SOFTWARE DEVELOPMENT

Franco Gasperoni

gasperon@act-europe.fr

http://libre.act-europe.fr

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Programming Distributed Systems

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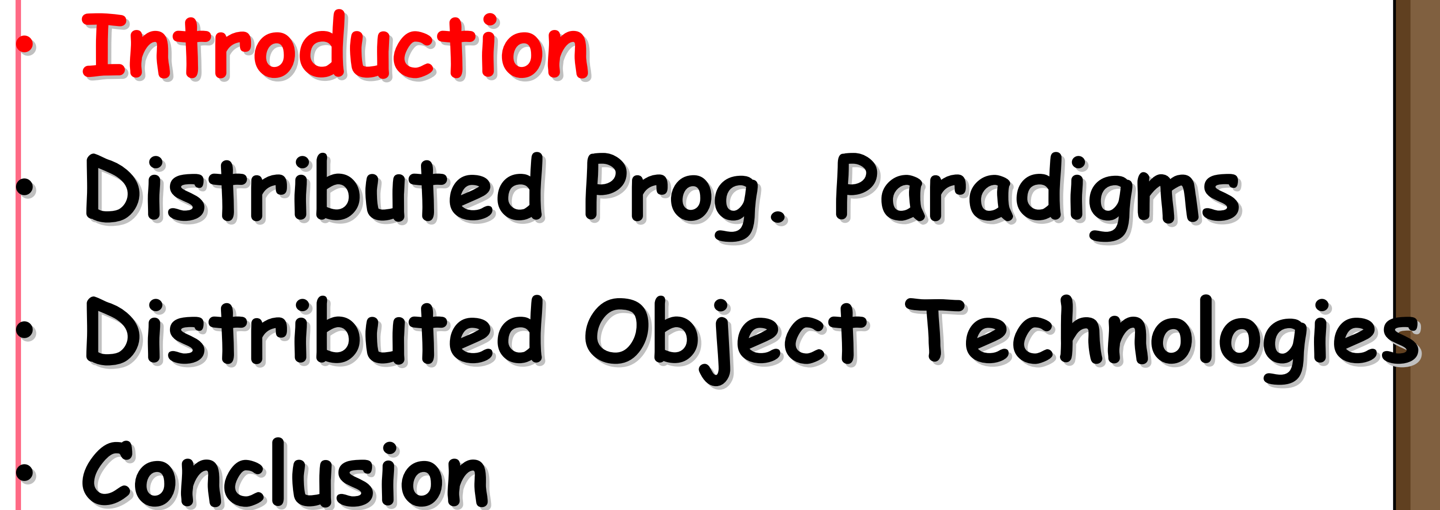

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- **Non-distributed application** = single process
  - running on a single computer

- **Distributed application** = several communicating processes
  - processes often run on different computers
  - computers are connected through a network

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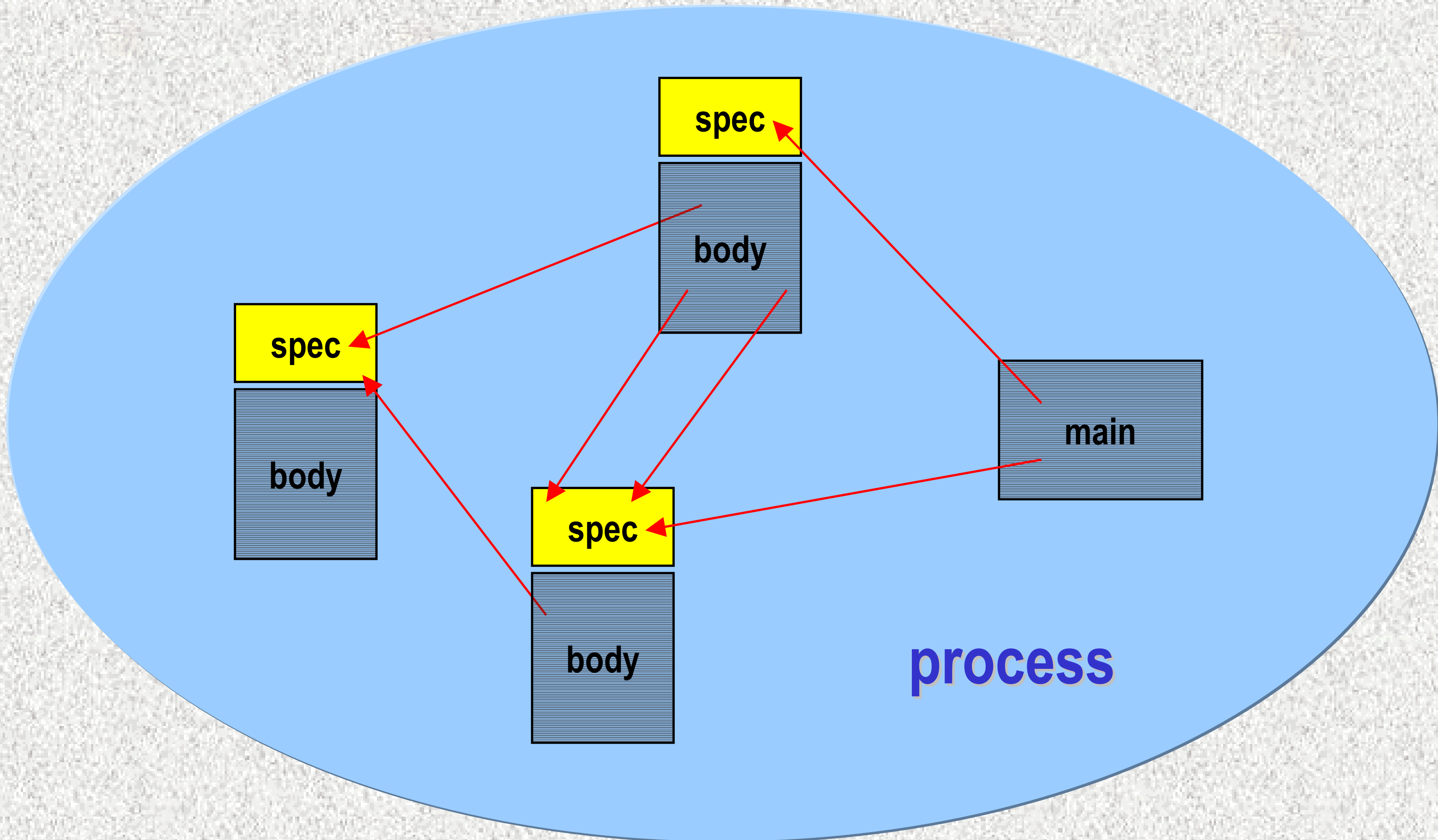
Single Process Application



