CSCU9YW

Introduction

Origins

- Distributed computing for
  - Linking networked computers and applications
  - Sharing computation
  - Sharing data
- Previous approaches
  - Java RMI (Remote Method Invocation)
  - OMG CORBA (Common Object Request Broker Architecture)
  - Microsoft DCOM (Distributed Component Object Model)
  - ODP (Open Distributed Model)
- Web was rapidly adopted as a means to share information, initially through static web pages, later dynamic and interactive web pages
- Web focussed on accessing information
- Web services focus on B2B communication

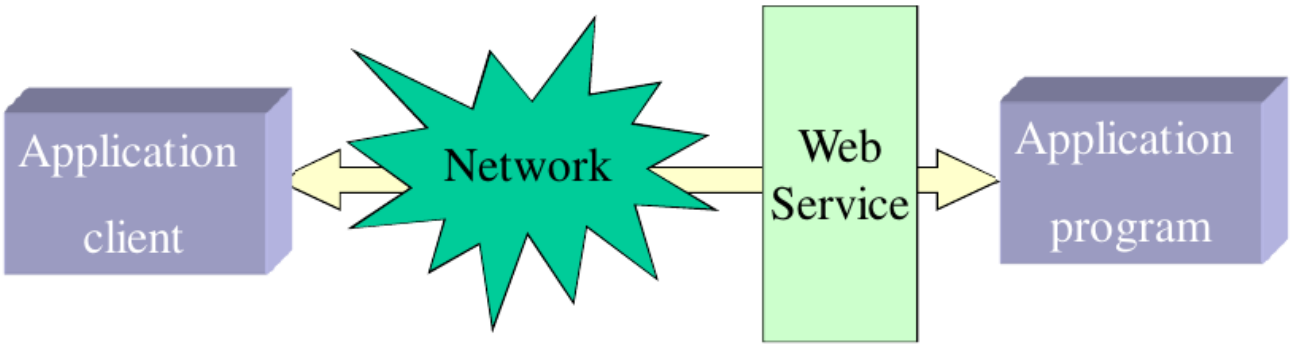
Characteristics

- Jeff Bezos (CEO Amazon), Tech. Review 01/2005 – “Web 1.0 was making the Internet for people; Web 2.0 is making the Internet better for computers”
- Gartner Research, – “Web services are loosely coupled software components delivered over Internet standard technologies”
- emphasise communication among applications rather than users
- follow open standards that are widely supported by industry
- architecture is loosely coupled, so web services can be designed in isolation
- can interwork even if they were not explicitly designed to do so
- supported by three classes of system:
  - service consumers (clients)

- service providers (servers)
- service brokers (registries)

What is a Web Service?

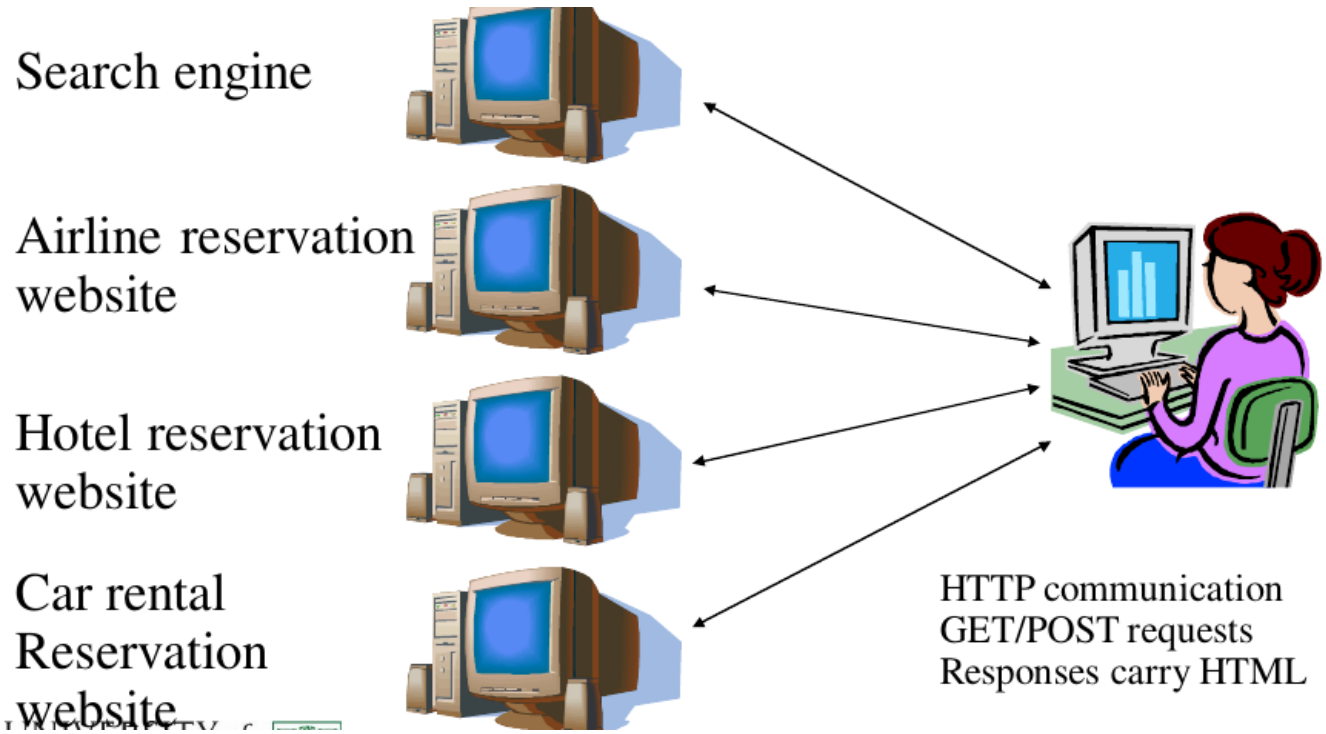
- A web service is a network accessible interface to application programs, built using standard Internet technologies.
- Clients of web services do **NOT** need to know how it is implemented.
- A Web Service is a URL-addressable software resource that performs functions (or a function).



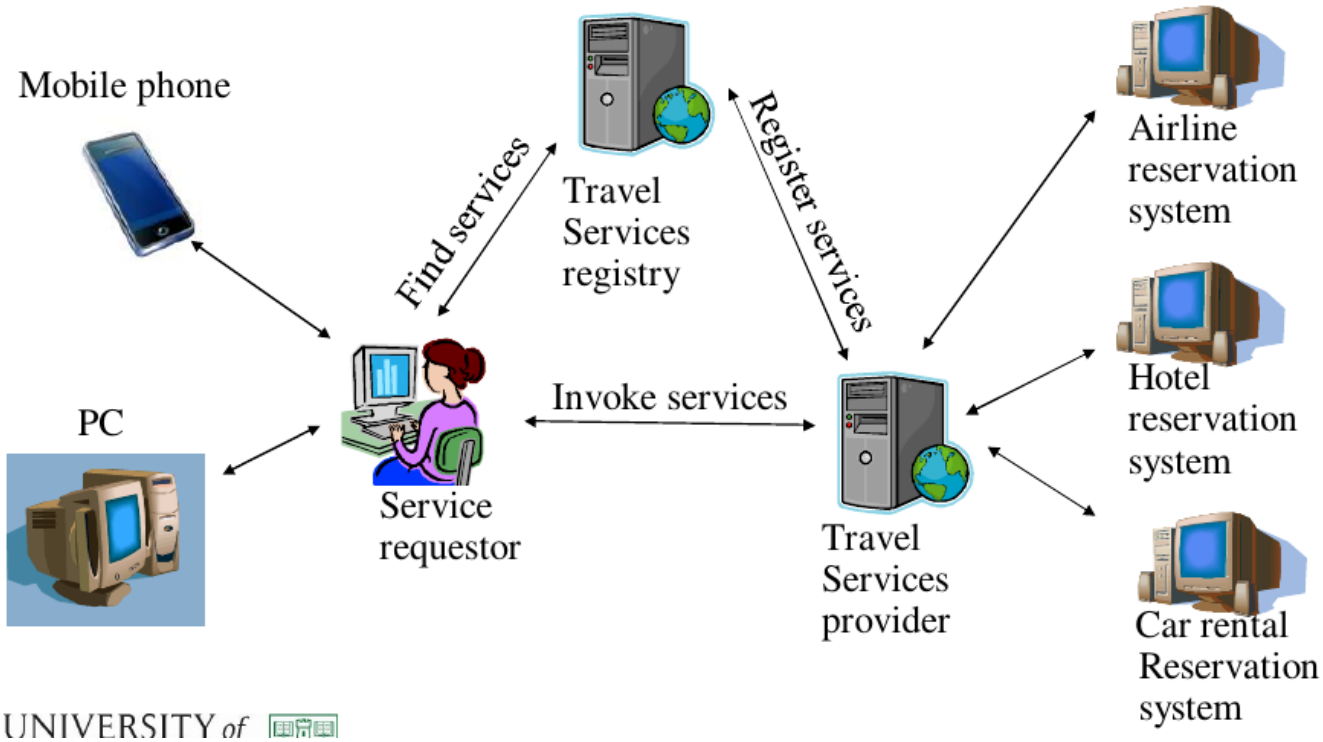
- "Web services are a new breed of Web application. They are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web. Web services perform functions, which can be anything from simple requests to complicated business processes. ... Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service." IBM web service tutorial

Example – booking a trip

WWW/HTML



Web Services



UNIVERSITY of

Evolution

Technology	Purpose	Applications	Outcome
TCP/IP	Connectivity	E-mail, FTP, ...	Create the web
Html	Presentation	Web pages	Browse the web
XML	Programmability	Web services	Program the web

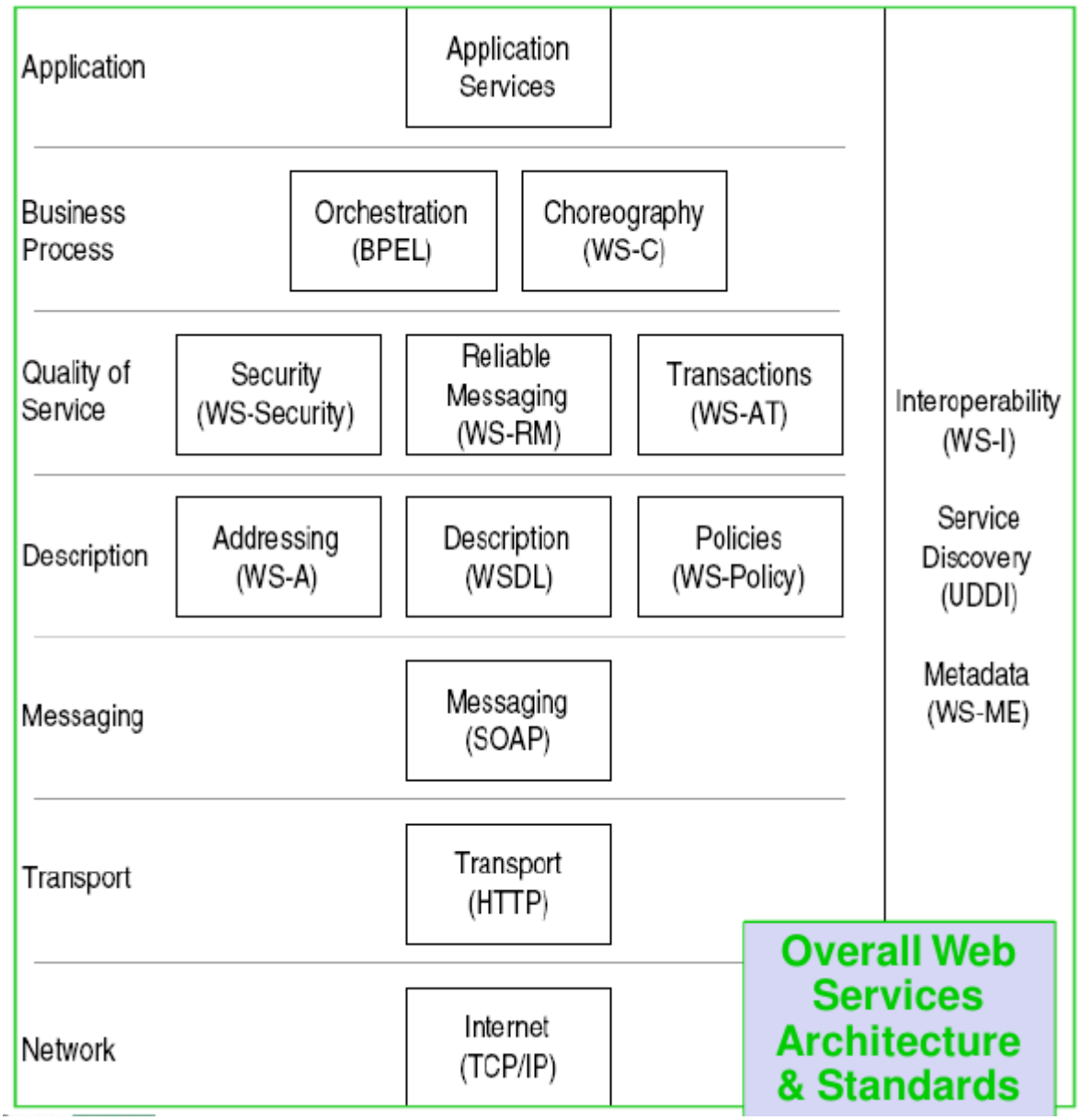
Usage

- Web services are used by business for managing partnerships
  - supply chains (e.g. a brake manufacturer automatically maintains stock levels of parts for a car manufacturer)
  - outsourcing (e.g. an electronics manufacturer has its web pages managed by an IT company)
  - contracting (e.g. an Internet shop goes to tender for management of online purchases)
  - combined services (e.g. a travel agent uses the services of airlines, hotel chains and car rental companies to offer a complete travel booking service)
- Web services support virtual organisations across the boundaries of conventional organisations

