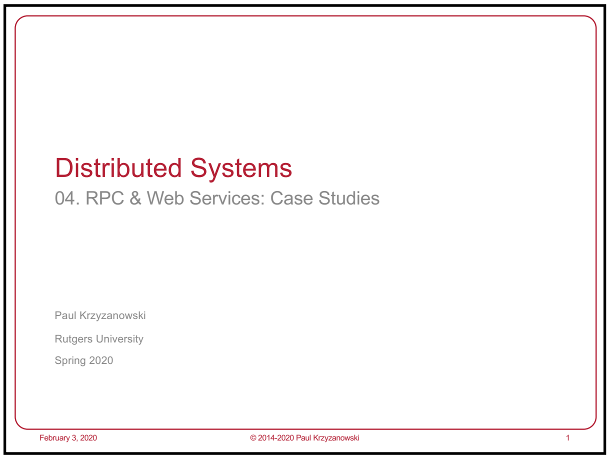

Distributed Systems

04. RPC & Web Services: Case Studies

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Spring 2020

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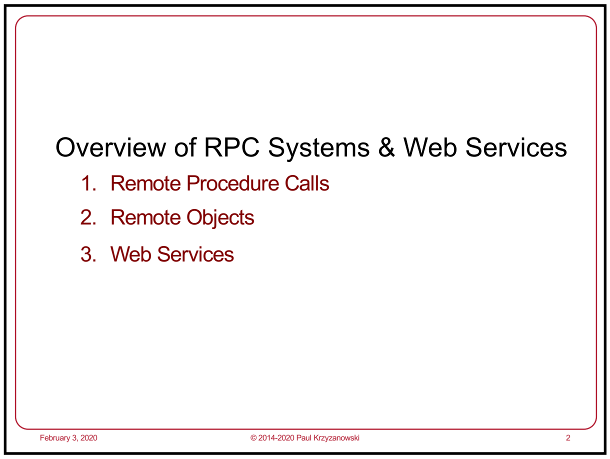
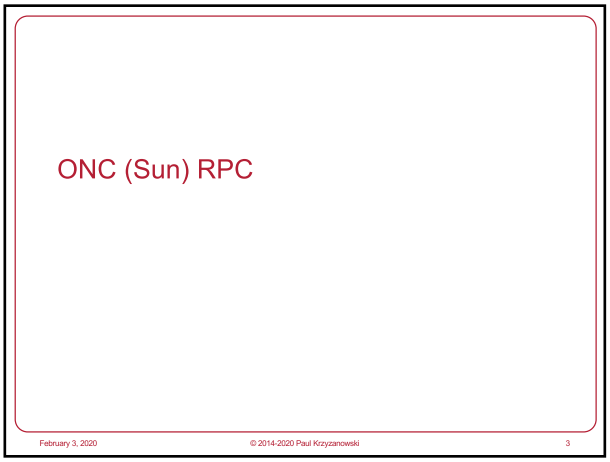


Overview of RPC Systems & Web Services

1. Remote Procedure Calls
2. Remote Objects
3. Web Services

2



ONC (Sun) RPC

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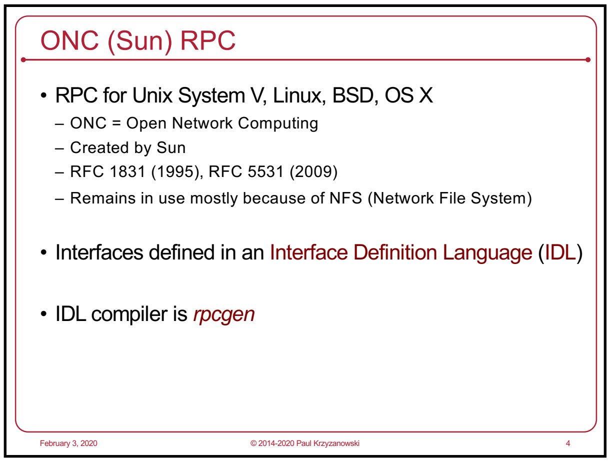

ONC (Sun) RPC

- RPC for Unix System V, Linux, BSD, OS X
  - ONC = Open Network Computing
  - Created by Sun
  - RFC 1831 (1995), RFC 5531 (2009)
  - Remains in use mostly because of NFS (Network File System)
- Interfaces defined in an Interface Definition Language (IDL)
- IDL compiler is *rpcgen*

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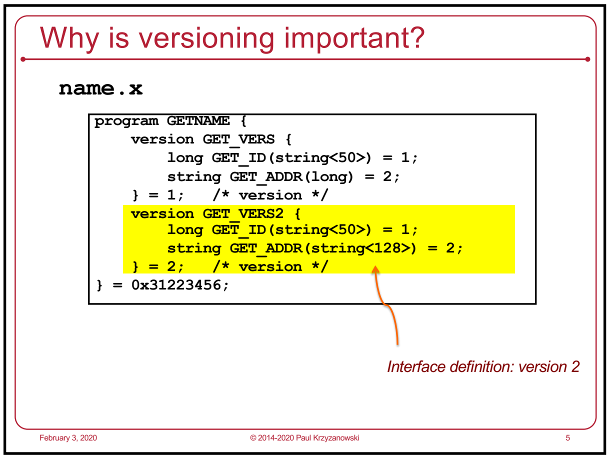

Why is versioning important?

name.x

```
program GETNAME {
    version GET_VERS {
        long GET_ID(string<50>) = 1;
        string GET_ADDR(long) = 2;
    } = 1;   /* version */
    version GET_VERS2 {
        long GET_ID(string<50>) = 1;
        string GET_ADDR(string<128>) = 2;
    } = 2;   /* version */
} = 0x31223456;
```

Interface definition: version 2

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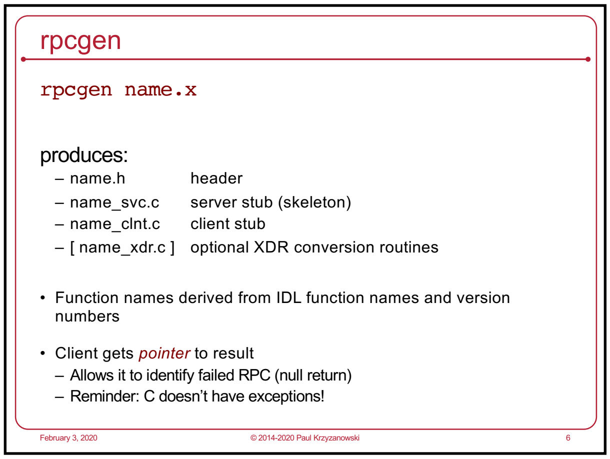

rpcgen

`rpcgen name.x`

produces:

– name.h	header
– name_svc.c	server stub (skeleton)
– name_clnt.c	client stub
– [name_xdr.c]	optional XDR conversion routines

- Function names derived from IDL function names and version numbers
- Client gets *pointer* to result
  - Allows it to identify failed RPC (null return)
  - Reminder: C doesn't have exceptions!

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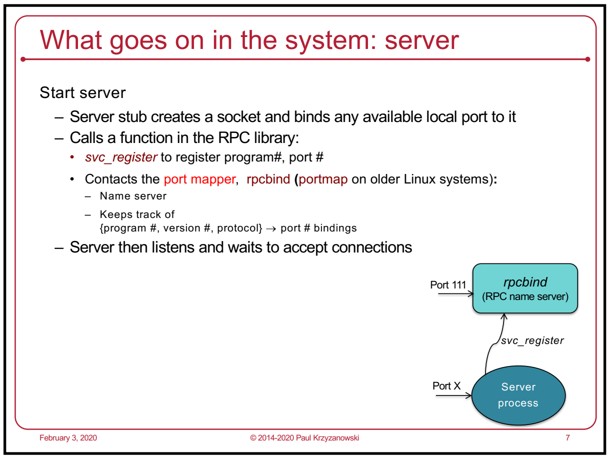

What goes on in the system: server

Start server

- Server stub creates a socket and binds any available local port to it
- Calls a function in the RPC library:
  - *svc_register* to register program#, port #
  - Contacts the port mapper, rpcbind (portmap on older Linux systems):
    - Name server
    - Keeps track of {program #, version #, protocol} → port # bindings
- Server then listens and waits to accept connections

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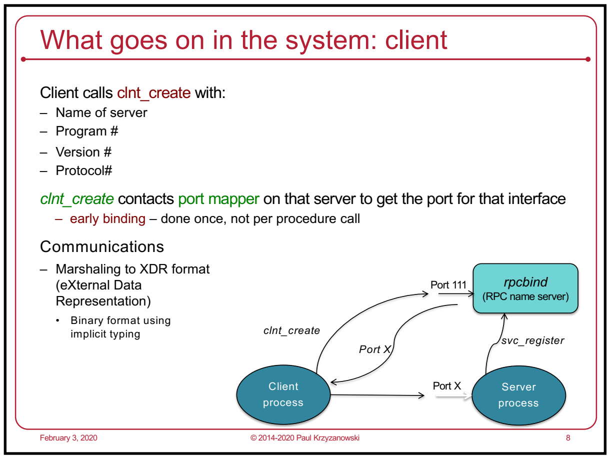

What goes on in the system: client

Client calls clnt_create with:

- Name of server
- Program #
- Version #
- Protocol#

clnt_create contacts port mapper on that server to get the port for that interface

- early binding – done once, not per procedure call

Communications

- Marshaling to XDR format (eXternal Data Representation)
  - Binary format using implicit typing

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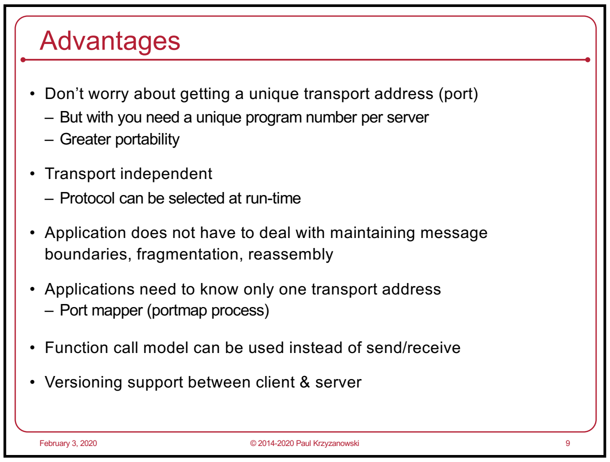

Advantages

- Don't worry about getting a unique transport address (port)
  - But with you need a unique program number per server
  - Greater portability
- Transport independent
  - Protocol can be selected at run-time
- Application does not have to deal with maintaining message boundaries, fragmentation, reassembly
- Applications need to know only one transport address
  - Port mapper (portmap process)
- Function call model can be used instead of send/receive
- Versioning support between client & server

