

On Context in Authorization Policy

Patrick McDaniel*
AT&T Labs – Research
Florham Park, NJ
pdmcdan@research.att.com

ABSTRACT

Authorization policy infrastructures are evolving with the complex environments that they support. However, the requirements and technologies supporting context are not yet well understood. Often implemented as condition functions or predefined attributes, context is used to more precisely control when and how policy is enforced. This paper considers context requirements and services in authorization policy. The properties and security requirements of context evaluation are classified. A key observation gleaned from this classification is the degree to which context functions share common properties. The Antigone Condition Framework (ACF) exploits these commonalities to provide a general purpose condition service and associated API. The prototype ACF design is presented and illustrated, and directions for future work considered.

General Terms

Security

Keywords

context, policy, authorization, security requirements, distributed systems, policy-oriented programming

Categories and Subject Descriptors

D.4.6 [Operating Systems]: Security and Protection

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1. INTRODUCTION

Authorization policy describes how access to protected resources is governed. Historically, policy has mapped tuples of identities and objects to collections of rights according to some system model [25]. Policies give the supported systems a road-map to operation, and allow administrators to develop a coherent strategy for protecting the environment.

Policy technologies have evolved in lock-step with the networks and environments they support. For example, novel access control models deal with the complexity of managing the large and fluid environments (e.g., RBAC [24]) or address the requirements of specific information models (e.g., lattice [2, 23]). Similarly, evolving policy infrastructures address widely distributed systems (e.g., KeyNote [5]) or arbitrate the policies of multiple end-points [16, 14]. These and many other works have served to increase the flexibility and ease with which access to protected resources is managed.

Context is increasingly used by policy infrastructures to allow environmental factors to influence how and when policy is enforced. When specified in an authorization policy, context defines the conditions that must (or must not) hold for the policy to be applied. For example, the following context definition (from [22]),

Token Type:	printer_load
Defining Authority:	local_manager
Value:	< 20%

defines context associated with a print queue. This context evaluates the status of a print queue by asking the `local_manager` if the print queue is less than 20% of its maximum capacity. Note that how this context is evaluated may be complex: an authority must be contacted (presumably using some secure means), and the result must be transformed (check whether the queue size less than 20%). A policy using this context might regulate print job submission based on this context. Hence, authorization policy (and indirectly context) is used to regulate the print queue length.

Context is modeled throughout as parameterized functions called *conditions*. Traditional conditions used in authorization policy simply poll local state variables (e.g., values recorded in the KeyNote action environment [7]). Recently, policy systems have begun to embrace more semantically rich conditions [18]. Such conditions can test the state of the environment, presence of qualified or authorized entities, or perform complex algorithms (e.g., query and interpret print queue length). However, existing implementations of these conditions are largely *ad hoc*: each new condition is typically hard coded in policy evaluating software.

This paper considers context requirements and services in authorization policy. We begin by classifying the use, properties, and security requirements of context evaluation. While context is

represented and obtained by contemporary policy infrastructures in vastly different ways, these classifications show that they all are defined along common dimensions. It is the identification of these dimensions that led to the design of the Antigone Condition Framework (ACF). Built within the existing Antigone/Ismene policy framework [17, 15], ACF provides a general purpose service and associated API used to integrate context into arbitrary policy infrastructures. We present and illustrate the ACF design, and conclude by considering directions for future work.

This work extends the traditional notion of policy conditions. Throughout, conditions are not seen as singular expressions over a fixed set of attributes, but viewed as general purpose programs. One key aspect of this extended view is the need for additional security infrastructure. Because the policy is driven by external forces, it is necessary to ensure that the means by which these forces are measured is consistent with local requirements (i.e., data is faithfully obtained from trusted sources). Condition security has largely been outside the scope of contemporary works in authorization policy, and is a central topic of this paper.

Our extended view of policy allows us to consider new ways of using context. *Policy-oriented programming* allows the issuers of policy to augment applications through policy specification. This is best illustrated by example. Consider an filesystem application spanning multiple clients. Assume the application is governed by a write-lock policy: no client can update a file unless it can get an exclusive lock on the file to be updated. Because the policy context implements the lock, the application need not be aware of them. Moreover, other policies will specify and implement entirely different filesystem semantics based on their use of policy. Because feature-enabling context is bound to the secure operations that govern the application, tight controls can be placed on the added functionality.

2. RELATED WORK

Many policy infrastructures do not explicitly support conditions. For example, the KeyNote system is a general purpose framework used to govern authorization policy. Signed policies, called credentials, define the conditions under which an authority grants access to a particular resource. KeyNote provides a flexible algebra for specifying logical condition expressions over string and numeric *attributes*. Each attribute value is known prior to the evaluation of policy. Hence, because the value is fixed before **any** policy is considered, there is no opportunity for policy to defer to external evaluation.¹ The Akenti system [26] also assumes attribute values are known prior to policy evaluation (Akenti’s authors indicate that run-time evaluated conditions are also on the horizon). Conditions are encoded in Akenti through *Use Certificates*. These certificates are similar in form and function to condition expressions of KeyNote, but are restricted to the vocabulary of the domain in which they exist.

