Distributed systems

Lecture 11: Object-Oriented Middleware (OOM), clocks and distributed time

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(With thanks to Dr Robert N. M. Watson
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The story so far…

- Distributed systems are hard
- Looking at simple **client/server** interaction, and use of **Remote Procedure Call (RPC)**
  - invoking methods on server over the network
  - middleware generates **stub code** which can **marshal** / **unmarshal** arguments and replies
  - saw case study of NFS (RPC-based file system)
- Other RPC systems (e.g., DCE RPC)

Object-Oriented Middleware

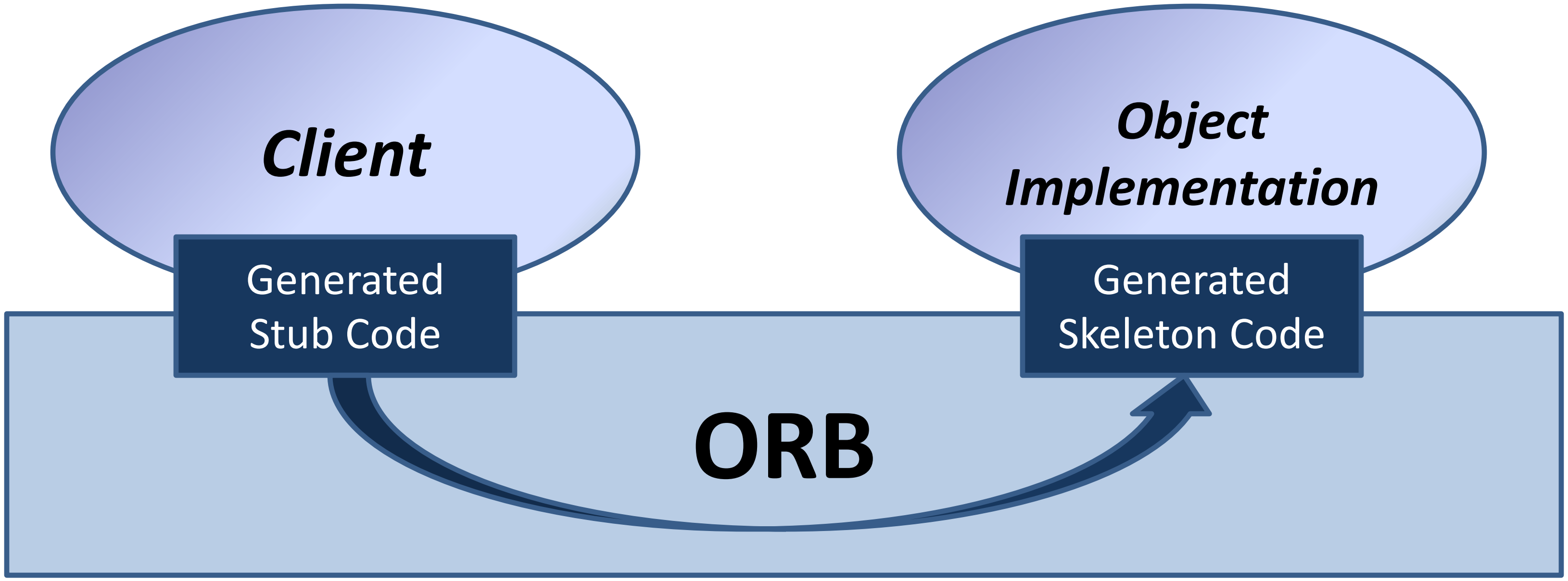
- SunRPC / DCE RPC forward **functions**, and do not support complex types, exceptions, or polymorphism
- **Object-Oriented Middleware (OOM)** arose in the early 90s to address this
  - Assume programmer is writing in OO-style (and language)
  - **Remote objects** will behave like local objects, but their methods will be forwarded over the network a la RPC
  - **References to objects** can be passed as arguments or return values – e.g., passing a directory object reference
  - Promote NFS's concept of a **handle** into the framework
- Makes it much easier to program – especially if your program is already object oriented!