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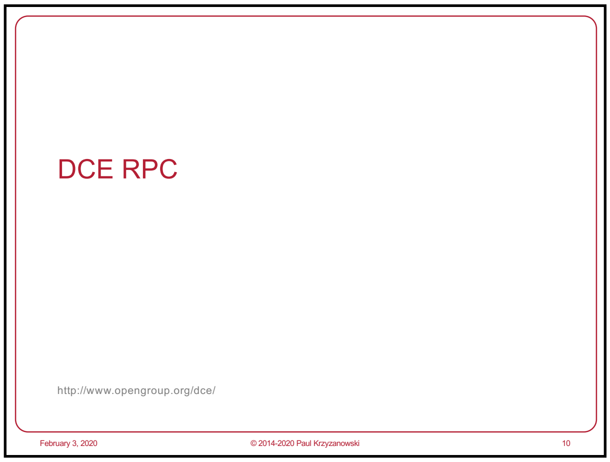

DCE RPC

http://www.opengroup.org/dce/

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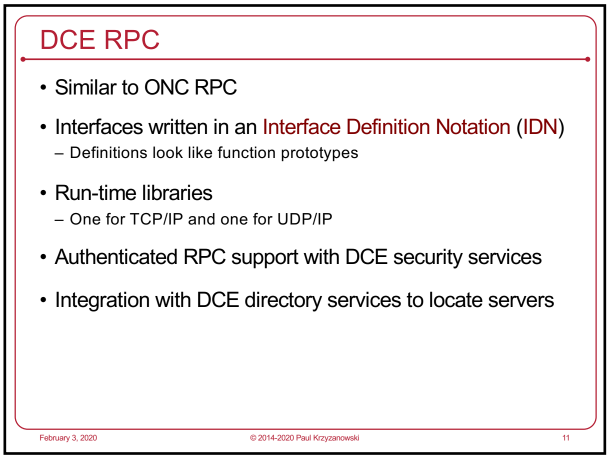

DCE RPC

- Similar to ONC RPC
- Interfaces written in an Interface Definition Notation (IDN)
  - Definitions look like function prototypes
- Run-time libraries
  - One for TCP/IP and one for UDP/IP
- Authenticated RPC support with DCE security services
- Integration with DCE directory services to locate servers

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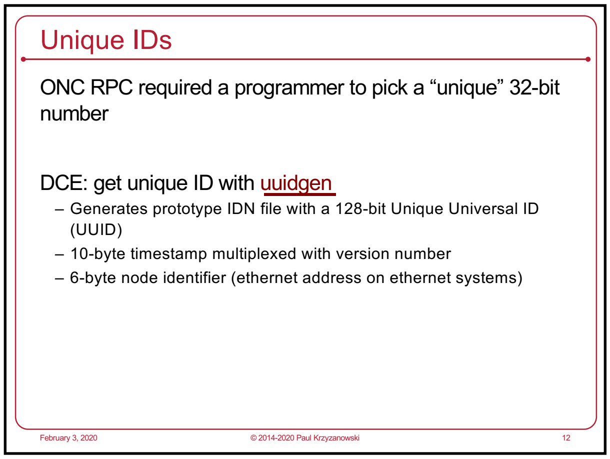

Unique IDs

ONC RPC required a programmer to pick a “unique” 32-bit number

DCE: get unique ID with uuidgen

- Generates prototype IDN file with a 128-bit Unique Universal ID (UUID)
- 10-byte timestamp multiplexed with version number
- 6-byte node identifier (ethernet address on ethernet systems)

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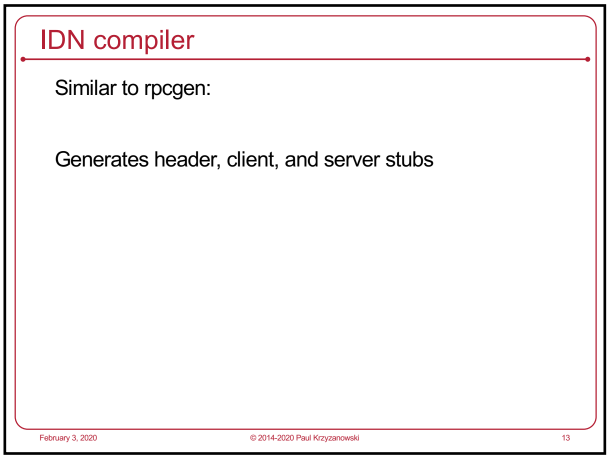

IDN compiler

Similar to rpcgen:

Generates header, client, and server stubs

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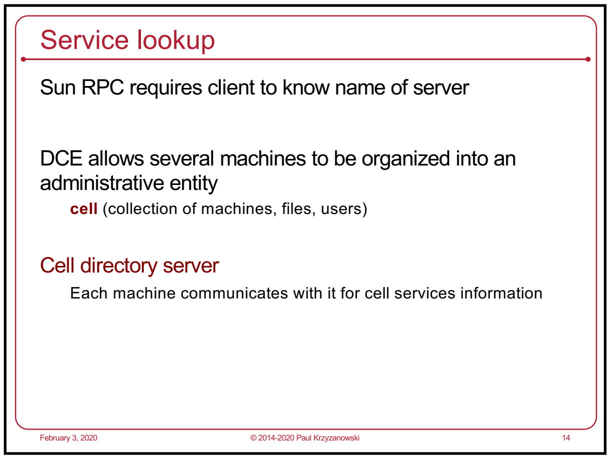

Service lookup

Sun RPC requires client to know name of server

DCE allows several machines to be organized into an administrative entity

cell (collection of machines, files, users)

Cell directory server

Each machine communicates with it for cell services information

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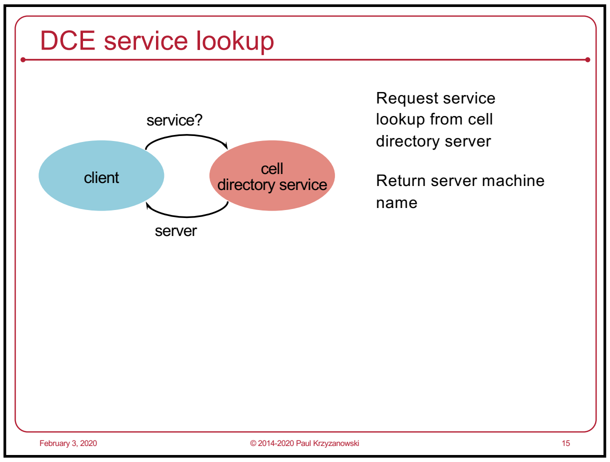

DCE service lookup

Request service lookup from cell directory server

Return server machine name

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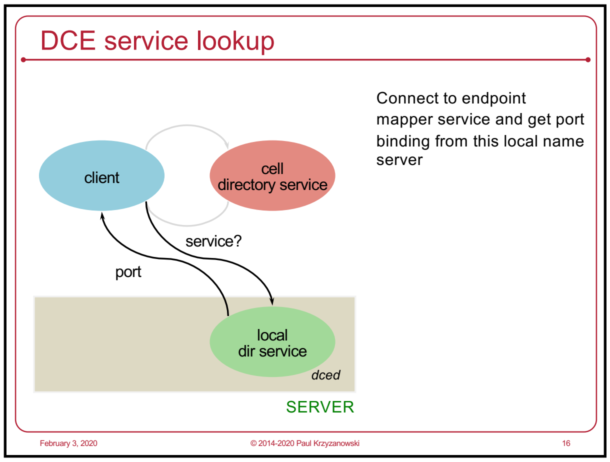

DCE service lookup

Connect to endpoint mapper service and get port binding from this local name server

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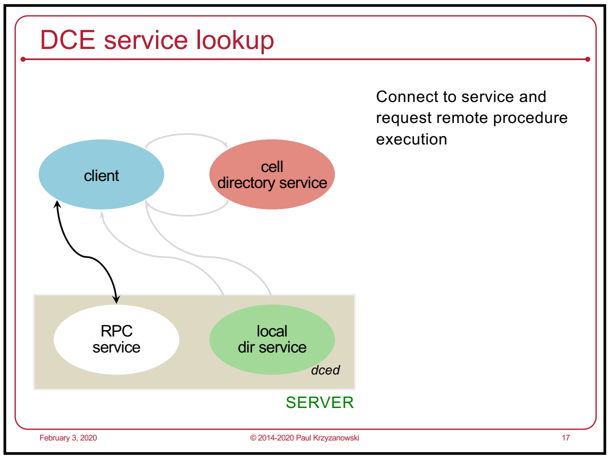

DCE service lookup

Connect to service and request remote procedure execution

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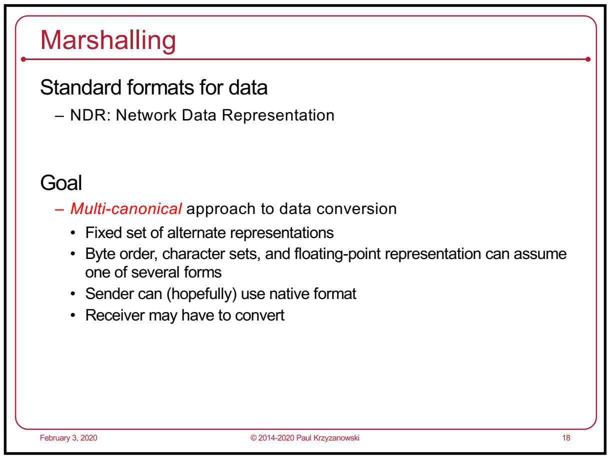

Marshalling

Standard formats for data

- NDR: Network Data Representation

Goal

- *Multi-canonical* approach to data conversion
  - Fixed set of alternate representations
  - Byte order, character sets, and floating-point representation can assume one of several forms
  - Sender can (hopefully) use native format
  - Receiver may have to convert

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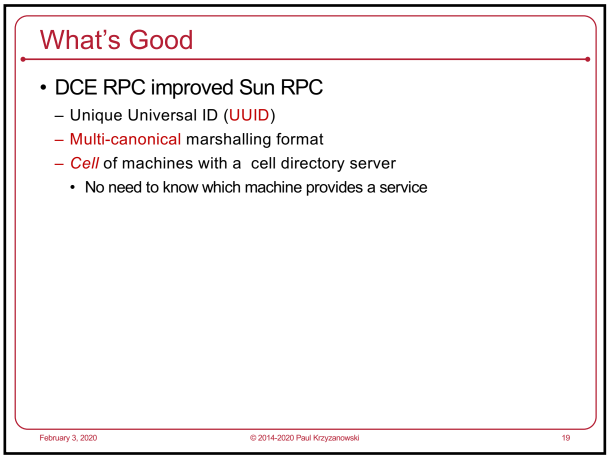

What's Good

- DCE RPC improved Sun RPC
  - Unique Universal ID (UUID)
  - Multi-canonical marshalling format
  - *Cell* of machines with a cell directory server
    - No need to know which machine provides a service