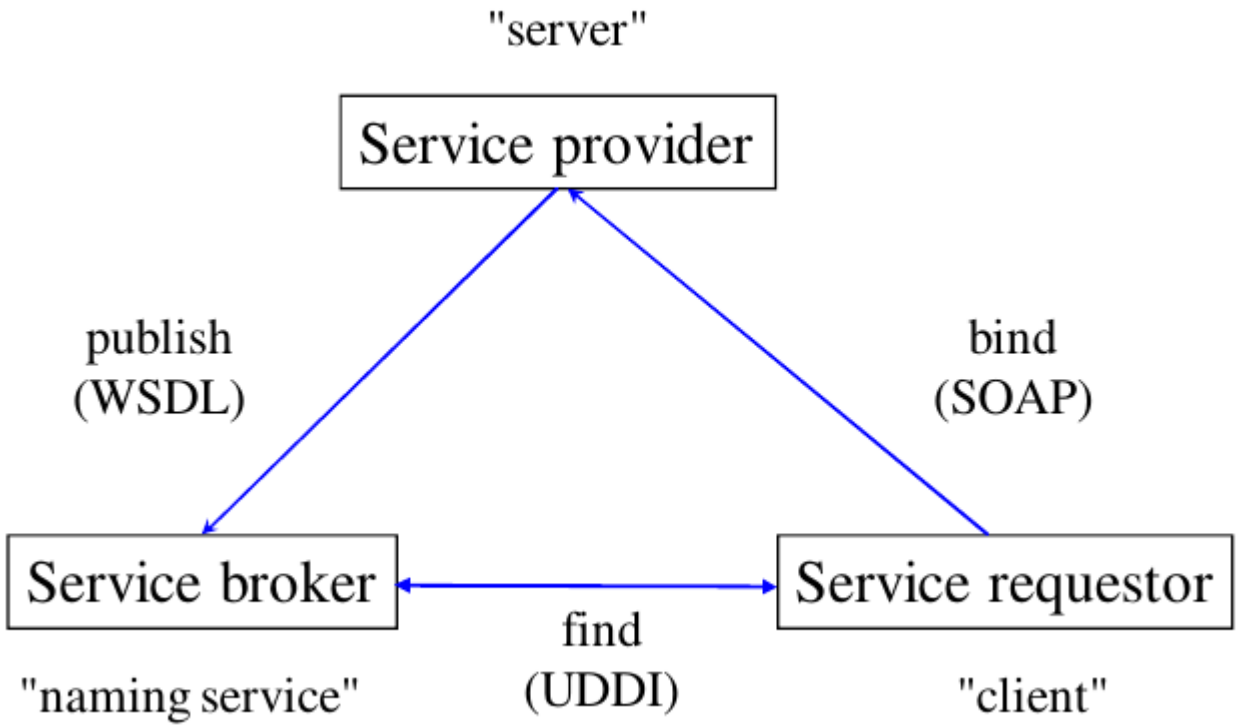
Web services standards

- standards for web services are defined by a number of organisations such as:
  - IETF (Internet Engineering Task Force, www.ietf.org)

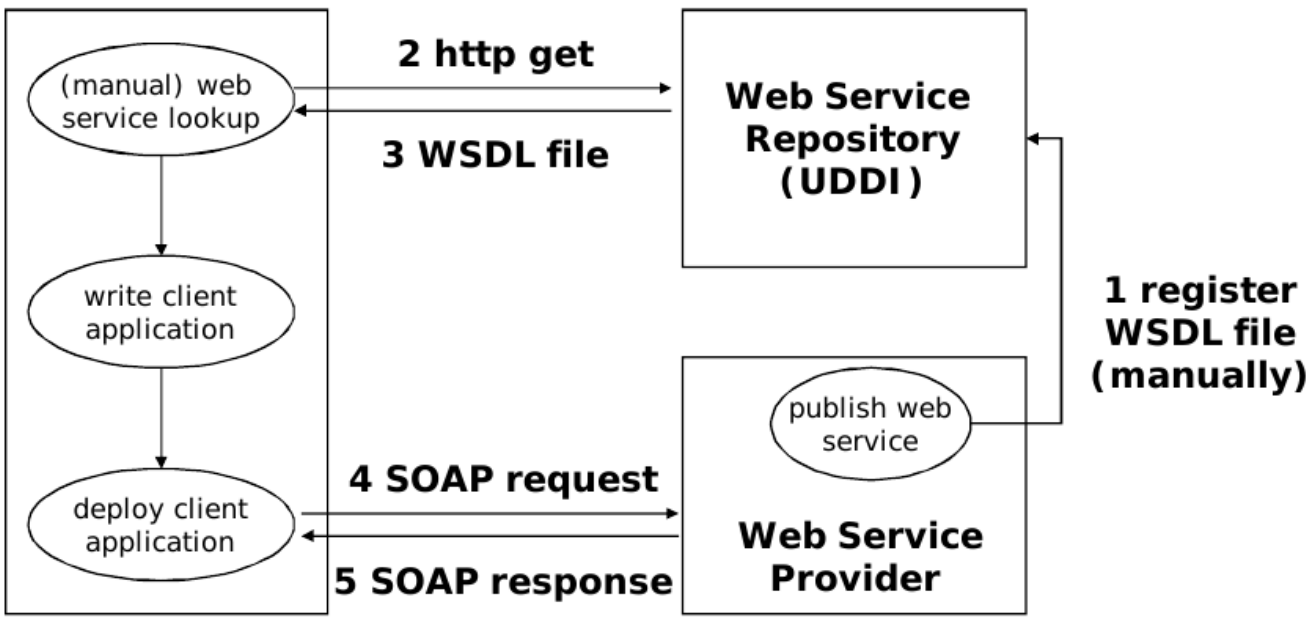
    - OASIS (Organization for The Advancement of Structured Information Standards, www.oasis-open.org)
    - W3C (World Wide Web Consortium, www.w3.org)
- web services share certain communication mechanisms with conventional use of the Web:
    - HTTP (HyperText Transfer Protocol, IETF RFC 2616) to support message exchange between web services
    - TCP (Transmission Control Protocol, IETF RFC 793) for reliable transfer of data across a collection of subnetworks (e.g. the Internet)
    - IP (Internet Protocol, IETF RFC 791) for routing across a collection of subnetworks
- many web service aspects have been (or are being) standardised in areas such as:
    - service description
    - service discovery
    - service addressing
    - security and authentication
    - reliable messaging and transaction
    - service orchestration and choreography
    - service policies



Web service usage



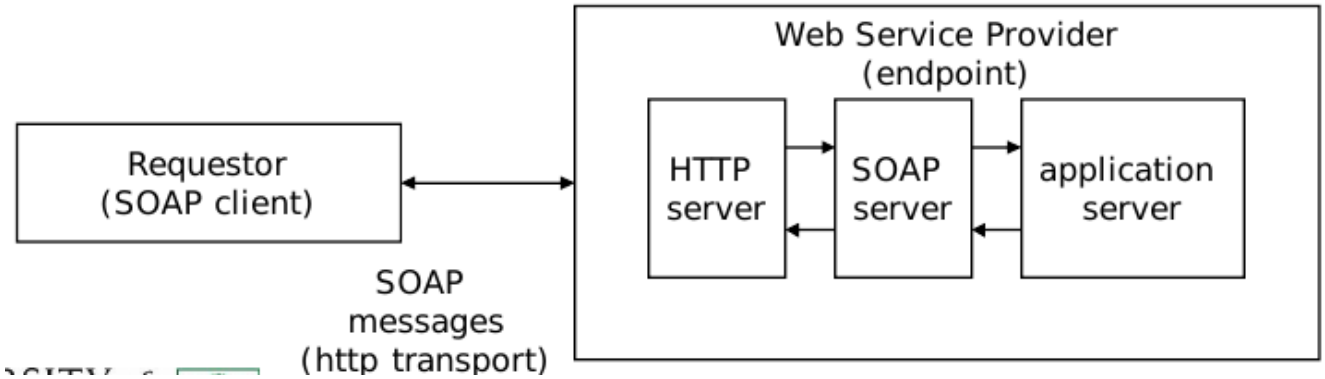
Example



Web Services Implementation

- Drastically simplified!
- Application Server (web service-enabled)
  - provides implementation of services and exposes it through WSDL/SOAP
  - implementation in Java, as EJB, as .NET (C#) etc.
- SOAP server, implements the SOAP protocol
- HTTP server, standard Web server

- SOAP client, implements the SOAP protocol on the client site



Examples

- http://aws.amazon.com/
  - Exposes world's largest product database through Web Services
  - Idea: let others figure out how to sell products for us
  - Associates program enables Web sites to link to Amazon.com and earn referral fees
- Some other interesting examples:
  - http://www.nbn.org.uk/Use-Data/Examples-Of-Use/Web-services.aspx
  - http://blog.elgg.org/pg/blog/cash/read/149/example-of-site-integration-using-web-services

SOA/SOC

- web services support what is generically called SOA (Service Oriented Architecture) in support of SOC (Service Oriented Computing)
- SOC views a distributed system from the perspective of the services it offers and how these relate to each other
- previous work on distributed computing was object oriented, but this describes the (close) coupling among distributed objects
- instead, web services maintain a loose coupling – only the services offered by a distributed application are exposed:
  - legacy applications can easily be given a web service wrapping
  - the internal design of a web service can readily be changed
  - new services can be created by combining existing services

Background: XML

- Meta-language
- XML uses markup to describe data.
  - So it is used to develop our own markup languages.
- Text files
- XML and HTML are for different purposes.
  - HTML is concerned with display (e.g. ,

    ,

)
    - XML is concerned with data representation
- The markup facilities in HTML are predefined
- In XML we define our own!

```
<pets>
    <animal>
        <type>Dog</type>
        <name>Jasper</name>
        <disposition>Enthusiastic</disposition>
    </animal>
    <animal>
        <type>Cat</type>
        <name>Barney</name>
        <disposition>Cynical</disposition>
    </animal>
</pets>
```

- XML attributes further define elements:

```
<price currency="GBP">1.15</price>
```

```
<price currency="USD">1.75</price>
```

- Required vs #Implied
- Well formed vs valid XML
- Two ways to specify the structure of XML documents:
    - Document Type Definitions (DTDs)
    - XML Schemas
- We need to specify
    - what elements (tags) will be used
    - how the various elements may be nested
    - what attributes they may contain
    - what types of data an element can contain

DTD vs Schemas

- DTDs are rather limited in how they describe the content of data (e.g. it cannot be stated that a particular element contains integers or strings)
- XSD (XML Schema Definition, W3C version 1.0) is now the preferred way to define applications of XML, giving:
    - the structural elements in the data, defining the types of data they contain
    - definitions of data types, including sophisticated constraints on their contents
    - the relationships among the structural elements
    - the attributes of elements
- XSI (XML Schema Instance, W3C version 1.0) defines XML documents as instances of their schemas

Namespaces

- a namespace is essentially just a unique string, though namespaces typically take the form of a URI (Uniform Resource Indicator)
- a namespace URI is typically a URL (Uniform Resource Locator) for where a schema is defined (e.g. www.cs.stir.ac.uk/schemas/mustard.xsd)
- a namespace URI may simply be a URN (Uniform Resource Name) that gives a (relatively) unique identifier (e.g. urn:MustardDefinition)
- since a namespace URI may be lengthy, it is commonly referred to by a short prefix – a string that is unique only within a document (e.g. mstd)

Defining a Namespace

- namespace prefixes are defined and used as follows (xmlns means XML NameSpace):
  - xmlns:mstd="www.cs.stir.ac.uk/schemas/mustard.xsd"
  - ...
  - mstd:sequence
- mstd:sequence is an example of using a namespace prefix
- a document may declare a default namespace (xmlns on its own) for elements and attributes that are used without an explicit namespace prefix
- a document may also declare a target namespace (targetNamespace) that applies to all elements and attributes that it defines
- it is often convenient to have a prefix corresponding to the target namespace; this is typically, but need not be, named tns
- the namespace prefix for XML Schema Definition is usually xsd (though sometimes xs), while that for XML Schema Instance is usually xsi

XML Schema

- With a schema, instead of having a definition in a file such as note.dtd, it is held in a file note.xsd
- When the XML file is specified by an XSD document held in note.xsd, the attributes within the note element in the XML file are:

```
<note
    xmlns="http://www.w3schools.com"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.w3schools.com note.xsd"
>
```

- The notation is therefore in XML.
- We have also defined namespaces.
- The default namespace in this example is: http://www.w3schools.com
- Let us now look at the structure of the XSD document.
- The `<schema>` element is the root element of every XML Schema and it normally has attributes.
- The following specifies that elements and data types used in the schema (schema, element, complexType, sequence, string, boolean, etc.) come from the namespace: http://www.w3.org/2001/

XMLSchema

- and that the elements and data types from that namespace should be prefixed with xs:

```
<xs:schema
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
    targetNamespace="http://www.w3schools.com"
    xmlns="http://www.w3schools.com"
    elementFormDefault="qualified"
>
```

- elements used by a XML document which are declared in this schema must be namespace **qualified**

Example

The root element in our XML is note. Suppose that it is composed of a sequence of four elements to, from, heading and body, it is an example of a complex element and its definition has the structure:

```
<xs:element name="note">
    <xs:complexType>
        <xs:sequence>
            ...
        </xs:sequence>
    </xs:complexType>
</xs:element>

```

- The term sequence indicates that the inner elements must appear in the specified order.

