Imperial College London

Computer Networks and Distributed Systems

Interaction Implementation

Course 527 – Spring Term 2014-2015

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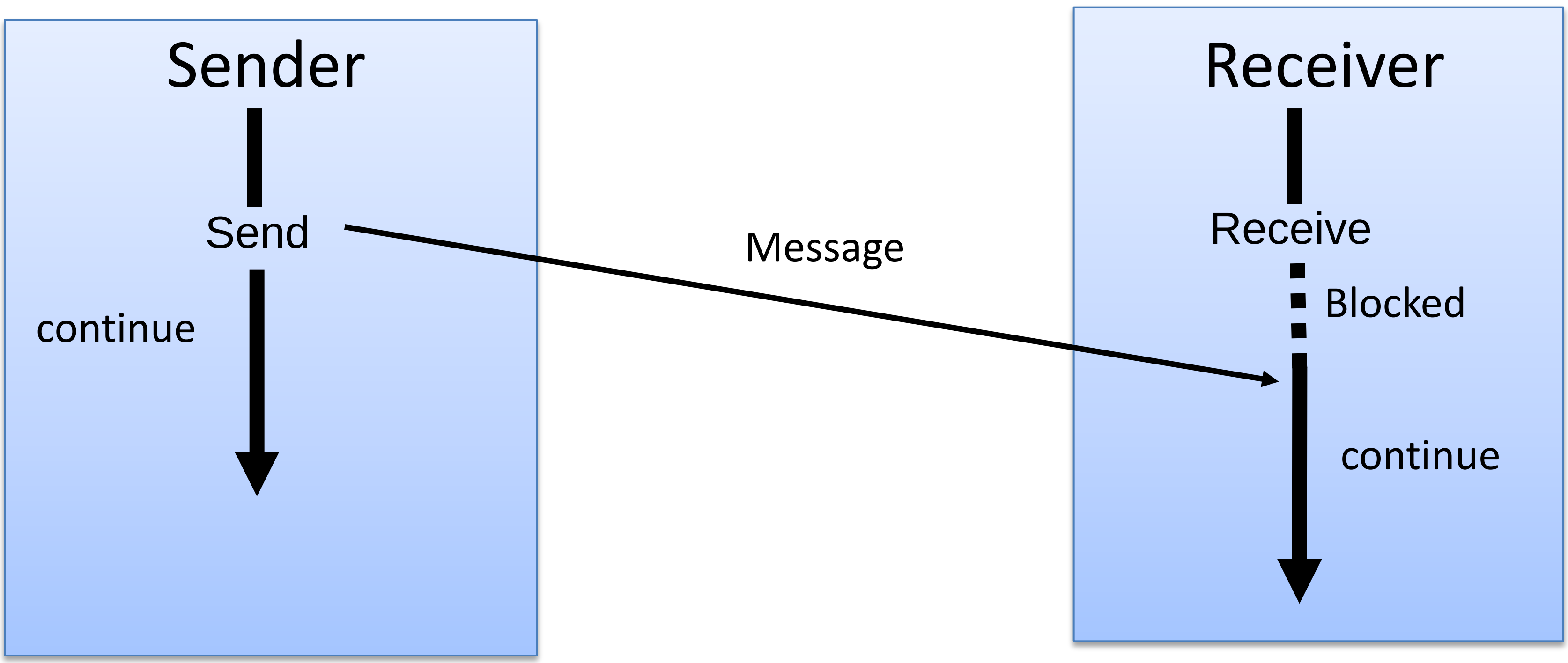
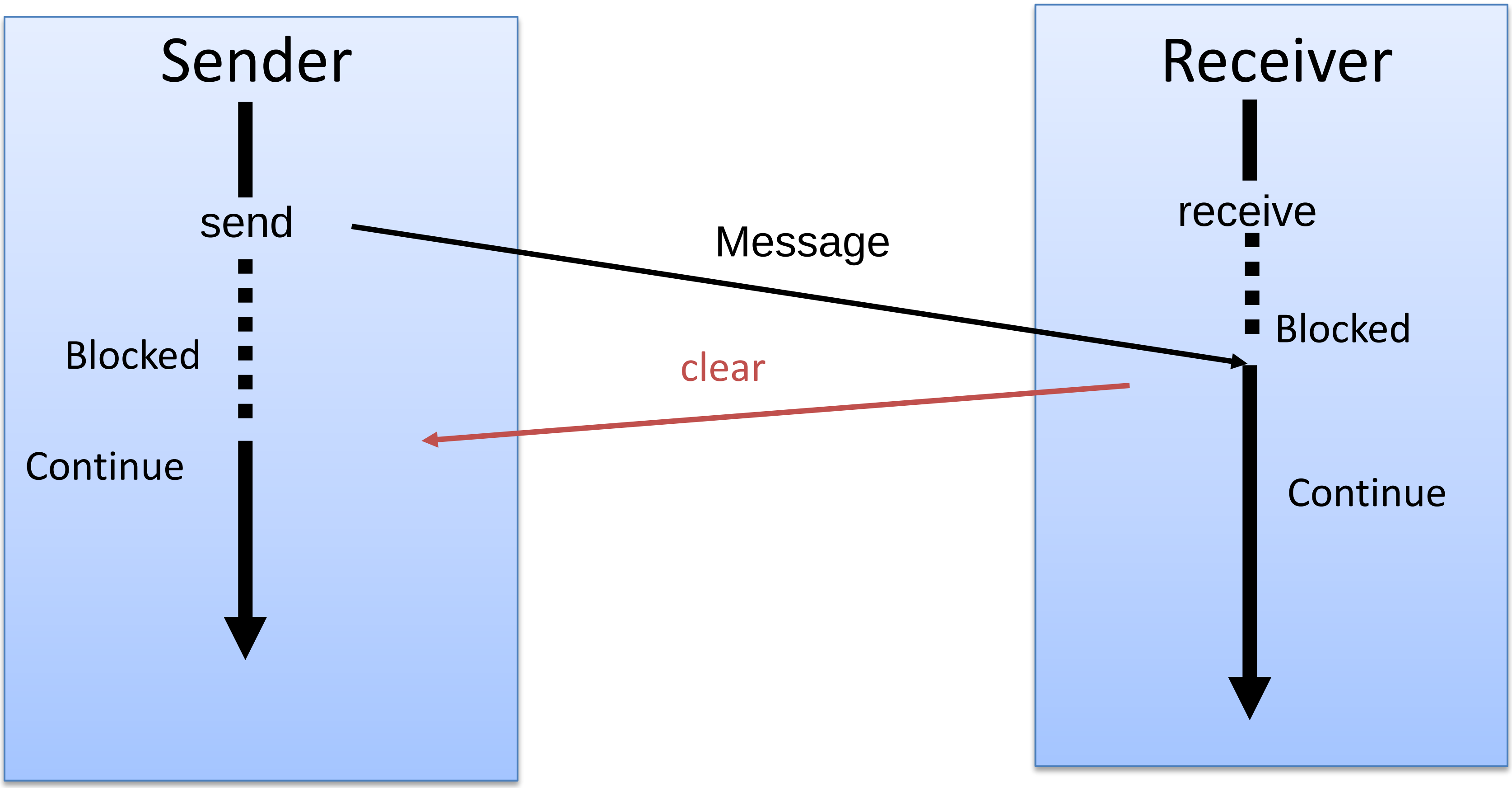
Outline

- Message passing
- RPC implementation
  - Binding
  - Concurrency
  - Error Control
- Heterogeneity
  - External Representations
  - Transformations