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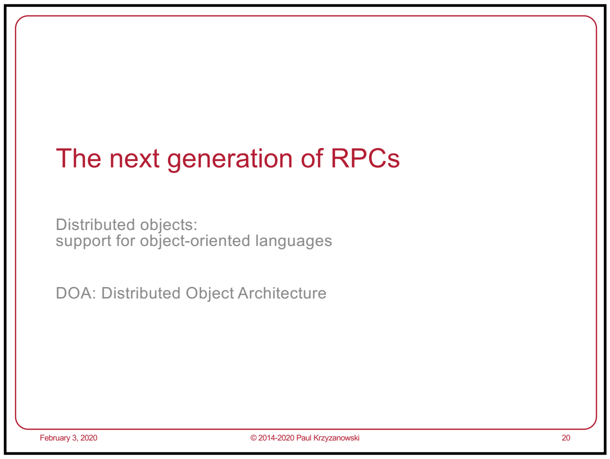

The next generation of RPCs

Distributed objects:
support for object-oriented languages

DOA: Distributed Object Architecture

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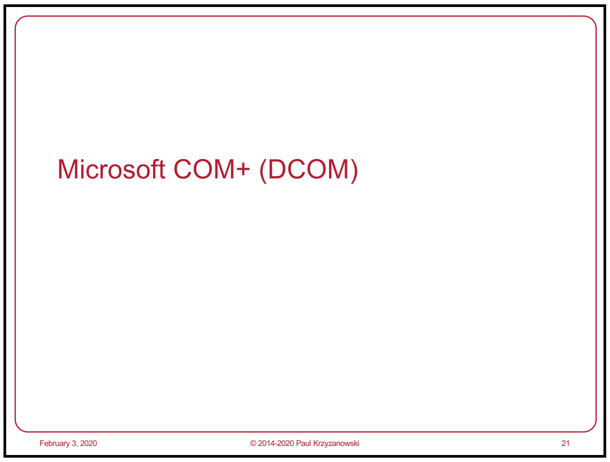

Microsoft COM+ (DCOM)

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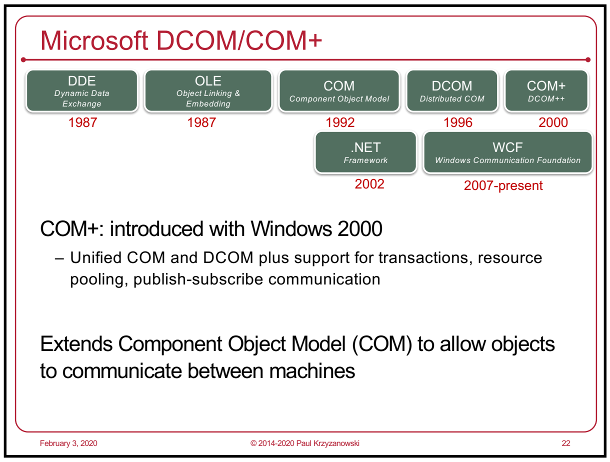

Microsoft DCOM/COM+

DDE
Dynamic Data Exchange
1987
OLE
Object Linking & Embedding
1987
COM
Component Object Model
1992
DCOM
Distributed COM
1996
COM+
DCOM++
2000
.NET
Framework
2002
WCF
Windows Communication Foundation
2007-present

COM+: introduced with Windows 2000

- Unified COM and DCOM plus support for transactions, resource pooling, publish-subscribe communication

Extends Component Object Model (COM) to allow objects to communicate between machines

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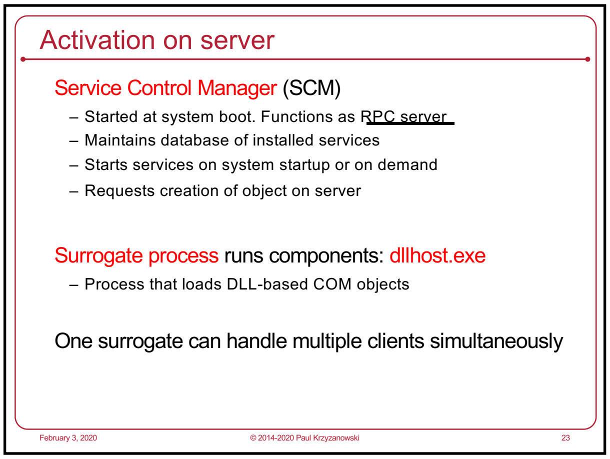

Activation on server

Service Control Manager (SCM)

- Started at system boot. Functions as RPC server
- Maintains database of installed services
- Starts services on system startup or on demand
- Requests creation of object on server

Surrogate process runs components: dllhost.exe

- Process that loads DLL-based COM objects

One surrogate can handle multiple clients simultaneously

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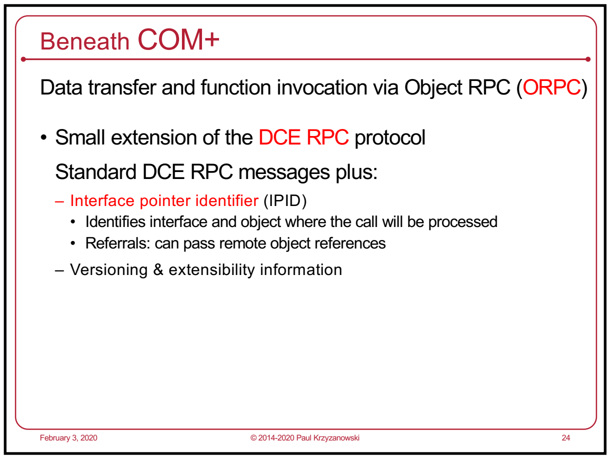

Beneath COM+

Data transfer and function invocation via Object RPC (ORPC)

- Small extension of the DCE RPC protocol

  Standard DCE RPC messages plus:
  - Interface pointer identifier (IPID)
    - Identifies interface and object where the call will be processed
    - Referrals: can pass remote object references
  - Versioning & extensibility information

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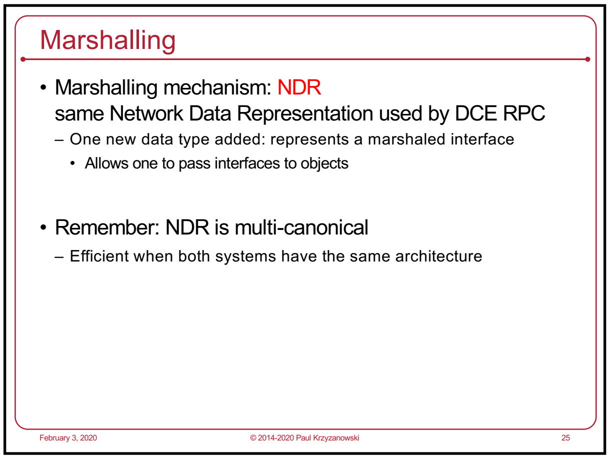

Marshalling

- Marshalling mechanism: NDR
  same Network Data Representation used by DCE RPC
  - One new data type added: represents a marshaled interface
    - Allows one to pass interfaces to objects
- Remember: NDR is multi-canonical
  - Efficient when both systems have the same architecture

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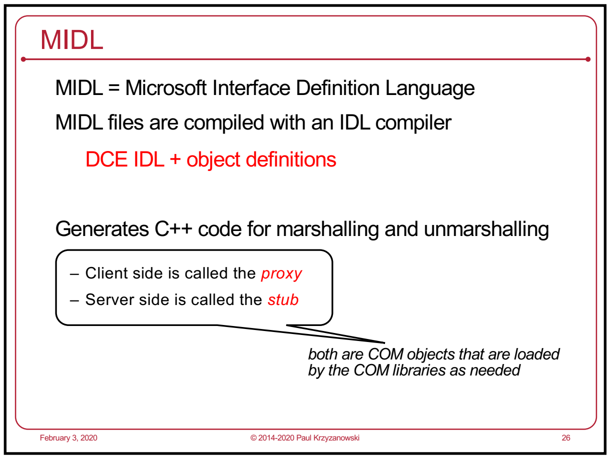

MIDL

MIDL = Microsoft Interface Definition Language

MIDL files are compiled with an IDL compiler

DCE IDL + object definitions

Generates C++ code for marshalling and unmarshalling

- Client side is called the *proxy*
- Server side is called the *stub*

both are COM objects that are loaded by the COM libraries as needed

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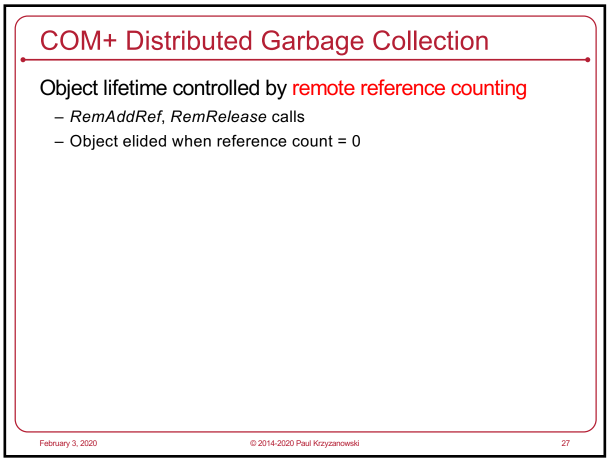

COM+ Distributed Garbage Collection

Object lifetime controlled by remote reference counting

- *RemAddRef*, *RemRelease* calls
- Object elided when reference count = 0

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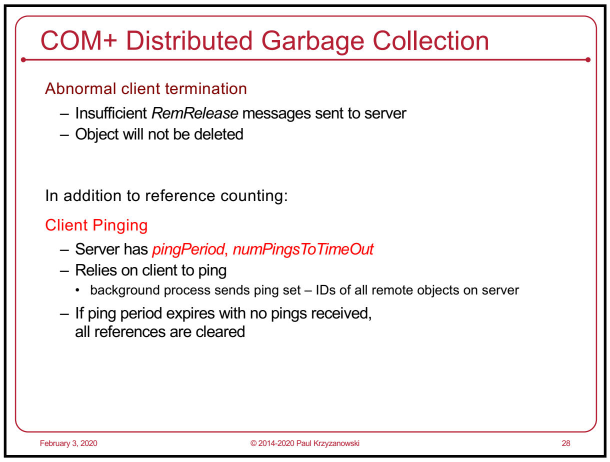

COM+ Distributed Garbage Collection

Abnormal client termination

- Insufficient *RemRelease* messages sent to server
- Object will not be deleted

In addition to reference counting:

Client Pinging

- Server has *pingPeriod, numPingsToTimeOut*
- Relies on client to ping
  - background process sends ping set – IDs of all remote objects on server
- If ping period expires with no pings received,
  all references are cleared