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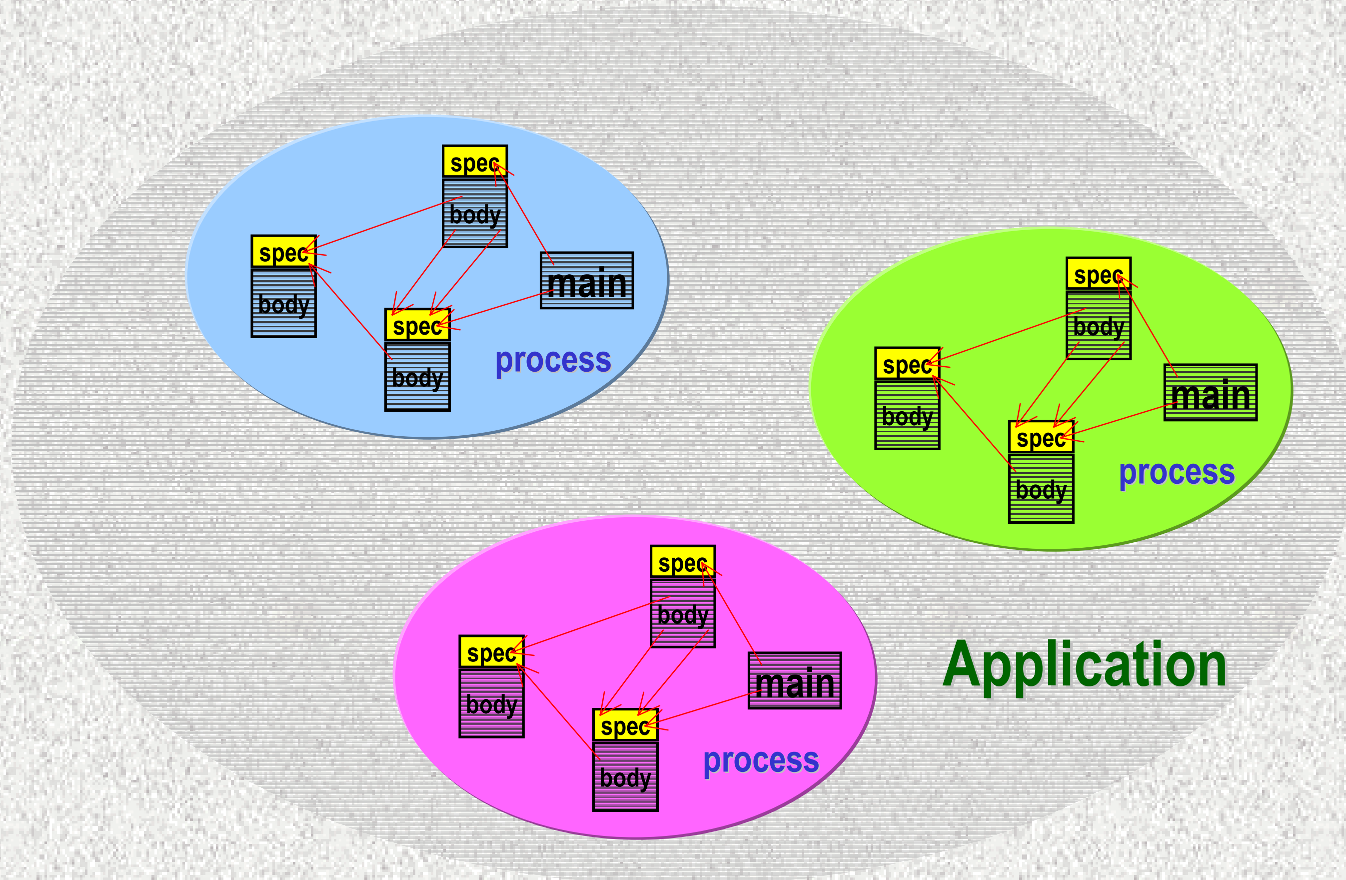
Distributed Application



