Social roles, from agents back to objects

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***Abstract*— In this paper we introduce a new view on roles in Object Oriented programming languages. This view is based on an ontological analysis of roles and attributes to roles the following properties: first, a role is always associated not only with an object instance playing the role, but also to another object instance which constitutes the context of the role and which we call institution. Second, the definition of a role depends on the definition of the institution which constitutes its context. Third, this second property allows to endow players of roles with powers to modify the state of the institution and of the other roles of the same institution. As an example of this model of roles in Object Oriented programming languages, we introduce a role construct in Java. We interpret these three features of roles in Java as the fact that, first, roles are implemented as classes which can be instantiated only in presence of an instance of the player of the role and of an instance of the class representing the institution. Second, the definition of a class implementing a role is included in the class definition of the institution the role belongs to. Thirdly, powers are methods of roles which can access private fields and methods of the institution they belong to and of the other roles of the same institution.**

I. Introduction

The concept of role is used quite ubiquitously in Computer Science: from databases to multiagent systems, from conceptual modelling to programming languages. According to Steimann [18], the reason is that even if the duality of objects and relationships is deeply embedded in human thinking, yet there is evidence that the two are naturally complemented by a third, equality fundamental notion: that of roles. Although definitions of the role concept abound in the literature, Steimann maintans that only few are truly original, and that even fewer acknowledge the intrinsic role of roles as intermediaries between relationships and the objects that engage in them. There are three main views of role:

- Names for association ends, like in UML or in Entity-Relationship diagrams.
- Dynamic specialization, like in the Fibonacci [2] programming language.
- Adjunct instances, like in the DOOR programming language [22].

The two last views are more relevant for modelling roles in programming languages. Both of them have pros and cons. For example, dynamic specialization captures the dynamic relation between a class and a role which can be played by it (e.g., a person can become a student), but it less easily models the intuition that roles can have their own state (e.g., an employee has a different phone number than the person playing that role). In contrast, roles as adjunct instances can obviously have their own state, but they may pose problems when role instances are detached from the object which plays the role.

There is a wide literature on the introduction of the notion of role in programming languages. However, most works, starting from Bachman and Daya [3]'s revision of database models, extend programming languages with roles starting from practical considerations. In contrast, the research question of this paper is the following: How to introduce in an Object Oriented programming language a notion of role which is ontologically well founded? We refer to the ontological analysis of the notion of role made in [7], [5], [6]. According to that proposal, roles have the following properties:

- Roles are always associated both to an object instance playing the role, and to another object instance which constitutes the context of the role and which we call the *institution*.
- The definition of a role depends on the definition of the institution which constitutes its context.
- This second property allows to endow players of roles with powers to modify the state of the institution and of the other roles of the same institution.

For example, the role *student* has a *person* as its player and it is always a student of a *school*, a *president* is always the president of an *organization*, a *customer* can be played by a *person* or an *organization*, and it is always a *customer* of an *enterprise*. In contrast, almost all current approaches focus only on the relation between the role and its player.

The methodology we follow is to introduce a new programming construct in a real programming language, Java, one of the most used Object Oriented languages and one of the most principled. To prove its feasibility, we translate the new language, called *powerJava*, to pure Java by means of a precompilation phase.

The role construct we introduce in Java promotes the separation of concerns between the core behavior of an object and its context dependent behavior. In particular, the interaction among a player object, the institution and the other roles is encapsulated inside the role the object plays.

In Section II we summarize the ontological definition of roles while, in Section III, we introduce roles Java with powerJava. Related work and conclusion end the paper.

II. Foundation, definitional dependence, and powers

The distinguishing features of roles in [7], [5], [6] are their foundation, their definitional dependence from the institution they belong to, and the powers attributed to the role by the institution. Consider the roles student and teacher. A student and a teacher are always a student and a teacher of some school. Without the school the roles do not exist anymore: e.g., if the school goes bankrupt, the actors (e.g. a person) of the roles cannot be called teachers and students anymore. The institution (the school) also specifies the properties of the student, which extend the properties of the person playing the role of student: the school specifies its enrollment number, its email address, its scores at past examinations, and also how the student can behave. For example, the student can give an exam by submitting some written examination. A student can make the teacher evaluate its examination and register the mark because the school defines both the student role and the teacher's role: the school specifies how an examination is evaluated by a teacher, and maintains the official records of the examinations. Otherwise the student could not have an effect on the teacher. But in defining such actions the school *empowers* the person who is playing the role of student: without being a student the person has no possibility to give an examination and make the teacher evaluate it.