CORBA (1989)

- First OOM system was CORBA
  - **Common Object Request Broker Architecture**
  - Specified by the OMG: Object Management Group
- OMA (Object Management Architecture) is the general model of how objects interoperate
  - **Objects** provide services
  - **Clients** makes a request to an object for a service
  - Client doesn't need to know where the object is, or anything about how the object is implemented!
  - **Object interface** must be known (public)

Object Request Broker (ORB)

- The **ORB** is the core of the architecture
  - Connects clients to object implementations
  - Conceptually spans multiple machines (in practice, ORB software runs on each machine)



Invoking Objects

- Clients obtain an **object reference**
  – Typically via the **naming service** or **trading service**
  – (Object references can also be saved for use later)
- Interfaces defined by **CORBA IDL**
- Clients can call remote methods in 2 ways:
  1. **Static Invocation**: using stubs built at compile time (just like with RPC)
  2. **Dynamic Invocation**: actual method call is created on the fly. It is possible for a client to discover new objects at run time and access the object's methods

CORBA IDL

- Definition of language-independent remote interfaces
  - **Language mappings** to C++, Java, Smalltalk, …
  - Translation by **IDL compiler**
- Type system
  - **basic types**: long (32 bit), long long (64 bit), short, float, char, boolean, octet, any, …
  - **constructed types**: struct, union, sequence, array, enum
  - **objects** (common super type **Object**)
- Parameter passing
  - **in**, **out**, **inout** (= send remote, modify, update)
  - basic & constructed types passed by value
  - objects passed by reference

CORBA Pros and Cons

- CORBA has some unique advantages
  - Industry standard (OMG)
  - Language & OS agnostic: mix and match
  - Richer than simple RPC (e.g. interface repository, implementation repository, DLL support, …)
  - Many additional services (trading & naming, events & notifications, security, transactions, …)
- However:
  - Really, really complicated / ugly / buzzwordy
  - Poor interoperability, at least at first
  - Generally to be avoided unless you need it!

Microsoft DCOM (1996)

- An alternative to CORBA:
  - MS had invested in COM (object-oriented local IPC scheme) so didn't fancy moving to OMA
- **Service Control Manager (SCM)** on each machine responsible for object creation, invocation, ...
  - Essentially a lightweight 'ORB'
- Added **remote operation** using MSRPC:
  - Based on DCE RPC, but extended to support objects
  - Augmented IDL called **MIDL**: DCE IDL + objects
  - Requests include **interface pointer IDs (IPIDs)** to identify object & interface to be invoked

DCOM vs. CORBA

- Both are language neutral, and object-oriented
- DCOM supports **objects with multiple interfaces**
  - but not, like CORBA, multiple inheritance of interfaces
- DCOM handles **distributed garbage collection**:
  - remote objects are **reference counted** (via explicit calls)
  - ping protocol handles abnormal client termination
- DCOM is widely used (e.g. SMB/CIFS, RDP, ...)
- But DCOM is MS proprietary (not standard)...
  - and no support for exceptions (return-code based)..
  - and lacks many of CORBAs services (e.g. trading)
- Deprecated today in favor of .NET

Java RMI

- 1995: Sun extended Java to allow RMI
  - RMI = **Remote Method Invocation**
- Essentially an OOM scheme for Java with **clients**, **servers**, and an **object registry**
  - Object registry maps from names to objects
  - Supports **bind()/rebind()**, **lookup()**, **unbind()**, **list()**
- RMI was designed for Java only
  - No goal of OS or language interoperability
  - Hence cleaner design, tighter language integration
  - E.g., distributed garbage collection

RMI: new classes

- **Remote class**:
  - one whose instances can be used remotely
  - within home address space, a regular object
  - within foreign address spaces, referenced indirectly via an **object handle**
- **Serializable class**: [nothing to do with transactions!]
  - object that can be marshalled/unmarshalled
  - if a serializable object is passed as a parameter or return value of a remote method invocation, the value will be copied from one address space to another
  - (for remote objects, only the object handle is copied)