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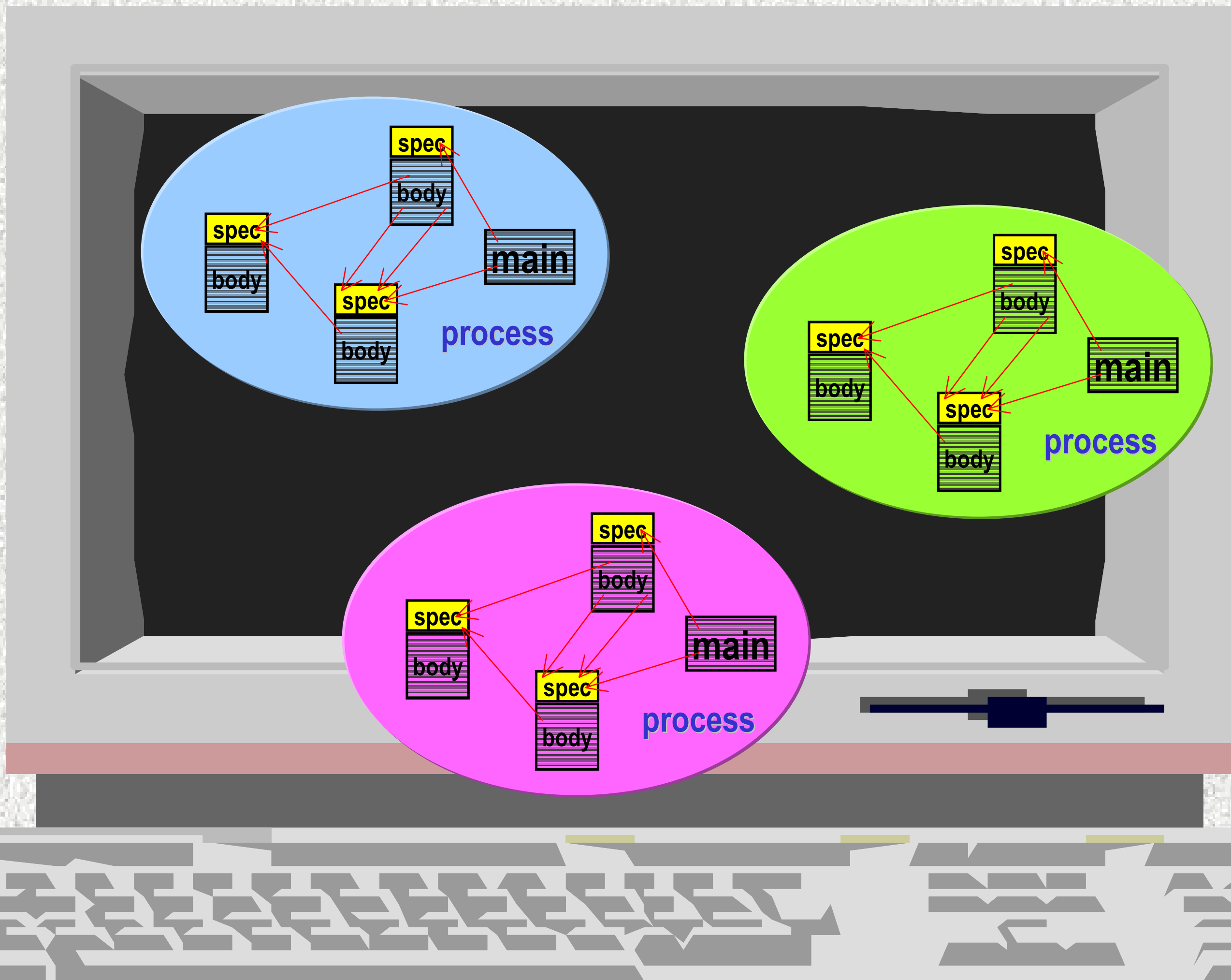
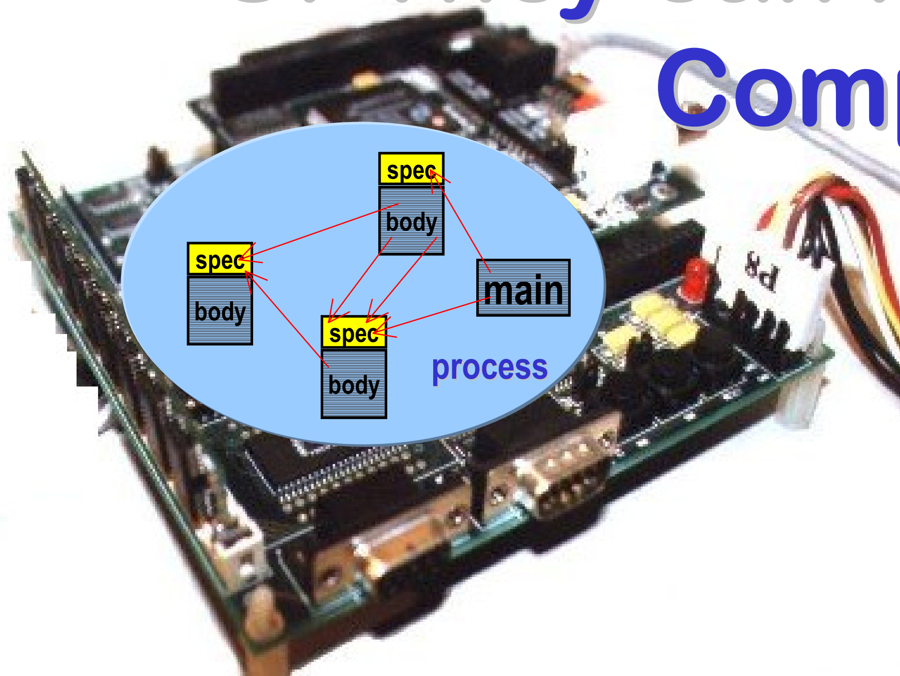
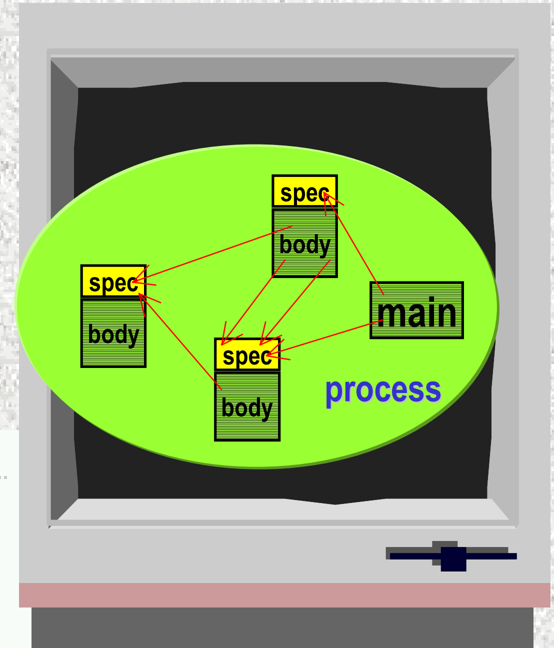
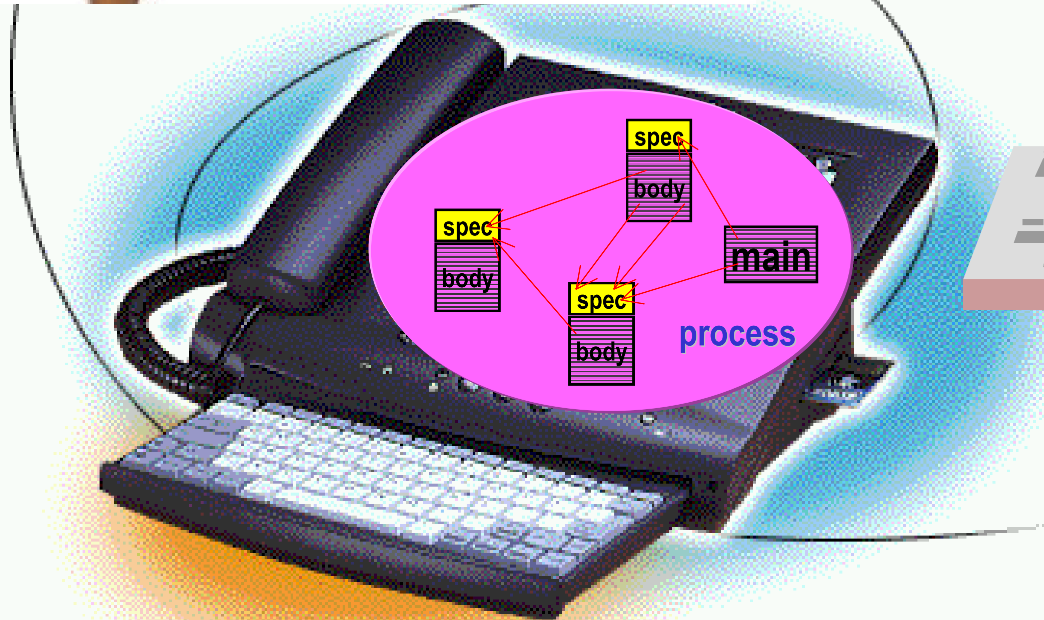
All Processes Can Run on the Same Computer



Or They can run on Different Computers







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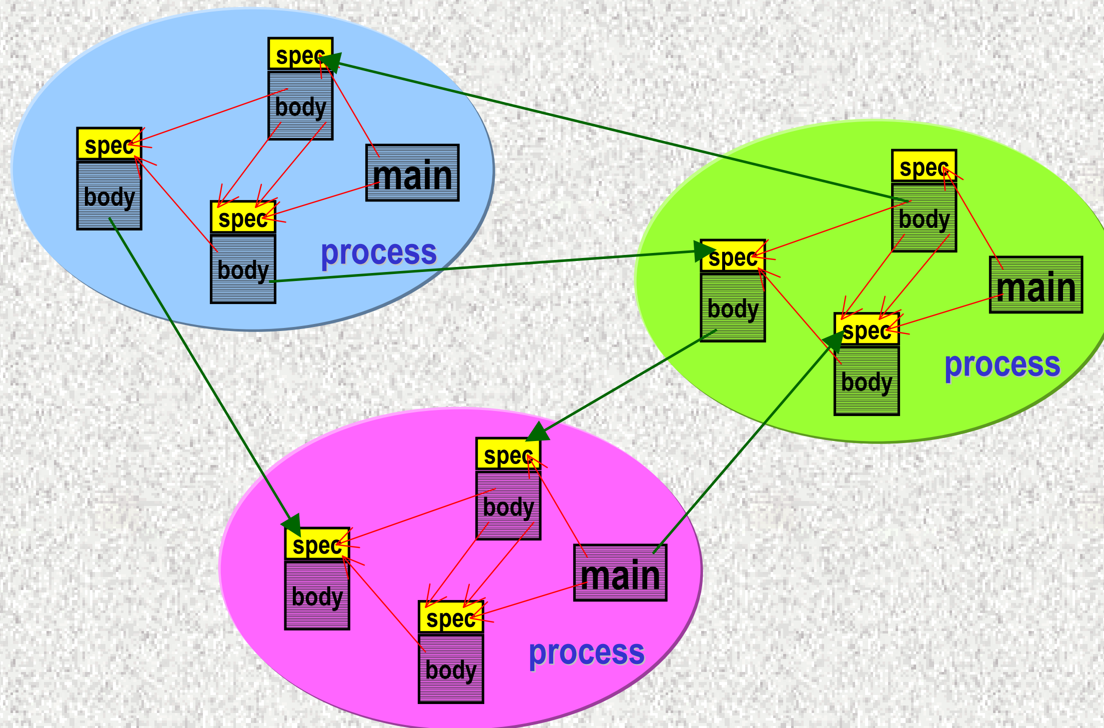
In All Cases This Requires Inter-Process Communication