Some approaches simplify evaluation by fixing the set of conditions available to policy. Both the MSME [21] and the Security Policy System (SPS) [30] limit conditions to only those needed by each target domain. In the case of SPS (which governs IPsec communication), ports and end-points largely dictate where access is granted. Because SPS is built on the more the general IETF Policy Framework [19], SPS can be extended to include run-time conditions. MSME similarly can support externally evaluated con-

¹The authors of the KeyNote system have considered extending this model to include *active attributes* [12]. These attributes would call external function (code) at the time a condition expression is evaluated.

ditions through the extension of the evaluation infrastructure. Note that because these systems assume policy conforms to a predefined schema, all conditions must be known *a priori*. Run-time conditions are supported by fixing the kinds of conditions that policy may use, rather than fixing values before evaluation (as seen in the systems above). Because support for each condition can be built directly into the enforcement infrastructure, no general condition framework is necessary.

Anticipating all possible conditions is not feasible in general purpose policy. In response to this, the Generic Authorization and Access-control API [22] (GAA-API) supports externally defined context functions. In GAA-API, conditions are arbitrary functions defined by their type, name, and governing authority. Conversely, the Ismene system [16] assumes very little. Ismene policies do not identify which authority, if any, should govern the evaluation process. Both of the systems leave the vast majority of condition evaluation to the supporting implementation. Each system provides an *upcall* interface, but neither mandates how security requirements are identified or addressed.

The OASIS system implements RBAC authorization and access control policy [1, 11]. OASIS role activation and service use are governed by policy expressions. These expressions define context that must be true at activation or access time. These contexts can further mandate that the context be sustained: the condition being measured must remain true while the role is activated or the action is being performed. If at any time the condition becomes false, the activator or service is notified via an event channel. Frameworks like OASIS are likely to benefit from the Antigone condition framework. However, sustained context will require infrastructure not available in the current implementation. For example, one implementation may poll and monitor the context implementation for state changes.

It is interesting to note that possibly the most flexible policy language, PolicyMaker, does not explicitly support externally evaluated conditions. PolicyMaker views policy, called filters, as having “the full complexity and expressiveness of general programs” [6]. Blaze continues by stating that, “There is no need [for the PolicyMaker policy infrastructure] to open files or interact with the network.” This paper seeks to extend the PolicyMaker model by deferring complex run-time operations to externally evaluated conditions. The remainder of this paper considers the properties, requirements, and implementation of such conditions.

3. POLICY AND CONTEXT

Policy infrastructures evaluate and enforce policy. Note that a single policy infrastructure may be used to govern many services and applications. For example, Blaze et. al. describe an infrastructure used to implement IPsec Policy [8]. The approach integrates KeyNote [5] (policy evaluation platform) with an OpenBSD implementation of IPsec (enforcement platform). We refer to the combination of a policy decision point (PDP) and policy enforcement point (PEP) as the policy infrastructure. Note that this does not mandate that both services coexist within the same host.

A generic condition environment is depicted in Figure 1. The policy infrastructure evaluates policy in response to some attempted action. A condition used by the policy is evaluated by the infrastructure by extracting state (possibly through a parameterized function) from a local or remote *condition source*. This state may be interpreted or transformed by the policy infrastructure to arrive at a condition result. An *adversary* attempts to alter the condition result by manipulating the environment (e.g., by altering messages passed between the source and PDP).

Conditions are simply functions used to measure context. Every condition is a function of zero or more arguments (a_1, a_2, \dots, a_n). Each parameter is a static or variable value (i.e., identified by the policy infrastructure at run-time). Throughout, it is assumed that all conditions return Boolean values (i.e., *true* or *false*). Non-Boolean conditions (i.e., functions with continuous or discrete output) can lead to complex policy evaluation in both the intuitive and complexity-theoretic sense. However, it is expected that the evaluation of non-binary conditions would not be qualitatively different than the procedures defined throughout.

Note that policy may require a Boolean result be further qualified. For example, where the result is positive, additional information can be provided (e.g., specify further provisioning requirements). Where the result is negative, providing details of why the condition returned false may be useful (e.g., condition failed because missing credential). The PolicyMaker system supports the inclusion of additional context by supporting annotations [6].² Support for such features would represent simple extensions to ACF. For ease of exposition, exploration of annotations is deferred to future work.

Conditions are mostly frequently used to construct policy rules. Each such rule represents a logical expression of conditions and Boolean operators. Subject to rule processing discipline (e.g., rule ordering), the policy rule is applied where the condition expression evaluates to true. For example, traditional firewall rules follow this model:

```
SRC=192.168.7.8:22,DST=192.168.7.27:* → accept
```

All traffic that satisfies the preceding rule's condition expression (i.e., where source address/port, and destination address are equal to the identified values) should be allowed pass through the firewall. Other policies languages generally work analogously, where the form of policy, the semantics of the expressions, and the range of supported conditions may differ. Other works have focused on issues of form and semantics, but have largely ignored supporting conditions. This paper is devoted to this last aspect of policy: *what kinds of conditions are needed, how are they implemented, and how do we make them secure.*

3.1 Condition Properties

Conditions are defined by their evaluation algorithm. Each such algorithm can be classified by the kinds of information it acquires, how it is acquired, and how the information is ultimately used. Gleaned from the collection of conditions used by the Ismene test-bed applications [14], the following properties characterize these algorithms:

- *local/remote* - As seen in traditional policy systems, local conditions are evaluated without any external input. For example, an condition *hostname(bob)* tests whether the local hostname is "bob". Clearly, this does not need external information, and can be evaluated through locally configured values.
- *data/computation* - Data driven conditions simply test the existence or value of some known state variable. Conversely, computation-driven conditions implement (sometimes complex) algorithms for computing results. For example, the *valueEquals(a,b)* condition tests whether the values *a* and *b* are equal. Conversely, the condition *sumGreaterZero(a,b)*

²These annotations are not strictly supported by the condition evaluation, but rather are added when a condition equation evaluates to *true*.