Implementing Asynchronous Send



Implementing Synchronous Send



Clear is a runtime system message – not sent by application process

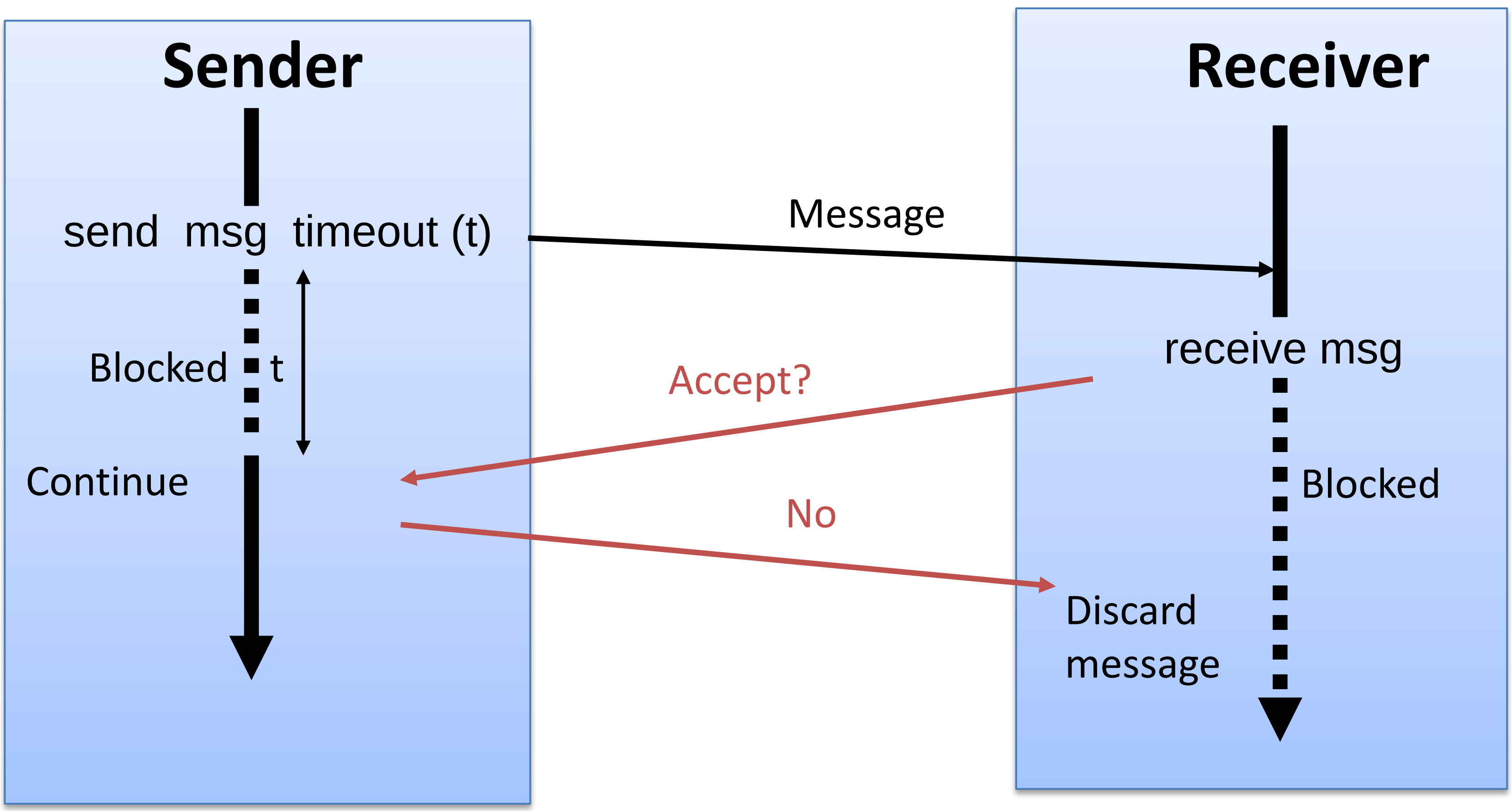
Exercise

- Modify the synchronous protocol to cater for a timeout on the send i.e. `send msg delay (t)`

- The sender continues after the timeout if the message has not yet been received – this implies the receiver should not get the message if the timeout expires

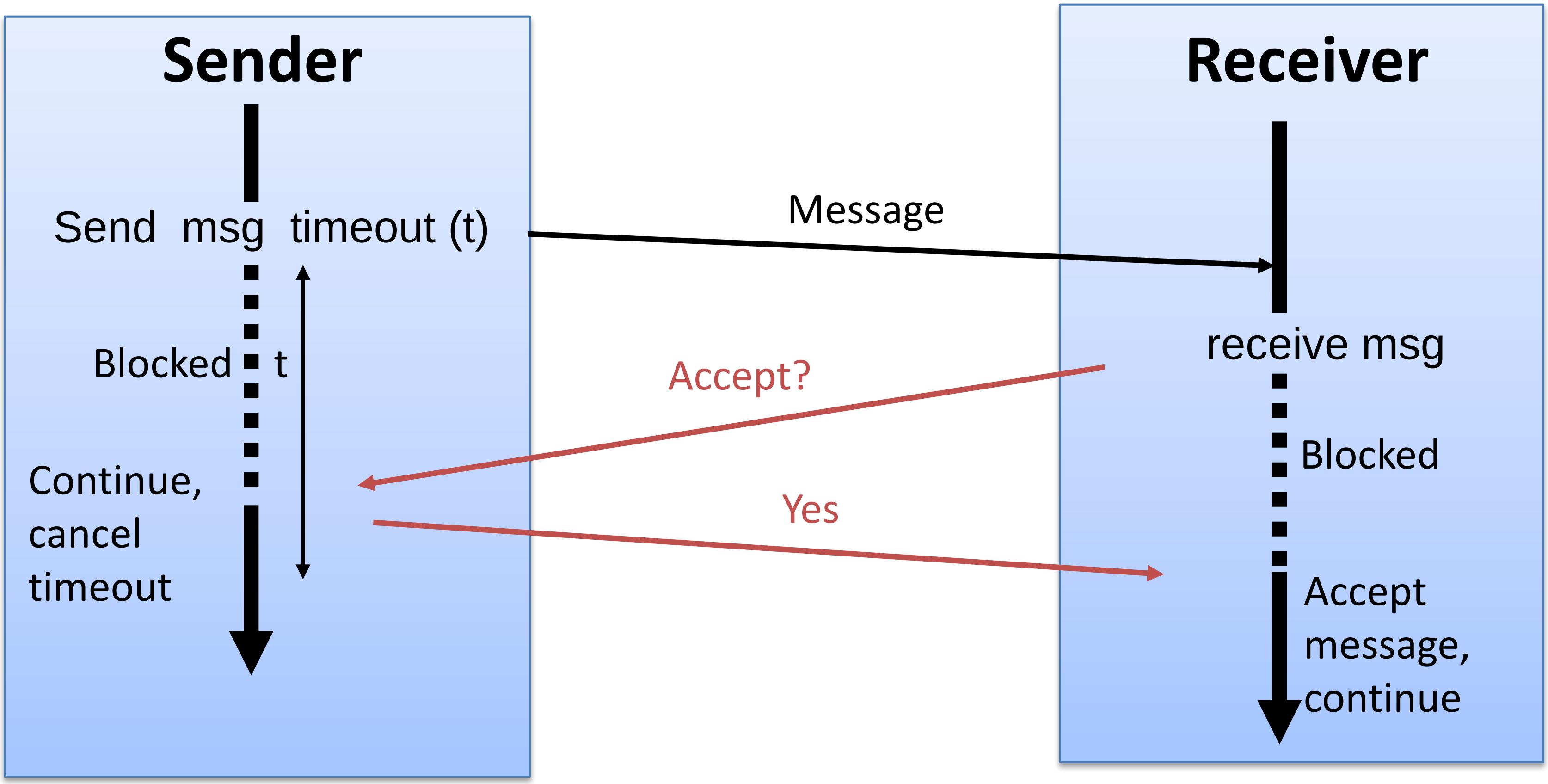
- Show the message exchanges that would occur:
  i. if the sender's timeout expires
  ii. if the sender's timeout does not expire