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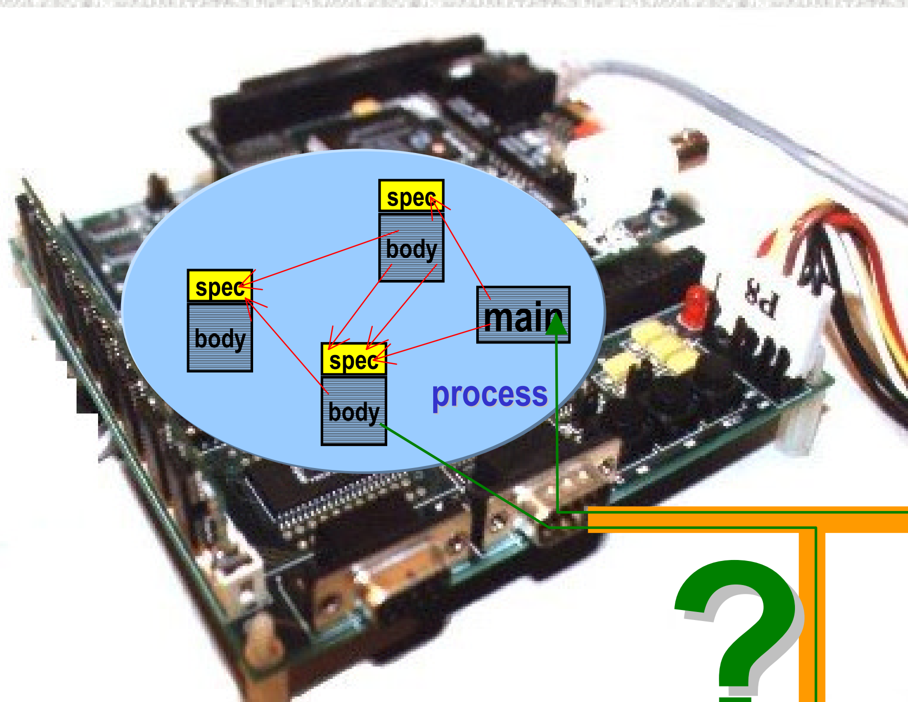

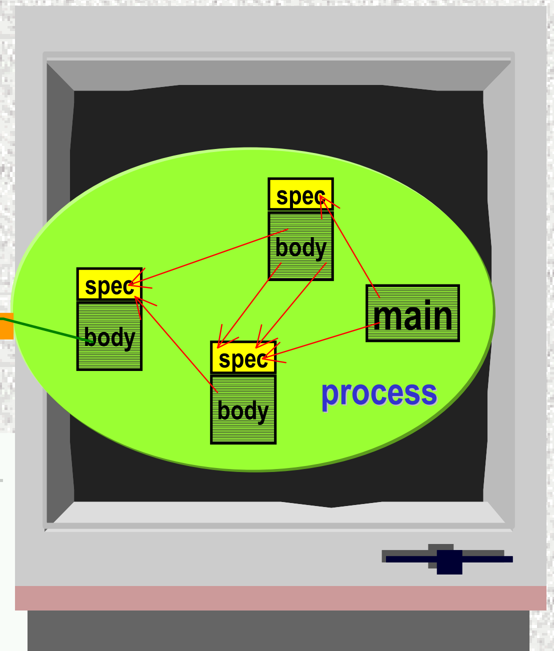

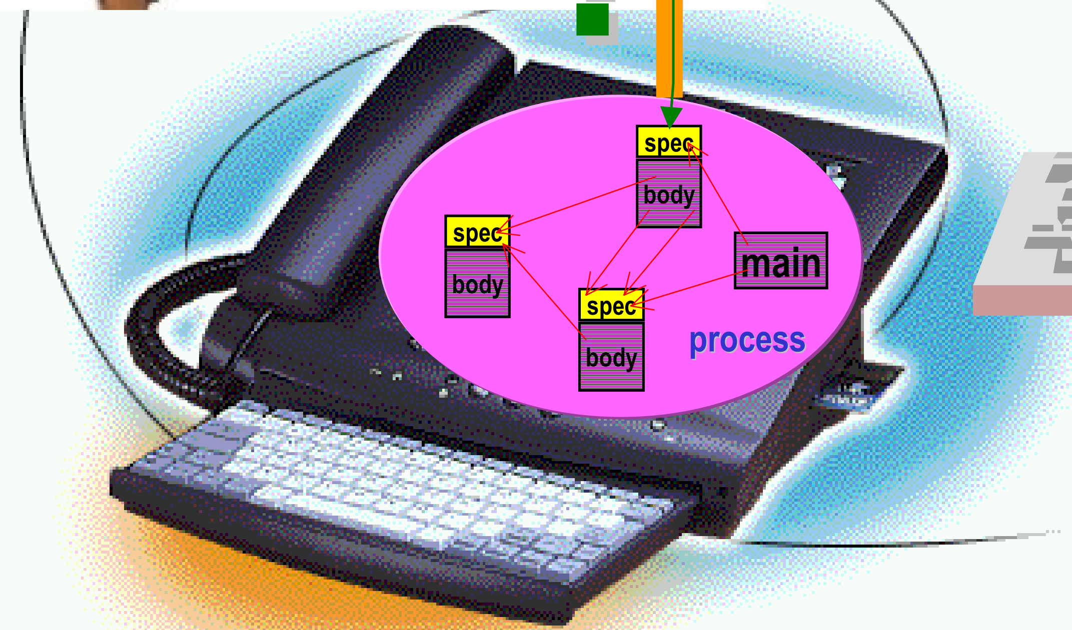

?
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The Main Topic of this Lecture

- **How distributed processes communicate at the *programming* level**
- **How the "*software chunks*" of a distributed app can *interact*.**
- **This lecture will NOT teach you how they communicate at the**
  - **physical level**
  - **or protocol level**