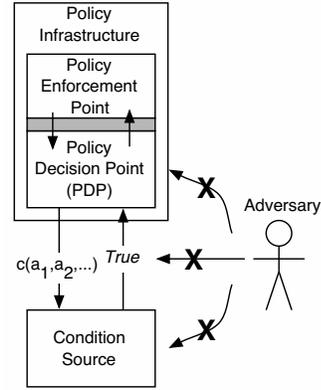


Figure 1: Condition Evaluation - policy infrastructures extract information from (internal or external) condition sources via parameterized functions. This information is used to determine how policy is enforced by the Policy Enforcement Point (PEP). An adversary may attempt to influence policy by manipulating the PEP, the PDP, or the condition source.

performs a computation on the parameters and tests the result. This distinction becomes interesting when the computation becomes complex, e.g., where multiple data sources must participate in the computation.

- *stateful* - Stateful conditions modify (rather than just access) state during evaluation. That is, the act of evaluation modifies some local or distributed state. This is useful where the access is *consumptive*. For example, some digital rights systems use an access counter to restrict the number of times an object is used. The stateful *accessCounter(id,threshold)* condition would test to see if the counter has remaining accesses, and if so increment the associated counter.

A related property is *idempotence*. Idempotence ensures that the same evaluation returns the same value no matter how many times it is called. One can think of data driven conditions as being idempotent: the act of obtaining the value has no effect on the value itself. Note that external factors may alter the underlying value (e.g., changing network conditions). Because the act of evaluating the condition does not affect the value, it is idempotent.

- *synchronous/asynchronous* - synchronous conditions are evaluated at the point at which the policy infrastructure requests it. Conversely, asynchronous conditions cannot be evaluated immediately. The policy infrastructure is free to proceed with other tasks while an asynchronous evaluation completes. Like many aspects of policy, the semantics of an asynchronous evaluation is subject to interpretation. One could be optimistic and allow access on the assumption that the evaluation return a positive result (and revoke access later if it proves not to be so), or pessimistic and delay or prevent access until the evaluation completes.

isDNSAuthority(dom,svr) is an example of an asynchronous condition. This condition tests whether the server *svr* is authoritative for the DNS domain *dom* as acquired from the distributed *whois* service. Because it would be highly undesirable to block until the *whois* lookup is completed (this could take seconds), would be advantageous to allow the condition to complete asynchronously.

Clearly, these categories are not mutually exclusive nor exhaustive. For example, a condition may use the result of stateful acquisition of remote values that are used as input to computation. Section 4 considers the degree to which the condition definition (as classified along these dimensions) dictates the ways the condition, and ultimately the policy, can be evaluated.

The semantics of a condition are often subtle. For example, consider a condition *timebetween(9am,5pm)*. How a particular policy infrastructure views time is largely defined by its security requirements. Where the policy only needs a local (and potentially insecure) timing source, the condition could be evaluated locally. If, however, the timing needed to be synchronized and secure across multiple enforcement points, it would have to be acquired from an external timing source. Note that because the desired semantics may differ from environment to environment, support for both conditions may be required (e.g., *localtime* and *networktime*).

3.2 Condition Security

Condition security is really a matter of environmental interpretation: each environment will place a unique set of requirements on the source and methods of condition evaluation. This is best illustrated by example. Consider the *timebetween()* condition as used in two application environments, a multiplayer game and an online trading application.

In this example, it is assumed that users in the multiplayer game are restricted to particular times defined by policy. Hence, in addition to testing the appropriate credentials, the authorization policy would test to see that user is allowed to participate at the current time. Conversely, *timebetween* is used in the trading application to ensure that every transaction occurs during normal trading hours (e.g., 9am-5pm).

Now consider the security requirements of each of these environments. In the online game, it is likely that the only requirement is for authenticity (i.e., to prevent the player from forging timing information and gaining access during restricted times). The same condition will have much stronger security requirements in the trading application. To protect all participants, the trading application will require some after-the-fact evidence that the transaction occurred at a normal time (non-repudiability). Moreover, existence of a transaction (and not necessarily its contents) may be deemed sensitive. Hence, the evaluator may require anonymity and/or confidentiality.

Note that many sources of condition information (the timing source in the previous example) will have their own *authorization policy*. Hence, where complex conditions are employed, it is important to consider how these policies are defined and used. Such organization can lead to recursive policy evaluation. We see the evaluation of the interaction between condition evaluation infrastructure and the supported policy systems as a key area of future investigation.

A essential feature of any general-purpose condition framework is flexible support for a large number of security requirements. This work serves as a starting point for just such a service. However, as seen in Section 5, one cannot anticipate all possible security requirements.

The condition schema defined in Section 4.1 is designed to specify the security requirements/properties listed below. These properties came about from a study of the conditions used by the AMirD multiparty file-system mirroring service and other applications [14]. While we acknowledge that many other properties and definitions exist, we argue that these are suitably representative to develop an understanding of condition security.

- *confidentiality* - An adversary must not be able to ascertain the condition or parameters being evaluated. Generally, this

requires that the content of communication be made inaccessible (e.g., via encryption).