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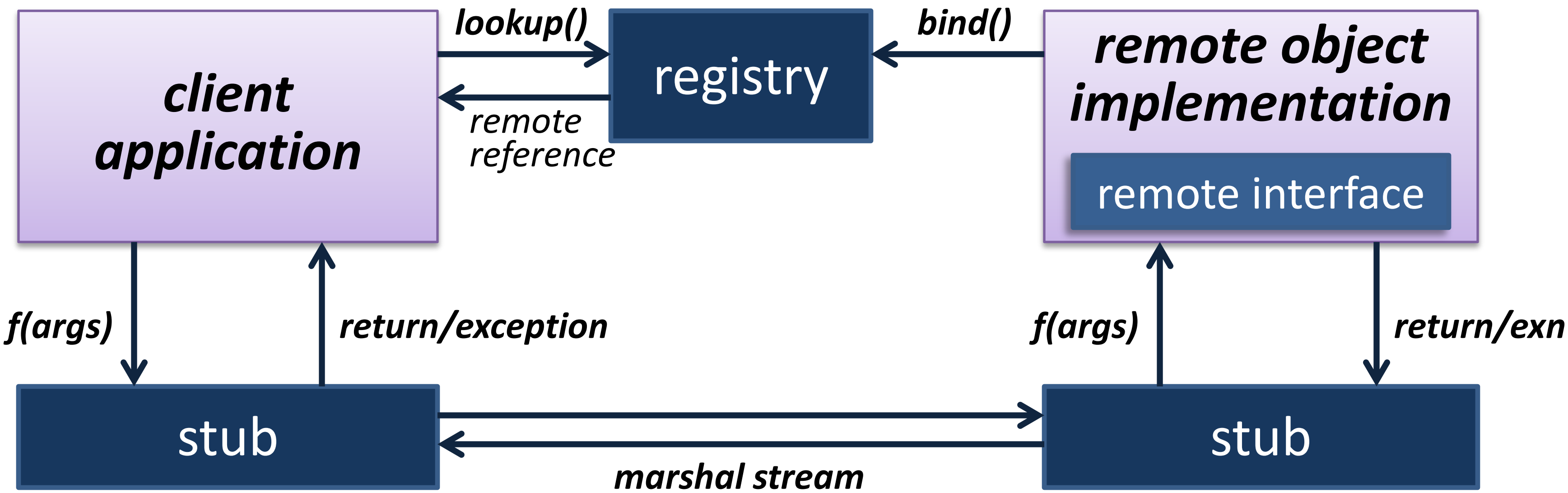
needed for parameters (when passing data)

RMI: the big picture



- Registry can be on server... or one per distributed system
  - client and server can find it via the **LocateRegistry** class
- Objects being serialized are annotated with a URL for the class
  - unless they implement **Remote** => replaced with a remote reference

Distributed garbage collection

- With RMI, can have local & remote object references scattered around a set of machines
- Build **distributed garbage collection** over local GC:
  - When a server exports object **O**, it creates a skeleton **S[O]**
  - When a client obtains a remote reference to **O**, it creates a proxy object **P[O]**, and remotely invokes **dirty**(O)
  - Local GC will track the liveness of **P[O]**; when it is locally unreachable, client remotely invokes **clean(O)**
  - If server notices no remote references, can free **S[O]**
  - If **S[O]** was last reference to **O**, then it too can be freed
- Like DCOM, server removes a reference if it doesn't hear from that client for a while (default 10 mins)

OOM: summary

- OOM enhances RPC with objects
  - types, interfaces, exceptions, …
- Seen CORBA, DCOM and Java RMI
  - All plausible, and all still used today
  - CORBA most general (language and OS agnostic), but also the most complex: design by committee
  - DCOM is MS-only; being phased out for .NET
  - Java RMI decent starting point for simple distributed systems… but lacks many features
  - (EJB is a modern CORBA/RMI/<stuff> megalith)

XML-RPC

- Systems seen so far all developed by large industry, and work fine in the local area…
  - But don't (or didn't) do well through firewalls ;-)
- In 1998, Dave Winer developed XML-RPC
  - Use XML to encode method invocations (method names, parameters, etc)
  - Use HTTP POST to invoke; response contains the result, also encoded in XML
  - Looks like a regular web session, and so works fine with firewalls, NAT boxes, transparent proxies, …

XML-RPC example

XML-RPC Request

```
<?xml version="1.0"?>
<methodCall>
<methodName>util.InttoString</methodName>
  <params>
    <param>
        <value><i4>55</i4></value>
    </param>
  </params>
</methodCall>
```

XML-RPC Response

```
<?xml version="1.0"?>
<methodResponse>
  <params>
    <param>
       <value><string>Fifty Five</string></value>
    </param>
  </params>
</methodResponse>
```

- Client side names method (as a string), and lists parameters, tagged with simple types
- Server receives message (via HTTP), decodes, performs operation, and replies with similar XML
- Inefficient & weakly typed… but simple, language agnostic, extensible, and eminently practical!