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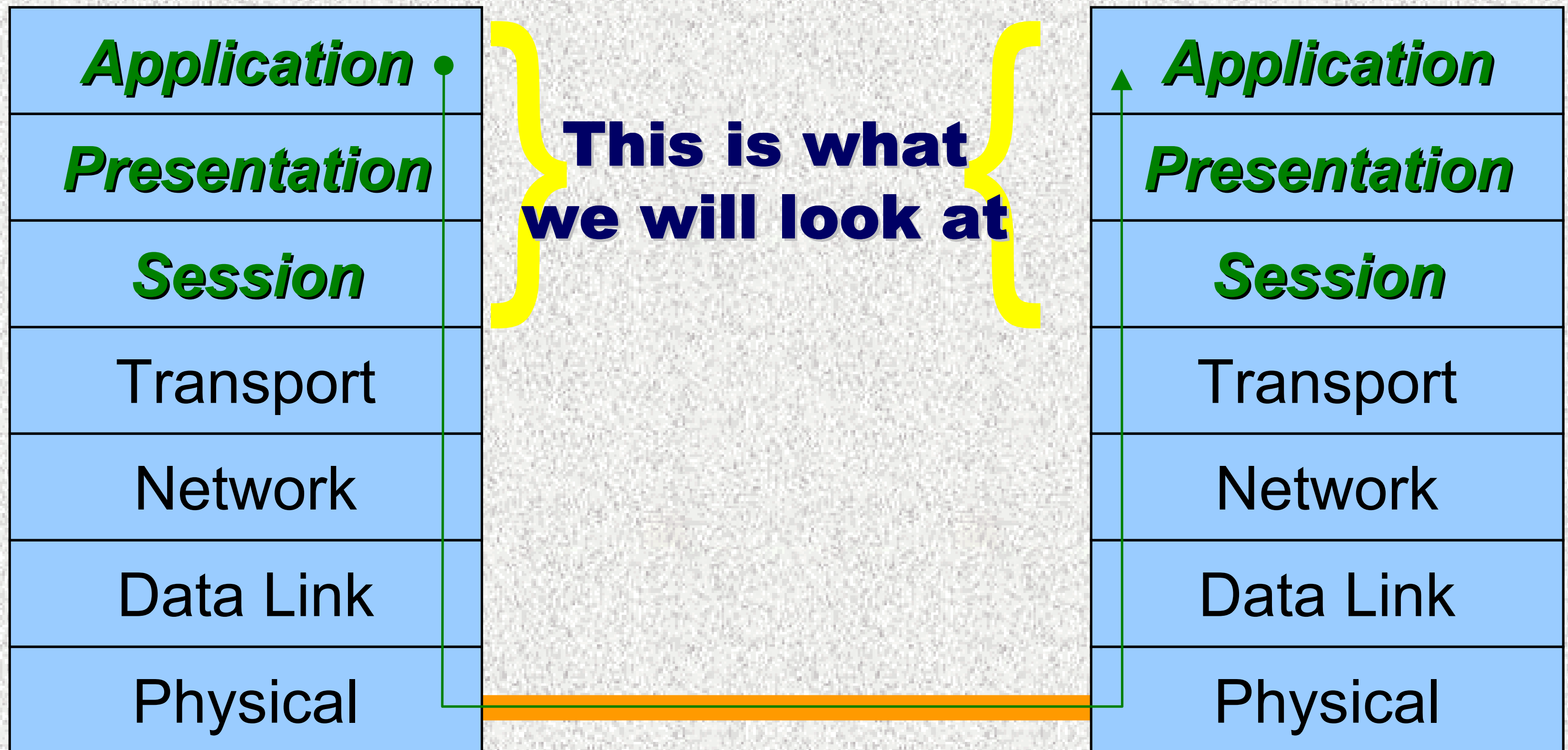
Remember OSI Layers ?



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Application	***Telnet, ftp, …***
Presentation	***Sending data in platform indep. manner***
Session	***Establish communication bw processes***
Transport	TCP, UDP, ...
Network	IP, X.25, ...
Data Link	Network drivers
Physical	The wire

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Why Distributed Apps ?

- Multiuser apps (e.g. e-mail, ftp)
- Sharing data (e.g. www, airline reservation)
- Sharing resources (e.g. printers)
- Fault tolerance
- App may be inherently distributed (cell phones, ATM machines, …)

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Distributed Prog. Is Hard

- Multiple failure modes
  - each individual process can fail (bugs, machine crash..)
  - the network can go ashtray
- Security issues
  - is someone else listening
- Testing & debugging
- Distributed prog. technologies not fully mature
  - interoperability is still an issue

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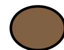
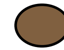
- Introduction
- Distributed Prog. Paradigms
  - Message Sending (Sockets)
  - Remote Procedure Calls
  - Distributed Objects





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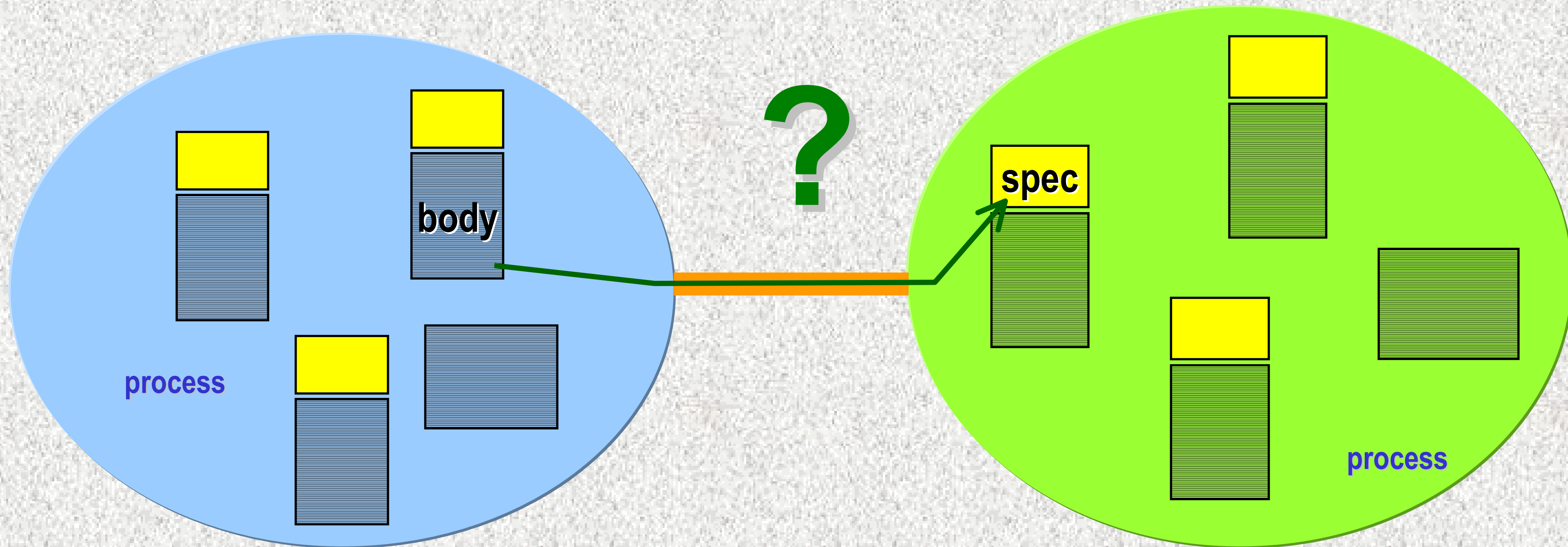
How to Formalize the Notion of an Interface in a Distributed Environment ?