- *integrity* - The adversary must not be able to alter the results of an evaluation. This implies that the parameters and results be faithfully transferred between the evaluator and the condition source.
- *authenticity* - The evaluator must be able to ascertain the origin of the evaluation result. If the source of condition evaluation is not authentic, the policy infrastructure is subject to manipulation. For example, either as a man-in-the-middle or by masquerading as the source, an adversary could intercept and alter results to allow itself or cohorts access. Moreover, the adversary could mount a denial of service by blocking access to the condition sources that indirectly govern sensitive resources and actions. 1
- *non-repudiability* - A condition source must not be able to claim that it did not assert a returned result. This is important where access to highly valued resources are being governed by authorization policy. For example, the trading example above will accept or reject transactions based on the evaluation result received from the timing source. Because this acceptance or rejection may have serious legal or financial ramifications, some evidence of the correct evaluation is necessary. Should a dispute arise, the trading service (application) must demonstrate that it correctly evaluated policy. Assuming non-repudiability is provided, a timing source that asserts an incorrect time cannot later deny having done so, and hence would be culpable.³
- *anonymity* - The identity of the evaluator should not be known by the source. Moreover, an adversary on the network should not be able to reasonably ascertain the existence of the evaluation or identity of the evaluator or source.

Note that in some instances, achieving anonymity is difficult (more than simply encrypting communication). Again consider the *timebetween()* condition. If a well known timing source is used, the existence of communication between the evaluator and the timing source may expose the evaluation, i.e., condition evaluation is the only reason that the evaluator would communicate with the timing source.

While these properties primarily address security requirements of remote evaluation, they also may be important in local environments. For example, any system may wish to prevent an adversary from manipulating locally stored system state.

3.3 Evaluation

Conditions are often characterized simply as functions. Each condition maps a set of simple inputs onto a set of simple outputs. However, such characterizations make a number of assumptions about the behavior of condition evaluation. The condition is assumed to have valid input that is always available (one can think of persistent state as input). The abstraction of function fails to capture the fact that conditions are not always mathematical operations, but must be sensitive to the constantly evolving environment in which they exist.

A more useful characterization of a condition is as a *program*. This extended view embraces the dynamicity of the environment:

³The above description simplifies secure transaction timing. In practice, the transaction itself must be tied to the timing information (in some cryptographically strong way).

conditions can fail because of insufficient or unavailable resources, have invalid input, or simply take too long to evaluate. This view of condition places additional requirements on the authorization policy infrastructure. That is, the infrastructure must accept and carefully consider how authorization policy is evaluated in the presence of such failures. Blanket policies such as “treat every failure as a negative response” may provide a means by which an adversary can manipulate policy evaluation. These meta-policies are often a function of the semantics of the policy language, and are not necessarily defined by the policy infrastructure.

A perfectly implemented application can be co-opted by a poorly implemented condition. For example, consider the trading example in the preceding section. Assume that every transaction is governed by a policy that uses the *timebetween()* condition. Any adversary that wishes to prevent transactions from occurring can DOS the timing source. This vulnerability is not a function of the trading application, but is a function of the policy that governs it.⁴ Such dependencies can be overlooked (or be unknown) at the time applications are built. Hence, it is incumbent upon the developers of the condition implementations to anticipate and address the needs of the target applications.

Policy infrastructures are increasingly allowing applications to provide the conditions upon which policy decisions are made. Systems like Antigone [17] and the Generic Authorization and Access-control API (GAA-API) [22] provide generic *upcall* interfaces to which condition implementations are built. Applications register at compile or run-time the set of conditions to be supported by the application. The policy infrastructure passes the relevant state through the upcalls. The condition specific code is executed and results returned to the policy infrastructure. Because these upcalls are essentially programs, they are free to implement a wide range of functions.

The following considers broad classes of condition implementations. These design patterns are a reflection of the conditions implemented by a range of relevant policy works.

Condition function - conditions of this type are simply computable functions. Often using state that is internal to the application, these conditions simply test some property of the environment. For example, consider the ubiquitous condition *username(name)*. This condition tests whether the local identity name is equal to the parameter string. Such conditions are encoded, for example in KeyNote, as programmatic equations, e.g.

```
(username == "bob")
```

The key aspect of these conditions is that they can be implemented directly in the application or the policy infrastructure. This pattern is representative of the vast majority of conditions seen in extant policy systems.

Local evaluation - locally enforced conditions perform some evaluation function by extracting and manipulating state on the local host, but external to the process address space. The distinction between local evaluation and condition function is useful because process external information is subject to external forces. Unseen adversaries can manipulate local resources and state (i.e., modify the */etc/passwd* file on a UNIX system). Hence, the threat models appropriate for the condition classes are fundamentally different. Moreover, depending on the nature of the condition, the

⁴Additional systems engineering (e.g., redundancy) of the condition evaluation infrastructure is the only means by which these issues can be dealt with. In this case, alternate timing sources can be used to mitigate this attack.

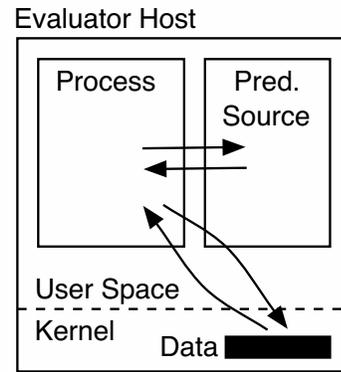


Figure 2: Local Evaluation - The condition is implemented by a call to some local host service. This information can be accessed using local services (e.g., via IPC) or by extracting information directly from the kernel (e.g., via system call).