Synchronous Send: timeout expires



Accept? & No are sent by runtime system, not application processes

Synchronous Send: timeout does not expire



Accept? & Yes are sent by runtime system, not application processes

Binding

- Binding is the assignment of a reference value (e.g. address or object reference) to a placeholder (e.g. message port or object reference variable)

- It is similar to opening a connection in the communication system or opening a file in an OS

- First Party Binding
  - Client initiates binding as in Java and CORBA

Interface Type Checking

- Client interface must be type compatible with server interface i.e. same interactions and signatures (set of parameters + data types)

- Client and server likely to be compiled independently and at different times
  - Use same interface type definition to generate client and server interface
  - Permit server to be subtype of client interface
  - Check for structural compatibility at run-time

Interface Type Checking

- Use same interface type definition to generate client and server interface
  - Client and server hold identity of interface derived from interface definition module
  - Generate Interface identity by
    - checksum over source
    - name + timestamp of last modification or compilation
  - At bind time, check type identities are equal
  - Strong type compatibility

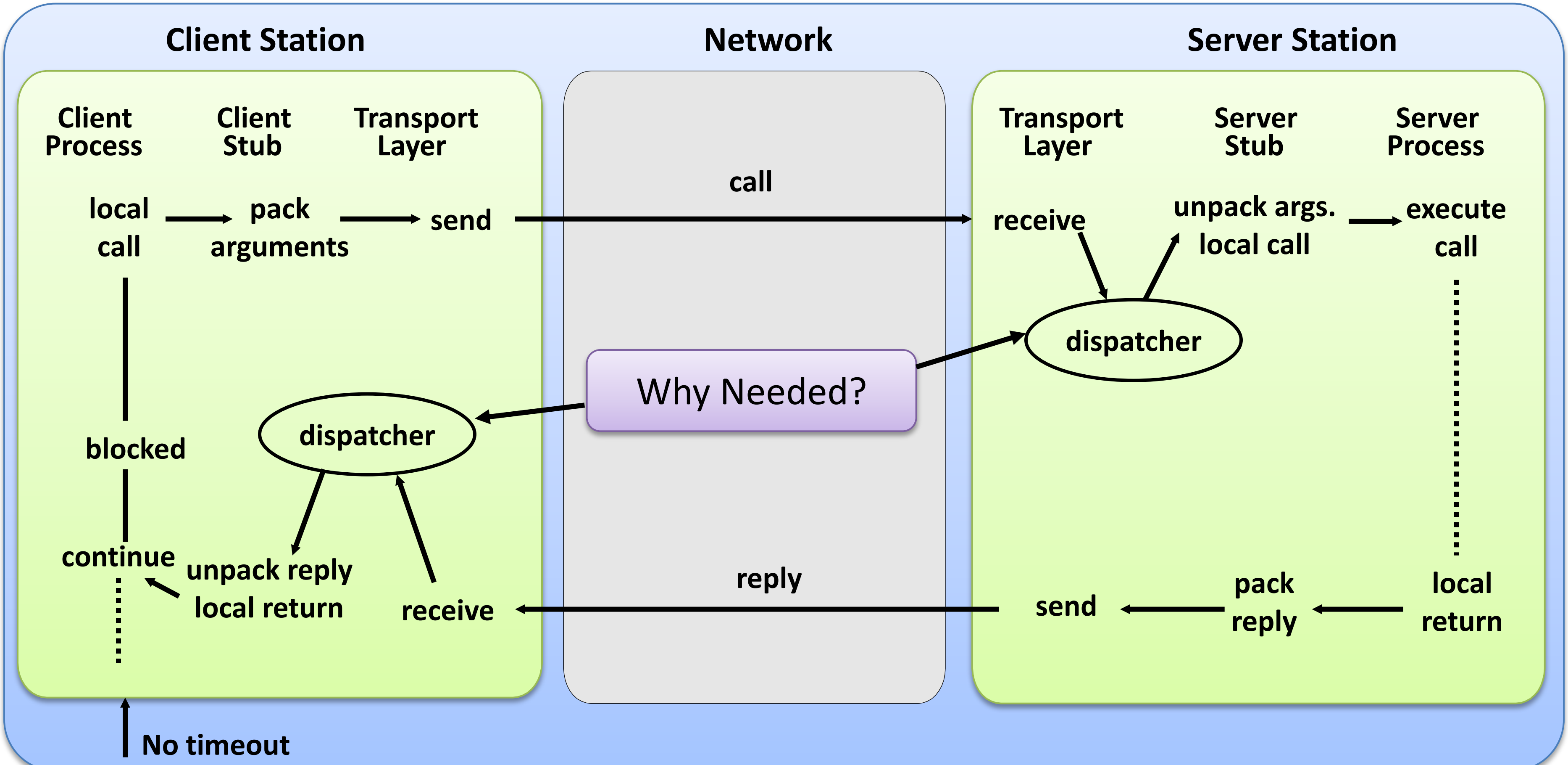
Interface Type Checking

- Permit server to be subtype of client interface
  i.e. provides *additional* operations which are not used by client, but must not extend operations in original interface
- Maintain run-time representation of interface and check for structural compatibility at bind time
  – *Weak* type compatibility e.g. the following two interfaces are structurally equivalent

```
interface A {
  opa1 (in string a1,
   in short a2 , out long a4);
  opa2 (in string a4);
}
```

```
interface B {
  opb1 (in string b1,
   in short b2 , out long b3);
  opb2 (in string b4)
}
```

Remote Procedure Call



At most once semantics

client receives reply - procedure executed exactly once

on failure i.e. no reply received – don't know

Dispatcher

- Server needs dispatcher to map incoming calls onto relevant procedure
- Dispatcher in client passes incoming reply message to relevant stub procedure
- Interface compiler generates a number (or name) for each procedure in interface – inserted into call message by client stub procedure
- Dispatcher at server receives all call messages and uses procedure number (name) to identify called procedure

RMI Dispatcher

- Java uses reflection and a generic dispatcher so no need for skeletons

- Client proxy (stub) includes information about a method in request message by creating instances of Method class containing
  - Class, types of arguments, type of return value, type of exceptions
  - Proxy marshalls object of class method, array of argument objects

RMI Dispatcher

- Dispatcher receives request,
  - unmarshalls method object,
  - uses method information to unmarshall arguments
  - converts remote object reference to local object reference
  - calls method object's invoke method supplying local object reference and arguments
  - when method executed, marshalls result or exceptions into reply message and sends it back to client

- See http://docs.oracle.com/javase/1.5.0/docs/api/java/lang/reflect/Method.html

RPC Binding

- A name server registers exported interfaces and is queried to locate a server when an interface is imported

- Server
  - Calls `export(interface type, server name, nameserver)`
  - Dispatcher address added by stub and passed to Transport
  - Server Transport
    - Generates unique exportid & sends a register message to name server containing type, name, exportid