XML Schema Datatypes

- XML Schema have a lot of built-in data types. Examples are:
  - xs:string
  - xs:decimal
  - xs:integer
  - xs:boolean
  - xs:date
  - xs:time
- This gives us a lot more control than we had with DTDs to specify what can go into our XML document. If the XML document contains a value of the wrong type then it will not validate.

Example

- Suppose that we had the following simple elements in XML:

```
<lastname>Smith</lastname>
<age>36</age>
<dateborn>1968-03-27</dateborn>
```

- Note that date is given as YYYY-MM-DD
- The corresponding simple element definitions in XSD are:

```
<xs:element name="lastname" type="xs:string"/>
<xs:element name="age" type="xs:integer"/>
<xs:element name="dateborn" type="xs:date"/>
```

In our **note** example, the inner elements are built-in simple elements. Their definition has the structure:

```
<xs:element name="aname" type="atype"/>
```

In fact, they are all strings. Hence the full definition of note is:

```
<xs:element name="note">
    <xs:complexType>
        <xs:sequence>
            <xs:element name="to" type="xs:string"/>
            <xs:element name="from" type="xs:string"/>
            <xs:element name="heading" type="xs:string"/>
            <xs:element name="body" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>
</xs:element>
```

Defining new types

- So, here we have defined a new element called note and described its structure.
- It has an anonymous type.
- An alternative would be to define a new complexType (e.g. NoteType) and then define the note element as:

```
<xs:element name= "note" type= "NoteType"/>
```

This approach is much better if we are going to have several elements with the same structure (type).

A new type

- We now define NoteType as:

```
<xs:complexType name="NoteType">
    <xs:sequence>
        <xs:element name="to" type="xs:string"/>
        <xs:element name="from" type="xs:string"/>
        <xs:element name="heading" type="xs:string"/>
        <xs:element name="body" type="xs:string"/>
    </xs:sequence>
</xs:complexType>
```

Another new type

- We can also define a new **simpleType**.
- We start from an existing **simpleType** (the base type) and impose a *restriction* by means of a **facet**.
- Example facets are:
  - maxInclusive and maxExclusive
  - minInclusive and minExclusive
  - pattern
  - enumeration

Restrictions on types

- Suppose that we wanted to restrict the range of allowable values in our age element.
- Instead of defining it as:

```
<xs:element name="age" type="xs:integer"/>
```

- We can define it as:

```
<xs:element name="age">
    <xs:simpleType>
        <xs:restriction base="xs:integer">
            <xs:minInclusive value="13"/>
            <xs:maxInclusive value="19"/>
        </xs:restriction>
    </xs:simpleType>
</xs:element>
```

- Further examples

```
<xs:element name="car">
    <xs:simpleType>
        <xs:restriction base="xs:string">
            <xs:enumeration value="Audi"/>
            <xs:enumeration value="Golf"/>
            <xs:enumeration value="BMW"/>
        </xs:restriction>
    </xs:simpleType>
</xs:element>
```

```
<xs:element name="initials">
    <xs:simpleType>
        <xs:restriction base="xs:string">
            <xs:pattern value="[A-Z][A-Z]"/>
        </xs:restriction>
    </xs:simpleType>
</xs:element>
```

- Can also define default or fixed values for a type:

```
<xs:element name="color" type="xs:string" default="red"/>
<xs:element name="color" type="xs:string" fixed="red"/>
```

XML Schema summary

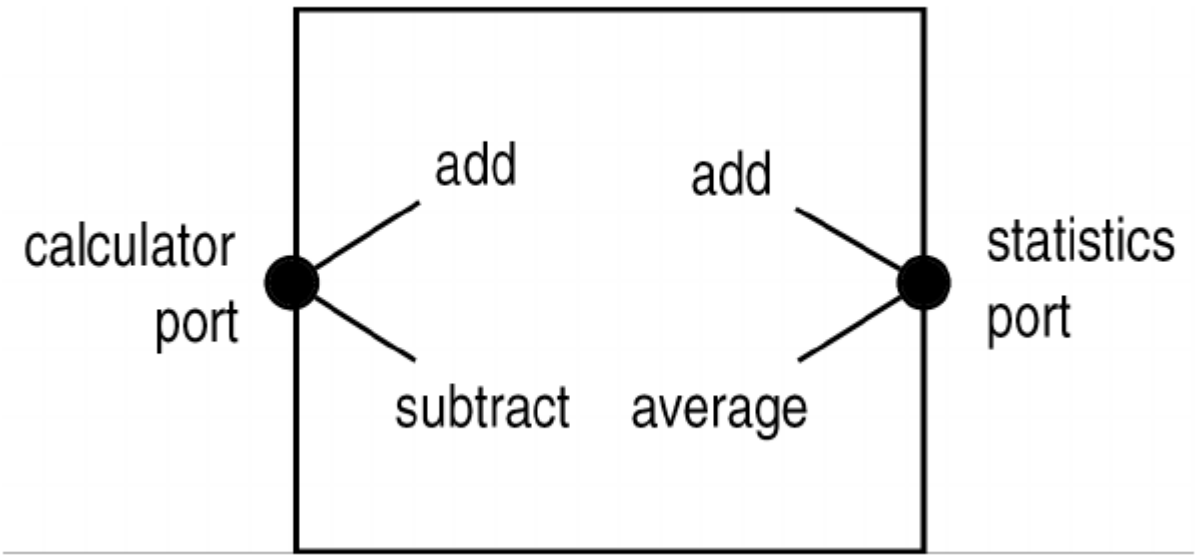
- schema data types use the following:
  - predefined types like boolean, date, double, float, int, integer (arbitrary length), nonNegativeInteger, string, time
  - element for a field in a type
  - complexType for structured types

```
<complexType name="fieldCount">
    <sequence>
        <element name="field" type="xsd:string"/>
        <element name="count" type="xsd:nonNegativeInteger"/>
    </sequence>
</complexType>

<complexType name="analysis">
    <sequence>
        <element name="fieldCount" type="defs:fieldCount" minOccurs="0"
maxOccurs="unbounded"/>
    </sequence>
</complexType>

```

WSDL

Web services

- a service supports:
  - ports whose interfaces are defined by port types
  - operations at ports that can take an input, return an output, and cause a fault
  - messages that are sent to or by an operation
  - faults that indicate failure of the service (not the underlying communications)



- note that
  - different operations with the same name (e.g. add here) may be supported at different ports
  - operation parameters are optional, e.g. an operation may not produce an output, may send an output without an input, or may not cause a fault
  - although a web service may offer multiple ports, each with multiple operations, in practice services have just one port with multiple operations

Calculator class

```
1  public class Calculator {
2      public int add(int i, int j) throws ArithmeticException {
3          int result = i + j;
4          if ((j >= 0 && result >= i) || (j < 0 && result < i))
5              return(result);
6          else
7              throw new ArithmeticException(”addition overflow”);
8      }
9
10     public int subtract(int i, int j) throws ArithmeticException {
11         int result = i - j;
12         if ((j >= 0 && result <= i) || (j < 0 && result > i))
13             return(result);
14         else
15             throw new ArithmeticException(”subtraction overflow”);
16     }
17 }
```

- Equivalent web service look as follows:
  - a Calculator service with a calculator port
  - operations add and subtract for a pair of integers
  - messages for the input and output of these operations
  - fault ArithmeticException for the case where the result of addition or subtraction is too large
- note that Java does not have the explicit equivalent of a port or of messages

- Axis2 (Apache Extensible Interaction System) is able to convert a simple Java class into a web service (POJO)

WSDL

- Web Service Definition Language (XML)
- Namespace is typically wsdl
- A WSDL document describes how to interact with a web service in terms of data types, operations provided and their parameters, protocols used, location of the service
- WSDL deals with syntax (how to call operations) and not semantics (what operations do), so other information is needed before a service can be fully understood
- Contract between service provider and requestor
- Described services can be implemented in any language & on any platform

Uses

- Used by application developers as a spec of the web service
  - Helps with development of both web services and web service clients
  - Source code for (parts of) service and client can be generated from WSDL
  - WSDL can also be generated from a web service implementation
- Used by applications to invoke a web service
  - Dynamically generating a call to the web service based on its description
- Published in service registries
  - Aids discovery and use of web services
- WSDL-described web service can be communicated with using any agreed protocol
  - SOAP (most common)
  - SMTP/MIME
  - HTTP/REST (used for simple cases)

WSDL messages

- Web services handle messages in one of two basic styles:
  - document style means that each message carries an XML document
  - rpc style (cf. remote procedure) means that a request message carries the name of the operation to be invoked plus its parameters, and the resulting response message carries the operation result
- Each of these has two encodings:
  - encoded means that the types of all values are explicitly stated
  - literal means that values are just given literally – types are implicit
- In practice, only the literal styles are used
- Disadvantage of document/literal over rpc/literal: operations cannot be overloaded (different operations cannot have the same parameters)

WSDL documents

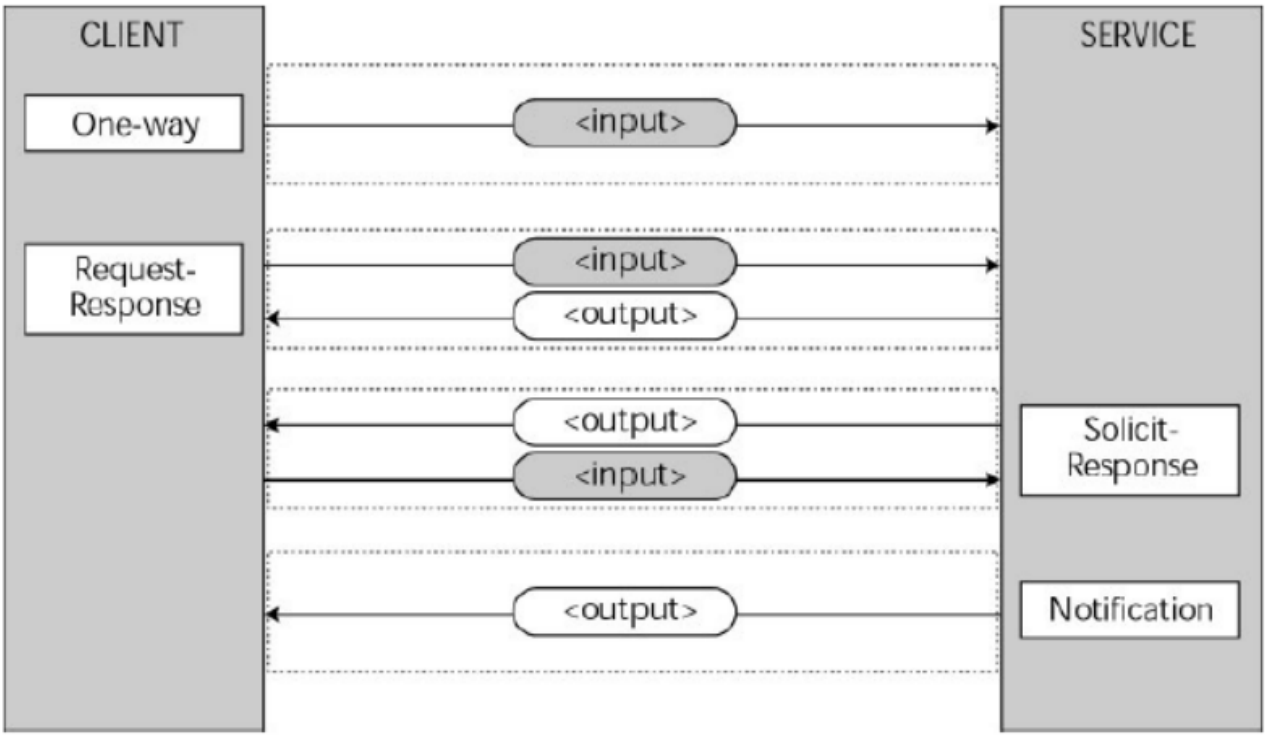
- WSDL separates the abstract description of a service interface from how it is actually supported