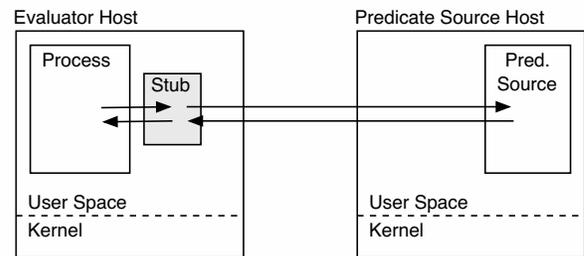


Figure 3: remote method invocation - The condition is implemented as a call to remote function. Existing mechanisms (e.g., RPC, CORBA) provide functional semantics, and can readily be used to implement policy conditions.

ways in which conditions are implemented are likely to be very different.

Depicted in Figure 2, each condition extracts state from the local environment. In the case where state is held or computed by a local service (e.g., monitor process), some IPC mechanism is necessary. The means and format of such communication is dependent on the service and semantics of the condition. Other mechanisms allow state to be retrieved from the operating system itself (e.g., via system call).

systemload(service,thresh) is an often used local condition. This condition tests whether a threshold load on some system service has been reached. As such, it can be used as a form of admission control in authorization policy: access is granted only where the system has sufficient resources to support it. This is often implemented by polling a monitoring process or directly extracting it from the kernel via system call.

Remote method invocation - these conditions simply poll external services. One can view these condition implementations as traditional remote procedure calls [4]. Figure 3 illustrates the common RMI condition design. The condition marshals and transmits input parameters to a remote service through a *stub* function, and receives and unmarshals the results. Frameworks supporting this design are common in contemporary distributed systems (e.g., CORBA [27], SOAP [9], Java RMI [10]). A key advantage of using these frameworks is that they often implement their own security infrastruc-

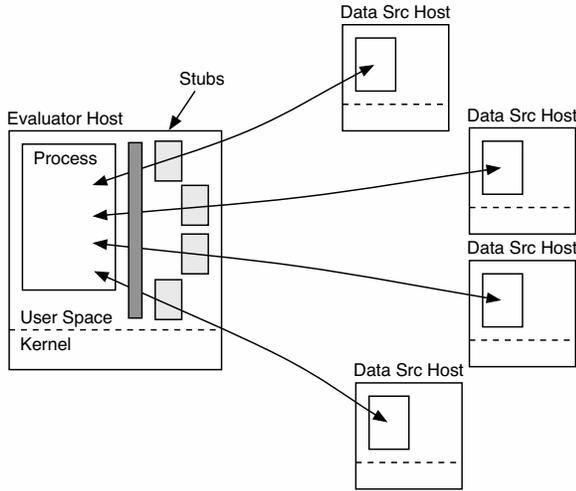


Figure 4: complex condition evaluation - Each condition is implemented by some distributed algorithm or protocol. These conditions are frequently designed to support specific authorization policy needed to govern the target application.

ture. The security requirements of RMI methods are very different from previous designs (i.e., remote vs. local threats).

While the preceding discussions have implied that it is the remote entities that “perform” condition evaluation, this is not necessarily the case. In practice, conditions may poll externally available interfaces to acquire the information needed to perform evaluation. This information is manipulated in some way to implement the condition semantics. The distinction here is that the remote service being polled need not necessarily be aware it is part of an evaluation process. This is best illustrated by example.

Consider yet again the *timebetween(start,end)* condition. In practice, the condition is most likely implemented by polling a remote timing source. The timing source simply returns the current time. The receiving stub will translate the current time into a result, i.e., determining if the current time is between *start* and *end*. Because time is returned, the same service can be used to implement any number of conditions (e.g., *isWeekday()*).

complex condition - conditions often require implementations that are hybrids of local, remote, and functional conditions. Such implementations can represent more extensive programs which may involve interactive protocols between many end-points. Depicted in Figure 4, the conditions can be presented to the policy infrastructure as a single stub function. However, beneath this simple veneer lies complex logic which coordinates the data and protocols needed to evaluate the condition. Note that it may be possible for an implementation to be (at least partially) constructed from more basic conditions. This is similar in philosophy to the component systems [3], and is illustrated in the following example.

A lock algorithm is a good example of a complex condition. Consider a condition *hasLock(lock-id)*, where *lock-id* is some lock passed between a number of peers. The condition returns *true* where the local host currently has or is able to obtain the lock *lock-id*. An implementation of the condition initially tests the local environment to see if it already has the lock (e.g., through, for example, a local or condition function *hasLockLocal(lock-id)*). If not, it will attempt to acquire the lock by performing a distributed computation (and possibly talking to every other peer in the system). If the

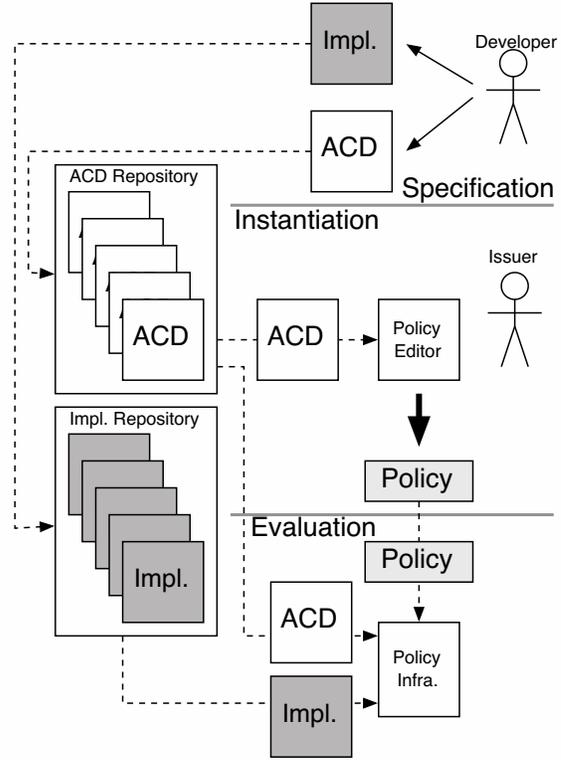


Figure 5: Condition Life-cycle - conditions are specified in Antigone Condition Documents (ACD) and implemented during condition *specification*. The ACD is subsequently used to validate issued policy (during *instantiation*), and ultimately to direct the use of the condition (during *policy evaluation*).