RPC Binding

- Client
  - Calls `import(interface type, server name, nameserver)`
  - Dispatcher address added by stub and passed to Transport
  - Client Transport
    - Send query message with type & name to nameserver; Reply contains type and address of server instance
    - Query server to check validity of type, name and exportid; Return interface reference (address) or error

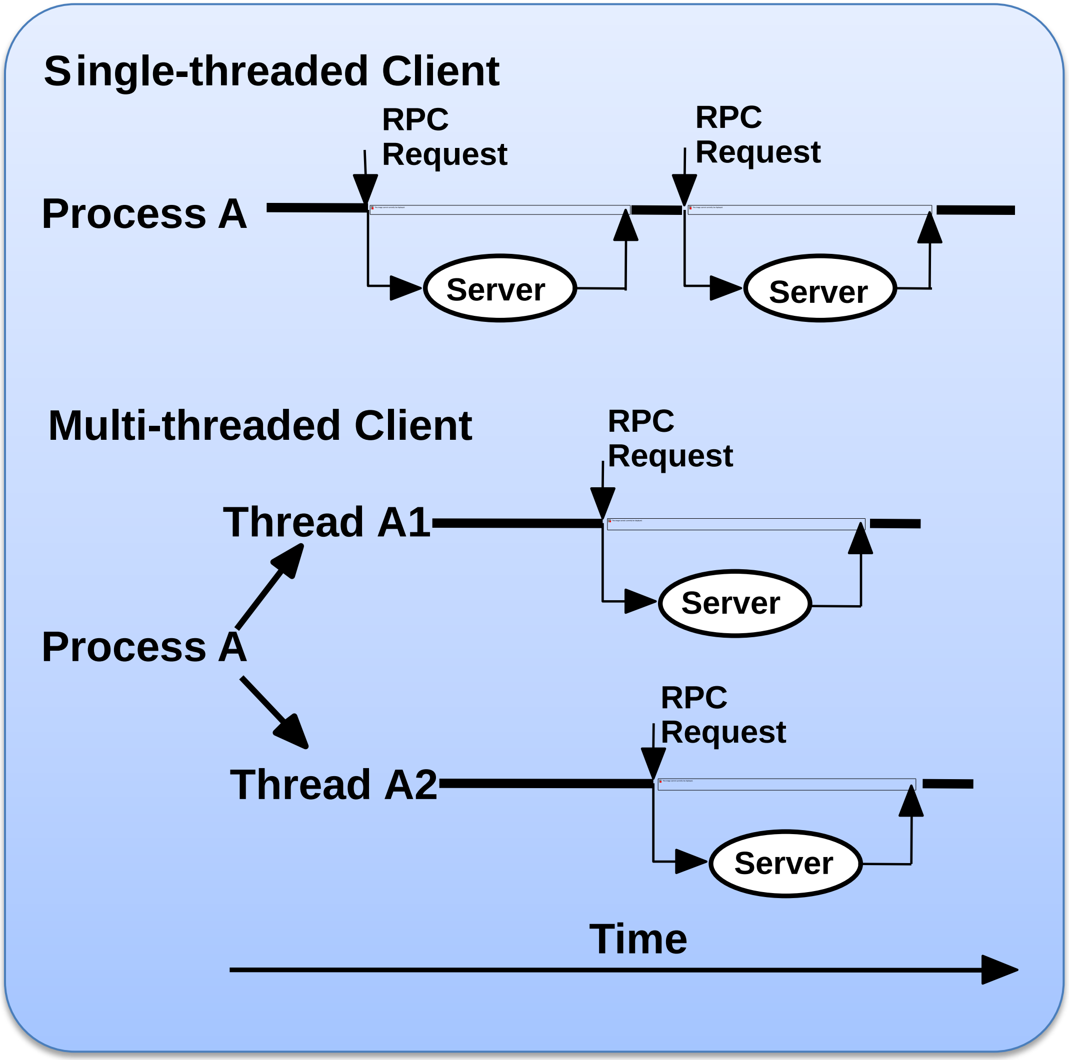
Failures

- Server Failure
  - Use exportid to detect failed server
  - On restart – exports interface again - generates a new exportid
  - All messages to server include exportid
  - Dispatcher aborts calls with incorrect exportid

- Client Failure
  - Orphans – client fails after making call but before receiving response
  - No ack to response
  - Server either implements a form of ‘rollback’ or does nothing

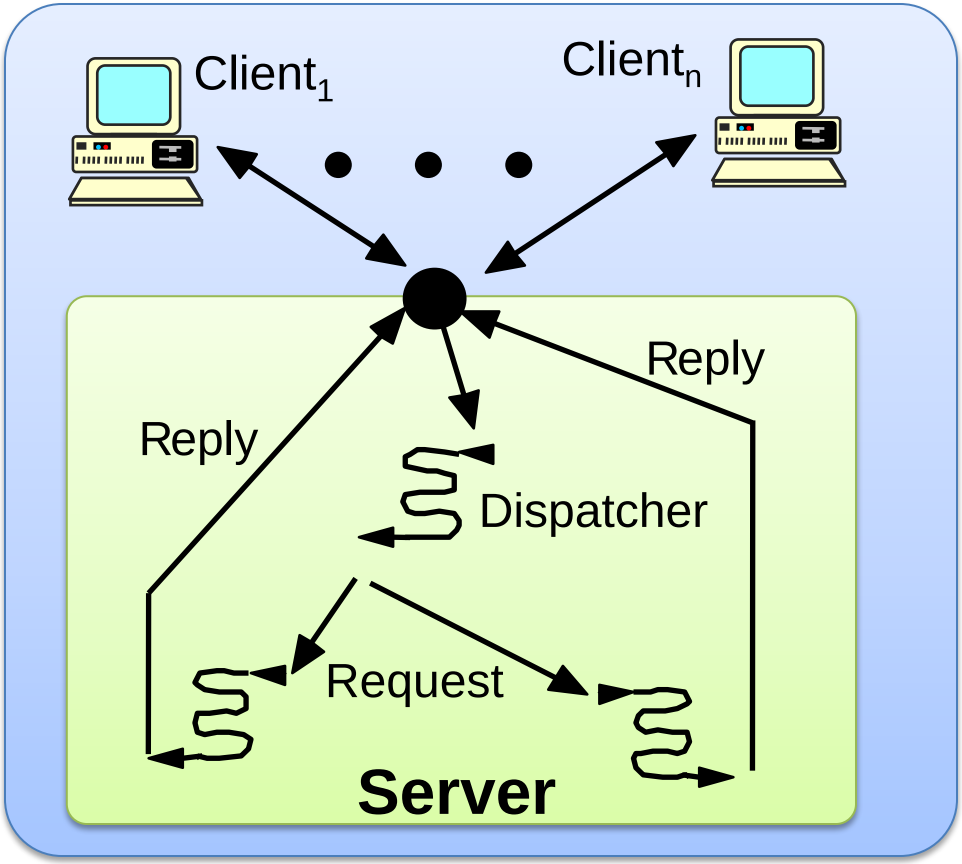
Client Threads

- In a single-threaded program which does RPCs to different servers, the RPCs must be done serially
- Each RPC blocks the program for at least 2 * the network delay. Throughput is adversely affected
- Using threads, remote invocations (RPC or object invocation) may be performed concurrently by a single client process