- The Abstract Service Interface Definition
  - Describes what the web service does (what operations it offers)
- The Concrete Service Implementation
  - Binds the abstract operations to concrete protocols; how to call those operations using those protocols
- Services support one or more ports (typically just one)
- Each port supports one or more operations
- Each operation may have an input, an output, and zero or more faults

Abstract Service Definition

- Data types used by the service
  - Typically XML Schema type definitions
  - Simple types, e.g.: int, float, string, boolean, etc...
  - Complex types, e.g.: Customer, Address, Stock Item
  - Types are used within messages...
- Messages sent/received by the service
  - A message is the payload of a single, one-way communication
  - A message consists of one or more parts
  - Each part is of a certain data type (as defined in data types)
  - Messages are used to make operations...
- How messages combine to form operations
  - At most one input message (input parameters)
  - At most one output message (output parameters)
  - Optional fault descriptions (exceptions)
  - WSDL supports four operation types...
- Operations combine to form a portType

Operation Types



Port Types

- Operations are combined to a portType
  - describes the interface(s) of a Web service
  - represent a logical aggregation of operations

```
<definitions>
    <types>
        data type definitions........
    </types>
    <message>
        definition of the data being communicated....
    </message>
    <portType>
        set of operations......
    </portType>
    <binding>
        protocol and data format specification....
    </binding>
</definitions>
```

Concrete Service Implementation

- Concrete bindings of the abstract service interface definition
  - Describe an implementation of a portType
  - Input, output and fault messages in the ops of each port type are mapped to:
    - The transport protocol(s) used
    - The message style (document or rpc)

        - The data encoding style (encoded or literal)
    - Although binding information has to be repeated for each port and operation parameter, these are usually all the same
- Overall Service is defined
    - Name of service
    - Each port has a name, binding and a location
- The entire Web Service is exposed via one or more ports (end point)
    - Each binding corresponds to a single port
    - A port is the actual address where the service can be found, eg:
        - http://some.web/service if binding to HTTP
        - some.web@service.com if binding to SMTP

Tools for WSDL

- all packages for web services include support for WSDL
- Apache Axis2 (Apache Extensible Interaction System) supports:
    - parsing WSDL, and interpreting SOAP messages in the context of this
    - WSDL2Java converts from WSDL to Java, creating stubs (outline client code) and skeletons (outline server code)
    - conversely, Java2WSDL converts from Java to WSDL
    - basic XML types have a direct Java mapping (e.g. boolean, double, float, int)
    - more complex XML types map onto Java classes

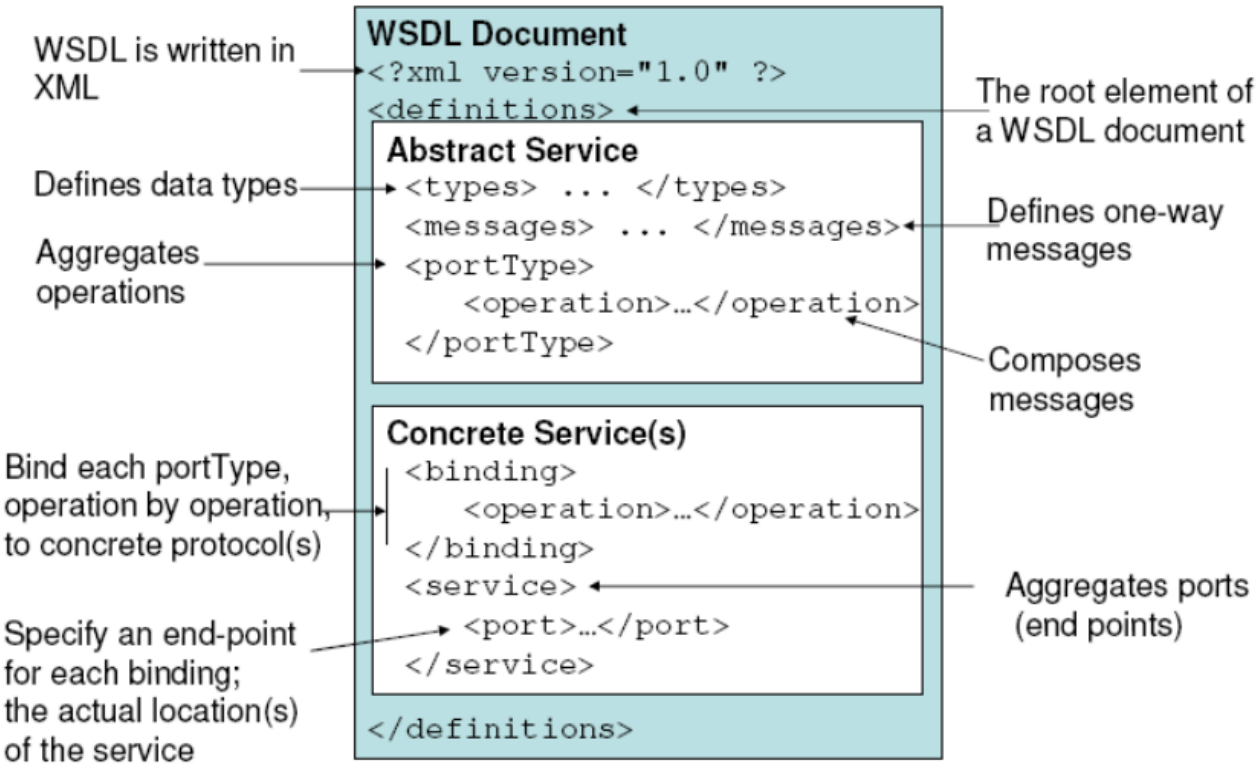
Limitations of WSDL

- Unable to describe complex business processes
    - E.g. sequences of related messages
- Does not describe business level requirements of the service
    - E.g. Quality of Service, Security

Important Namespaces

- The principle WSDL namespaces are:
    - http://schemas.xmlsoap.org/wsdl/ (Version 1.1)
    - http://www.w3.org/ns/wsdl (Version 2.0)
- The namespace for binding to SOAP messaging
    - http://schemas.xmlsoap.org/wsdl/soap/
- XML Schema –for XML Schema data type encoding
    - http://www.w3c.org/2001/XMLSchema
- SOAP Encoding – for SOAP messages using SOAP encoding
    - http://schemas.xmlsoap.org/soap/encoding/
- WSDL documents may also reference other namespaces
    - Usually this will be for application specific purposes

Overview of WSDL documents



Examples

Messages and Porttypes

```wsdl
<message name="getTermRequest">
    <part name="term" type="xs:string"/>
</message>

<message name="getTermResponse">
    <part name="value" type="xs:string"/>
</message>

<portType name="glossaryTerms">
    <operation name="getTerm">
        <input message="getTermRequest"/>
        <output message="getTermResponse"/>
    </operation>
</portType>
```

Binding

```
<binding type="glossaryTerms" name="b1">
    <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"
/>
    <operation>
        <soap:operation soapAction="http://example.com/getTerm"/>
        <input><soap:body use="literal"/></input>
        <output><soap:body use="literal"/></output>
    </operation>
</binding>
```

Example: Hello World (Lab 1)

- WSDL for Hello World Lab Example
- Abstract service definition
- One possible binding to SOAP

Definitions

- `<definitions>` is the root element of a WSDL document

```
<wsdl:definitions xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/"
    xmlns:ns="http://ws.apache.org/axis2"
    xmlns:wsaw="http://www.w3.org/2006/05/addressing/wsdl"
    xmlns:mime="http://schemas.xmlsoap.org/wsdl/mime/"
    xmlns:http="http://schemas.xmlsoap.org/wsdl/http/"
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
    xmlns:soap12="http://schemas.xmlsoap.org/wsdl/soap12/"
    xmlns:ns1="http://org.apache.axis2/xsd"
    xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
    targetNamespace="http://ws.apache.org/axis2">

<wsdl:documentation>
    This is a first Hello World Service.
</wsdl:documentation>
```

- This document also uses elements defined in a number of other Namespaces, e.g.
  - WSDL (wsdl)
  - Binding WSDL to SOAP (soap)
  - XML Schema (xs)

WSDL Types

```
<wsdl:types>
    <xs:schema attributeFormDefault="qualified"
    elementFormDefault="qualified" targetNamespace="http://ws.apache.org/axis2">
        <xs:element name="echoMsg">
            <xs:complexType>
                <xs:sequence>
                    <xs:element minOccurs="0" name="arg" nillable="true"
type="xs:string" />
                </xs:sequence>
```

```
            </xs:complexType>
        </xs:element>

        <xs:element name="echoMsgResponse">
            <xs:complexType>
                <xs:sequence>
                    <xs:element minOccurs="0" name="return" nillable="true"
type="xs:string" />
                </xs:sequence>
            </xs:complexType>
        </xs:element>
    </xs:schema>
</wsdl:types>

```

WSDL Messages

```
<wsdl:message name="echoMsgRequest">
    <wsdl:part name="parameters" element="ns:echoMsg" />
</wsdl:message>

<wsdl:message name="echoMsgResponse">
    <wsdl:part name="parameters" element="ns:echoMsgResponse" />
</wsdl:message>
```

- Two messages are defined:
  - echoMsgRequest is of type “ns:echoMsg”
  - echoMsgResponse is of type “ns:echoMsgResponse”

WSDL operations & portType

```
<wsdl:portType name="helloWorldWSPortType">
    <wsdl:operation name="echoMsg">
        <wsdl:input message="ns:echoMsgRequest" wsaw:Action="urn:echoMsg" />
        <wsdl:output message="ns:echoMsgResponse" wsaw:Action="urn:echoMsgResponse"
/>
    </wsdl:operation>
</wsdl:portType>
```

- A portType is declared, it is called “helloWorldWSPortType”
- The portType has only one operation, called “echoMsg”
- This operation consists of:
  - An input which is in the form of the message “ns:echoMsgRequest”
  - An output which is in the form of the message “ns:echoMsgResponse”

WSDL: Binding SOAP11

```
<wsdl:binding name="helloWorldWSSoap11Binding" type="ns:helloWorldWSPortType">
    <soap:binding transport="http://schemas.xmlsoap.org/soap/http"
style="document" />
    <wsdl:operation name="echoMsg">
        <soap:operation soapAction="urn:echoMsg" style="document" />
        <wsdl:input>
            <soap:body use="literal" />
        </wsdl:input>
        <wsdl:output>
            <soap:body use="literal" />
        </wsdl:output>
    </wsdl:operation>
</wsdl:binding>
```

- A binding called “helloWorldWSSoap11Binding” is declared.
- This binds the portType “ns:helloWorldWSPortType” to SOAP11 messaging using the document style and literal data type encoding.
- Each input/output (and fault) of each operation in the portType is bound.
- Two more bindings for SOAP12 (identical to SOAP11 binding, but different namespace) and HTTP

WSDL: Binding HTTP

```
<wsdl:binding name="helloWorldWSHttpBinding" type="ns:helloWorldWSPortType">
    <http:binding verb="POST" />
    <wsdl:operation name="echoMsg">
        <http:operation location="echoMsg" />
        <wsdl:input>
            <mime:content type="application/xml" part="parameters" />
        </wsdl:input>
        <wsdl:output>
            <mime:content type="application/xml" part="parameters" />
        </wsdl:output>
    </wsdl:operation>
</wsdl:binding>
```

WSDL: Service

```
<wsdl:service name="helloWorldWS">
    <wsdl:port name="helloWorldWSHttpSoap11Endpoint"
binding="ns:helloWorldWSSoap11Binding">
        <soap:address
location="http://127.0.0.1:8080/axis2/services/helloWorldWS.helloWorldWSHttpSoap11
Endpoint/"/>
    </wsdl:port>
    <wsdl:port name="helloWorldWSHttpSoap12Endpoint"
binding="ns:helloWorldWSSoap12Binding">
        <soap12:address
location="http://127.0.0.1:8080/axis2/services/helloWorldWS.helloWorldWSHttpSoap12
Endpoint/"/>
    </wsdl:port>
    <wsdl:port name="helloWorldWSHttpEndpoint"
binding="ns:helloWorldWSHttpBinding">
        <http:address
location="http://127.0.0.1:8080/axis2/services/helloWorldWS.helloWorldWSHttpEndpoi
nt/" />
    </wsdl:port>
</wsdl:service>
```