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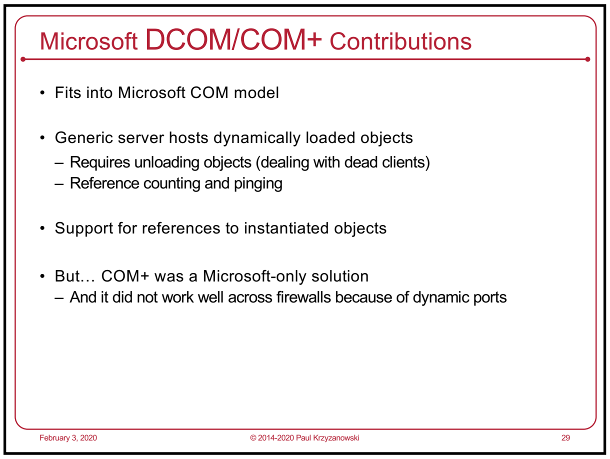

Microsoft DCOM/COM+ Contributions

- Fits into Microsoft COM model
- Generic server hosts dynamically loaded objects
  - Requires unloading objects (dealing with dead clients)
  - Reference counting and pinging
- Support for references to instantiated objects
- But… COM+ was a Microsoft-only solution
  - And it did not work well across firewalls because of dynamic ports

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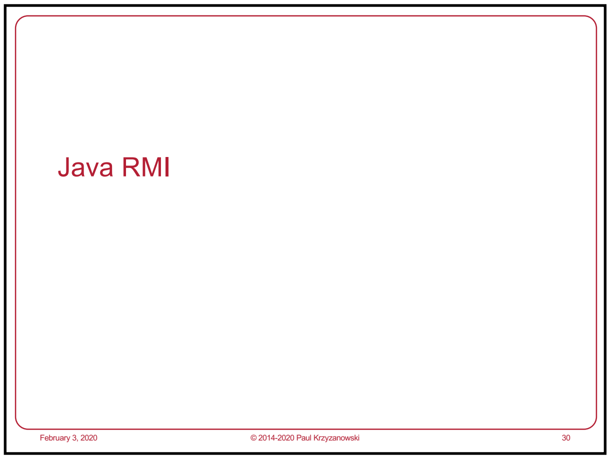

Java RMI

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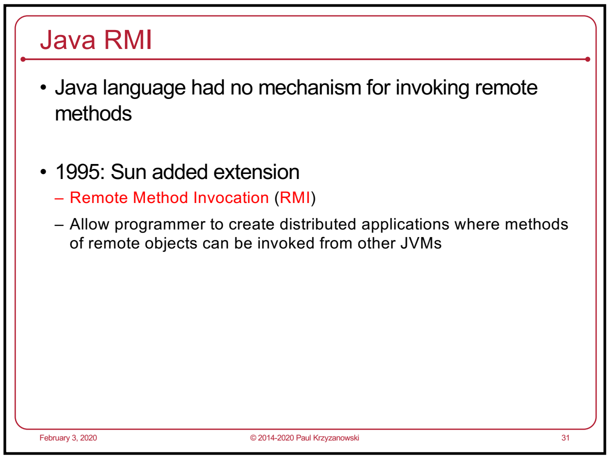

Java RMI

- Java language had no mechanism for invoking remote methods
- 1995: Sun added extension
  - Remote Method Invocation (RMI)
  - Allow programmer to create distributed applications where methods of remote objects can be invoked from other JVMs

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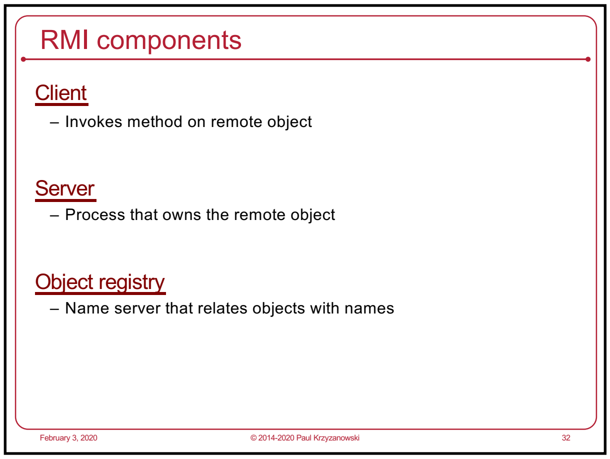

RMI components

Client

- Invokes method on remote object

Server

- Process that owns the remote object

Object registry

- Name server that relates objects with names

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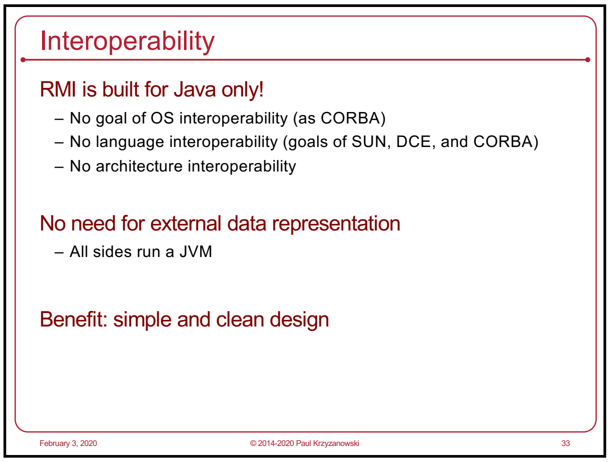

Interoperability

RMI is built for Java only!

- No goal of OS interoperability (as CORBA)
- No language interoperability (goals of SUN, DCE, and CORBA)
- No architecture interoperability

No need for external data representation

- All sides run a JVM

Benefit: simple and clean design

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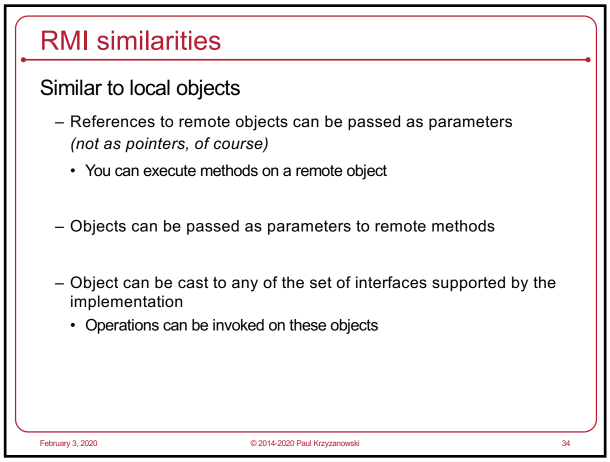

RMI similarities

Similar to local objects

- References to remote objects can be passed as parameters *(not as pointers, of course)*
  - You can execute methods on a remote object
- Objects can be passed as parameters to remote methods
- Object can be cast to any of the set of interfaces supported by the implementation
  - Operations can be invoked on these objects

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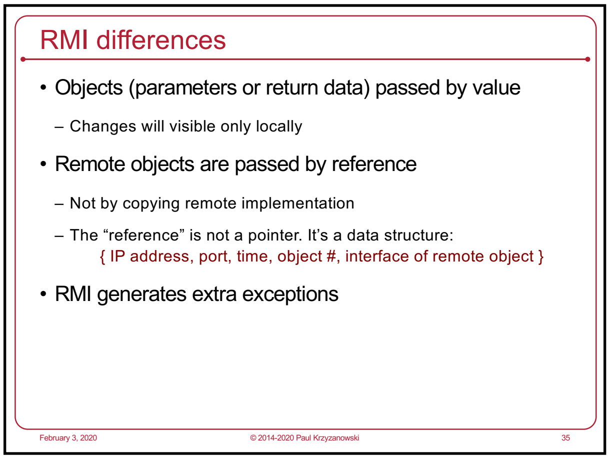

RMI differences

- Objects (parameters or return data) passed by value
  - Changes will visible only locally
- Remote objects are passed by reference
  - Not by copying remote implementation
  - The “reference” is not a pointer. It’s a data structure:
    { IP address, port, time, object #, interface of remote object }
- RMI generates extra exceptions

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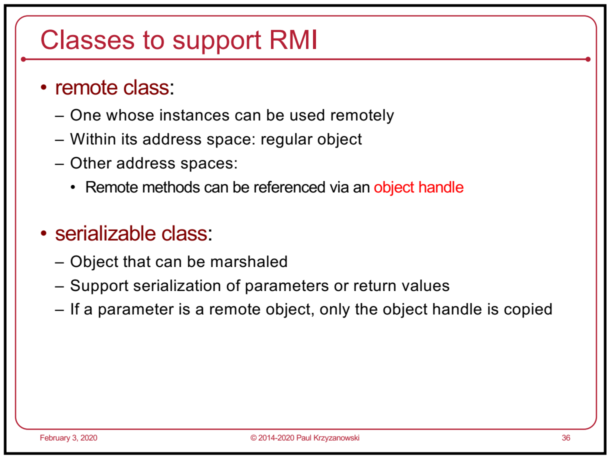

Classes to support RMI

- remote class:
  - One whose instances can be used remotely
  - Within its address space: regular object
  - Other address spaces:
    - Remote methods can be referenced via an object handle
- serializable class:
  - Object that can be marshaled
  - Support serialization of parameters or return values
  - If a parameter is a remote object, only the object handle is copied

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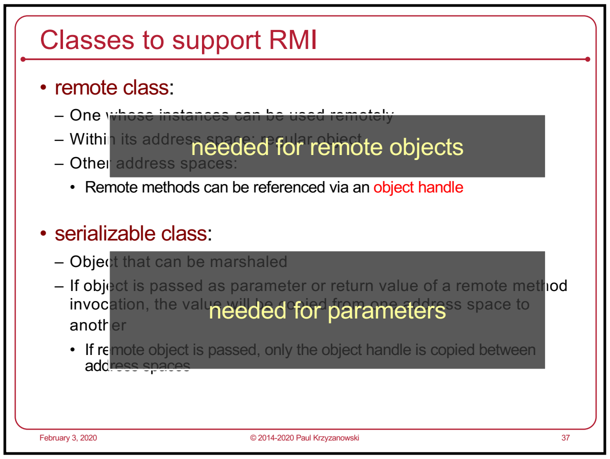

Classes to support RMI

- remote class:
  - One whose instances can be used remotely
  - Within its address space: regular object
  - Other address spaces:
    - Remote methods can be referenced via an object handle

needed for remote objects

- serializable class:
  - Object that can be marshaled
  - If object is passed as parameter or return value of a remote method invocation, the value will be copied from one address space to another
    - If remote object is passed, only the object handle is copied between address spaces

needed for parameters

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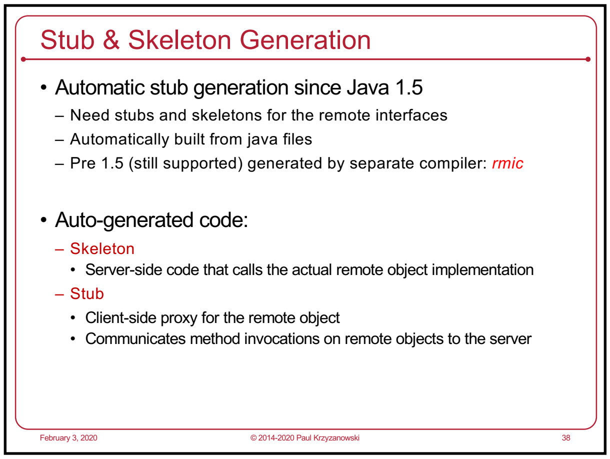