This example highlights the following properties that roles have in our model [7], [5], [6]:

- *Foundation*: a (instance of) role must always be associated with an instance of the institution it belongs to (see Guarino and Welty [10]), besides being associated with an instance of its player.
- *Definitional dependence*: The definition of the role must be given inside the definition of the institution it belongs to. This is a stronger version of the definitional dependence notion proposed by Masolo *et al.* [14], where the definition of a role must use the concept of the institution.
- *Institutional empowerment*: the actions defined for the role in the definition of the institution have access to the state and actions of the institution and of the other roles: they are powers.

Moreover, as Guarino and Welty [10] notice, contrary to natural classes like person, roles lack *rigidity*: a player can enter and leave a role without losing its identity; a person can stop being a student but not being a person. Finally, Steimann [19]'s highlights that a role can be played by different kinds of actors. For example, the role of customer can be played by instances both of person and of organization, i.e., two classes which do not have a common superclass. The role must specify how to deal with the different properties of the possible actors. This requirement is in line with UML, which relates roles and interfaces as partial descriptions of behavior.

This last property compels to avoid modelling roles as dynamic specializations as, e.g., [2], [9] do. If customer were a subclass of person, it could not be at the same time a subclass of organization, since person and organization are disjoint classes. Symmetrically, person and organization cannot be subclass of customer, since a person can be a person without ever becoming a customer.

III. Introducing roles in Java: powerJava

Roles are useful in programming languages for several reasons, from dealing with the separation of concerns between the core behavior of an object and its interaction possibilities, to reflecting the ontological structure of domains where roles are present, from modelling dynamic changes of behavior in a class to fostering coordination among components.

In our proposal, we model roles as instances of role classes, which can be associated at runtime with objects which can play a role. However, roles are special kind of objects, and instances of role classes do not exist on their own, but they always require to be associated with an object instance of its player and an object instance of the related institution. The relations of a role with these two instances are different. Concerning the former relation, the player of the role is an object whose properties and behavior are extended when it is seen under the perspective of the role. Moreover , the role does not affect the core behavior. In contrast, concerning the latter relation, the object instance which represents the institution which the role belongs to gives the role powers: the role is enabled to access the institution's own state and the state of the other roles via its methods; thus, role's behavior can effect the institution's behavior. Accessing the institution's state is possible only if the classes defining it and its roles are connected. This is what it is called definitional dependence and it requires that the role class belongs to the namespace of the institution class.

Analogously to classes and interfaces in OO, we distinguish the role implementation in an institution from the role definition (both powers and requirements). A role implementation should implements the role powers definition while a player should implements a role requirements definition.

Finally, the constraint of foundation requires that the creation of a role instance involves both an institution instance and an object instance. A power can be invoked from a role only by specifying the role which the player had to play. Note that an object can play not only several roles, but also the same role in different institutions at the same time. Hence, the role under which a player is seen must be specified using not only the role but also the institution instance.

In this paper we extend Java with these desired features of roles in OO programming languages. In summary, in our proposal, first a role is defined specifying what is requested to play a role and what is offered by a role by an abstract definition similar to a Java interface. Second, since Java inner classes allow a class to belong to the namespace of another class, we use them to give powers to roles in institutions. Moreover, implementing a role definition as an inner class of an outer class defining an institution parallels exactly the definitional dependence. Third, the association of a role instance with an institution instance can be dealt with the implicit reference in Java of an inner class from its outer class. So we are left only to deal explicitly with the association of a

```
interface StudentReq //Student's requirements
{ String getName();
  int getSocialSecNumber(); }

role Student playedby StudentReq  // Student's powers
{ String getName();
  void takeExam(int examCode, HomeWork hwk);
  int getMark(int examCode); }

interface TeacherReq  // Teacher's requirements
{ String getName();
  int getSocialSecNumber();
  int getQualificationNumber();
  int read(HomeWork hwk); }

role Teacher playedby TeacherReq  // Teacher's powers
{ String getName();
  int evalHomeWork(HomeWork hwk); }
```

Fig. 1. Definition of roles and their requirements.

role instance with a player instance, to complete foundation. Finally, seeing an object under a role is paralleled with type casting in Java.