- A service called “helloWorldWS” is declared
- The service consists of three ports corresponding to the three bindings

```
<?xml version="1.0" encoding="UTF-8"?>

<definitions name="MusicDefinitions"
 targetNamespace="urn:Music"
 xmlns="http://schemas.xmlsoap.org/wsdl/"
 xmlns:music="urn:Music"
 xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
 xmlns:xsd="http://www.w3.org/2001/XMLSchema">

    <types>
        <xsd:schema
         targetNamespace="urn:Music"
         xmlns="http://www.w3.org/2001/XMLSchema"
         xmlns:xsd="http://www.w3.org/2001/XMLSchema">
                <complexType name="trackDetail">
                    <sequence>
                        <element name="discNumber" type="xsd:int" />
                        <element name="trackNumber" type="xsd:int" />
                        <element name="composerName" type="xsd:string" />
                        <element name="workName" type="xsd:string" />
                        <element name="titleName" type="xsd:string" />
                    </sequence>
                </complexType>

                <complexType name="trackDetails">
                    <sequence>
                        <element name="track" minOccurs="1" maxOccurs="unbounded"
type="music:trackDetail" />
```

```
                    </sequence>
                </complexType>

                <element name="trackDetails" type="music:trackDetails" />
                <element name="ErrorFaultElement" type="xsd:string" />
        </xsd:schema>
    </types>

    <message name="getComposerRequest">
        <part name="getComposerPart" type="xsd:string" />
    </message>
    <message name="getByDiscRequest">
        <part name="getByDisc" type="xsd:int" />
    </message>

    <message name="trackDetailList">
        <part name="trackDetailListPart" type="music:trackDetails"/>
    </message>
    <message name="ErrorFault">
        <part name="ErrorFaultPart" element="music:ErrorFaultElement"/>
    </message>

    <portType name="musicPort">
        <operation name="getByComposer">
            <input message="music:getComposerRequest" />
            <output message="music:trackDetailList" />
            <fault name="ErrorFault" message="music:ErrorFault" />
        </operation>
        <operation name="getByDisc">
            <input message="music:getByDiscRequest" />
            <output message="music:trackDetailList" />
            <fault name="ErrorFault" message="music:ErrorFault" />
        </operation>
    </portType>

    <binding name="musicBinding" type="music:musicPort">
        <soap:binding style="rpc"
transport="http://schemas.xmlsoap.org/soap/http"/>

        <operation name="getByComposer">
            <soap:operation soapAction=""/>
            <input>
                <soap:body use="literal" namespace="urn:musicBinding"
                encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" />
            </input>
            <output>
                <soap:body use="literal" namespace="urn:musicBinding"
                encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" />
            </output>
            <fault name="ErrorFault">
                <soap:body use="literal" namespace="urn:musicBinding"
                    encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" />
            </fault>
```

```
        </operation>

        <operation name="getByDisc">
            <soap:operation soapAction=""/>
            <input>
                <soap:body use="literal" namespace="urn:musicBinding"
                encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"/>
            </input>
            <output>
                <soap:body use="literal" namespace="urn:musicBinding"
                encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"/>
            </output>
            <fault name="ErrorFault">
                <soap:body use="literal" namespace="urn:musicBinding"
                    encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" />
            </fault>
        </operation>
    </binding>

    <service name="MusicService">
        <port name="MusicPort" binding="music:musicBinding">
            <soap:address
location="http://127.0.0.1:8080/axis2/services/MusicService"/>
        </port>
    </service>
</definitions>
```

SOAP

Introduction

- Simple Object Access Protocol
- Not a programming language!
- A structured XML message format
- A protocol for exchanging messages
- An encoding scheme for representing data types in those messages
- Uses an underlying transport protocol (HTTP, SMTP etc) through binding

- SOAP provides platform neutral:
  - Message and Information exchanging
  - Invocation of remote functionality
- SOAP enables:
  - Distributed applications
  - Business-to-Business integration
  - Web Services
- SOAP version 1.2

    - W3C Recommendation (standard), April 2007
    - From XML Protocol Working Group
    - http://www.w3.org/TR/soap/

Why SOAP

- Many applications communicate using Remote Procedure Calls (RPC) between objects like DCOM and CORBA.
- RPC represents a compatibility and security problem; firewalls and proxy servers will normally block this traffic.
- A better way to communicate between applications is over HTTP, because HTTP is supported by all Internet browsers and servers. SOAP was created to accomplish this.
- SOAP provides a way to communicate between applications running on different operating systems, with different technologies and programming languages.

SOAP messages

- SOAP messages are
    - Stateless
    - One-way
    - Composable, e.g. WSDL operation types
        - One-way
        - Request-response
        - Solicit-response
        - Notification
    - Transferred between SOAP nodes (apps)

SOAP nodes

- SOAP Sender
    - Generates & sends the message
- SOAP Receiver
    - Ultimately receives and processes the message
    - May generate a SOAP response, message or fault as a result
- SOAP Intermediary
    - Zero or more
    - Receives, processes (e.g. routes) and resends the message

SOAP Intermediaries

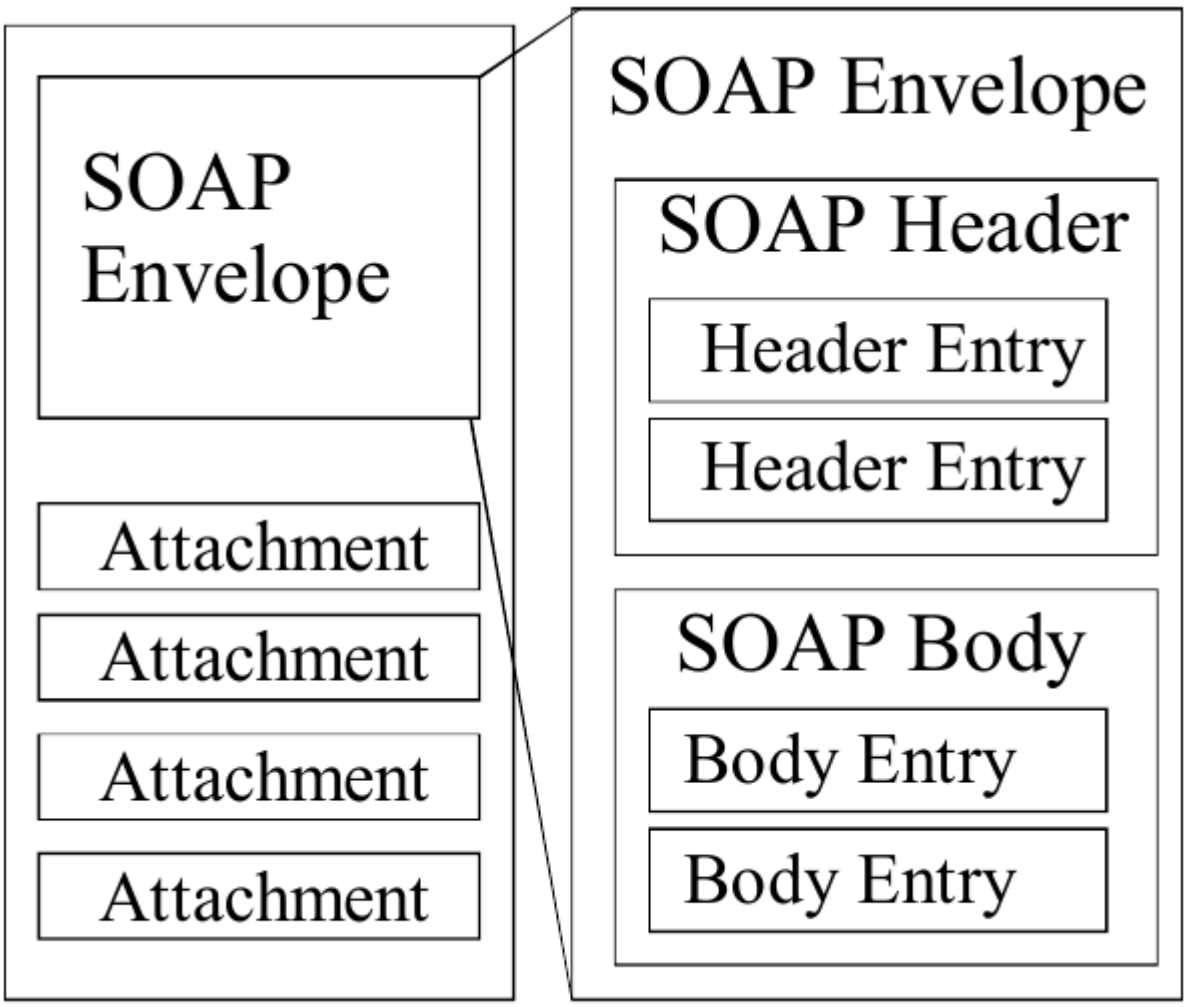
- Forwarding intermediaries
    - Uses and updates the SOAP header blocks to pass the message (body unchanged) on to the next node
- Active intermediaries
    - Perform additional processing on the SOAP message before sending

SOAP binding to Transport Protocol

- SOAP messages can be sent in many different ways
  - Over HTTP
  - Over HTTP/SSL
  - Over SMTP
- A binding specifies how SOAP messages are passed using an underlying transport protocol

SOAP Message structure

- Envelope
  - Identifies that this is a SOAP message.
- Header
  - Optional & application specific
  - Entries may be addressed to a particular SOAP node
- Body
  - Mandatory
  - Contains message “payload”



- Additional components:

- Faults
  - Details of what and where something went wrong
- Attachments
  - E.G. Binary Data (GIF, JPEG, MP3 etc)
  - Typically carried outside envelope
  - Uses Multipurpose Internet Mail Extensions (MIME)

SOAP Message

```
<?xml version="1.0"?>
<soap:Envelope xmlns:soap="http://www.w3.org/2001/12/soap-envelope"
soap:encodingStyle="http://www.w3.org/2001/12/soap-encoding">
    <soap:Header> ... ... </soap:Header>
    <soap:Body> ... ...
        <soap:Fault> ... ... </soap:Fault>
    </soap:Body>
</soap:Envelope>
```

- Note Namespace
- Encoding defines data types

SOAP Header

- attributes
  - soap:mustUnderstand

```
<soap:Header>
    <m:Trans xmlns:m="http://www.w3schools.com/transaction/"
soap:mustUnderstand="1">234 </m:Trans>
</soap:Header>
```

SOAP Body

- Request

```
<?xml version="1.0"?>
<soap:Envelope xmlns:soap="http://www.w3.org/2001/12/soap-envelope"
soap:encodingStyle="http://www.w3.org/2001/12/soap-encoding">
    <soap:Body>
        <m:GetPrice xmlns:m="http://www.w3schools.com/prices">
            <Item>Apples<Item>
        </m:GetPrice>
    </soap:Body>
</soap:Envelope>
```

- Response

```xml
<?xml version="1.0"?>
<soap:Envelope xmlns:soap="http://www.w3.org/2001/12/soap-envelope"
soap:encodingStyle="http://www.w3.org/2001/12/soap-encoding">
    <soap:Body>
        <m:GetPriceResponse xmlns:m="http://www.w3schools.com/prices">
            <Price>1.90</Price>
        </m:GetPriceResponse>
    </soap:Body>
</soap:Envelope>

```

SOAP Faults

- Fault elements consists of:
  - `<faultcode>` A code for identifying the fault
  - `<faultstring>` A human readable explanation of the fault
  - `<faultactor>` Information on who caused the fault to happen
  - `<detail>` Application specific error information related to the Body element
- Fault codes
  - VersionMismatch: Found an invalid namespace for the SOAP Element
  - MustUnderstand: An immediate child element of the Header element, with the mustUnderstand attribute set to "1", was not understood
  - Client: Message was incorrectly formed or contained incorrect information
  - Server: Problem with the server, the message could not proceed

Communication

- SOAP provides two communication models
- SOAP RPC
  - Synchronous request-response
  - Request encodes method & arguments
  - Response encodes result value or fault
- SOAP Messaging (document)
  - Document-driven: XML
  - Normal XML description e.g. of products can be sent
  - No reference to operation names
  - Operations must have a single element
  - Confusion: Synchronous and/or asynchronous messaging

SOAP RPC

- The Request body describes
  - The name of the method to invoke
  - Optional arguments to pass to that method
- Includes the WSDL operation
- Parameters are based on WSDL types