Stub & Skeleton Generation

- Automatic stub generation since Java 1.5
  - Need stubs and skeletons for the remote interfaces
  - Automatically built from java files
  - Pre 1.5 (still supported) generated by separate compiler: *rmic*

- Auto-generated code:
  - Skeleton
    - Server-side code that calls the actual remote object implementation
  - Stub
    - Client-side proxy for the remote object
    - Communicates method invocations on remote objects to the server

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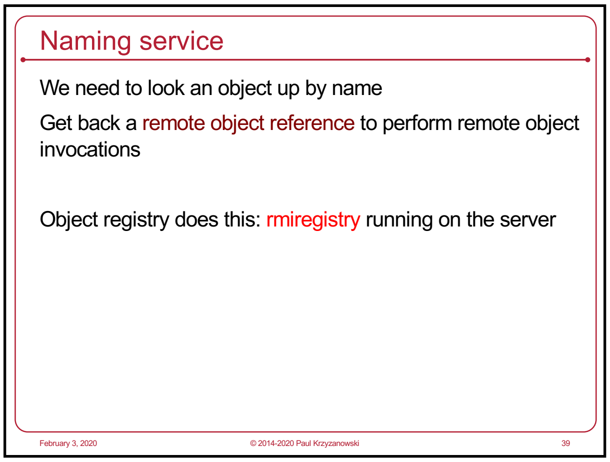

Naming service

We need to look an object up by name

Get back a remote object reference to perform remote object invocations

Object registry does this: rmiregistry running on the server

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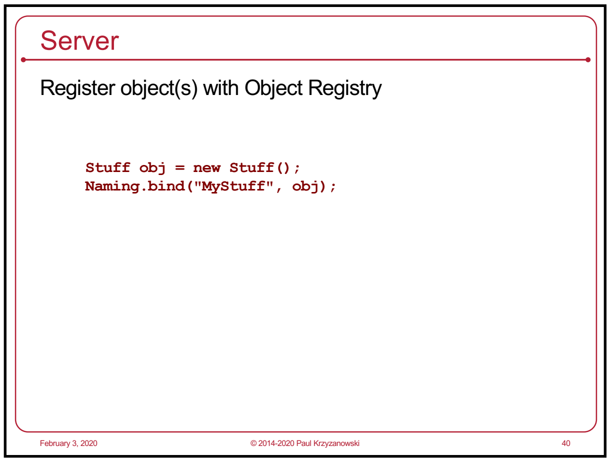

Server

Register object(s) with Object Registry

```
Stuff obj = new Stuff();
Naming.bind("MyStuff", obj);
```

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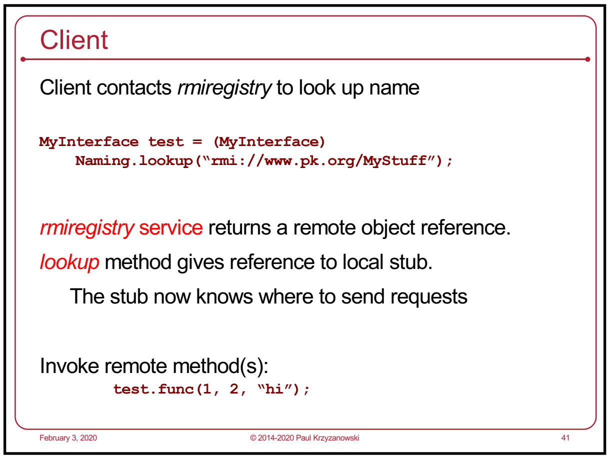

Client

Client contacts *rmiregistry* to look up name

```
MyInterface test = (MyInterface)
    Naming.lookup("rmi://www.pk.org/MyStuff");
```

rmiregistry service returns a remote object reference.

lookup method gives reference to local stub.

The stub now knows where to send requests

Invoke remote method(s):

```
        test.func(1, 2, "hi");
```

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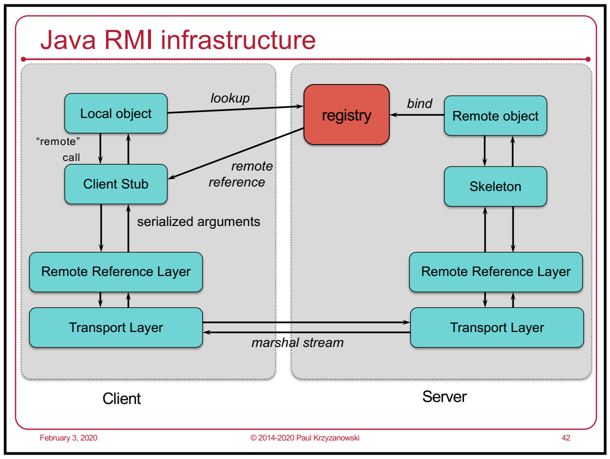

Java RMI infrastructure

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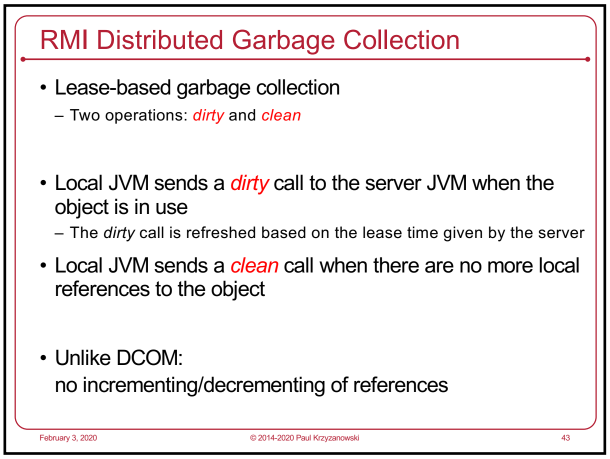

RMI Distributed Garbage Collection

- Lease-based garbage collection
  - Two operations: *dirty* and *clean*
- Local JVM sends a *dirty* call to the server JVM when the object is in use
  - The *dirty* call is refreshed based on the lease time given by the server
- Local JVM sends a *clean* call when there are no more local references to the object
- Unlike DCOM:
  no incrementing/decrementing of references

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Web Services

From RPC to Web Services

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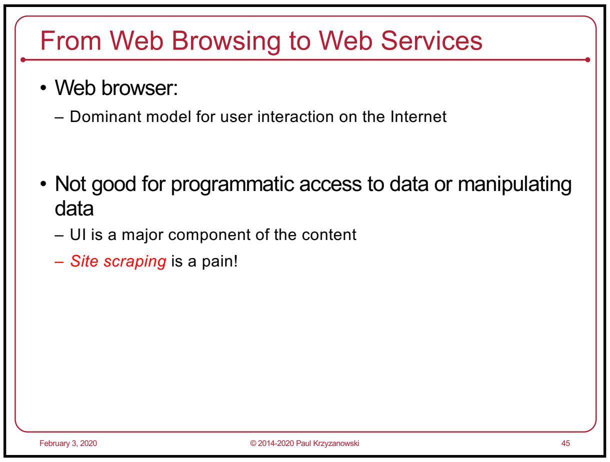

From Web Browsing to Web Services

- Web browser:
  - Dominant model for user interaction on the Internet
- Not good for programmatic access to data or manipulating data
  - UI is a major component of the content
  - *Site scraping* is a pain!

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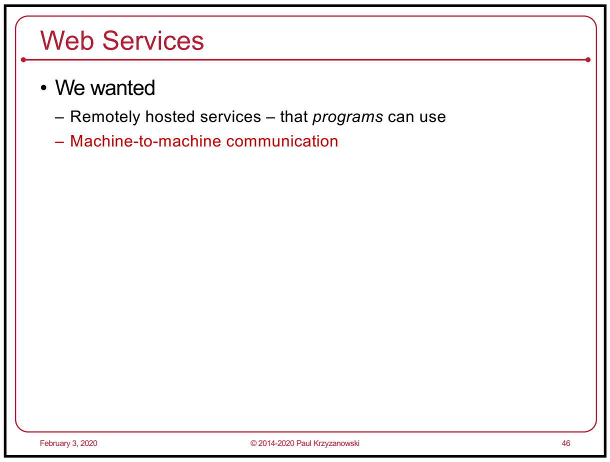

Web Services

- We wanted
  - Remotely hosted services – that *programs* can use
  - Machine-to-machine communication

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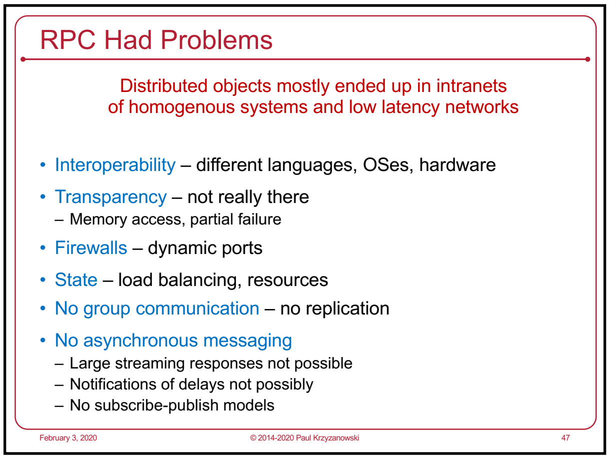

RPC Had Problems

Distributed objects mostly ended up in intranets of homogenous systems and low latency networks

- Interoperability – different languages, OSes, hardware
- Transparency – not really there
  - Memory access, partial failure
- Firewalls – dynamic ports
- State – load balancing, resources
- No group communication – no replication
- No asynchronous messaging
  - Large streaming responses not possible
  - Notifications of delays not possibly
  - No subscribe-publish models

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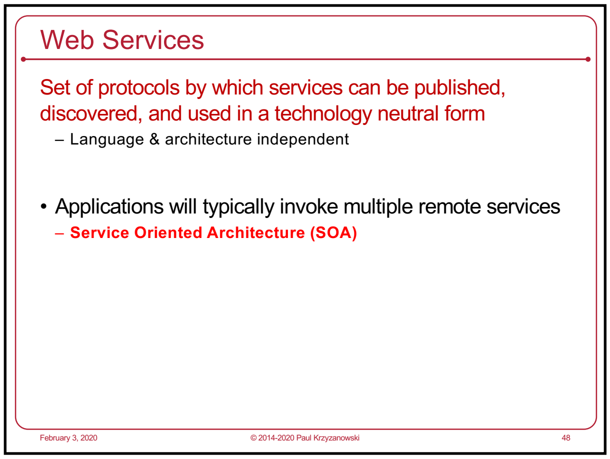