A. The definition of roles

The definition of a role has to specify both what is required to play the role and which powers the player have in the institution the role will be implemented. In order to make role systems reusable, it is necessary that a role is not played by a class only. For Steimann and Mayer [20], roles define a certain behavior or protocol demanded in a context independently of how or by whom this behavior is to be delivered (and, we add, roles also empowers the player in the context). Thus, roles must be specified independently of the particular classes playing the role, so that the objects which can play the role might be of different classes and can be developed independently of the implementation of the role. This is a form of polymorphism. In order to achieve such polymorphism we associate with a role descriptions of classes listing the signatures of the methods which are requested to and object in order to play a role. We, thus, have that a role definition must express, first, the methods required to objects playing the role: *requirements*. For the instances of a class to play a role, the class must offer some methods. These are specified by the role as an interface. Second, the methods offered to objects playing the role: *powers*. If an object of a class offering the requirements, plays the role, it is empowered with these new methods. The definition of a role using the keyword `role` is similar to the definition of an interface; it is the specification of the powers acquired by the role in the form of abstract methods signatures. The only difference is that the role definition by means of the keyword `playedby` refers also to another interface, that in turn specifies the requirements which an object playing the role must satisfy.

In Figure 1, the definitions of the roles `Student` and `Teacher` are introduced. The roles specify, like an interface, the signatures of the methods that correspond to the powers that are assigned to the objects playing the role. For example, returning the name of the `Student` (`getName`), submitting an homework as an examination (`takeExam`), and so forth. Moreover, we couple a role definition with the specification of its requirements by the keyword `playedby`. This specification is given by means of the name of a Java interface, e.g., `StudentReq`, imposing the presence of methods `getName` and `getSocialSecNum` (his social security number).

B. Institutions and definitional dependence

In [7], [5], [6] roles are always associated with an instance of, and are definitionally dependent on, an institution. Roles add powers to objects playing the roles. Power means the possibility to modify also the state of the institution which defines the role and the state of the other roles defined in the same institution. In our running example, we have that the method for taking an exam in the school must be able to modify the private state of the school. For example, if the exam is successful, the grade should be added to the registry of exams in the school by the teacher. Analogously, the student's method for taking an exam can invoke the teacher's method of evaluating an examination. Powers, thus, seems to violate the standard encapsulation principle, where the private variables are visible to the class they belong to only. However, here, the encapsulation principle is preserved: all roles of an institution depend on the definition of the institution; so it is the institution itself which gives to the roles access to its private fields and methods. Since it is the institution itself which defines its roles, there is no risk of abuse by part of the role of its access possibilities. Enabling a class to belong to the namespace of another class without requiring it to be defined as friend is achieved in Java by means of the inner class construct. Thus, we extend the notion of inner class to allow roles to be implemented inside an institution (the outer class). The inner class construct is extended with the keyword `realizes` which specifies the name of the role definition the inner class is implementing. An institution is simply a class with an inner class realizing roles in the very same way as a class implements an interface. In Figure 2, `StudentImpl` (`TeacherImpl`) realizes the role definition `Student` (`Teacher`), inside the institution `School`. Note that, a role (implementation) could itself be an institution with its own role implementations, it could enact other roles and, analogously, an institution could play a role. Moreover, roles can be implemented in different ways in the same institution.