- WSDL operations can include one or more parts
- May be identified by order and/or by name
- The Response body describes
  - The return value(s) from the method or
  - SOAP fault

SOAP Message (document)

- Each message body is an XML document or “literal XML”
  - can be validated against pre-defined XML schema document
  - A body element type typically identifies the message type
  - And therefore how/by what it should be handled
- No Operation name in SOAP message
- Parts of a message are based on schema element definitions rather than WSDL types
- Operations have a single part

RPC vs Message

- RPC is function-centric
  - RPC has tight coupling between the message and the implementation
- Messaging is data-centric
  - Messaging has loose coupling between the message and the implementation

Data encoding

- Literals: XML fragments, defined in XML Schema
  - Commonly used in XML messaging scenarios
- Encoded values: defined in SOAP Encoding
  - A set of rules for representing data types (not supported in Axis2)
- Defines standard XML encoding for commonly observed programming language types
  - Simple types, Enumerations
  - Compound types, e.g. structs, objects
  - Arrays, References

Examples

- suppose a service supports an add operation that accepts two integers (i, j) and returns their sum; it may also report a ‘result too large’ fault

rpc/literal

```
<soap:Envelope>
    <soap:Body>
        <add>
            <i>12</i>
            <j>5</j>
        </add>
    </soap:Body>
</soap:Envelope>
```

```
<soap:Envelope>
    <soap:Body>
        <addResponse>
            <res>17</res>
        </addResponse>
    </soap:Body>
</soap:Envelope>

```

- request to add 12 to 5 defines arguments by name, and wraps them in the operation (add)
- response must be a data structure even if a simple type is being returned; conventionally this is the operation name with Response appended

```
<soap:Envelope>
    <soap:Body>
        <add>
            <operands>
                <i>12</i>
                <j>5</j>
            </operands>
        </add>
    </soap:Body>
</soap:Envelope>
```

```
<soap:Envelope>
    <soap:Body>
        <addResponse>
            <res>17</res>
        </addResponse>
    </soap:Body>
</soap:Envelope>
```

- request now wraps two parameters in an operands element inside the operation (add)
- response unchanged

Fault in rpc/literal

```
<soap:Envelope>
    <soap:Body>
        <soap:Fault>
            <soap:faultcode> soap:Sender</soap:faultcode>
            <soap:faultstring>Addition result too large</soap:faultstring>
            <soap:faultactor>http://aws.xyz.com/lists</soap:faultactor>
        </soap:Fault>
    </soap:Body>
</soap:Envelope>
```

Document /literal

- Same request
- Missing operation
- Must have single element as parameter

```
<soap:Envelope>
    <soap:Body>
        <operands>
            <i>12</i>
            <j>5</j>
        </operands>
    </soap:Body>
</soap:Envelope>
```

```
<soap:Envelope>
    <soap:Body>
        <res>17</res>
    </soap:Body>
</soap:Envelope>
```

rpc/encoded & document/encoded

- Broadly resemble their literal counterparts
- however, the encoded variants include explicit type information and may make use of multiRefs
- a multiRef is really intended for the case where there are multiple references to a value
- this might happen through structures sharing a value, or through a type referring to itself directly or indirectly (e.g. a linked list)
- a multiRef is like a separate value identified by an id where the value might have appeared, an href (hyper-reference) refers to the multiRef definition

Data encoding

- Literals: XML fragments, defined in XML Schema
    - Commonly used in XML messaging scenarios
- Encoded values: defined in SOAP Encoding
    - A set of rules for representing data types
    - Commonly used in RPC scenarios

- Defines standard XML encoding for commonly observed programming language types
  - Simple types, Enumerations
  - Compound types, e.g. structs, objects
  - Arrays, References
- Leads to the following combinations: RPC literal, RPC SOAP encoding, Document literal

Basic Example (Hello World)

```
public class SimpleHelloService {
    public String echoMsg(String arg) {
        return arg.toUpperCase();
    }
}
```

```
POST /axis2/services/helloWorldWS.helloWorldWSHttpSoap12Endpoint/ HTTP/1.1
Content-Type: application/soap+xml; charset=UTF-8; action="urn:echoMsg"
User-Agent: Axis2
Host: 139.153.254.167:8080
Transfer-Encoding: chunked
```

```
<?xml version='1.0‘ encoding='UTF-8‘ ?>
<soapenv:Envelope xmlns:soapenv="http://www.w3.org/2003/05/soap-envelope">
    <soapenv:Header/>
    <soapenv:Body>
        <ns1:echoMsg xmlns:ns1="http://ws.apache.org/axis2">
            <ns1:arg> Hello my world!! </ns1:arg>
        </ns1:echoMsg>
    </soapenv:Body>
</soapenv:Envelope>
```

SOAP Envelope

- `<Envelope>` is the root element of a SOAP message
  - Declared using the namespace: http://www.w3.org/2003/05/soap-envelope
  - Identifies that this is a SOAP message
- If `<Envelope>` is not the root element, or the namespace is not correct, a SOAP application will generate a fault

SOAP Header & Body

- The `<Header>` is optional, it may be used to extend a SOAP message for application specific reasons
- If present, the `<Header>` must be the first child of `<Envelope>`
- The `<Header>` can contain one or more entries, typical uses include:
  - Authentication/Security
  - Transaction management
- There is exactly one `<Body>`, a child of SOAP `<Envelope>`

- These are the “payload” of the message
  - RPC method and its parameters
  - Target application (receiver) specific data
  - SOAP fault for reporting errors/status

The Response

```
HTTP/1.1 200 OK
Server: Apache-Coyote/1.1
Content-Type: application/soap+xml; action="urn:echoMsgResponse";charset=UTF-8
Transfer-Encoding: chunked
Date: Sun, 24 Jan 2016 11:23:45 GMT\
```

```
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://www.w3.org/2003/05/soap-envelope">
    <soapenv:Body>
        <ns:echoMsgResponse xmlns:ns="http://ws.apache.org/axis2">
            <ns:return>
                HELLO MY WORLD!!
            </ns:return>
        </ns:echoMsgResponse>
    </soapenv:Body>
</soapenv:Envelope>
```

AddTwoNumbers examples

- Possible implementations for the Web service “AddTwoNumbers”
- All examples show SOAP messages transferred by HTTP (SOAP over HTTP)
- In each example the semantics of the messages are the same, but the implementation differs in:
  - The SOAP communication model used
  - The data type encoded used.
- Communication model: RPC; Data type encoding: Literal

RPC/literal

Request

```
POST /axis/services/AddNumbersServer HTTP/1.0
Content-Type: text/xml; charset=utf-8
Accept: application/soap+xml, application/dime
User-Agent: Axis/1.4
Host: localhost:8090
Cache-Control: no-cache
SOAPAction: “”
Content-Length: 362
```

```
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
    <soapenv:Body>`
        <ns1:addTwoNumbersOperation
xmlns:ns1="http://localhost:8080/axis/AddTwoNumbers">
            <a>4.0</a>
            <b>3.0</b>
        </ns1:addTwoNumbersOperation>
    </soapenv:Body>
</soapenv:Envelope>
```

Response

```
HTTP/1.1 200 OK
Cache-Control: no-cache
Content-Type: text/xml; charset=iso-8859-1
Content-Length: 365
Server: Jetty(6.1.5)
```

```
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
    <soapenv:Body>
        <ns1:AddTwoNumbersOperationResponse
xmlns:ns1="http://localhost:8080/axis/AddTwoNumbers">
            <answer>7.0</answer>
        </ns1:AddTwoNumbersOperationResponse>
    </soapenv:Body>
</soapenv:Envelope>
```

RPC/encoded

- Behaviour is the same but data types are encoded using SOAP encoding instead of literal encoding
- Communication model: RPC
- Data type encoding: SOAP encoding
- Type info is included in the message

Request – Payload

Version 1

```
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
    <soapenv:Body>
        <ns1:addTwoNumbersOperation
soapenv:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" xmlns:ns1="
http://localhost:8080/axis/AddTwoNumbers ">
            <a xsi:type=“xsd:float”>1.0</a>
            <b xsi:type=“xsd:float”>2.0</b>
        </ns1:addTwoNumbersOperation>
    </soapenv:Body>
</soapenv:Envelope>
```

Version 2

```
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <soapenv:Body>
        <ns1:addTwoNumbersOperation
soapenv:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" xmlns:ns1="
http://localhost:8080/axis/AddTwoNumbers ">
            <a href="#id0" />
            <b href="#id1" />
        </ns1:addTwoNumbersOperation>
        <multiRef id="id0" soapenc:root="0“
soapenv:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
xsi:type="xsd:float“ xmlns:soapenc="http://schemas.xmlsoap.org/soap/encoding/">
            1.0
        </multiRef>
        <multiRef id="id1" soapenc:root="0"
soapenv:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
xsi:type="xsd:float" xmlns:soapenc="http://schemas.xmlsoap.org/soap/encoding/">
            2.0
        </multiRef>
    </soapenv:Body>
</soapenv:Envelope>
```

Response - Payload

```xml
<?xml version="1.0" encoding="utf-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <soapenv:Body>
        <ns1:addTwoNumbersOperationResponse
soapenv:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" xmlns:ns1="
http://localhost:8080/axis/AddTwoNumbers ">
            <answer xsi:type="xsd:float">
                3.0
            </answer>
        </ns1:addTwoNumbersOperationResponse>
    </soapenv:Body>
</soapenv:Envelope>
```

Document/Literal

- Operation name specified in WSDL does not appear in the SOAP request. The operation is implied by the document being submitted.

Request Message

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
    <soapenv:Body>
        <ns1:addMessage xmlns:ns1="http://ws.apache.org/axis2">
            <ns1:a>4.0</ns1:a>
            <ns1:b>5.0</ns1:b>
        </ns1:addMessage>
    </soapenv:Body>
</soapenv:Envelope>
```

Response

```xml
<?xml version="1.0" encoding="utf-8" ?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
    <soapenv:Body>
        <ns1:answer xmlns:ns1="http://ws.apache.org/axis2">
            9.0
        </ns1:answer>
    </soapenv:Body>
</soapenv:Envelope>
```

RESTful services and Security

Introduction

- All the web services considered so far:

        - Use SOAP for communication with the service
        - Have service interfaces defined in WSDL
    - Some developers believe that the overheads and complexity of this kind of web service are undesirable
    - REST (Representational State Transfer) has been introduced more closely aligned with the original design of the web
    - Web contains resources
    - Resource is an item of interest, e.g. html pages, images
    - E.g. Amazon online store holds a resource for a new digital camera. Clients can access this resource at www.amazon.co.uk/canon/dslr
    - On clicking the link, a representation of the resource is returned to the client (canon_dslr.html). The representation places the client into a certain state
    - The result of the client traversing a hyperlink in canon_dslr.html is it access a second resource which places the client into a different state
    - Thus the client application transfers (changes) states with each resource representation downloaded
    - Consequently, the web is a REST system
    - You have been using REST services for some time!
    - Web servers support four basic methods collectively known as CRUD:
        - Create, supported by POST in HTTP
        - Read, supported by GET in HTTP
        - Update, supported by PUT in HTTP
        - Delete, supported by DELETE in HTTP
    - Of these, GET (used in ordinary web browsing) and POST (often used with forms) are the best-known
    - The four HTTP operations are sufficient to implement a wide variety of web services
    - A key idea in REST is that a URI should identify a resource on which operations can be performed, e.g.:
    - An online shop has stocks considered as a resource; the whole stocks might be identified by the URI www.shop.com/stocks
    - Each product is itself a resource within the overall stocks; one product might be identified by the URI www.shop.com/stocks/product4059
    - HTTP methods can then be used to create, read, update or delete the whole stocks or an individual product in stock
    - Like other web services, RESTful services normally send and receive XML documents (though this is not essential)
    - RESTful services are best suited for database type systems
    - Simple datatypes can be transmitted as part of the request URI (GET)
    - Complex datatypes can be transmitted as message payload (XML), but cannot be accessed with the GET message
    - Opinions are split on REST vs. SOAP; in fact it is possible to create web services that support both:

    - Major supporters of REST include del.icio.us, Flickr and Yahoo
    - Major supporters of SOAP include Google
    - Major companies supporting both include Amazon and eBay
- Several toolsets support REST, e.g.:
- Axis2 is a widely used tool for supporting both REST and SOAP messaging
- JDK (Java Development Kit, java.sun.com/javase) has packages (e.g. javax.xml, javax.xml.ws) that support XML in general and REST in particular
- JAX-WS (Java API for XML – Web Services, jax-ws.dev.java.net) defines an API for Java programs to use REST, also offers a REST-compatible application server called GlassFish
- Restlet (www.restlet.org) provides Java support for developing RESTful services

Parameters

A service like this cannot be accessed with HTTP GET:

