Securing Service-Oriented Systems Using State-Based XML Firewall

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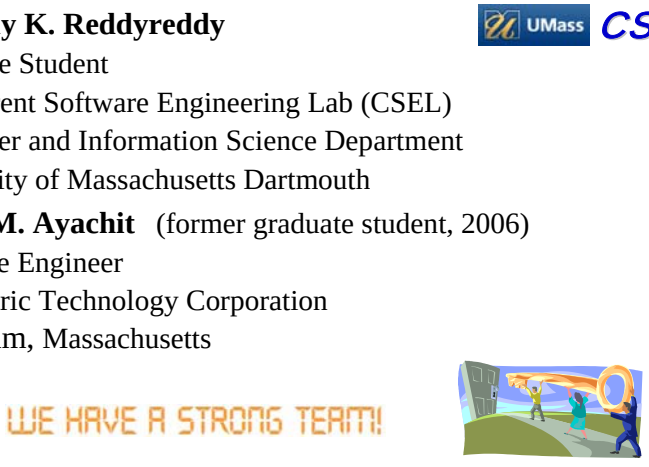

Outline

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- Background and Motivations
- XML Firewall Architectural Design
- Role-Based Access Control Polices
- Real-Time Detection of XML-Based Attacks
- A Case Study with Experimental Results
- Conclusions and Future Work

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Introduction to Service-Oriented Architecture and Web Services

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- Service-Oriented Architecture (**SOA**) is a key means to share information and capabilities through published service interface.
- Web services-based SOA can significantly speed up the application development process.
  - Are Internet-based software components that support open, XML-based standards and communication protocols.
  - Are software components defined using WSDL, registered using UDDI, and invoked using SOAP.
  - Make software functionalities available over the Internet.

Service-Oriented Architecture (SOA)

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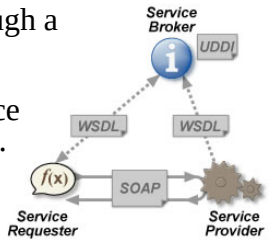
In the context of SOA, a ***service*** is a self-contained function in which consumers interact through a well-defined interface.



- **Service Provider** implements the service and makes it available over the network.
- **Service Requester** utilizes an existing web service by opening a network connection and sending a request.
- **Service Broker** is centralized directory of registered web services.

Major concern: Services are vulnerable to be attacked!

Examples of XML-Based Attacks

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- **XML-Based Denial of Service (XDoS):** An XDoS attack directs malicious XML-based traffic to a web service to exhaust the resources at the server side.
- **SQL Injection:** An SQL injection attack could tamper the input fields of database requests to obtain unauthorized access to data or stored procedures.
- **Overloaded Payload:** An overloaded payload attack can exhaust the XML parser of a service provider by sending huge XML data in a service request.

Conventional Firewall

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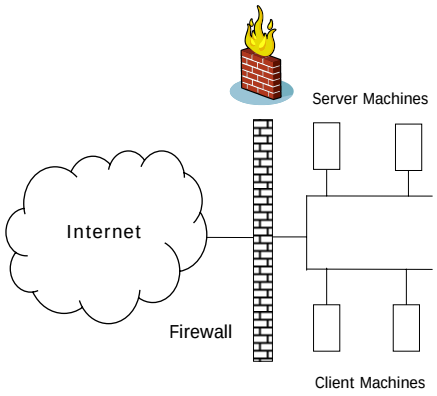
- **Firewall:** a fireproof wall used as a barrier to prevent the spread of a fire.
- Firewall is a component that limits network access.
- Three major types of conventional firewalls
  - Packet filtering firewall
  - Stateful inspection firewall
  - Application-level firewall



Conventional Firewalls are NOT sufficient for SOA!

Why XML Firewall ?

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- A conventional firewall typically
  - Restricts IP addresses or TCP ports, but port 80 reserved for HTTP and SOAP traffic cannot be blocked on a server that hosts web services.
  - Does not look into packet contents, and does not support parsing or validating XML data.
  - Does not support authentication and authorization for web services access.
- A state-based XML firewall can
  - Inspect XML messages including head and data segments.
  - Support authentication and authorization using state-based info for web services invocation.

Major Features of State-Based XML Firewall

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- Is based on a Petri net based XML firewall formal model we proposed previously.
- Grants only those users who are properly authenticated and authorized for access of web services.
- Adopts dynamic role-based access control (D-RBAC) for user authorization.
- Is supported by policy rules based on user & state info
  - Policy rules for user authentication and authorization.
  - Detection rules for identifying XML-based security threats.
- Can examine the contents of incoming XML-based messages (SOAP messages).