SOAP & web services

- XML-RPC was a victim of its own success
- WWW consortium decided to embrace it, extend it, and generally complify it up
  - SOAP (**Simple Object Access Protocol**) is basically XML-RPC, but with more XML bits
  - Support for namespaces, user-defined types, multi-hop messaging, recipient specification, …
  - Also allows transport over SMTP (!), TCP & UDP
- SOAP is part of the **Web Services** world
  - As complex as CORBA, but with more XML ;-)

Moving away from RPC

- SOAP 1.2 defined in 2003
  - Less focus on RPC, and more on moving XML messages from A to B (perhaps via C & D)
- One major problem with all RPC schemes is that they were **synchronous**:
  - Client is blocked until server replies
  - Poor responsiveness, particularly in wide area
- 2006 saw introduction of AJAX
  - **Asynchronous Javascript with XML**
  - Chief benefit: can update web page without reloading
- Examples: Google Maps, Gmail, Google Docs, …

Representational State Transfer (REST)

- AJAX still does RPC (just asynchronously)
- Is a procedure call / method invocation really the best way to build distributed systems?
- **Representational State Transfer** (REST) is an alternative 'paradigm' (or a throwback?)
  - Resources have a name: URL or URI
  - Manipulate them via POST (create), GET (select), PUT (create/overwrite), and DELETE (delete)
  - More recently added: PATCH (partial update in place)
  - Send state along with operations
- Very widely used today (Amazon, Flickr, Twitter)

Client-server interaction: summary

- Server handles requests from client
  - Simple request/response protocols (like HTTP) useful, but lack language integration
  - RPC schemes (SunRPC, DCE RPC) address this
  - OOM schemes (CORBA, DCOM, RMI) extend RPC to understand objects, types, interfaces, exns, …
- Recent WWW developments move away from traditional RPC/RMI:
  - Avoid explicit IDLs since can slow evolution
  - Enable asynchrony, or return to request/response

Clocks and distributed time

- Distributed systems need to be able to:
  - **order events** produced by concurrent processes;
  - **synchronize** senders and receivers of messages;
  - **serialize** concurrent accesses to shared objects; and
  - generally **coordinate** joint activity
- This can be provided by some sort of **clock**:
  - **physical clocks** keep time of day
    - (must be kept consistent across multiple nodes – why?)
  - **logical clocks** keep track of event ordering
- Relativity can't be ignored: think satellites

Physical clock technology

- Quartz Crystal Clocks (1929)
  - resonator shaped like a tuning fork
  - laser-trimmed to vibrate at 32,768 Hz
  - standard resonators accurate to 6ppm at 31°C... so will gain/lose around 0.5 seconds per day
  - stability better than accuracy (about 2s/month)
  - best resonators get accuracy of ~1s in 10 years
- Atomic clocks (1948)
  - count transitions of the cesium 133 atom
  - 9,192,631,770 periods defined to be 1 second
  - accuracy is better than 1 second in 6 million years...

Coordinated Universal Time (UTC)

- Physical clocks provide **ticks** but we want to know the actual time of day
  - determined by astronomical phenomena
- Several variants of universal time
  - **UT0**: mean solar time on Greenwich meridian
  - **UT1**: UT0 corrected for polar motion; measured via observations of quasars, laser ranging, & satellites
  - **UT2**: UT1 corrected for seasonal variations
  - **UTC**: civil time, tracked using atomic clocks, but kept within 0.9s of UT1 by occasional leap seconds

Computer clocks

- Typically have a **Real-Time Clock (RTC)**
  - CMOS clock driven by a quartz oscillator
  - battery-backed so continues when power is off
- Also have range of other clocks (PIT, ACPI, HPET, TSC, ...), mostly **higher frequency**
  - free running clocks driven by quartz oscillator
  - mapped to real time by OS at boot time
  - programmable to generate interrupts after some number of ticks (~= some amount of real time)

Operating-system use of clocks

- OSes use time for many things
  - Periodic events – e.g., time sharing, statistics, at, cron
  - Local I/O functions – e.g., peripheral timeouts; entropy
  - Network protocols – e.g., TCP DELACK, retries, keep-alive
  - Cryptographic certificate/ticket generation, expiration
  - Performance profiling and sampling features
- **Ticks** trigger interrupts
  - Historically, timers at fixed intervals (e.g., 100Hz)
  - Now, **tickless**: timer reprogrammed for next event
  - Saves energy, CPU resources – especially as cores scale up

Which of these require **physical time** vs **logical time**? What will happen to each if the real-time clock **drifts** or **steps** due to synchronization?

Summary + next time (!)

- Object-Oriented Middleware (OOM)
  - CORBA, DCOM, RMI, XML-RPC, SOAP, REST
- Clocks and distributed time
  - Physical clock technology, UTC
  - What clocks in computers are for…

- More on physical time
- Time synchronization
- Ordering
  - The “**happens-before**” relation
  - Logical and vector clocks