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How to Formalize the Notion of an Interface in a Distributed Environment ?

- **Answer 1**: don't formalize it, send a message
  - e.g. sockets

- **Answer 2**: Remote Procedure Call (RPC)

- **Answer 3**: RPCs + Distributed Objects
  - Language dependent: Ada 95, Java RMI
  - Language independent: CORBA, COM/DCOM

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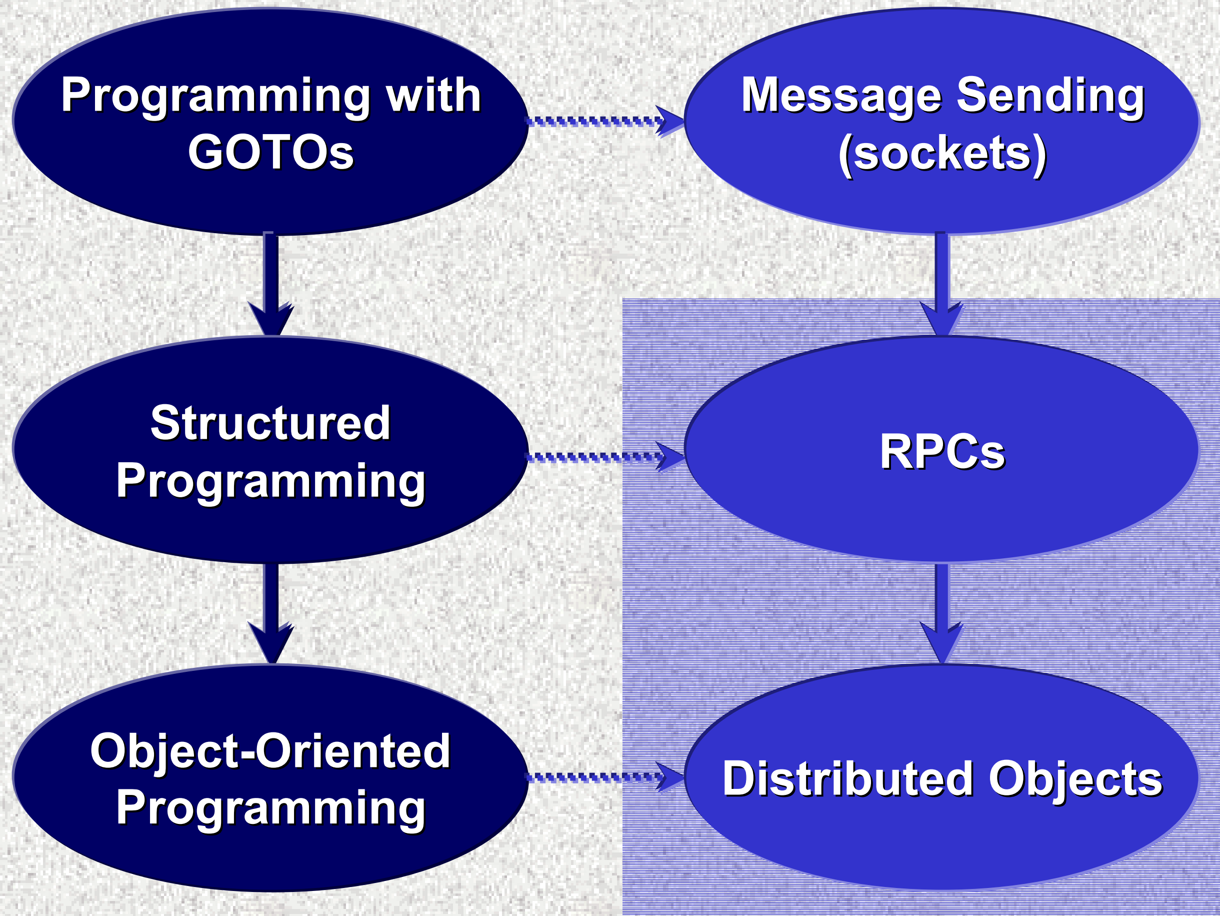
A Simple Comparison



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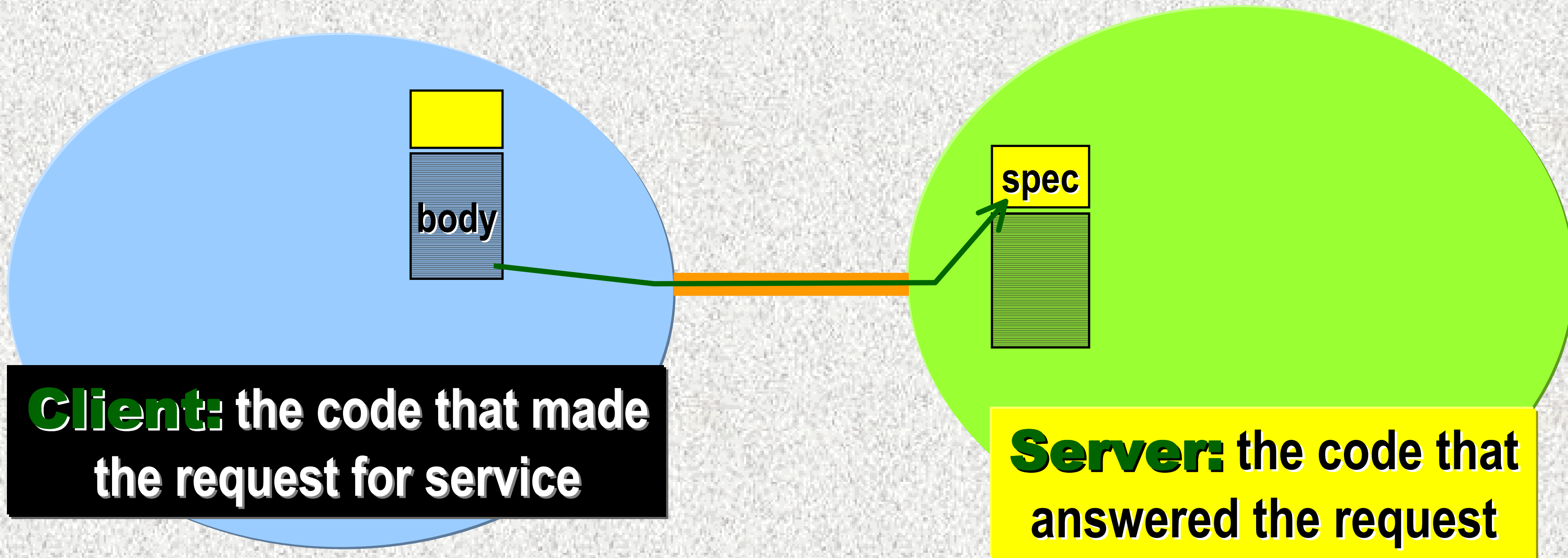
Some Terminology