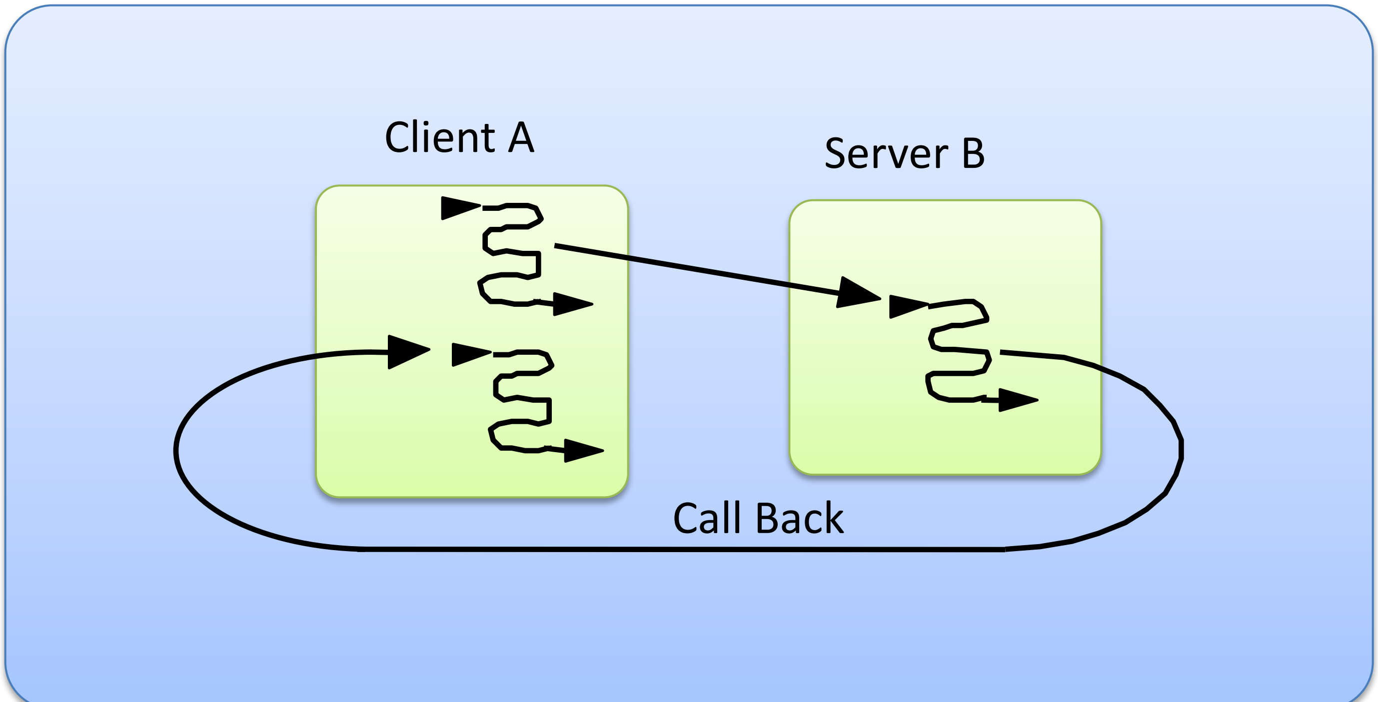
Server Concurrency

- Multi-threading can improve server responsiveness since if requests are processed concurrently, long requests will not block short requests



Client Concurrency

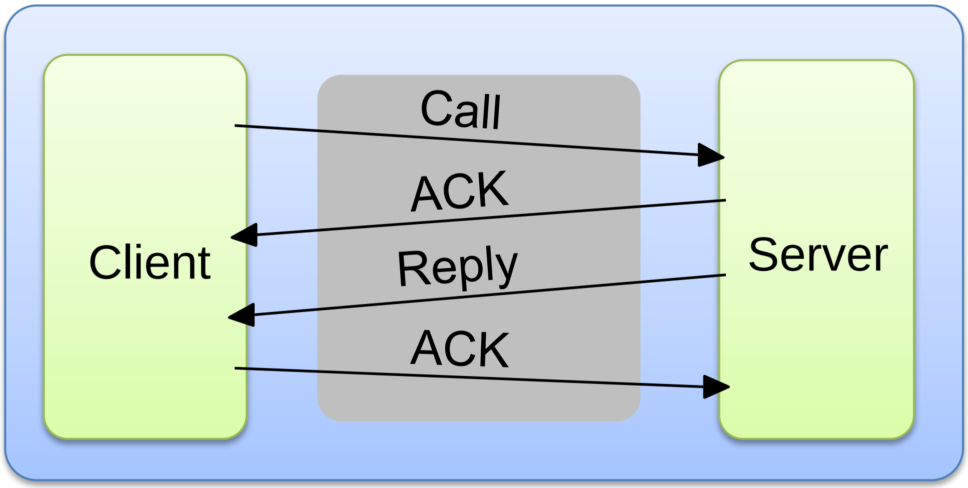
No dead-locks with callbacks if client multi-threaded



Server Implementation Options

- Server is single active process
  - Dispatcher processes one request at a time and calls the relevant stub procedure which calls the actual procedure. Problems?
- Thread-per-Request
  - Dispatcher creates a new thread to handle each request. Problems?
- Thread Pool
  - A fixed number of threads are generated at start-up and free threads are allocated to requests by the dispatcher
  - Concurrency but lower creation overheads
- Thread-per-Session
  - A thread is created at connection set up to process all requests from the particular client. Problems?