Since the behavior of a role instance depends on the player of the role, in the method implementation, the player instance can be retrieved via a new reserved keyword: `that`. So this keyword refers to *that* object which is playing the role at issue, and it is used only in the role implementation. The value of `that` is initialized when the constructor of the role implementation is invoked. The referred object has the type defined by the role requirements or a subtype. We do not need a special expression for creating instances of the inner classes implementing roles, because we use the Java inner classes syntax: starting from an institution instance (or from a class name in case of static inner classes), the keyword `new` allows the creation of an instance of the role as an instance of the

```
class School {
  private int[][] marks;
  private Teacher[] teachers;
  private String schoolName;
  public School (String schoolName) {
    this.schoolName = schoolName;
    ...
  }

  class StudentImpl realizes Student {
    private int studentID;
    public int getStudentID() {
      return studentID;
    }
    public void takeExam(int examCode; HomeWork hwk) { }
      marks[studentID][examCode] =
        teachers[examCode].evalHomeWork(hwk);
    }
    public String getName() {
      return that.getName() +
        ", student at " + schoolName;
    }
  }

  class TeacherImpl realizes Teacher {
    private int teacherID;
    public int getTeacherID() { return teacherID; }
    public int evalHomeWork(HomeWork hwk) { ...
      mark = that.read(hwk); ...
      return mark;
    }
    public String getName() {
      return that.getName() + ", teacher at "
        + schoolName;
    }
  }
}

class Person implements StudentReq {
  private String name;
  private int socialSecNumber;
  public Person(String name, int socialSecNumber) {
    this.name = name;
    this.socialSecNumber = socialSecNumber; }
  public String getName() { return name; }
  public int getSocialSecNumber() {
     return socialSecNumber;
  }
}

class QualifiedPerson extends Person
    implements TeacherReq {
  private int qualificationNumber;
  public QualifiedPerson(String name,
      int socialSecNumber,
    int qualificationNumber) {
    super(name, socialSecNumber);
    this.qualificationNumber = qualificationNumber;
  }
  public int getQualificationNumber() {
    return qualificationNumber;
  }
  public int read(HomeWork hwk) { ... }
}
```

Fig. 2. Definition of an institution and its role implementations.

```
class TestRole {
  public static void main(String[] args) {
    Person  chris = new Person("Christine", 1234);
    Person  george =
      new QualifiedPerson("George", 5678, 9876);
    School  harvard = new School("Harvard");
    School  mit = new School("MIT");
    harvard.new StudentImpl(chris);
    harvard.new TeacherImpl(george);
    mit.new TeacherImpl(george);
    String x =
      ((harvard.StudentImpl) chris).getName();
    String y =
      ((harvard.TeacherImpl) george).getName();
    String z =
      ((Teacher)(mit.TeacherImpl) george).getName();
    ((harvard.StudentImpl) chris).takeExam(...,...);
  }
```

Fig. 3. Using roles.

inner class, e.g., `harvard.new StudentImpl(chris)` in Figure 3. Note that, all the constructors of role implementations have at least a (implicit) parameter which must be bound to the player of the role and become the value of `that`.

In order for an object to play a role it is sufficient that it conforms to the role requirements. Since the role requirements are a Java interface, it is sufficient that the class of the object implements the methods of such an interface. In Figure 2, the class `Person` can play the role `Student`, because it conforms to the interface `StudentReq` by implementing it.

C. Exercising the powers of a role

A role represents a perspective on an object. An object has different (or additional) properties when it is seen in the perspective of a certain role, and it can perform new activities, which we call powers, as specified by the role definition. In Steimann [18]'s terminology, a role is a type specifying behavior.

When an object is seen under the perspective of a role, we want that the object has a specific state for it. This state is different from the player's one, it is specific to each role in each institution, and it can evolve with time by invoking methods on the roles (or on other roles of the same institution as we have seen in the running example). This state is given by a role instance which is associated with the player. Since a role represents the perspective on an object, the object playing the role should be able to invoke the role's methods without any explicit reference to the instance of the role. In this way the association between the object instance and the role instance is transparent to the programmer. The object should only specify in which role it is invoking the method. For example, if a person is a student and a student can be asked to return its enrollment number, we want to be able to invoke the method on the person as a student without referring to the student role instance.

The same methods will have a different behavior according to the role which the object plays when they are invoked. On the other hand, methods of a role can exhibit different

behaviors according to whom is playing it. So a method of student returning the name of the student together with the name of the school returns different values for the name according to whom is playing the role of student. This is possible since the implementation of methods representing powers uses the methods required by the role to its player in order to play the role. These required methods obviously can access the state of the player since they are part of the implementation of the player.

