to assume in order to make the box containment shorthand complete. The rule is: if both boxes are thick, the arrow is thick; otherwise, the arrow is thin.

3.1.6 Building Bigger Constraints

So far, we have only considered simple constraints composed of at most two boxes and a single arrow, but in fact a group of many boxes and constraint arrows may work together to specify a bigger constraint pattern. We expect most constraint pictures to be relatively small, consisting of at most four or five boxes and three or four arrows. We require that no boxes overlap in these bigger constraints although strict containment is still allowed.

Given a more complex constraint picture, it is necessary to define carefully what it means for a Miró picture to match that constraint. We first convert all instances of box containment in the constraint to the equivalent form using containment arrows and starred containment arrows. We now present some useful definitions. A **sub-picture** of either a Miró picture or a Miró constraint picture is a (possibly empty) subset of the boxes and arrows comprising the original picture. It is important to note that a sub-picture need not be well-formed: it may have dangling arrows.

A sub-picture P_M of a Miró picture P **matches** a sub-picture P_C of a constraint if:

- there is a one-to-one mapping α from box patterns of P_C to boxes of P_M such that for each box pattern b of P_C, the box $\alpha(b)$ satisfies the box predicate of b,

- there is a one-to-one mapping β from syntax arrows of P_C to arrows of P_M such that for each syntax arrow a (with label S) of P_C, the type of $\beta(a)$ is in S,

- there is a one-to-one mapping γ from semantics arrows of P_C to access matrix entries determined by P such that for each semantics arrow a (with label S) of P_C, the type of $\gamma(a)$ is in S, and

- there is a one-to-one mapping from direct containment arrows (or starred containment arrows) of P_C to instances of direct containment (or containment) in P_M

such that for each constraint arrow a in P_C, if B denotes the set of box patterns in P_C incident on a (note that B may be a pair, singleton, or empty), it is the case that the corresponding boxes in P_M are connected in the same way that a and B are. Informally, this definition says that a Miró sub-picture matches a constraint sub-picture if each individual object matches, and if the relations between Miró boxes are connected to the correct boxes according to the constraint.

We are now ready to define matching between entire Miró pictures and constraints. We first split the constraint picture P_C into its thick (trigger) and thin (required) sub-pictures, which we call P_T and P_R respectively. A Miró picture P_M is **legal** with respect to the constraint picture P_C if, for each sub-picture of P_M that matches P_T, there is another sub-picture of P_M that, when combined with the first sub-picture, matches all of P_C. Furthermore, the one-to-one mappings used in the latter matching must be extended functions of the one-to-one mappings in the former matching.
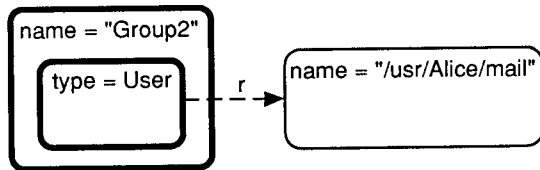
Figure 9: A Composite Constraint

Consider the (probably undesirable) constraint of Figure 9 in reference to the Miró picture of Figure 1 (pg. 2). This constraint says: "For every **User** directly contained in a box **Group2**, there must exist a file **/usr/Alice/mail** to which that **User** has read access." Since **Bob** does not have such permission, the Miró picture in this case does not match the constraint.

3.1.7 Numeric and Negative Constraints

A constraint picture can also have a numeric constraint associated with it that specifies some range of non-negative integers. To determine whether a Miró picture is legal with respect to the constraint, do the following: for each sub-picture that matches the trigger, count the number of sub-pictures matching the entire constraint. This number should be within the given range. When there is no explicit range, the default is "≥ 1." Visually, such restrictions appear below the boxes and arrows, as in example 5 of section 3.2.

Sometimes it is more natural to express a constraint by depicting what should *not* be allowed. Negative constraints are used for this purpose. A negative constraint is simply a positive constraint (as described above) with a large "X" through its frame. Informally, a Miró picture is legal with respect to a negative constraint if and only if it is illegal with respect to the positive version of the constraint. Since negated constraints with counts can be confusing, we only allow constraints without a numeric constraint to be negated. Hence, a negative constraint is equivalent to its positive version with the numeric constraint "$= 0$."
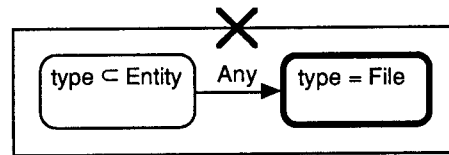
Figure 10: No File May Have Any Arrows Pointing At It

Figure 10 depicts an aspect of the Andrew file system[1]. Protections in Andrew are associated with directories — files inherit the protection of their parent directory. Therefore, we require that no **File** in a Miró picture for Andrew can have an arrow pointing to it.

3.2 Constraints for Unix

In this section we present some typical constraints for the Unix operating system. Before each example, we describe the constraint being specified.

1. Every arrow must connect an **Entity** to a **Sysobj**.
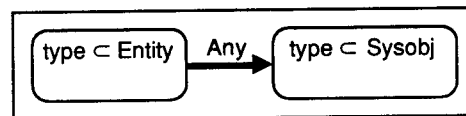
2. Whenever a **User** has write access to a **File**, he should also have read access to that **File**.

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[1] Andrew is a distributed Unix-like operating system with a common file server [11].