Web Services

Set of protocols by which services can be published, discovered, and used in a technology neutral form

- Language & architecture independent

- Applications will typically invoke multiple remote services
  - **Service Oriented Architecture (SOA)**

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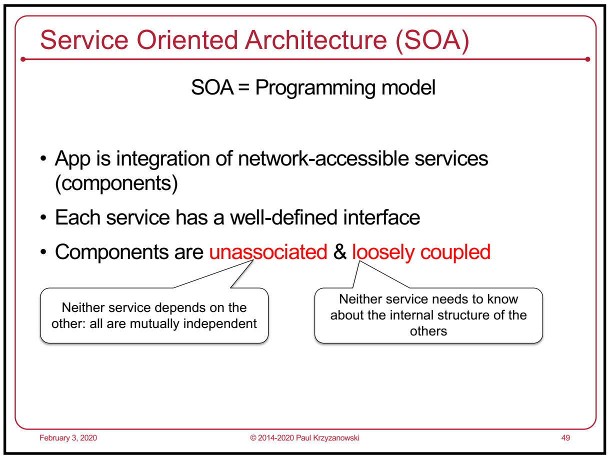

Service Oriented Architecture (SOA)

SOA = Programming model

- App is integration of network-accessible services (components)
- Each service has a well-defined interface
- Components are unassociated & loosely coupled

Neither service depends on the other: all are mutually independent

Neither service needs to know about the internal structure of the others

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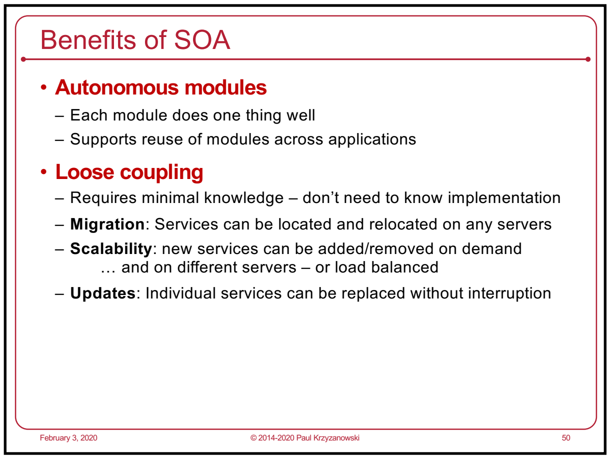

Benefits of SOA

- **Autonomous modules**
  - Each module does one thing well
  - Supports reuse of modules across applications
- **Loose coupling**
  - Requires minimal knowledge – don't need to know implementation
  - **Migration**: Services can be located and relocated on any servers
  - **Scalability**: new services can be added/removed on demand
    … and on different servers – or load balanced
  - **Updates**: Individual services can be replaced without interruption

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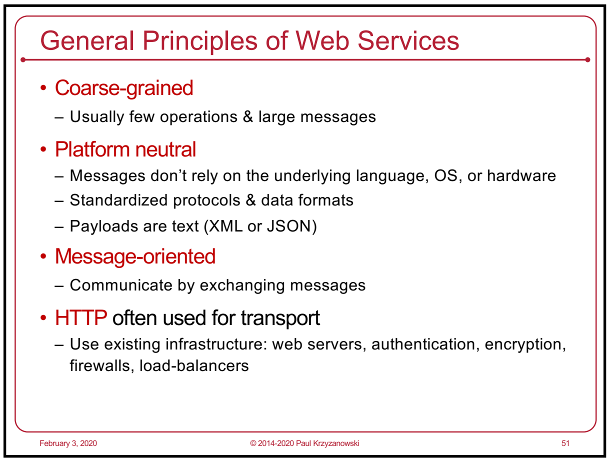

General Principles of Web Services

- Coarse-grained
  - Usually few operations & large messages
- Platform neutral
  - Messages don't rely on the underlying language, OS, or hardware
  - Standardized protocols & data formats
  - Payloads are text (XML or JSON)
- Message-oriented
  - Communicate by exchanging messages
- HTTP often used for transport
  - Use existing infrastructure: web servers, authentication, encryption, firewalls, load-balancers

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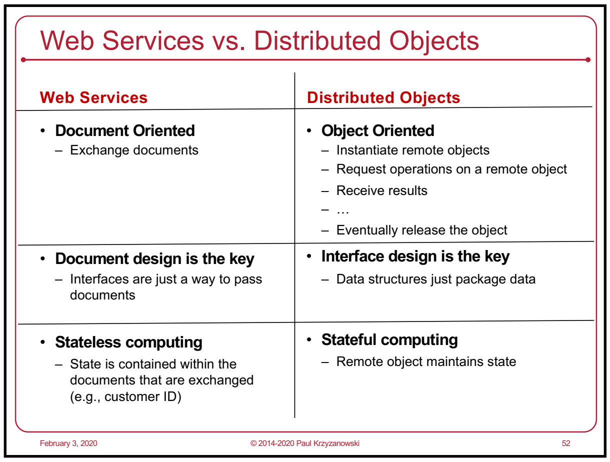

Web Services vs. Distributed Objects

Web Services	Distributed Objects
• **Document Oriented** – Exchange documents	• **Object Oriented** – Instantiate remote objects – Request operations on a remote object – Receive results – … – Eventually release the object
• **Document design is the key** – Interfaces are just a way to pass documents	• **Interface design is the key** – Data structures just package data
• **Stateless computing** – State is contained within the documents that are exchanged (e.g., customer ID)	• **Stateful computing** – Remote object maintains state

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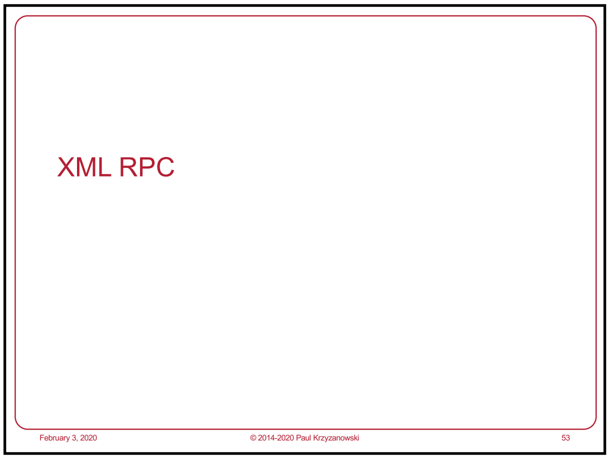

XML RPC

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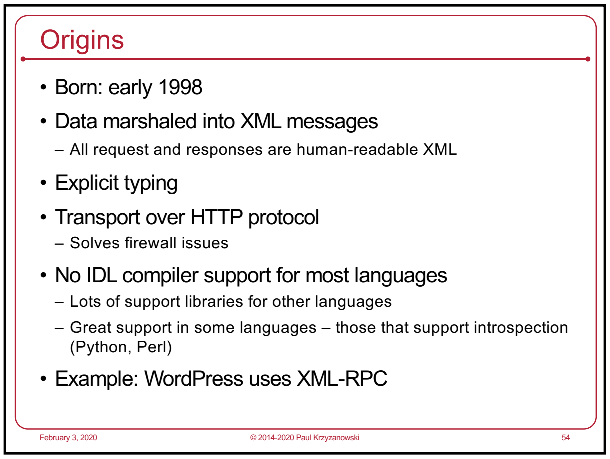

Origins

- Born: early 1998
- Data marshaled into XML messages
  - All request and responses are human-readable XML
- Explicit typing
- Transport over HTTP protocol
  - Solves firewall issues
- No IDL compiler support for most languages
  - Lots of support libraries for other languages
  - Great support in some languages – those that support introspection (Python, Perl)
- Example: WordPress uses XML-RPC

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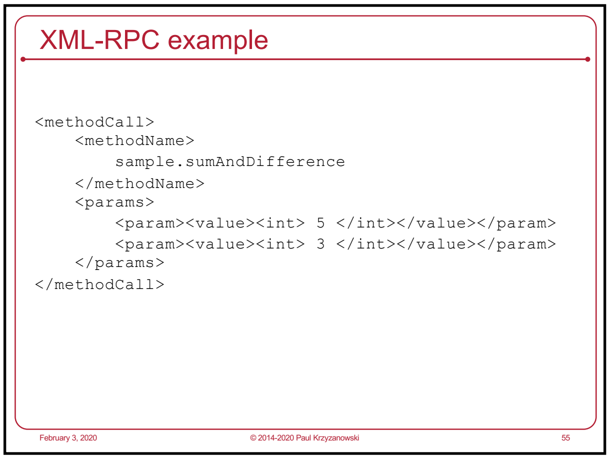
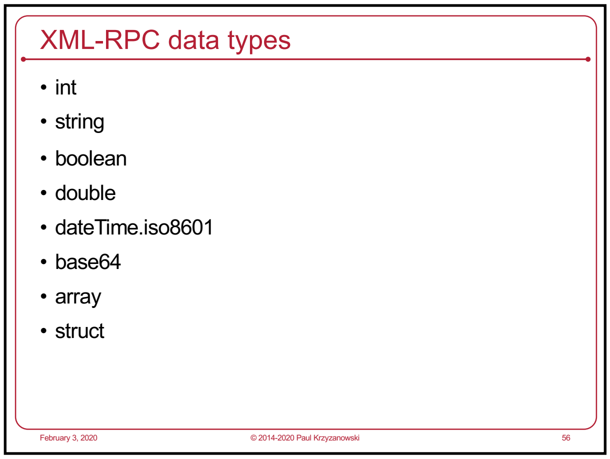


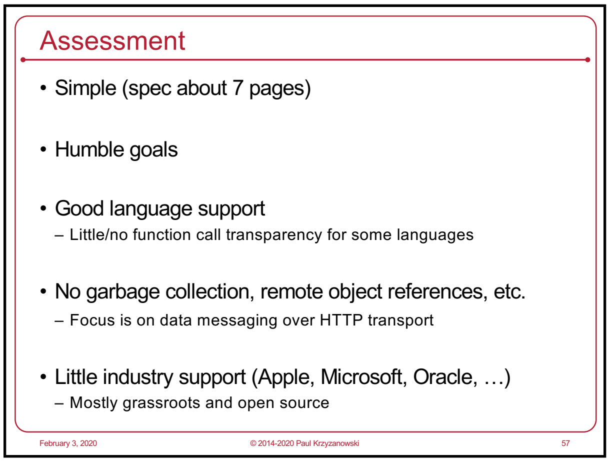
XML-RPC example

```
<methodCall>
    <methodName>
        sample.sumAndDifference
    </methodName>
    <params>
        <param><value><int> 5 </int></value></param>
        <param><value><int> 3 </int></value></param>
    </params>
</methodCall>
```