XML Firewall

XML Firewall Protected Service-Oriented System

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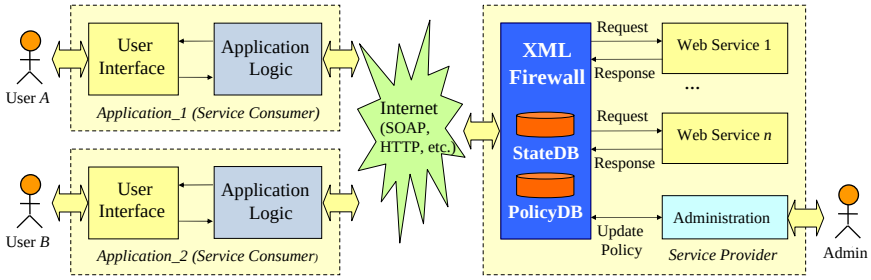

- Works as a proxy for web services, and is transparent for users.
- Supports concurrent web services invocations.
- Supports real-time state-based policy updating.

Architectural Design of State-Based XML Firewall

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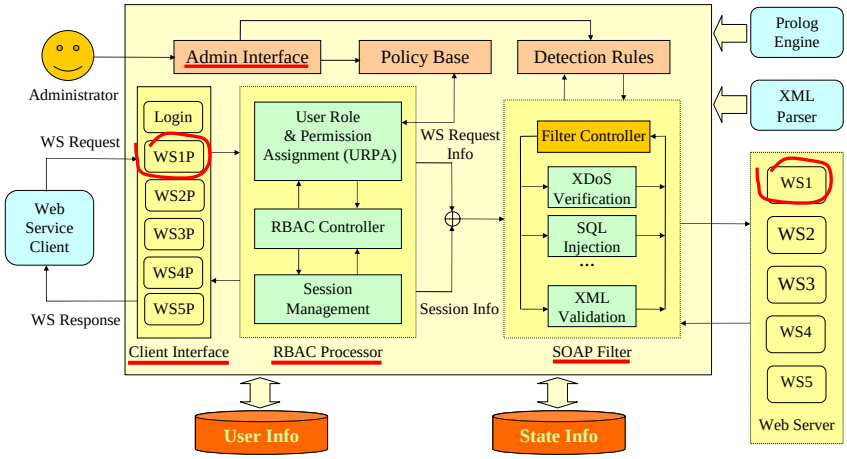

Database Design for State-Based XML Firewall

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- ***User_Info*** database: records user information, e.g., a user's trust level.
  - Supports user authentication and user authorization.
  - Supports verification of XML-based attacks.
- ***State_Info*** database: records system states and user's current state.
  - Supports detection of suspicious XML-based attacks.
  - Supports verification of XML-based attacks.

Examples of User and State Information for XDoS Detection

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- **Definition 1:** A ***user session*** is defined as a 5-tuple *(UID, SID, RO, ST, ET)*, where *UID* is a user ID, *SID* is a session ID, *RO* is a set of roles that will be assigned to the user, *ST* is the session start time, and *ET* is the session expiration time.
- **Definition 2:** A ***user credential*** is a 4-tuple *(UN, PW, UID, TL)*, where *UN* is the user name, *PW* is the password specified by the user at registration time, *UID* is the user ID, and *TL* is the current trust level assigned to the user.
- **Definition 3:** A ***user state*** is a 5-tuple *(UID, SID, TR, FR, TL)*, where *UID* is the user ID assigned at the time of registration, *SID* is the ID of the session that is initiated, *TR* is the total number of requests made by the user in the current session, *RF* is the request frequency, i.e., the number of requests made by the user in a recent time interval, and *TL* is the user's current trust level.
- **Definition 4:** A ***firewall state*** is a triple *(RE, DE, RT)*, where *RE* is the number of requests that are received by the XML firewall but not yet forwarded to the web server. *DE* is the number of requests that are being processed by the detection modules in the SOAP filter. *RT* is the number of requests in a recent time interval, e.g., the last five minutes.