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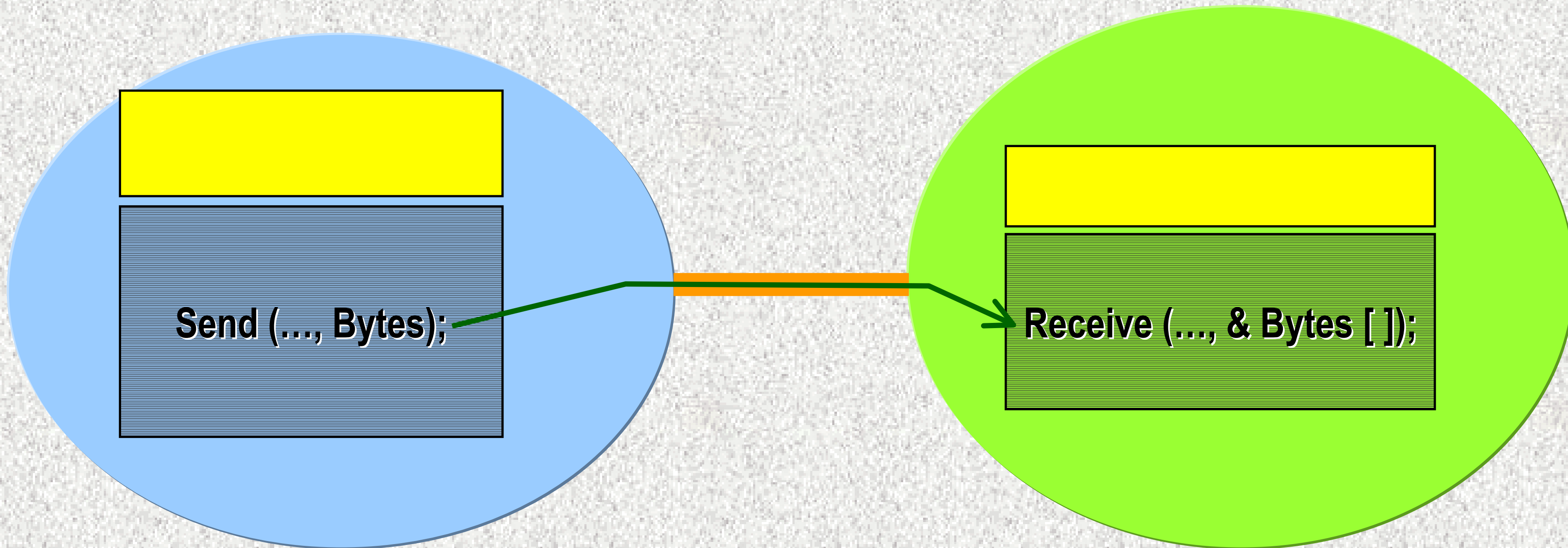
Answer 1: Don't Formalize It
Send a Message (e.g. Sockets)



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Client Process

Server Process

Open socket

Open socket

Wait for connection

Compute

raw bytes

Send bytes

Get bytes

Wait for reply

Compute

Send bytes

Get bytes

raw bytes

Close socket

Close socket

time

time

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What are the problems

with this approach ?

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Problems with Sockets/Message Sending

- No interfaces - very low-level programming
  - does not scale up
- Sockets exchange bytes
  - How do you exchange more complex data structures ?
  - How do you handle heterogeneous systems ?

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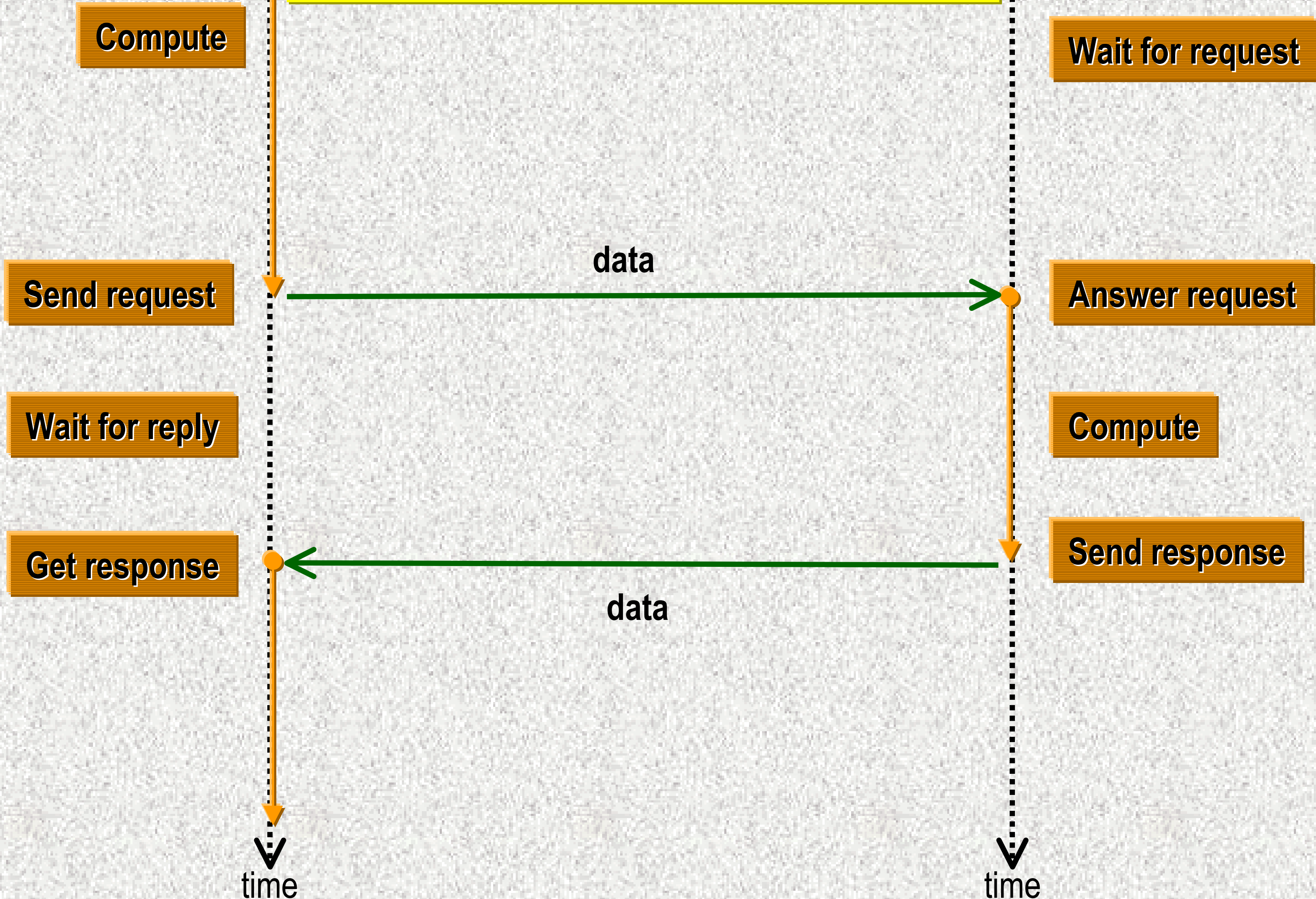