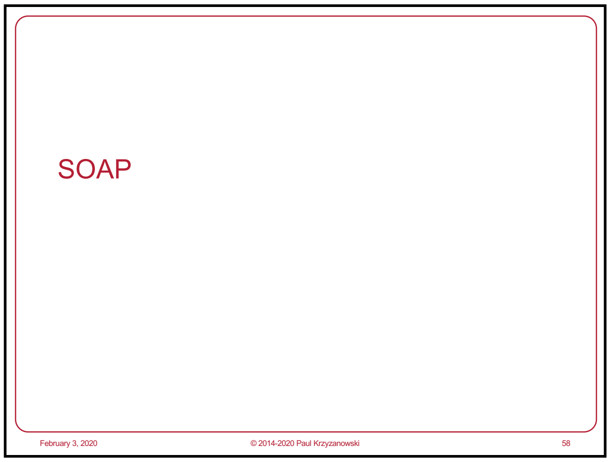
XML-RPC data types

- int
- string
- boolean
- double
- dateTime.iso8601
- base64
- array
- struct

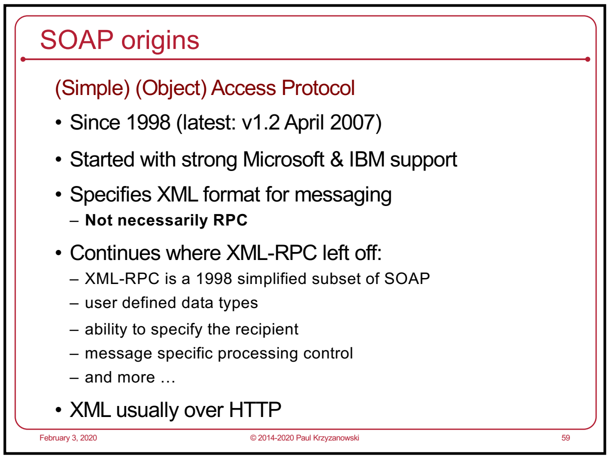


Assessment

- Simple (spec about 7 pages)
- Humble goals
- Good language support
  - Little/no function call transparency for some languages
- No garbage collection, remote object references, etc.
  - Focus is on data messaging over HTTP transport
- Little industry support (Apple, Microsoft, Oracle, …)
  - Mostly grassroots and open source



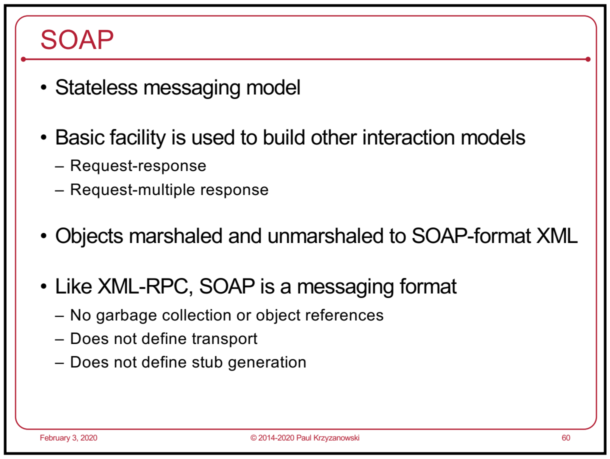
SOAP



SOAP origins

(Simple) (Object) Access Protocol

- Since 1998 (latest: v1.2 April 2007)
- Started with strong Microsoft & IBM support
- Specifies XML format for messaging
  - **Not necessarily RPC**
- Continues where XML-RPC left off:
  - XML-RPC is a 1998 simplified subset of SOAP
  - user defined data types
  - ability to specify the recipient
  - message specific processing control
  - and more …
- XML usually over HTTP



SOAP

- Stateless messaging model
- Basic facility is used to build other interaction models
  - Request-response
  - Request-multiple response
- Objects marshaled and unmarshaled to SOAP-format XML
- Like XML-RPC, SOAP is a messaging format
  - No garbage collection or object references
  - Does not define transport
  - Does not define stub generation

SOAP Web Services and WSDL

- Web Services Description Language
  - Analogous to an IDL
- A WSDL document describes a set of services
  - Name, operations, parameters, where to send requests
  - Goal is that organizations will exchange WSDL documents
    - If you get WSDL document, you can feed it to a program that will generate software to send and receive SOAP messages

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WSDL Structure

```
<definitions>
  <types>
    data type used by web service: defined via XML Schema syntax
  </types>
  <message>
    describes data elements of operations: parameters
  </message>
  <portType>
    describes service: operations, and messages involved
  </portType>
  <binding>
    defines message format & protocol details for each port
  </binding>
</definitions>
```

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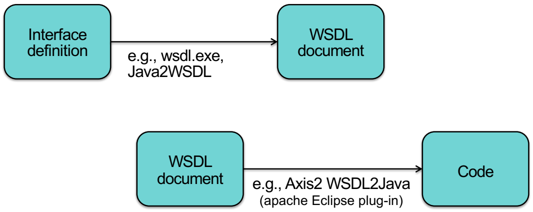
What do we do with WSDL?

It's an IDL – not meant for human consumption


Interface definition
e.g., wsdl.exe, Java2WSDL
WSDL document
WSDL document
e.g., Axis2 WSDL2Java (apache Eclipse plug-in)
Code

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Java Web Services

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JAX-WS: Java API for XML Web Services

- Lots of them! We'll look at one
- JAX-WS (evolved from earlier JAX-RPC)
  - Java API for XML-based Web-Service messaging & RPCs
  - Invoke a Java-based web service using Java RMI
  - Interoperability is a goal
    - Use SOAP & WSDL
    - Java not required on the other side (client or server)
- Service
  - Defined to clients via a WSDL document

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JAX-WS: Creating an RPC Endpoint

- Server
  - Define an interface (Java interface)
  - Implement the service
  - Create a publisher
    - Creates an instance of the service and publishes it with a name
- Client
  - Create a proxy (client-side stub)
    - *wsimport* command takes a WSDL document and creates a stub
  - Write a client that creates an instance of the service and invokes methods on it (calling the proxy)

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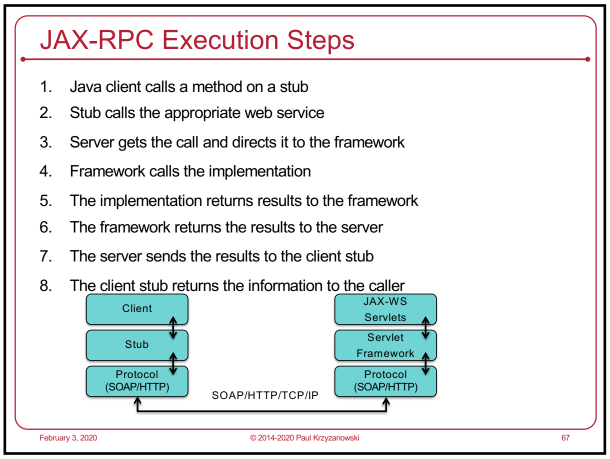

JAX-RPC Execution Steps

1. Java client calls a method on a stub
2. Stub calls the appropriate web service
3. Server gets the call and directs it to the framework
4. Framework calls the implementation
5. The implementation returns results to the framework
6. The framework returns the results to the server
7. The server sends the results to the client stub
8. The client stub returns the information to the caller

Client

Stub

Protocol (SOAP/HTTP)

JAX-WS Servlets

Servlet Framework

Protocol (SOAP/HTTP)

SOAP/HTTP/TCP/IP

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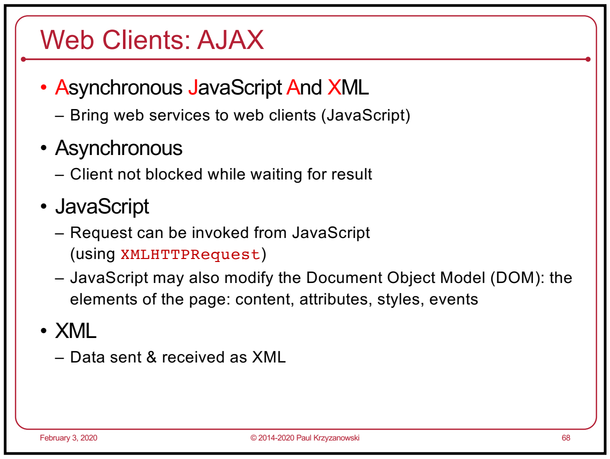

Web Clients: AJAX

- Asynchronous JavaScript And XML
  - Bring web services to web clients (JavaScript)
- Asynchronous
  - Client not blocked while waiting for result
- JavaScript
  - Request can be invoked from JavaScript (using `XMLHTTPRequest`)
  - JavaScript may also modify the Document Object Model (DOM): the elements of the page: content, attributes, styles, events
- XML
  - Data sent & received as XML

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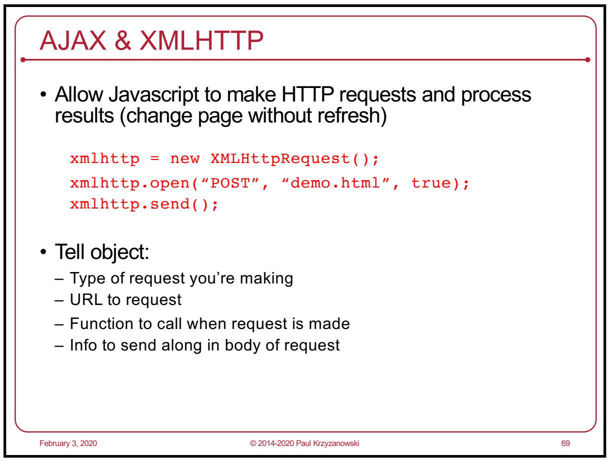

AJAX & XMLHTTP

- Allow Javascript to make HTTP requests and process results (change page without refresh)

```
xmlhttp = new XMLHttpRequest();
xmlhttp.open("POST", "demo.html", true);
xmlhttp.send();
```

- Tell object:
  - Type of request you're making
  - URL to request
  - Function to call when request is made
  - Info to send along in body of request

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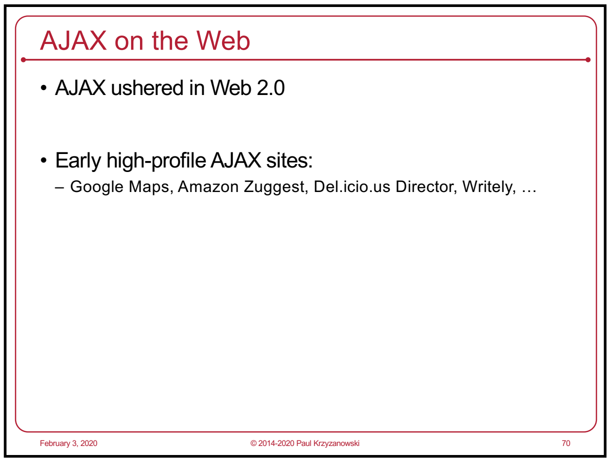

AJAX on the Web

- AJAX ushered in Web 2.0
- Early high-profile AJAX sites:
  - Google Maps, Amazon Zuggest, Del.icio.us Director, Writely, …

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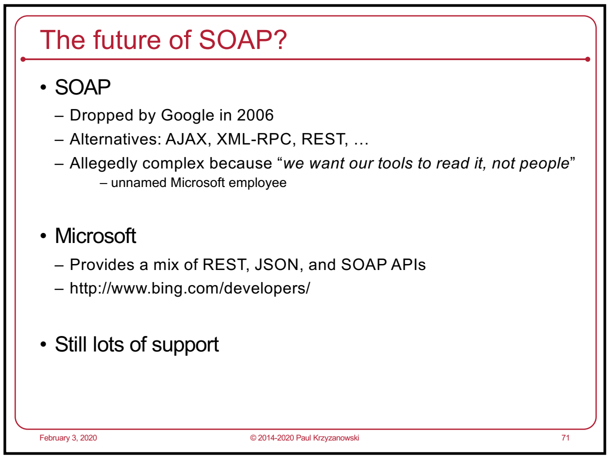

The future of SOAP?