RPC Error Control



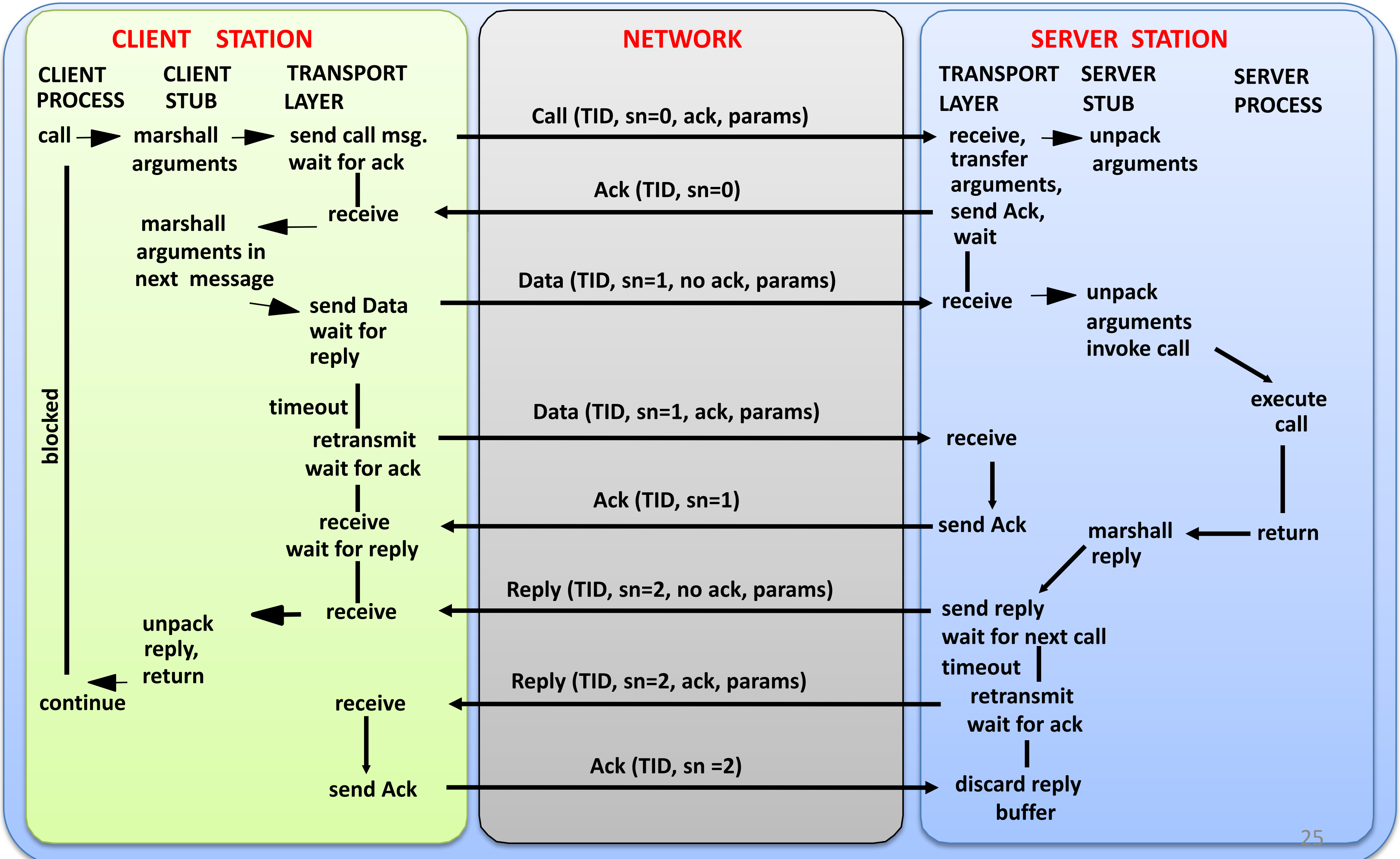
Error Control

- After sending message set timeout
- Retransmit if no ACK
- Save reply until ACK received in case call repeated

How can this be optimised?

Must also cater for long parameters requiring multiple messages to transfer

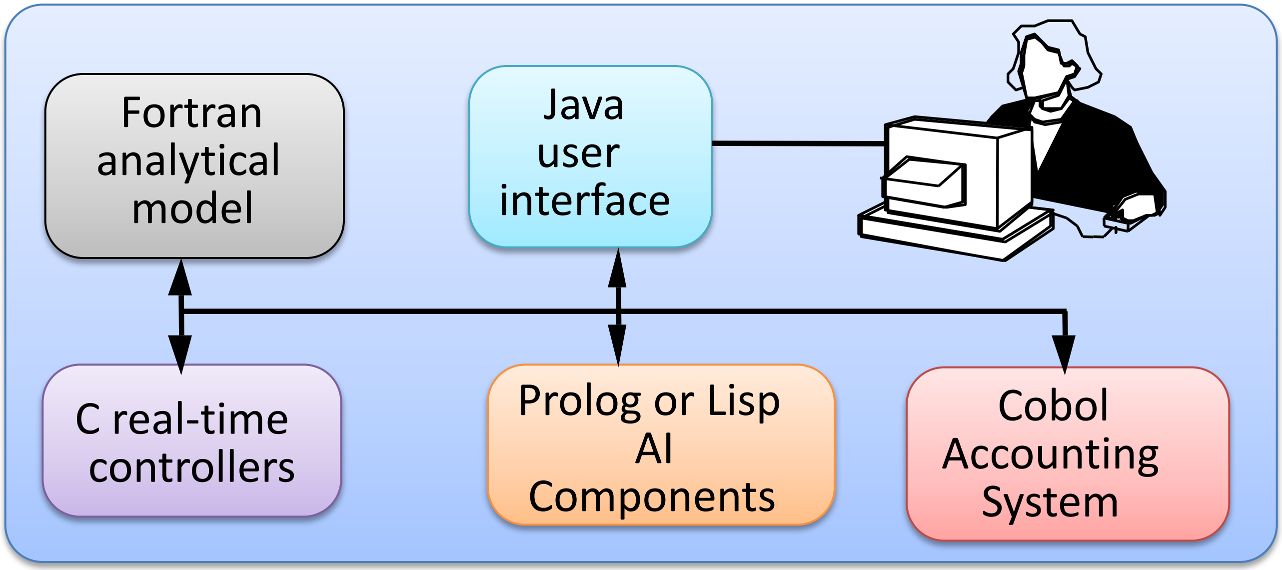
RPC Implementation



RPC Parameters

- TID = Transaction identifier plus interface export identifier
- sn = message sequence number
- ack = please acknowledge message
- no ack = no acknowledgement expected
- params = in or out parameters

Language Heterogeneity

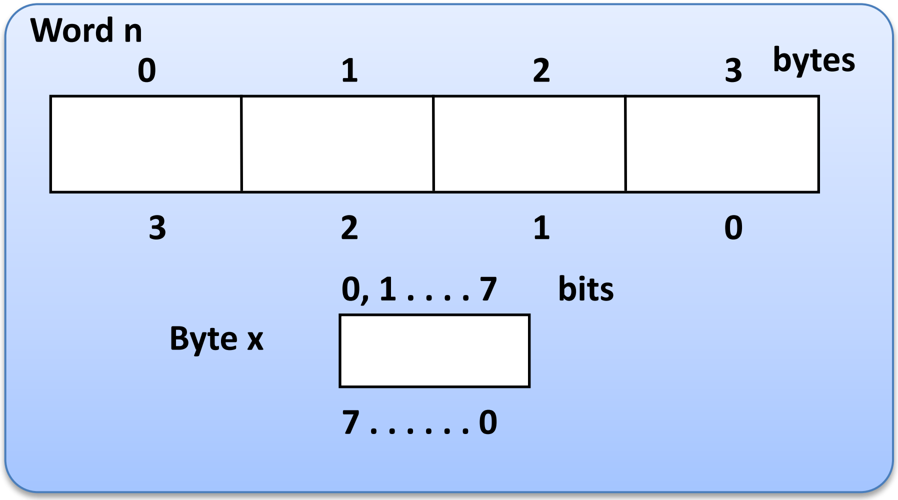


- Data structure representation differences:
  - Array implementation
  - Record implementation
  - Alignment of bytes on words etc.
  - No equivalent data structure e.g. no records in Fortran, no lists in C
- What can be done about this?

Processor Heterogeneity

Computers differ in representation of:

- Characters - Ascii, Ebcdic, graphics……
- Integers - 1 or 2's complement
- length
- Reals: mantissa & exponent length, format, base 2, 16 …
- Bit and byte addressing within a word