3. Every Group must be directly contained in at least one World, and a Group can only be contained in a World.

```
┌─────────────────┐     ┌─────────────────────┐
│ ╭─────────────╮ │     │ ╭─────────────────╮ │
│ │ type = World│ │     │ │ ! ( type = World )│ │
│ ╰─────────────╯ │     │ ╰─────────────────╯ │
│        ▲        │     │         ✳           │
│        │        │     │         ▲           │
│ ╭─────────────╮ │     │         ✕           │
│ │ type = Group│ │     │ ╭─────────────────╮ │
│ ╰─────────────╯ │     │ │  type = Group   │ │
└─────────────────┘     │ ╰─────────────────╯ │
                        └─────────────────────┘
```
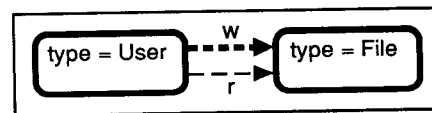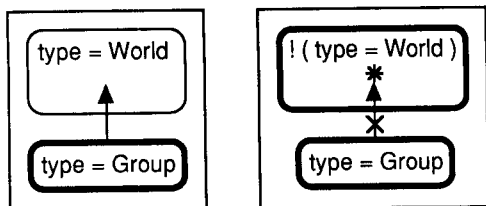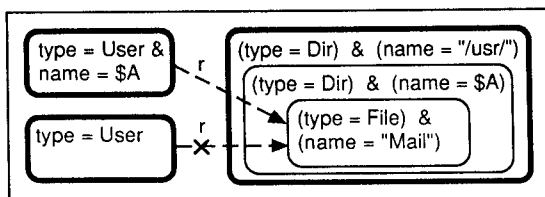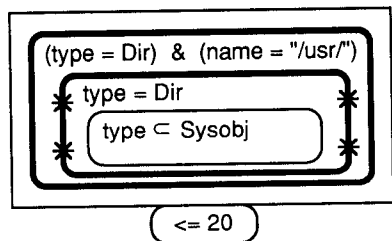
4. For each User named A, there should be a Dir named A in /usr/, and that Dir should contain a File called Mail to which user A is the only User given read access. This constraint denies all other Users read access on A's mail file because, when we match boxes of the Miró picture against the trigger, every box matching the bottom User box pattern must be different from the box matching the top User box pattern.

```
┌──────────────────────────────────────────────────┐
│ ╭──────────────╮  r  ╭──────────────────────────╮ │
│ │ type = User &│╌╌╌╮ │(type = Dir) & (name = "/usr/")│
│ │ name = $A    │   ╲ ╰──────────────────────────╯ │
│ ╰──────────────╯    ╲│(type = Dir) & (name = $A) │ │
│                      ╰──────────────────────────╯ │
│ ╭──────────────╮  r   ▲╭──────────────────────╮   │
│ │ type = User  │╌╌✕╌╌╌─│(type = File) &        │  │
│ ╰──────────────╯    ──▶│(name = "Mail")        │  │
│                        ╰──────────────────────╯   │
└──────────────────────────────────────────────────┘
```

5. Below is a numeric constraint that a system administrator might wish to establish. It states that no user's Dir (i.e., no Dir in the user's home directory subtree) should contain more than 20 entries.

```
┌──────────────────────────────────────────────┐
│ ╭──────────────────────────────────────────╮ │
│ │ (type = Dir)  &  (name = "/usr/")        │ │
│ │ ✕╭──────────────────────────────────╮ ✕ │ │
│ │  │  type = Dir                       │   │ │
│ │  │ ╭──────────────────────────────╮ │   │ │
│ │  │ │  type ⊂ Sysobj               │ │   │ │
│ │  │ ╰──────────────────────────────╯ │   │ │
│ │ ✕╰──────────────────────────────────╯ ✕ │ │
│ ╰──────────────────────────────────────────╯ │
└──────────────────────────────────────────────┘
            ╭──────────╮
            │  <= 20   │
            ╰──────────╯
```

4 Implementation

Miró provides a way of specifying complex relations in a simple way. The hierarchical structure provided by our box and arrow notation provides a straightforward representation of binary relations between files and users, and the constraint mechanism provides the capability to delimit acceptable and unacceptable Miró pictures.

We are designing a set of tools that will allow us to exploit Miró's capabilities. Our front-end tools are operating system independent, and use an intermediate file format to represent Miró pictures and constraints; the back-end tools use the intermediate file format to interface with actual operating systems.

The front-end tools include the *Miró graphical editor*, which allows users to view and modify Miró pictures and constraints. The editor runs under the X Window system and is built on top of the Garnet system [8]. The editor provides simple syntactic checks, and translates pictures and constraints into our intermediate file format. It also provides the ability to "zoom" out and in to allow the user to abstract

away or focus in on details of a picture, and to "highlight" the sub-pictures of interest. The *Miró printing package* takes the intermediate file format and produces a PostScript file of the Miró picture. The *Miró static semantics checker* checks a picture for ambiguity or violations of constraints, and reports any errors.

The back-end tools include the *Miró file system checker*, which probes the file system to check whether a given file system's protection conforms with its Miró description. A different file system checker is needed for each operating system on which Miró will be used. We are investigating the feasibility of a *Miró file system inspection tool* which could alter a Miró picture to correspond to the actual state of the file system. The file system inspection tool raises a number of interesting questions in the area of automated production of attractive graphs. Of the tools mentioned, we have prototypes of the graphical editor, static semantics checker, and the printing package.

In conclusion, the Miró system provides a convenient visual language for specifying security properties. Our future work will concentrate on applying the Miró language to domains other than security.

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David Harel provided us with the inspiration for our basic visual language with his notation and semantics for higraphs. Brad Myers urged us to develop a visual language for specifying constraints and convinced us that such a means of specification was feasible. He has also been extremely helpful in bootstrapping our editor on top of his Garnet system.

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