Roles are always roles in an institution. Hence, an object can play at the same moment the same role more than once, albeit in different institutions. Instead, we do not consider the case of an object playing the same role more than once in the same institution. An object can play several roles in the same institution. In order to specify the role under which an object is referred, we evocatively use the same terminology used for casting by Java: we say that there is a casting from the object to the role. However, to refer to an object in a certain role, both the object and the institution where it plays the role must be specified. We call this methodology *role casting*. Type casting in Java allows to see the same object under different perspectives while maintaining the same structure and state. In contrast, role casting views an object as having a different state and different behaviors when playing different roles. So, the last syntactic change in powerJava is the introduction of *role casting expressions* extending the original Java syntax for casting. A role cast specifies both the role and the instance of the institution the role belongs to. For example, in `(harvard.TeacherImpl) george`, in Figure 3, the person `george` is casted to its role `harvard.TeacherImpl` of type `School.TeacherImpl`. It is important to observe that role casting is done to the inner class implementing the role but the role instance can always be type casted to the role as well as it can be done with Java interfaces: `((Teacher)(harvard.TeacherImpl) george).getName()`. While in the previous case it was possible to use all the methods of the specific implementation, in this case, only the methods that are specified in the role definition can be applied.

IV. Translating roles in Java

In this section we provide a translation of the role construct into Java. This is done by means of a precompilation phase, as, e.g., Guillen-Scholten *et al.* [11] propose for introducing components and channels in Java, or in the way inner classes are implemented in Java. The precompiler has been implemented by means of the tool javaCC, provided by Sun Microsystems [1]. The translation of the example is shown in Figures 4–7.

The role definition is simply an interface (see Figure 4) to be implemented by the inner class defining the role. So the role powers and its requirements form a pair of interfaces used to match the player of the role and the institution the role belongs to. The relation between the role interface and the requirement interface is used in the constructor of an inner class implementing a role. The requirement interface is used

```
interface Student {
  String getName();
  void takeExam(int examCode, HomeWork hwk);
  int getMark(int examCode);
}

interface Teacher {
  String getName();
  int evalHomeWork(HomeWork hwk);
}
```

Fig. 4. Translation of role definitions.

```
class School {
  private int[][] marks;
  private String schoolName;

  class StudentImpl implements Student {
    StudentReq that; // Added by the precompiler
    public StudentImpl (StudentReq that) {
      this.that = that;  // Added the by precompiler
      ((ObjectWithRoles)this.that).
         setRole(this, School.this);
    }
    // role's fields and methods ...
  }
  class TeacherImpl implements Teacher {
    TeacherReq that; // Added by the precompiler
    public TeacherImpl (TeacherReq that) {
      this.that = that;  // Added by the precompiler
      ((ObjectWithRoles)this.that).
         setRole(this, School.this);
    }
  }    // role's fields and methods ...
}   // institution's fields and methods ...
```

Fig. 5. Translation of an institution.

to constrain the creation of role instances relatively to players that conform to the requirements.

When an inner class implements a role (see Figure 5), the role specified by the `realizes` keyword is simply added to the interfaces implemented by the inner class. The correspondence between the player and the role object, represented by the construct `that`, is precompiled in a field called `that` of the inner class. If the inner class implements the role `Student` the variable is of type `StudentReq`. This field is automatically initialized by means of the constructors which are extended by the precompiler by adding a first parameter to pass the suitable value. The constructor adds to its player `that` also a reference to the role instance (by means of `setRole` method). The remaining link between the instance of the inner class and the outer class defining it is provided automatically by the language Java (`School.this` in our running example).

To play a role an object must be enriched by some methods and fields to maintain the correspondence with the different role instances it plays in the different institutions (see Figure 6). Since every object can play a role, it is worth noticing that the ideal solution would be that the `Object` class offered directly these features.

Every object can play many roles simultaneously. This is obtained by adding, at precompilation time, to every class a

```
interface ObjectWithRoles {
  public void setRole(Object pwr, Object inst);
  public Object getRole(Object inst, String pwr);
}

class Person implements StudentReq,
   TeacherReq, ObjectWithRoles {
  /** Added by the precompiler: BEGIN */
  private java.util.Hashtable roleslist =
    new java.util.Hashtable();
  public void setRole(Object pwr, Object inst) {
    roleslist.put(inst.hashCode() +
      pwr.getClass().getName(), pwr);
  }
  public Object getRole(Object inst, String pwr) {
    return roleslist.get(inst.hashCode() +
      inst.getClass().getName() + "$" + pwr);
  }
  /** Added by the precompiler: END */
  private String name;
  private int socialSecNumber;

  public String getName() {
    return name;
  }
  public int getSocialSecNumber() {
    return socialSecNumber;
  }
}
```