lock protocol is successful (in the sense that the local entity obtains the lock), then the condition returns true.

4. CONDITION FRAMEWORK

A key observation gleaned from the classification presented in the preceding section is the degree to which conditions share common properties. We exploit these commonalities in designing a general purpose condition service and associated API. The Antigone Condition Framework (ACF) specifies and directs the use of conditions through common artifacts and processes. The remainder of this section considers in detail the design and use of this framework and concludes with a discussion of the advantages, limitations, and opportunities afforded by its architecture.

ACF supports the creation and evaluation of policy conditions. Depicted in figure 5, the life-cycle of a condition in ACF is defined by three central processes: condition *specification*, *instantiation*, and *evaluation*. Initially, infrastructure developers define the sets of conditions that are made available to the policy issuers. This includes the creation of an implementation as well as *specifying* a defining Antigone Condition Document (ACD). This document is used to detect incorrect usage when the policy is issued (*instantiation*). The condition is *evaluated* when it is used to make policy decisions.

The ACF is policy agnostic: that is, any policy language is free to use conditions built within this framework. However, the policy infrastructures often must modify the evaluation process to embrace run-time condition evaluation.

```

<!DOCTYPE condition [
<!-- General Section -->
<!ELEMENT condition ( name, version,
                      secpolicy?, parameter* )>
  <!ATTLIST mode (synch|asynch) "synch">
<!ELEMENT name (#PCDATA)>
<!ELEMENT version (#PCDATA)>
<!ELEMENT implref (#PCDATA)>

<!-- Security Policy Section -->
<!ELEMENT secpolicy (service,authority*)>
  <!ATTLIST secpolicy confidentiality (T|F) "T">
  <!ATTLIST secpolicy integrity (T|F) "T">
  <!ATTLIST secpolicy authenticity (T|F) "T">
  <!ATTLIST secpolicy nonrepudiation (T|F) "F">
  <!ATTLIST secpolicy anonymity (T|F) "F">

<!ELEMENT service (#PCDATA)>
<!ELEMENT authority (name?,encoding,credential)>
<!ELEMENT encoding (#PCDATA)>

<!-- Parameters Section -->
<!ELEMENT parameter ( order, const,
                     value, encoding? )>
  <!ATTLIST parameter ( string | boolean |
                       float | integer |
                       encoded ) #REQUIRED>
  <!ATTLIST const type (T|F) #REQUIRED>
<!ELEMENT order (integer)>
<!ELEMENT value (#PCDATA)>
<!ELEMENT encoding (#PCDATA)>

<!-- Base Types -->
<!ELEMENT integer (#PCDATA)>
]

```

Figure 6: Antigone Condition Document DTD - an ACD defines the basic condition type, a security policy, and a set of expected parameters. This information is used at policy issuance and evaluation to ensure correct condition usage, as well as provide a roadmap for execution.

An initial version of ACF is under construction. As is true of any large framework, any number of issues will emerge as the implementation matures. For this reason, this section centrally focuses on the means and use of ACF interfaces. We plan to complete the construction and report on performance and usability issues in the future.

4.1 Specification

A condition is *specified* by creating an implementation and an associated ACD. The ACD defines how a policy must communicate with this implementation. The ACD is simply a XML document conforming to the ACD document type definition (DTD). Presented in Figure 6, this DTD is comprised of three main sections, a general section, a security policy, and the parameters section.

The general section specifies the high level attributes of the condition. This includes a definition of the name and version information, as well as its mode of operation. The *mode* determines whether the condition is synchronous or asynchronous (see Section 3.1), and the *implref* field identifies the implementation (see Implementing Conditions 4.4 below).

The security policy identifies the security requirements that are relevant to the condition. The requirements are represented through a set of flags indicating what specific properties are of interest. The service element is an opaque string used to identify which security infrastructure should be used to implement security (e.g., IPsec). Finally, the set of authorities used to perform evaluation, if any, are encoded as indicated by the element definition. Note that the secu-

```

<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE note SYSTEM "acd.dtd">

<condition mode="asynch">

  <!-- Security Policy -->
  <name>hasToken</name>
  <version>1.0</version>
  <implref>libhtok.1.0.so</implref>

  <!-- Security Policy -->
  <secpolicy confidentiality="T"
    integrity="T"
    authenticity="T"
    nonrepudiation="F"
    anonymity="F">
    <!-- Note that run-time policy evaluation
         will insert authorities -->
  </secpolicy>

  <!-- Parameter List -->

  <!-- Token ID -->
  <parameter type="string" const="T">
    <order>1</order>
  </parameter>

  <!-- Token Authority Certificate -->
  <parameter type="encoded" const="F">
    <order>2</order>
    <value></value>
    <encoding>PKCS#12</encoding>
  </parameter>

  <!-- Wait Time -->
  <parameter type="integer" const="T">
    <order>3</order>
    <value>60</value>
  </parameter>

</condition>

```

Figure 7: Example ACD - the *hasToken* condition attempts to acquire a named token from the authority identified in the parameter list.

rity policy is optional (e.g., condition functions that do not access external data have no need for security policy).