Architectural Design of State-Based XML Firewall

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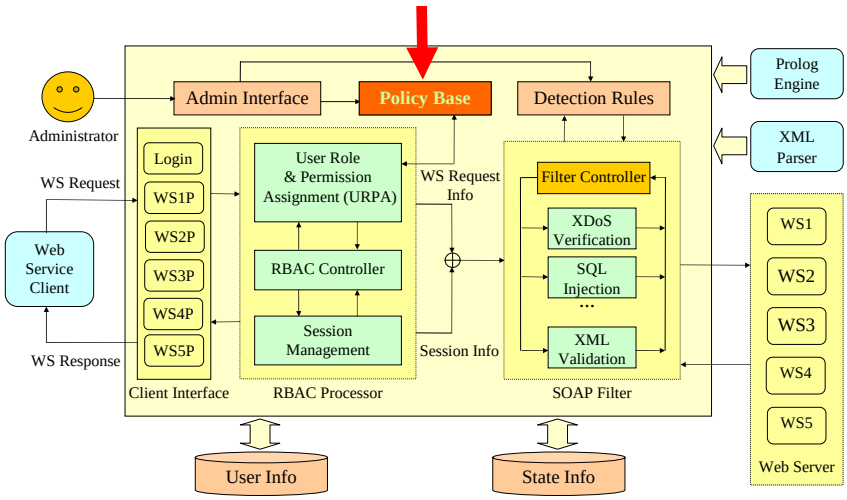

Role-Based Access Control (Authorization) Polices

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- A role is an abstraction of a position
  - Represents a set of responsibilities.
  - Represents a set of permissions.
- Role-based authorization polices
  - Specify the roles that a user may adopt.
  - Specify the permissions associated with each role.
  - Can be updated dynamically at runtime.
- Separation of policies from the application code
  - Policy language must be expressive and computable
  - We choose Prolog for policy specification.

A Hospital Management Example

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```
isValidRole(patient). isValidRole(doctor). isValidRole(nurse).
isValidRole(staff). isValidRole(pharmacist).
assignRole(U,R) :- isValidRole(R).
canInvoke(R,T,billingService,accessBill):-
  contains(R,[staff,pharmacist,patient]),
  contains(T,[normal,high]).
canInvoke(R,T,billingService,computeBill):-
  contains(R,[staff,pharmacist]),
  contains(T,[normal,high]).
canInvoke(R,T,accessService,readRecord):-
  contains(R,[doctor,nurse,patient]),
  contains(T,[normal,high]).
canInvoke(R,T,accessService,writeRecord,P,U):-
  contains(R,[doctor,nurse]),
  contains(T,[normal,high]), assignPatient(P,U),
  assignRole(P,patient), assignRole(U,R).
canInvoke(R,T,contactService,accessContact):-
  contains(R,[staff,doctor,nurse,patient]),
  contains(T,[normal,high]).
```

Architectural Design of State-Based XML Firewall

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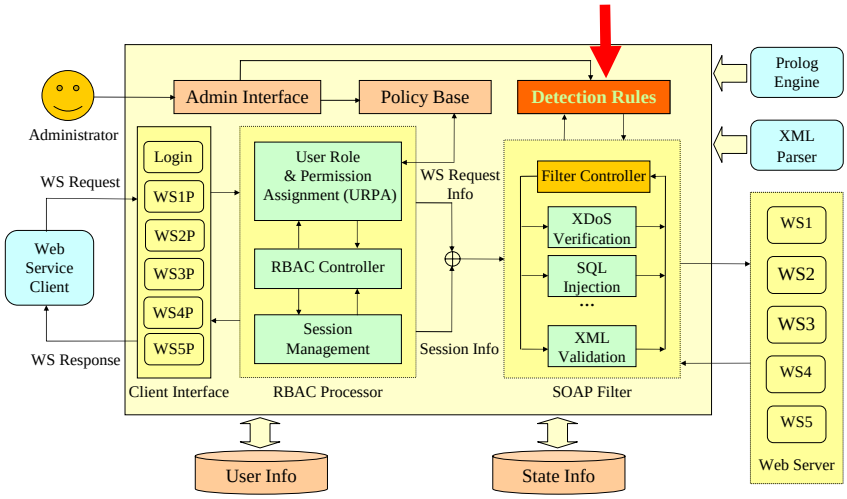

Real-Time Detection of XML-Based Attacks

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- SOAP filter is responsible for real-time detection of XML-based attacks
  - Detection of suspicious SOAP messages
  - Verification of XML-based attacks
- Example of suspicious XDoS attack detection rules

```
checkThreshold(W,S,X):- threshold(W,SI,Y),X > Y.
threshold(accessService,busy,20).
threshold(accessService,normal,40).
threshold(accessService,free,60).
```

- Example of XDoS attack verification