```
public class Man {
    String name;
    int age;
    Address address
}
public String getName(Man man) { //doSomething}
```

But a service like the following can easily be accessed using HTTP GET:

```
public String getName(String id, int age) {//doSomething}
```

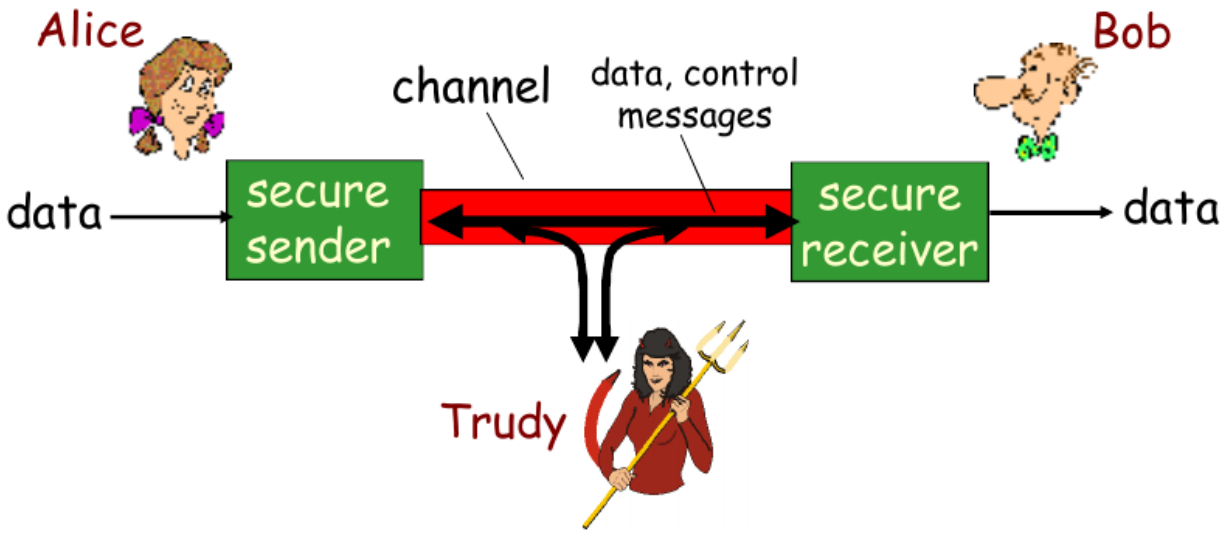
`http://ws.stir.ac.uk:8080/axis2/services/NameService/getName?id=Paul&age=10`

Requirements for web service security

- Security requirements are diverse, depending on the purpose of the web service application
    - Maybe not required at all
    - Full security for commercial operations
- Needs to be open and extensible
- Needs to be interoperable and work between different organisations
- Should leverage existing standards
- A family of related standards has been developed to address three major issues
- WS-Security (Web Services Security)
    - provides secure transfer over SOAP
- WS-Trust (Web Services Trust)
    - allows organisations to validate each other, and to develop chains of trust
- WS-SecureConversation (Web Services Secure Conversation)
    - uses security tokens to allow efficient encryption of messages
- Encryption for secure transfer of data must meet the following challenges:

        - eavesdropping on, interference with, and reply of messages
        - authentication of the communicating parties
        - non-repudiation (no denial) of messages having been sent
    - A widely used approach is based on PKI (Public Key Infrastructure)
    - Encryption and decryption use inverse algorithms that make encryption with the public key easy, but decryption without the private key very difficult
        - A receiver publishes a public key for messages it should receive
        - A sender uses this key to encrypt messages
        - A receiver also has a private key that it uses to efficiently decrypt messages
        - Although the public and private keys are related, it should be impracticable to determine the private key from the public key
    - Digital certificates are widely used to establish the authenticity of a party:
        - CA (Certificate Authority) issues parties with digital certificates that guarantee they are who they claim to be
        - For large-scale use, certificates are signed by chains of CAs starting from a root CA that everyone trusts (e.g. Thawte, Verisign)
        - Chain of trust might be Verisign, JISC (Joint Information Services Committee), University of Stirling, M. Kolberg
        - HTTPS, HTTP over SSL (Secure Sockets Layer), employs digital certificates for secure use of the web

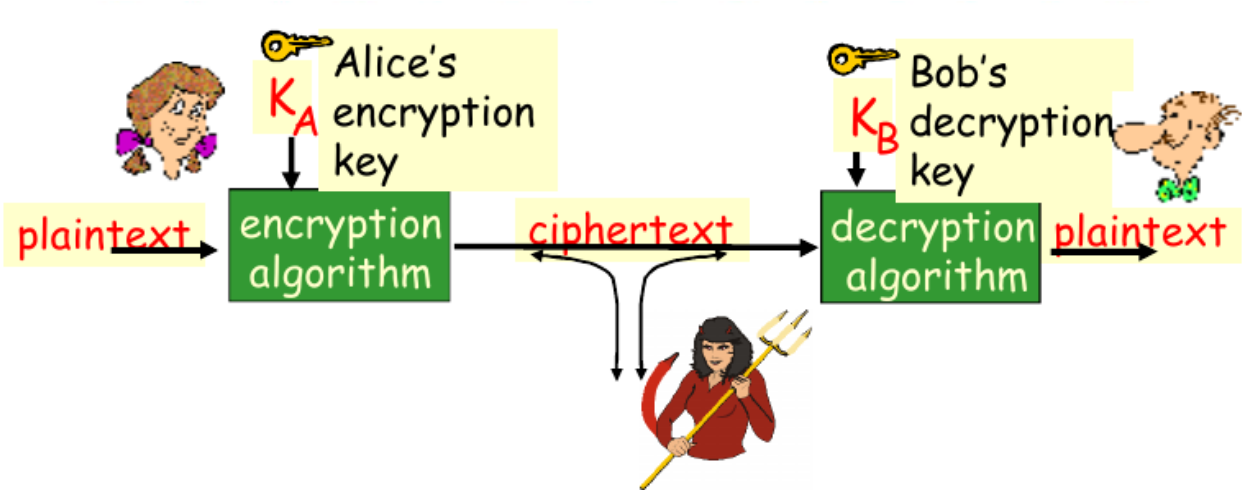
Case study



Q: What can a “bad guy” do? A: a lot!

- eavesdrop: intercept messages
- actively insert messages into connection
- impersonation: can fake (spoof) source address in packet (or any field in packet)
- hijacking: “take over” ongoing connection by removing sender or receiver, inserting himself in place
- denial of service: prevent service from being used by others (e.g., by overloading resources)

General Cryptography



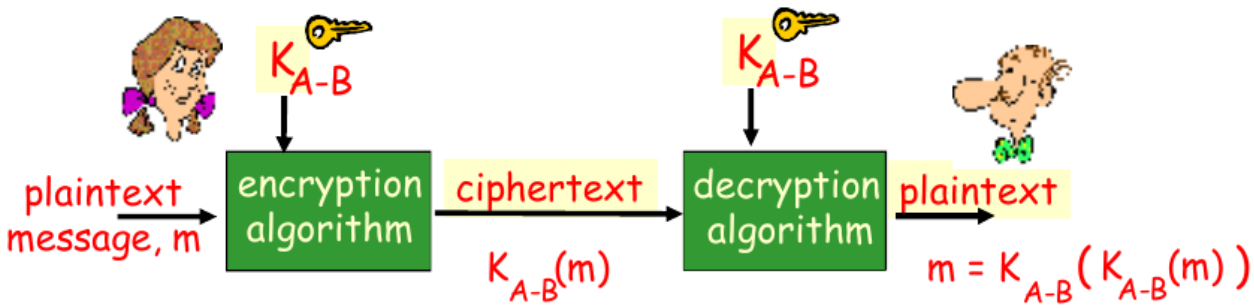
- symmetric key crypto: sender, receiver keys identical
- public-key crypto: encryption key public, decryption key secret (private)

Symmetric key cryptography

- substitution cipher: substituting one thing for another
  - monoalphabetic cipher: substitute one letter for another
  - E.g. add 3 to ASCII to encrypt, subtract 3 to decrypt
  - Encrypter and decrypter are the same (i.e. not “one-way”)
  - Fast! – good for bulk en/decryption
  - More complex algorithms & larger keys slow the process down, but increase security