Finally, the parameter section defines the expected input. This includes the obligatory ordering and type enumeration, as well as constant and encoding definitions. The *const* element indicates whether the input value is fixed by policy definition or asserted at run-time (e.g., like KeyNote attributes). Where the type is not atomic, encoded forms are supported (e.g., PKCS#12 encoded certificates).

An ACD is created by partially instantiating the objects defined in the DTD. For example, Figure 7 presents an ACD for a *hasToken* condition. This condition takes three arguments, a token identifier, a certificate, and a wait timer. The corresponding implementation attempts to acquire a token associated with the identifier from a service defined in the certificate. If a response is received prior within the wait time (seconds), *true* is returned if the token is acquired, and *false* otherwise. The condition fails if no response is received in the allotted time.

4.2 Instantiation

A policy editor is an application used to issue policy [28]. Such editors are responsible for validating that the policy is consistent with the policy representation, and is self consistent (e.g., is enforceable [15]). For example, consider the following call to the *hasToken()* included as part of a larger Ismene policy:

```
hasToken(tigertoken, $cert)
```

A policy editor making use of the ACF would begin by looking up the ACD for *hasToken()* (defined in Figure 7). The ACD indicates the three parameters are used. The first parameter is a string constant defined by the policy. The *tigertoken* string fulfills that definition and the parameter is accepted as valid. The second parameter is marked as a run-time attribute (i.e., `const="F"`). Because the second parameter is marked as a run-time (`'$'`-symbols indicate attribute replacement in Ismene), the second parameter is accepted. One might assume that because definition is missing the last argument that the condition would be rejected. However, because the ACD defines a default value for the last parameter (i.e., in the value element), it is automatically inserted. Because all parameters are consistent with the definition, the condition is deemed correct.

In practice, policy editors will use libraries of ACDs to interpret and verify issued policy. It is incumbent upon the administrators to provide ACDs for all of relevant conditions. For example, an LDAP directory [29] of ACDs XML documents could be maintained by the policy issuers. The design and maintenance of these repositories is outside the scope of the current work.

4.3 Evaluation

The policy infrastructure calls the `ACF_evaluate` function to execute the evaluation process. This call (and the ACF-specific return enumerate type) are defined:

```
typedef enum { ACF_false = 0,
              ACF_true  = 1,
              ACF_fail  = 2,
              ACF_asynch = 3
            } ACF_result;

ACF_result
ACF_evaluate( char *func, int argv,
             char *argc, void *context );
```

Note that all parameters are passed as null terminated strings (as in standard C programming `argc/argv` style). Parameters such as credentials must be encoded prior being passed to the ADF framework (e.g., PKCS#12 encoding of certificates). This has the advantage that the policy infrastructure need not be share domain specific structures (e.g., internal representations of Kerberos tickets). Where necessary, the ACD specifies the expected encoding scheme in the `encoding` field of the parameter element.

The evaluate function returns one four return values. `ACF_true` or `ACF_false` are returned where the condition successfully evaluates to *true* or *false*, respectively. `ACF_fail` is returned when the condition cannot be successfully evaluated. The policy infrastructure must decide how to handle these errors. `ACF_asynch` is returned whenever the called condition is asynchronous.

Asynchronous conditions are handled by threads created during the initial evaluation call. The policy infrastructure registers an opaque `context` object with the ACF through the evaluation call. When the evaluation is completed, the framework signals the completion of the evaluation via a callback to the policy infrastructure. The callback supplies a return value (i.e., true, false, fail) and the originally registered context object. The policy infrastructure maps the context object back onto the suspended operation.

The evaluate function initially acquires the ACD associated with the `func` parameter from a ACD repository. The parameters are validated as in the instantiation (with the exception that all non-const values are now instantiated). A new ACD with the new parameters values is created. The registered implementation is called with a single argument, the ACD.

4.4 Implementing Conditions

Conditions are implemented as threads. Each such thread accepts the singular ACD object, and interprets the parameters accordingly. A number of utility functions are being created to ease the process of condition creation (e.g., parameter extraction, credential decoding). What the condition does and how it does it is entirely up to the developer.

The ACF does not provide a specific security infrastructure: all details of how the security policy is enforced is left to the condition implementation. The reasoning for this decision is simple: we cannot possibly anticipate all the possible infrastructures and approaches to providing security.⁵ Hence, we defer issues to the implementation. It is important note that does not mean that condition security is fixed service. Inasmuch is possible, each implementation should be able to deal with the the security policies communicated by ACDs. This adds additional flexibility, where the particular environment can dictate the security needs by modifying the ACD, rather than the implementation.

An interesting question arises when a security policy is received by a condition that it cannot implement. For example, consider a *timebetween(9am,5pm)* condition that obtains a timestamp via SSL. Now assume that the condition receives an ACD that defines a security policy requiring non-repudiability. Because SSL does not provide non-repudiability, the condition must return `ACF_fail`. However, it would be advantageous to indicate to a policy issuer what a particular condition implements (so such problems can be avoided before a policy is issued). This information could be used by the policy editor to further validate a policy prior to issuance. We are current looking at ways to extend the ACD DTD to include an *implements* section of the security policy definition to provide this information.