```
xdosVerify(U,T):- inspectHistory(U,T,V).
inspectHistory(U,T,V):-
  T = high, dataConnect(U,3,V), V = '3',
    degradeTrustLevel(U,normal).
inspectHistory(U,T,V):-
  T = normal, dataConnect(U,5,V), V = '3',
    degradeTrustLevel(U,low).
inspectHistory(U,T,V):-
  T = low, dataConnect(U,7,V), V = '3'.
    degradeTrustLevel(U,permanentlyBlocked)
dataConnect(U,X,V):-
    java_object('DataConnect',[],data),
    data<-getHistorySessionStatus(U,X) returns V.
degradeTrustLevel(U,T):-
    java_object('DataConnect',[],data),
    data <- recordTrustLevel(U,X).
```


- Develop a prototype XML firewall and a service-oriented system for hospital management.
- Simulate an SQL injection attack by accessing the web service *accessService*.
- Consider `User1` with a patient role who is assigned to nurse `User2`. A legitimate request from the nurse could be `writeRecord("User2", "User1", "The patient reacted abnormally to new drugs.", "Observation")`

```
INSERT INTO patientRecords VALUES('User2', 'User1',
'The patient reacted abnormally to new drugs.',
'Observation'); DELETE FROM users; -- dummystring');
```

Log Information for SQL Injection Detection

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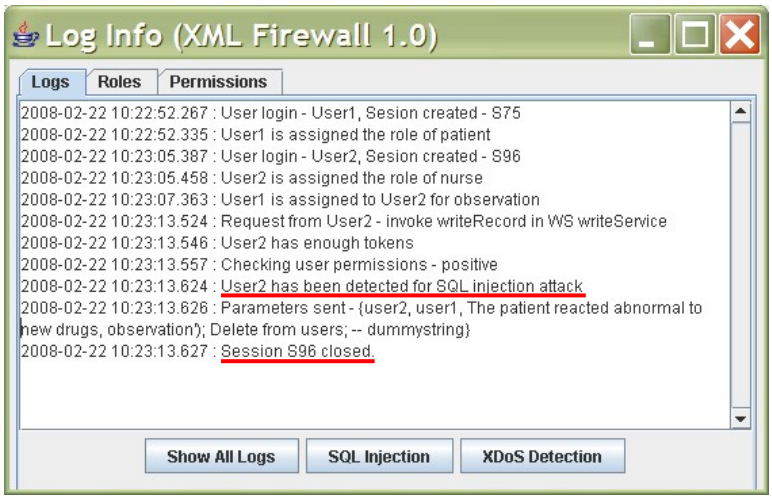

A Case Study (XDoS Attack)

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- Simulate request flooding attacks on a service (report generation service)
  - Use large number of requests from the attacker.
  - Record the response behavior from a normal user.
- The attacked service takes around 10 seconds as normal processing time.
- Perform two experiments with thresholds for the firewall are set to 80 and 60, respectively.

Experimental Results for XDoS Attacks

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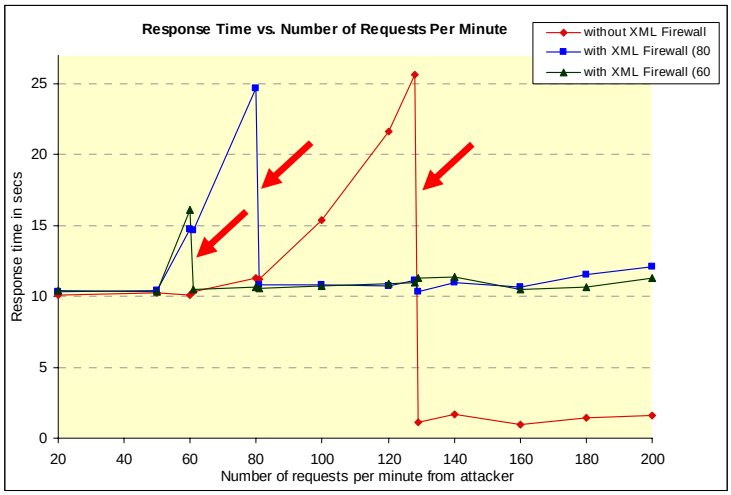

Conclusions

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- We introduced a new security mechanism called **state-based XML firewall** to protect service-oriented systems.
- The system supports attack detection and attack verification.
- Experimental results show that our approach can effectively protect web services from XML-based attacks.

Future Work

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- Study new types of XML-based attacks and show how their corresponding attack verification modules can be easily integrated.
- Adopt agent-based technology to introduce more intelligence into our current design.
- Develop an agent-based XML firewall with learning capability that can protect service-oriented systems for novel attacks.

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Discussions

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