- SOAP
  - Dropped by Google in 2006
  - Alternatives: AJAX, XML-RPC, REST, …
  - Allegedly complex because "*we want our tools to read it, not people*"
    – unnamed Microsoft employee
- Microsoft
  - Provides a mix of REST, JSON, and SOAP APIs
  - http://www.bing.com/developers/
- Still lots of support

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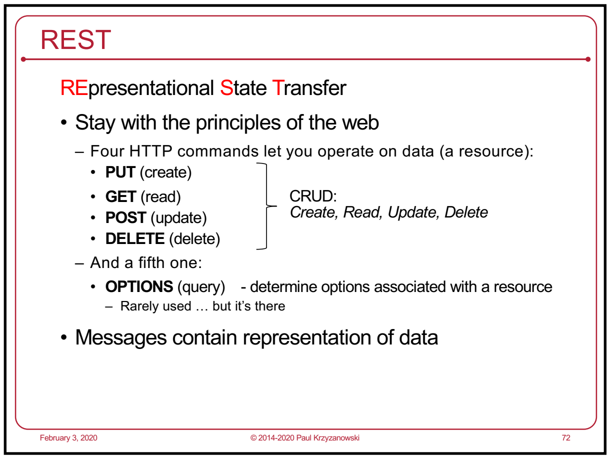

REST

REpresentational State Transfer

- Stay with the principles of the web
  - Four HTTP commands let you operate on data (a resource):
    - **PUT** (create)
    - **GET** (read)
    - **POST** (update)
    - **DELETE** (delete)

    CRUD: *Create, Read, Update, Delete*
  - And a fifth one:
    - **OPTIONS** (query) - determine options associated with a resource
      - Rarely used … but it's there
- Messages contain representation of data

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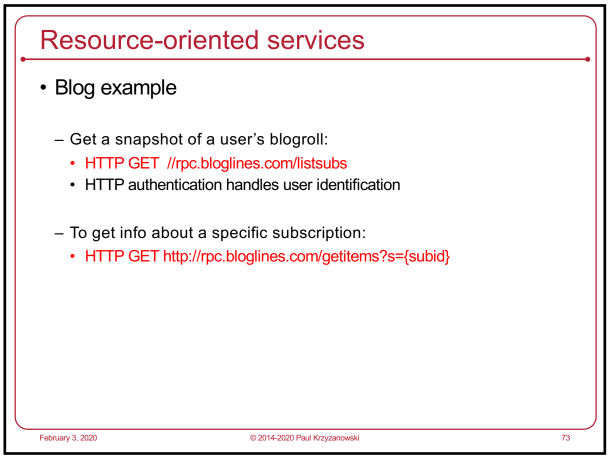

Resource-oriented services

- Blog example
  - Get a snapshot of a user's blogroll:
    - HTTP GET //rpc.bloglines.com/listsubs
    - HTTP authentication handles user identification
  - To get info about a specific subscription:
    - HTTP GET http://rpc.bloglines.com/getitems?s={subid}

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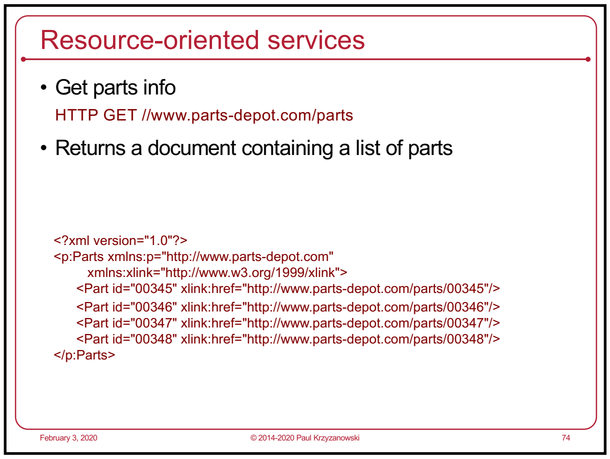

Resource-oriented services

- Get parts info

  HTTP GET //www.parts-depot.com/parts
- Returns a document containing a list of parts

```
<?xml version="1.0"?>
<p:Parts xmlns:p="http://www.parts-depot.com"
       xmlns:xlink="http://www.w3.org/1999/xlink">
    <Part id="00345" xlink:href="http://www.parts-depot.com/parts/00345"/>
    <Part id="00346" xlink:href="http://www.parts-depot.com/parts/00346"/>
    <Part id="00347" xlink:href="http://www.parts-depot.com/parts/00347"/>
    <Part id="00348" xlink:href="http://www.parts-depot.com/parts/00348"/>
</p:Parts>
```

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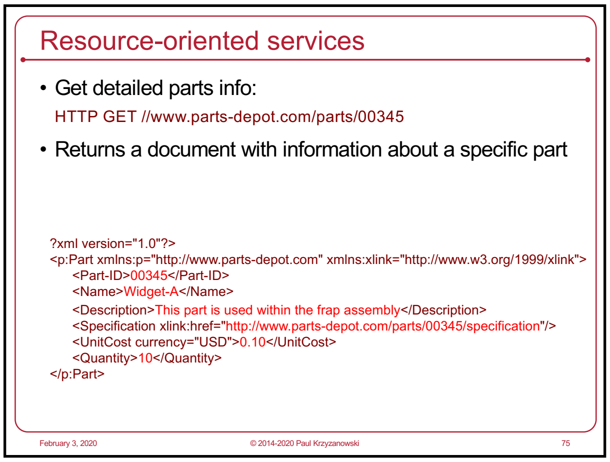

Resource-oriented services

- Get detailed parts info:

  HTTP GET //www.parts-depot.com/parts/00345
- Returns a document with information about a specific part

```
?xml version="1.0"?>
<p:Part xmlns:p="http://www.parts-depot.com" xmlns:xlink="http://www.w3.org/1999/xlink">
    <Part-ID>00345</Part-ID>
    <Name>Widget-A</Name>
    <Description>This part is used within the frap assembly</Description>
    <Specification xlink:href="http://www.parts-depot.com/parts/00345/specification"/>
    <UnitCost currency="USD">0.10</UnitCost>
    <Quantity>10</Quantity>
</p:Part>
```

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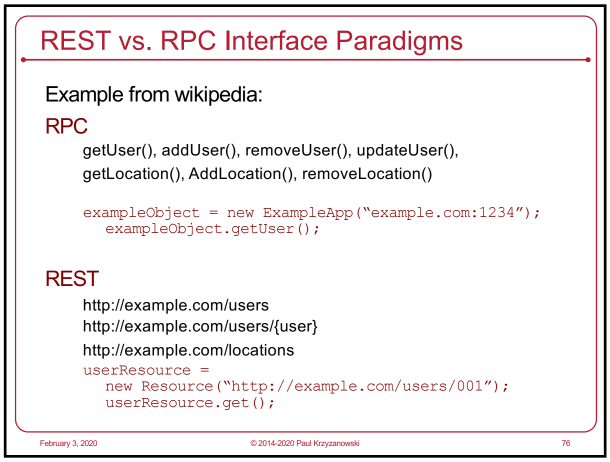

REST vs. RPC Interface Paradigms

Example from wikipedia:

RPC

getUser(), addUser(), removeUser(), updateUser(),
getLocation(), AddLocation(), removeLocation()

```
exampleObject = new ExampleApp(“example.com:1234”);
   exampleObject.getUser();
```

REST

http://example.com/users
http://example.com/users/{user}
http://example.com/locations

```
userResource =
   new Resource(“http://example.com/users/001”);
   userResource.get();
```

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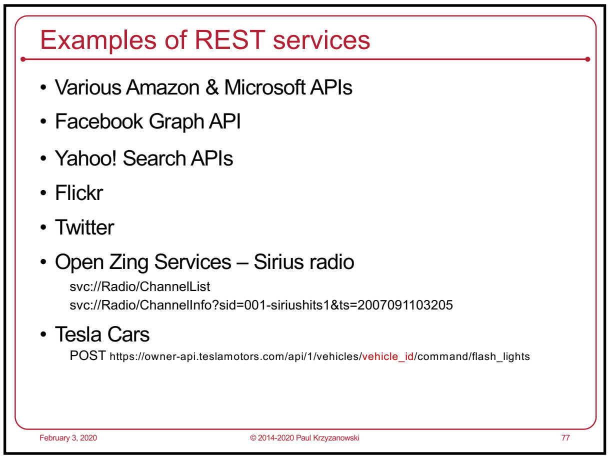

Examples of REST services

- Various Amazon & Microsoft APIs
- Facebook Graph API
- Yahoo! Search APIs
- Flickr
- Twitter
- Open Zing Services – Sirius radio

  svc://Radio/ChannelList
  svc://Radio/ChannelInfo?sid=001-siriushits1&ts=2007091103205
- Tesla Cars

  POST https://owner-api.teslamotors.com/api/1/vehicles/vehicle_id/command/flash_lights

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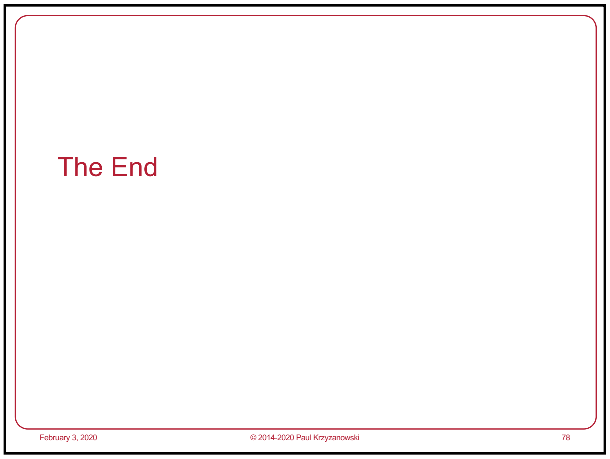

The End

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