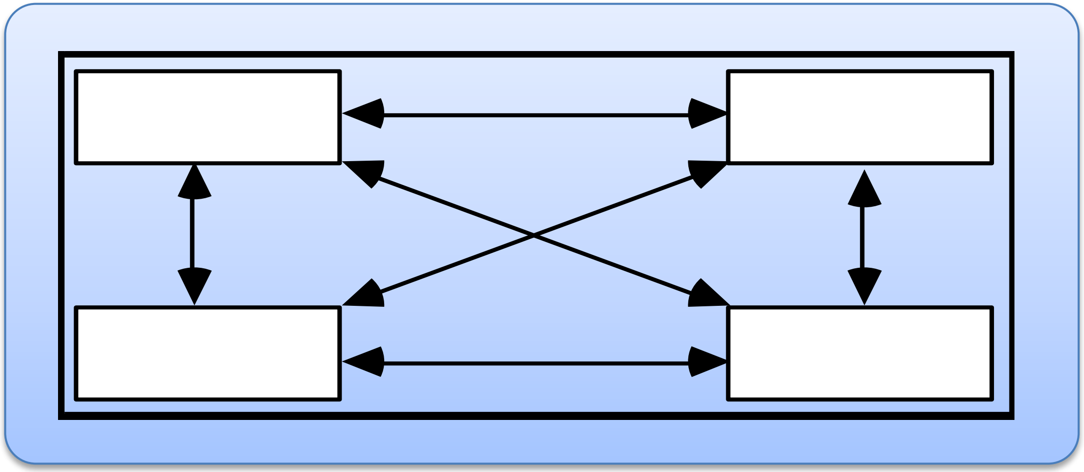


Need to transform representations when transferring data

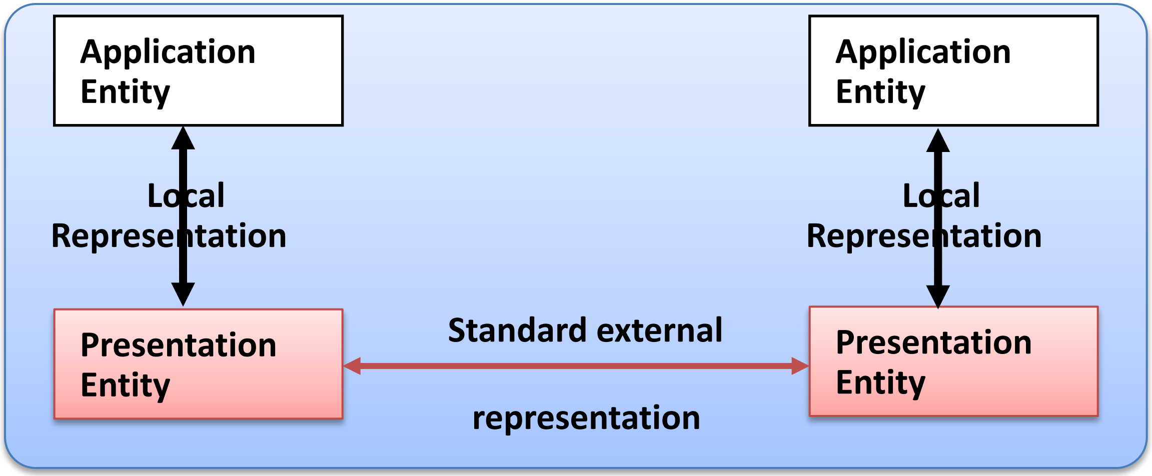
N * (N-1) translators

for N machines

What can be done about this?



Standard External Data Representation (XDR)



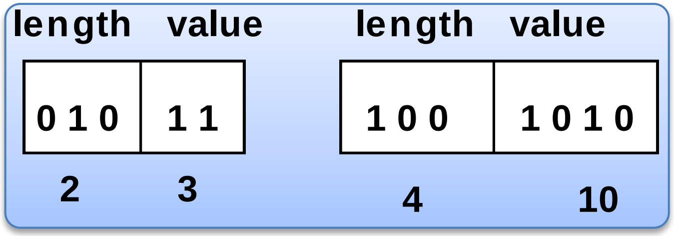
- Standard network wide external data representation (XDR) reduces number of translators → 2N translators (to and from external standard) for N different machine types. Transformation must:
  - preserve meaning – can be difficult
  - resolve syntax differences

Standard External Data Representation (XDR)

- Each Machine knows only about its own data representation and external representation
- Overhead of conversion when communicating between machines of same type
- What to do if only a few different machines?

Data Encoding e.g. XDR Characteristics

- Fixed Length
  - 16 or 32 bit integers
  - more efficient transformation
  - maximum value limitation → truncation
- Variable length
  - E.g. strings of printable characters to represent numbers
  - Requires length indicator or end delimiter
  - No value limitation
  - Inefficient
  - Packed binary → discard leading 0's
  - Length field usually fixed length or extensible in bytes
    - most significant bit set → another byte follows



Data Encoding e.g. XDR Characteristics

- Implicit Type
  - Types must be known in advance at receiver e.g. ports, object method parameters
  - Fewer overheads

- Explicit Tag or Type Identifier
  - Increased overheads
  - Information to perform transformation is self contained in message
  - Position independent
  - Needed for variant types
  - Can perform dynamic type checking

Type id	Length	Value

Extensible Markup Language (XML)

- Text based, explicit tags → human readable
- Very verbose, not human friendly → really aimed at machine processing
- Data items tagged with ‘markup’ strings describing logical structure
- Use start and end tags rather than length
- Extensible – users can define own tags
- Used for internet interactions and data storage e.g. XML databases
- Very inefficient encoding but can be compressed

XML Elements and Attributes

Element: container for data – enclosed by start and end tag

Attribute: used to label data – usually name/value

```
<person id="123456789">
        <name>Smith</name>
        <place>London</place>
        <year>1934</year>
        <!-- a comment -->
</person >
```

Attribute

Place element

Person Element

XML Namespace

- Namespace used to scope names
- A set of names for a collection of element types and attributes
- Referenced by a url
- Specify namespace by a xmlns attribute
- Can use namespace name as prefix for names

```
<person pers:id="123456789" xmlns:pers =
  "http://www.example.com/person">
  <pers:name> Smith </pers:name>
  <pers:place> London </pers:place >
  <pers:year> 1934 </pers:year>
</person>
```

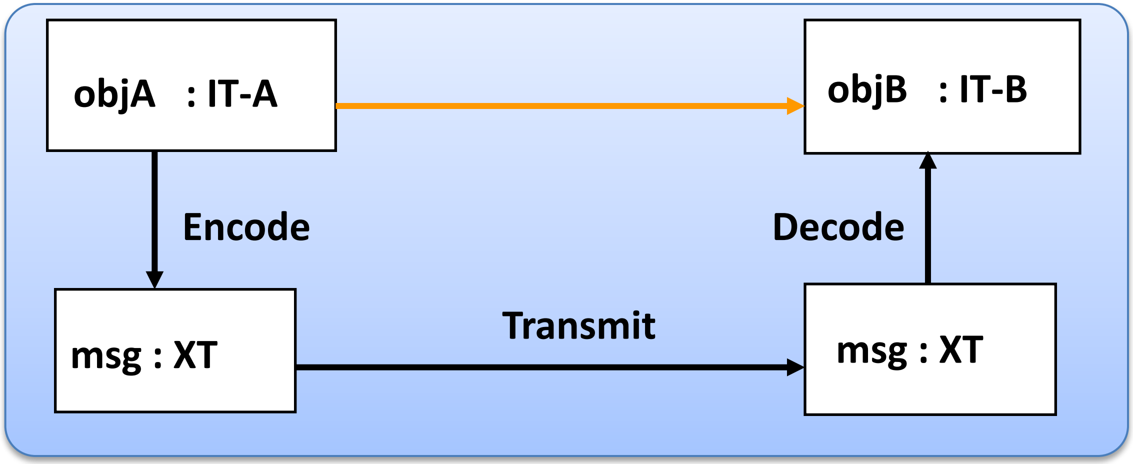
Namespace attribute

XML Schema

- Defines elements and attributes that can appear in a document
- Defines element nesting, number, ordering, whether empty or can include text
- For each element defines type and default value

```
<xsd:schema  xmlns:xsd = URL of XML schema definitions  >
  <xsd:element name= "person" type ="personType" />
  <xsd:complexType name="personType">
    <xsd:sequence>
      <xsd:element name = "name"  type="xs:string"/>
      <xsd:element name = "place"  type="xs:string"/>
      <xsd:element name = "year"  type="xs:positiveInteger"/>
    </xsd:sequence>
    <xsd:attribute name= "id"   type = "xs:positiveInteger"/>
  </xsd:complexType>
</xsd:schema>
```

Representation Transformation



- What problems could occur when doing transformations, e.g. with numbers?