```
plaintext: abcdefghijklmnopqrstuvwxyz
ciphertext: mnbvcxzasdfghjklpoiuytrewq

e.g.:
Plaintext: bob. i love you. Alice
ciphertext: nkn. s gktc wky. mgsbc
```

- Bob and Alice share know same (symmetric) key: K
  - E.g., key is knowing substitution pattern in mono alphabetic substitution cipher
  - How do Bob and Alice agree on key value?



Public Key cryptography

- symmetric key crypto
  - Requires sender, receiver know shared secret key

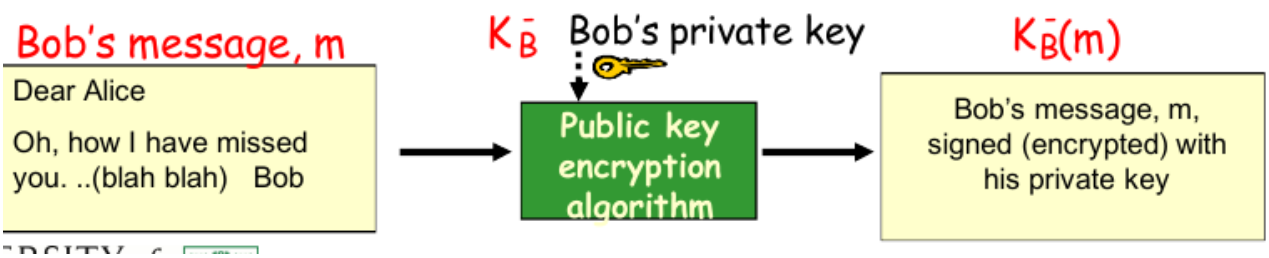
    - How to agree on key in first place (particularly if never “met”)?
- public key cryptography
    - radically different approach [Diffie-Hellman76, RSA78]
    - sender, receiver do not share secret key
    - public encryption key known to all
    - private decryption key known only to receiver
- Keys A and B are different & related □ cannot be derived from the other
- Either key may be used for encryption, only the other key can decrypt the message (encryption is one-way!)
    - $K_{BPRIV}(K_{BPUB}(m)) = m = K_{BPUB}(K_{BPRIV}(m))$
- If a message is decryptable by one key, it could only be have been encrypted using the other key – GUARANTEED!
- Very large key sizes are used
    - JSSE has RSA (Rivest, Shamir, Adelson algorithm) key scheme with 2048 bit keys
- Disadvantages: encryption and decryption are slow
    - Not useful for bulk data
    - But good for authentication and key agreement
- Usage:
    - Obtain a unique pair of keys
    - Keep private key private, make public key available on “who needs to know” basis

Confidentiality & Authentication

- A sends a message to B encrypted using B’s public key
    - Only B can decrypt using private key (confidentiality)
- B sends a message to A encrypted with B’s private key
    - Anyone who knows B public key can decrypt it (not confidential, but useful for authentication)

Message integrity – Digital Signatures

- Cryptographic technique analogous to hand-written signatures.
- Small piece of information added to a message
    - Bob digitally signs document (private key), establishing he is document owner/creator.
    - verifiable, nonforgeable: Alice can prove that Bob, and no one else, must have signed document (decrypting message using Bob’s public key)
    - Document was not damaged in transit (Bob signed m and not m’)
- Attacker can decrypt signature, but not create new, correct one

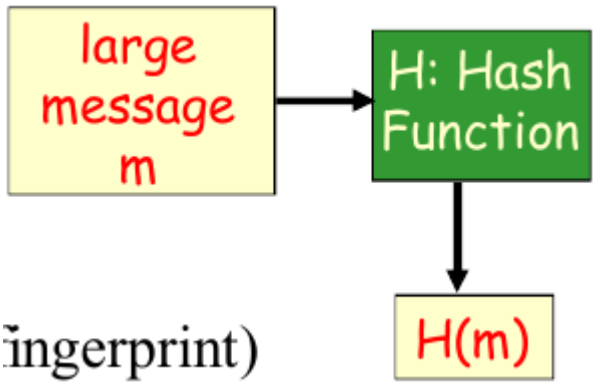


Message Digests

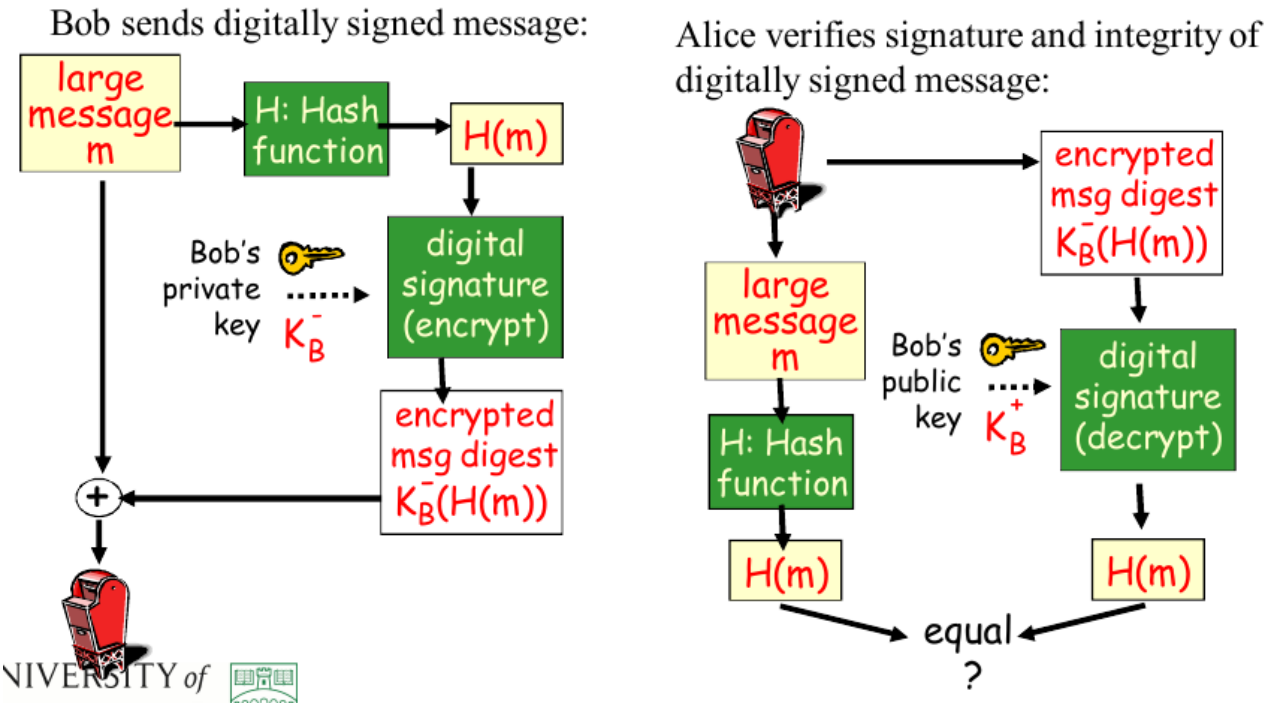
- Computationally expensive to encrypt long messages
- Goal: fixed-length, easy- to-compute digital “fingerprint”
- Apply hash function H to m, get fixed size message digest, H(m).

Hash function properties:

- many-to-1
- produces fixed-size message digest (fingerprint)
- given message digest x, computationally infeasible to find m such that $x = H(m)$



Signed message digest



Public Key Problem

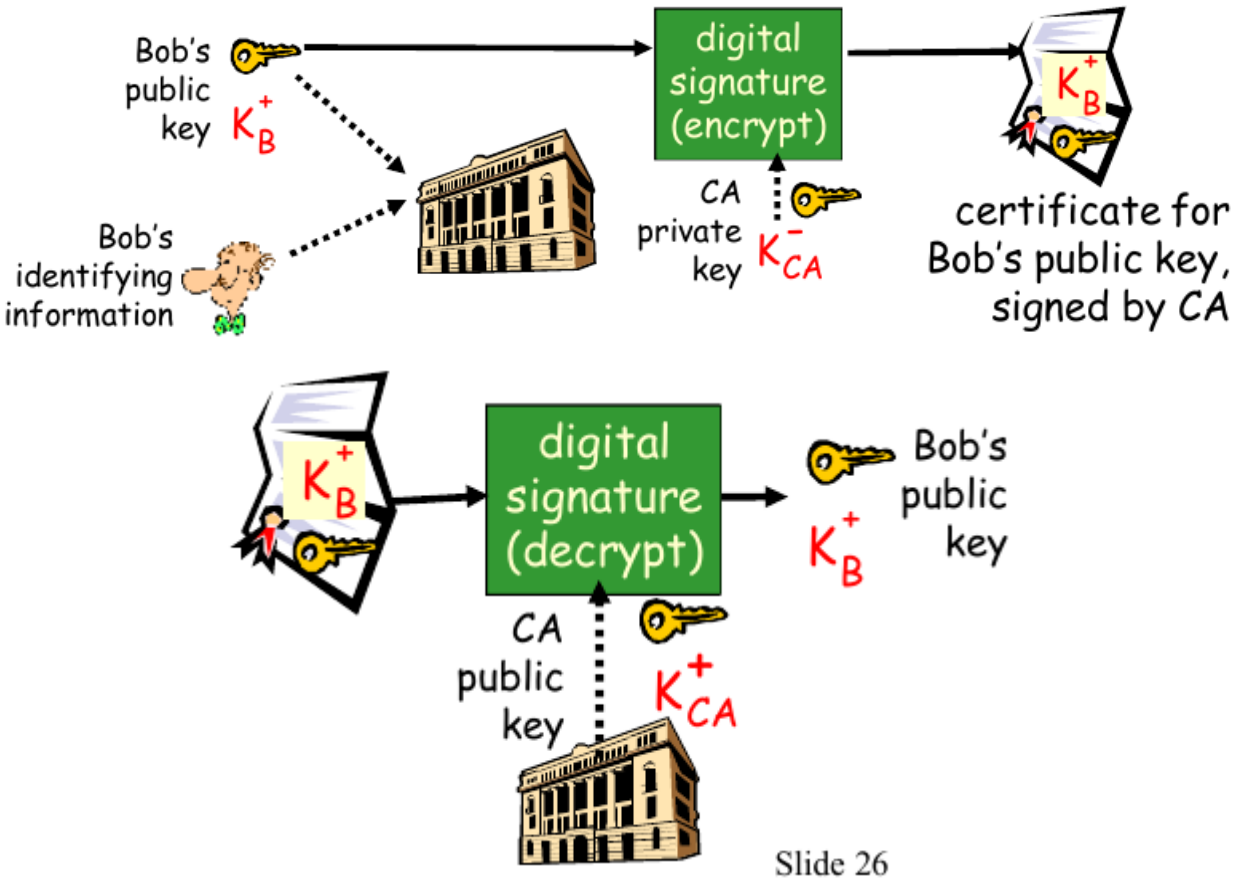
- When Alice obtains Bob’s public key (from web site, e-mail, diskette), how does she know it is Bob’s public key, not Trudy’s?

Solution:

- trusted certification authority (CA) which binds public key to particular entity, E.
- E (person, router) registers its public key with CA.
  - E provides “proof of identity” to CA.
  - CA creates certificate binding E to its public key.
  - certificate containing E’s public key digitally signed by CA – CA says “this is E’s public key”

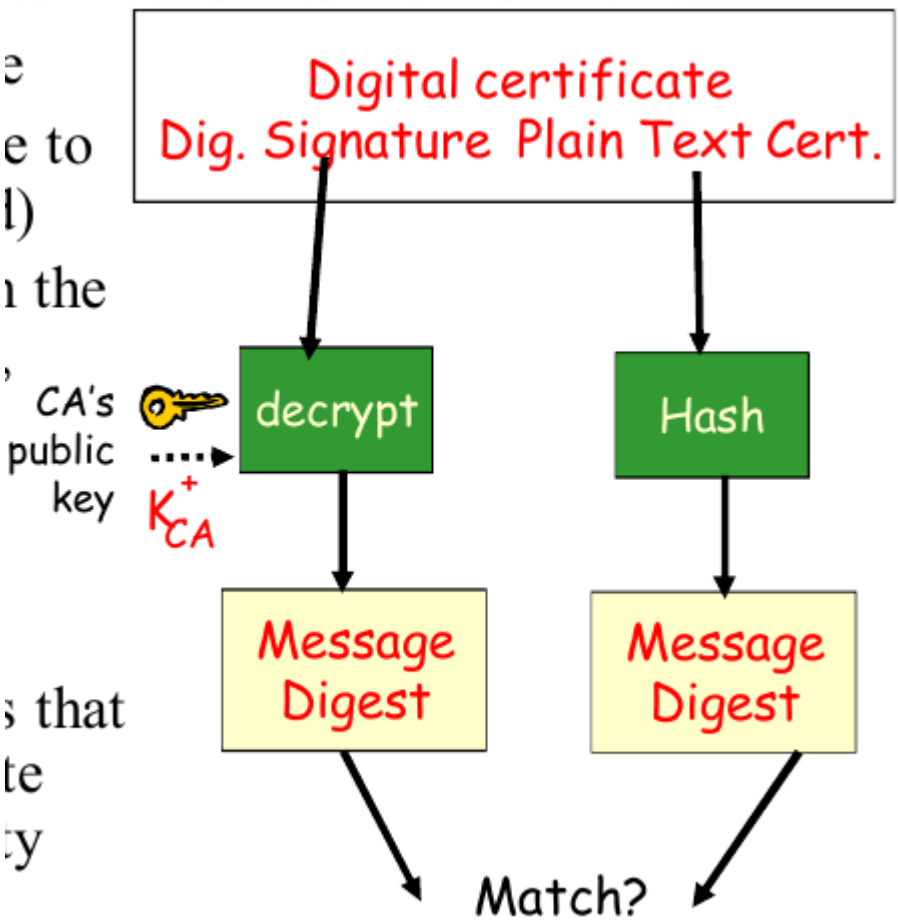
Digital Certificates

- When Alice wants Bob’s public key:
  - gets Bob’s certificate (Bob or elsewhere).
  - apply CA’s public key to Bob’s certificate, get Bob’s public key



Authentication

- Server holds digital certificate
- Server sends digital certificate to client (no encryption required)
- Client looks up CA’s name in the digital certificate and obtains, CA’s public key
- Client verifies the digital signature attached to the certificate
- Successful verification means that the public key in the certificate really does belong to the entity named in the certificate



The complete picture

- Finally we have a complete apparatus:
  - Connection
  - Server sends digital certificate
  - Client verifies digital certificate & extracts server's public key
  - Client chooses a new key for symmetric encryption
  - Client encrypts the new key with server's public key & sends it to server
  - Client and server both know the symmetric key and encrypt subsequent communications using it
- This is how Secure Socket Layer (SSL) works and the base for PKI

Past exam paper

1. The following outline Java class computes statistical measures of sample values: how many there are or their standard deviation. If the standard deviation of an empty list is requested, an exception with explanatory text is thrown. This question requires you to write the WSDL needed to call this class as a web service. Assume that all the WSDL definitions have namespace prefix meas (measures).

```java
import uk.ac.stir.cs.Statistics;

public class Measures {
    public int count(double[] values) {
        return(Statistics.getCount(values));
    }
    public double standardDeviation(double[] values) throws StatisticsException {
        return(Statistics.getStandardDeviation(values));
    }
}
```

- With reference to the class above, explain how the web service concepts of service, port and operation map onto Java. Although the rest of this question asks you to write the WSDL for this class, explain how Axis could be used to deploy it directly as a web service.
- Define the XML complex type values corresponding to the Java parameter used above. This should use a sequence of value elements with type double.
- Define the WSDL messages for this class: valuesMessage for inputs, countMessage and deviationMessage for outputs, and errorMessage for faults. Each will need one part.
- Define the WSDL port supported by this class: measuresPort that defines two operations. You do not need to define the port binding measuresBinding.
- Define the WSDL service supported by this class: MeasuresService with the corresponding port and SOAP address of your choice.

1. The Simple Object Access Protocol is widely used with web services.
    - Explain the sense in which you agree or disagree that SOAP is simple, deals with objects, supports access, and is a communications protocol.
    - Suppose a web service maintains a list of novels indexed by title. Among other capabilities, the service supports an analyse operation that is given a function to perform (e.g. words to count words) and a document title. For this function, the service returns the word count in the document. You have observed the following SOAP request and response messages:

```xml
<soap:Envelope>
    <soap:Body>
        <function xsi:type="xsd:string">words</function>
        <title xsi:type="xsd:string">
            A Tale of 2 Cities
        </title>
    </soap:Body>
</soap:Envelope>

<soap:Envelope>
    <soap:Body>
        <count xsi:type="xsd:integer">135842</count>
    </soap:Body>
</soap:Envelope>
```

      State what SOAP style and encoding this service uses, explaining your reasoning.
    - There are three other combinations of style and encoding that this service could use. For the example above, state how the SOAP messages would differ for these combinations. What purpose might these alternatives serve?

2. Representation State Transfer is also used as an alternative way of communicating with web services.
    - Suppose the same web service for novels is to be accessed using REST. Give a plausible interpretation of the DELETE, GET, POST and PUT operations for this service. Explain what format of URL might be used with these operations.
    - For this web service, what benefits might REST offer compared to SOAP? What limitations might REST have for this service? Could the same service make use of both REST and SOAP?