Many conditions are implemented as external programs or require external interpreters (i.e., shell scripts [6]). ACF supports these implementation by creating a thread that, after extracting the parameter values, simply forks the appropriate process and sleeps until that process terminates.

One of the central issues associated with implementations is the means by which they are loaded. Requiring that ACF be linked against every possible condition implementation is problematic. Firstly, this would require that every condition be known *a priori*, which is exactly the kind of assumption ACF is designed to avoid. Secondly, even if one knew (and could acquire) beforehand the implementations of every condition, the resulting executable would be huge. Finally, this requires that the ACF be rebuilt every time a new condition is introduced.

For all of these reasons, we determined that it is imperative that condition implementation be *dynamically loadable*. To accomplish this, ACF is being built with a condition loader facility. This uses the UNIX dynamic load functions [20] (e.g., `dlopen`, `dlsym`) to open and read local libraries. Each condition implementation is provided in a shared library whose name is specified in the *implref* element of the ACD. The library exports a single condition function that receives the instantiated ACD as its only parameter.

We intend to investigate more flexible condition distribution methods in the future. For example, the ACF could download implementation from an authenticated repository when a local copy is not available. However, such methods must be carefully designed to avoid introducing new vulnerabilities (e.g., possibility of DoS).

⁵We expect to explore standard security services as more experience with the framework is garnered.

5. DISCUSSION

The ability to integrate complex and distributed condition evaluation within authorization policy opens the door to new uses of policy. For example, consider the *hasToken* condition in the previous section. Applications which are regulated by this condition automatically implement token-based operation. Hence, authorization policy can define application behavior through condition evaluation. This *policy-oriented programming* enables application features to be transparently added through the use of context.

Aspect-oriented programming [13] seeks to implement high-level features through object technologies (e.g., inheritance). Policy-oriented programming differs not only in approach, but by whom and when application behavior is defined and augmented. Policy approaches allow domain administrators (issuers), rather than developers to decide which features an application will implement. Judicious use of conditions allow the developer to clearly specify how, when, and by whom these features are used. Moreover, policy based programming occurs at a finer-grain: features are applied to individual actions, rather than on the application as a whole.

State maintenance in condition evaluation can complicate policy. For example, consider an authorization policy rule representing the conjunction of two stateful conditions *hasToken(a)* and *hasToken(b)*. Now assume in a particular evaluation, an evaluator obtains the a lock, but not b. The operation would be rejected. The evaluator would hold the lock a but not perform the associated action (which we assume releases the lock). Moreover, if another evaluator obtained the lock b, but could not obtain a, a deadlock would occur.

Ryutov and Neuman [22] address the state maintenance problem by introducing *pre-*, *mid-*, and *post-conditions*. These conditions essentially identify the operations that must occur at different phases of the action. Hence, the underlying code can manipulate state as is necessary for the application. We are currently looking at a condition-centric version of this approach. The modified approach informs condition implementations that the action/rule to which they are attached was rejected, failed, or completed successfully. Each implementation is expected to perform the appropriate processing based on the result information.

While this work has discussed the security needs of condition evaluation, the infrastructure described in the preceding section does not indicate how these needs are addressed. The reason for this is two-fold. Firstly, building a security infrastructure that meets the needs of all possible environments is impossible. Hence, specifying specific technologies (e.g., PKI, AES) is inherently limiting. For this work, we have chosen to focus on the interfaces and definition of conditions, rather than their implementation.

Secondly, security requirements often can only be met through integration with existing security services. One illustrative application is a shopping application. An authorization policy governing the purchase action would indicate that the credit card purchase must be accepted by the Secure Electronic Transactions (SET) protocol. Because it is unlikely that any general purpose infrastructure will implement SET, it must be implemented within the condition (or application). Because many such dependencies exist in real applications, attempting to construct a single framework that addresses all conditions is not realistic.

6. CONCLUSIONS

In this paper, we have considered traditional and extended views of policy conditions. In its extended form, we view conditions as programs, rather than as expressions defined over a fixed set of attributes (as one would see in contemporary policy systems).

However, we must acknowledge the additional security and infrastructure requirements that this view introduces. Our taxonomies of condition type, evaluation method, and security requirements show that conditions are largely defined along similar axes. Because conditions share similar properties, we can contemplate general-purpose facilities.

We have presented the design of the novel Antigone Condition Framework (ACF). This framework implements a general-purpose condition specification, implementation, and evaluation service. In ACF, conditions are defined by XML Antigone Condition Documents (ACD) and implemented by dynamically loaded libraries. At run-time, ACDs are used to validate and initiate condition evaluation, and to reference (and potentially acquire) condition implementing libraries. ACF is a general purpose framework. Subject to semantic restrictions, any policy infrastructure can be augmented with ACF conditions. Hence, the ACF can be used to expand existing policy with more flexible context.

The extended view of conditions affords new ways of leveraging policy. *Policy based programming* allows policy issuers to augment existing applications with new features through the specification of authorization policy (e.g., implement distributed locking through condition evaluation). Hence, issuers are able to use *late-binding* to add environment-specific application behavior. Moreover, the applications need not be aware of the added functionality.

The current ACF implementation is a very rough prototype. In the near future, we intend to complete the code and experiment with many different kinds of conditions. As part of this process, we will refine the schema and consider the design of directory services used to store ACDs and implementations. Other works will investigate how policy-based programming is used to support flexible environments. It is through these works that we hope to expose the semantic depth, and hence the value, of policy context.

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