Fig. 6. Translation of players.

structure for book-keeping its role instances. This structure can be accessed by the methods whose signature is specified by the `ObjectWithRole` interface. The two methods that are introduced by the precompiler are `setRole` and `getRole` which respectively adds a role to an object specifying where the role is played and returns the role played in the institution passed as parameter. Further methods can be added for using single institutions, leaving a role, transferring it, *etc.*

We present one possible implementation of these methods which is supported by a private hashtable `rolelist`. As key in the hashtable we use the institution instance address and the name of the inner class. Role casting is precompiled using the `getRole` method. The expression referring to an object in its role (a `Person` as a `Teacher`, e.g., `(harvard.TeacherImpl) george`) is translated into the selector returning the reference to the inner class instance, representing the desired role with respect to the specified institution. The translation will be `george.getRole(harvard, "TeacherImpl")` (see Figure 7). The string `"TeacherImpl"`, that is the name of the inner class that implements the role inside the institution `School`, is provided because in our solution it is used as a part of the index and, therefore, it is necessary in order to retrieve the proper definition of the role.

Note that, the interfaces that implement the requirements of a role extend the interface `ObjectWithRoles` (see Figure 6. This interface requires that the players implement the methods for book-keeping their roles. Observe that if the Java `Object` class supplied these features, this extension would not be necessary.

```
Person chris = new Person("Christine");
Person george = new Person("George");
School harvard = new School("Harvard");
School mit = new School("MIT");
harvard.new StudentImpl(chris);
harvard.new TeacherImpl(george);
mit.new TeacherImpl(george);
String x = ((School.StudentImpl) chris.
  getRole(harvard, "StudentImpl")).getName());
String y = ((School.TeacherImpl) george.
  getRole(harvard, "TeacherImpl")).getName());
String z = ((Teacher)(School.TeacherImpl) george.
  getRole(mit, "TeacherImpl")).getName());
...
((School.StudentImpl) chris.
  getRole(harvard, "StudentImpl")).takeExam(...,...);
```

Fig. 7. Translation of the use of roles.

V. Conclusions and related work

In this paper we introduce a new view on roles in OO programming languages based on an ontological analysis of the notion of role. We introduce this model of roles in an extention of Java, called powerJava. Many works on the introduction of roles in programming languages [2], [9], [8], [16] consider roles as dynamic specializations of classes, e.g., a customer is seen as a specialization of the class person. This methodology does not capture the fact that a role like customer can be played both by a person and by an organization (that is not a person). Roles as specializations prevent realizing that a role is always associated not only with a player, but also to an institution, which defines it. This intuition sometimes emerges also in these frameworks: in [16] the authors say “a role is *visible* only within the scope of the specific application that created it”, but context are not first class citizens like institutions are in our model.

Some other works adopt a closer methodology: roles are seen as instances which are associated with objects. Wong *et al.* [22] introduce a parallel role class hierarchy connected by a “played-by” relationship to the object class hierarchy. However, they fail to capture the intuition that a role depends on the context defining it. Moreover, the method lookup as delegation they adopt has a troublesome implication: when a method is invoked on some object in one of its roles, the meaning of the method can change depending on all the other roles played by the object. This is not a desired feature in a language like Java.

In [13] it is recognized that a role depends on its player and that the properties of the role are present only due to the perspective the role is seen from. However, they consider roles as a form of specialization, albeit one distinguishing the role as an instance related to but separated from its player. As a consequence, the properties of the role include the properties inherited from its player. This idea conflits with our position, which we adopt from Steimann [21], of roles as interfaces: roles are partial descriptions of behavior, they shadow the other properties of their players, rather than inheriting them.

Our approach share the idea of gathering roles inside wider

entities with languages like Object Teams [12] and Caesar [15]. However, these languages emerge as refinements of *aspect oriented* languages aiming at resolving some of their practical limitations. Aspects fit our conceptual model as well: e.g., when the execution of methods gives raise, by advice weaving, to the execution of a method of a role, in our model this means that the actions of an object playing a role "count as" actions executed by the role itself. Finally, our notion of role, as a double-sided interface, bears some similarities with Traits [17] and Mixins. However, they are different as, with a few exceptions, e.g., [4], they are not used to extend instances, like roles do, but classes.

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