Semantics of Representation

- Two representations can have similar syntax but different meaning
  - E.g. complex numbers – (float x, y) = rectangular or polar coordinates → transformation is application dependent
- Type may have no meaning outside own context
  - E.g. pointer, file name
- Procedures passed as parameters
  - Cannot transfer code to different computer for execution
- What should be done?

Example of Use of Encode

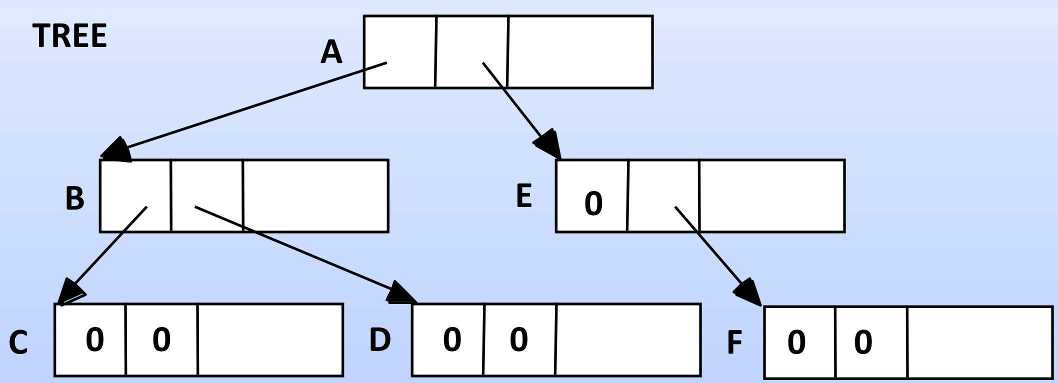
```
struct rec {
        int a;
        boolean b;
};
struct form {
        int x;
        float y;
        rec z  [3];  /* assume 3 elements */
};
form obj = (5, 23.75, 10, true, 5, false, 7, true)
```

→ can be "flattened" for transfer:
where I = int, F = float, B = boolean

$$\underset{x}{\mathbf{I}}\quad \underset{y}{\mathbf{F}}\quad \underbrace{\mathbf{I}\ \ \mathbf{B}\ \ \mathbf{I}\ \ \mathbf{B}\ \ \mathbf{I}\ \ \mathbf{B}}_{\text{3 elements of z}}$$

Structural Information

- Structural information must be maintained
  - Structural information represented internally by pointers (addresses)
  - must be flattened into a linear message



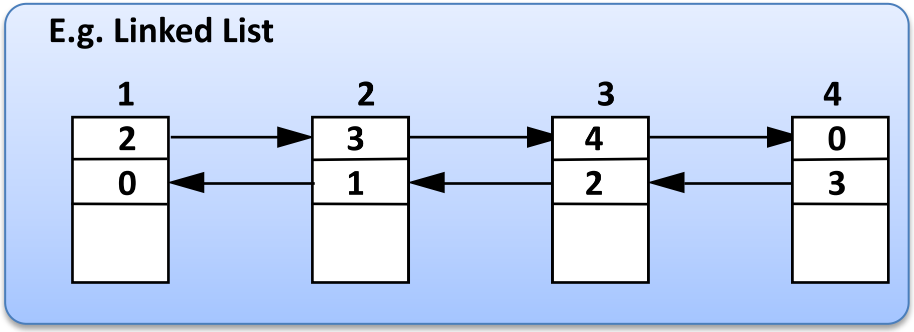
Recursively Flattened Tree

{ { {0, 0, value C} {0, 0 value D} value B} {0 {0, 0 value F} value E} value A}

Transferring Cyclic Structures

- Use Encode and Decode procedures for primitive types and simple constructed types
- Structural information must be flattened:
  - Number sub-objects
  - Transform pointers into handles (i.e. number) of sub-objects

Sub object 1
Handle 2
Null
Contents
Sub object 2
Handle 3
Handle 1
Contents
Sub object 3
Handle 4
Handle 2
Contents



Sub object 4
Null
Handle 3
Contents

Java Object Serialization

- Java objects can be passed as arguments and results in RMI. Object is an instance of a Java serializable class

```
public class Person implements Serializable {
    private String name;
    private String place;
    private int year;
    public Person (String aName, String aPlace, int aYear) {

        name = aName;
        place = aPlace;
        year = aYear;
    }
    // methods for accessing instance variables
}
```

Java Object Serialization

```
FileOutputStream fos = new
     FileOutputStream(“t.tmp”);

ObjectOutputStream out =
     new ObjectOutputStream(fos);

out.writeObject
     (new Person(“Anandha”, “London”, 2015));

out.close();
```

http://docs.oracle.com/javase/7/docs/api/java/io/ObjectOutputStream.html
https://docs.oracle.com/javase/7/docs/platform/serialization/spec/protocol.html

Java Object Serialization

- Java objects can contain references to other objects
  - All referenced objects are serialized together

- References are converted to handles i.e. internal references to object within the serialized form

- Each object is serialized only once – detect multiple references to same object

Java Object Serialization

- Serialization
  - Write class information
  - Write types and names of instance variables
  - If instance variables are of a new class, then write their class information followed by types and names of instance variables
  - Uses reflection – ability to enquire about properties of a class e.g. names and types of instance variables and methods

Java Object Serialization

1. Specifies it's a serialization protocol
2. Serialization version
3. Specifies new Object
4. Specifies new Class
5. Length of class name
6. Name of class (Person)
7. SerialVersionUID
8. Flags – object supports serialization
9. Number of fields in class
10. Field type (Int)
11. Length of field name
12. Field name (year)
13. Field type (String)
14. Length of field name
15. Field name (name)
16. String instance (type + length + "java/lang/string;")
17. Field type (String)
18. Length of field name
19. Field name (place)
20. End of block data for this object
21. No more superclasses
22. Int value ($7 * 16^2 + 13 * 16 + 15 = 2015$)
23. String
24. Length of value
25. Value (Anandha)
26. String
27. Length of value
28. Value (London)

ac ed 00 05 73 72 00 06 50 65 72 73 6f 6e b1 49
3f a5 9f 2f a4 0e 02 00 03 49 00 04 79 65 61 72
4c 00 04 6e 61 6d 65 74 00 12 4c 6a 61 76 61 2f
6c 61 6e 67 2f 53 74 72 69 6e 67 3b 4c 00 05 70
6c 61 63 65 71 00 7e 00 01 78 70 00 00 07 df 74
00 07 41 6e 61 6e 64 68 61 74 00 06 4c 6f 6e 64
6f 6e

Hex dump of the t.tmp file from earlier

- Using `od -t x1 t.tmp`

Summary

- Message passing systems map closely onto the underlying communication services, however RPCs and Object invocation are more complex to implement
- They require binding implementation and have to cater for failures of client, server, name servers or communication system
- RPCs and invocations can either be implemented by an optimised special purpose protocol or by a general purpose Transport protocol such as TCP

Summary

- Translation to a standard external representation should be optional to avoid unnecessary overheads
- Typed interfaces do not need explicit tags in the XDR
- Some types cannot be transferred e.g. memory addresses
- Complex data types must be “flattened” for transfer to a remote machine (or to disc store) and addresses transformed to local references (e.g. array index)