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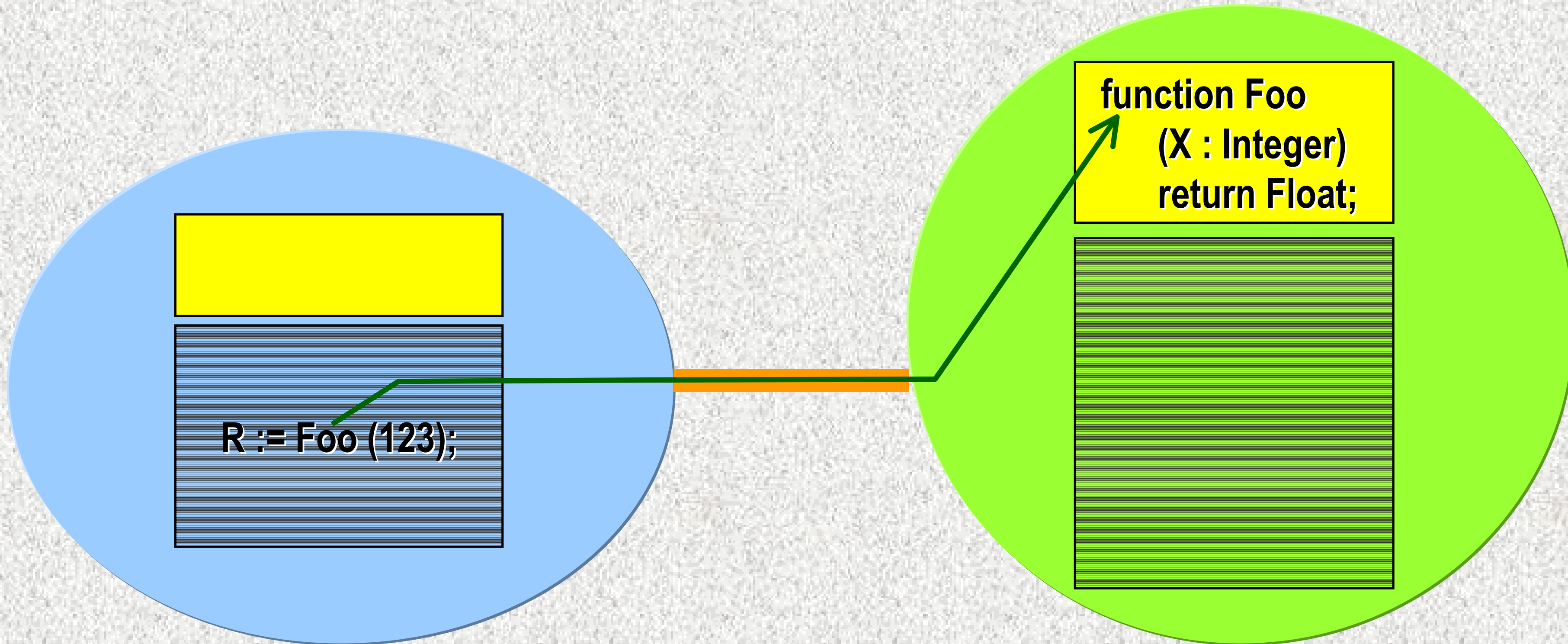
Answer 2: Remote Procedure Calls



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RPC

Client

Server

Compute

R := Foo (123);

send parameters

```
function Foo (X: Integer)
   return Float
is
 ...
begin
   ...
   return ...;
end Foo;
```

Wait for reply

Get result

send result or modified parameters

time

time

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RPCs

- Remote procedure call completely handled by the system
- Parameters and results passed across the network without programmer intervention
- Heterogeneity handled transparently

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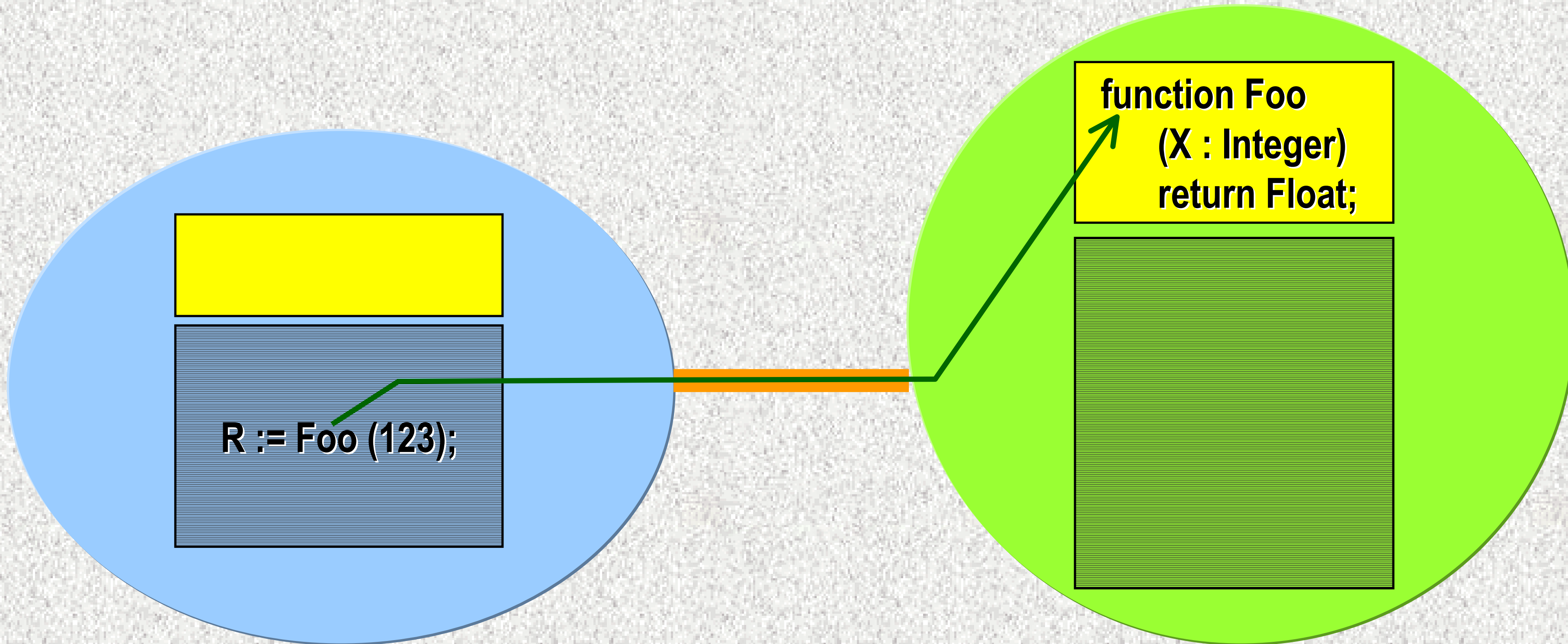
Where is the Magic ?



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Client Stub & Server Skeleton

- From the server spec the system generates a client stub:
  - Marshals the parameters
  - Sends the request over the network
  - Waits for the response and unmarshals the result
- From the server spec (and server body) the system generates a server skeleton
  - Receives the RPC request
  - unmarshals the parameters
  - Selects and calls the appropriate subprogram
  - Marshals the result and sends the response

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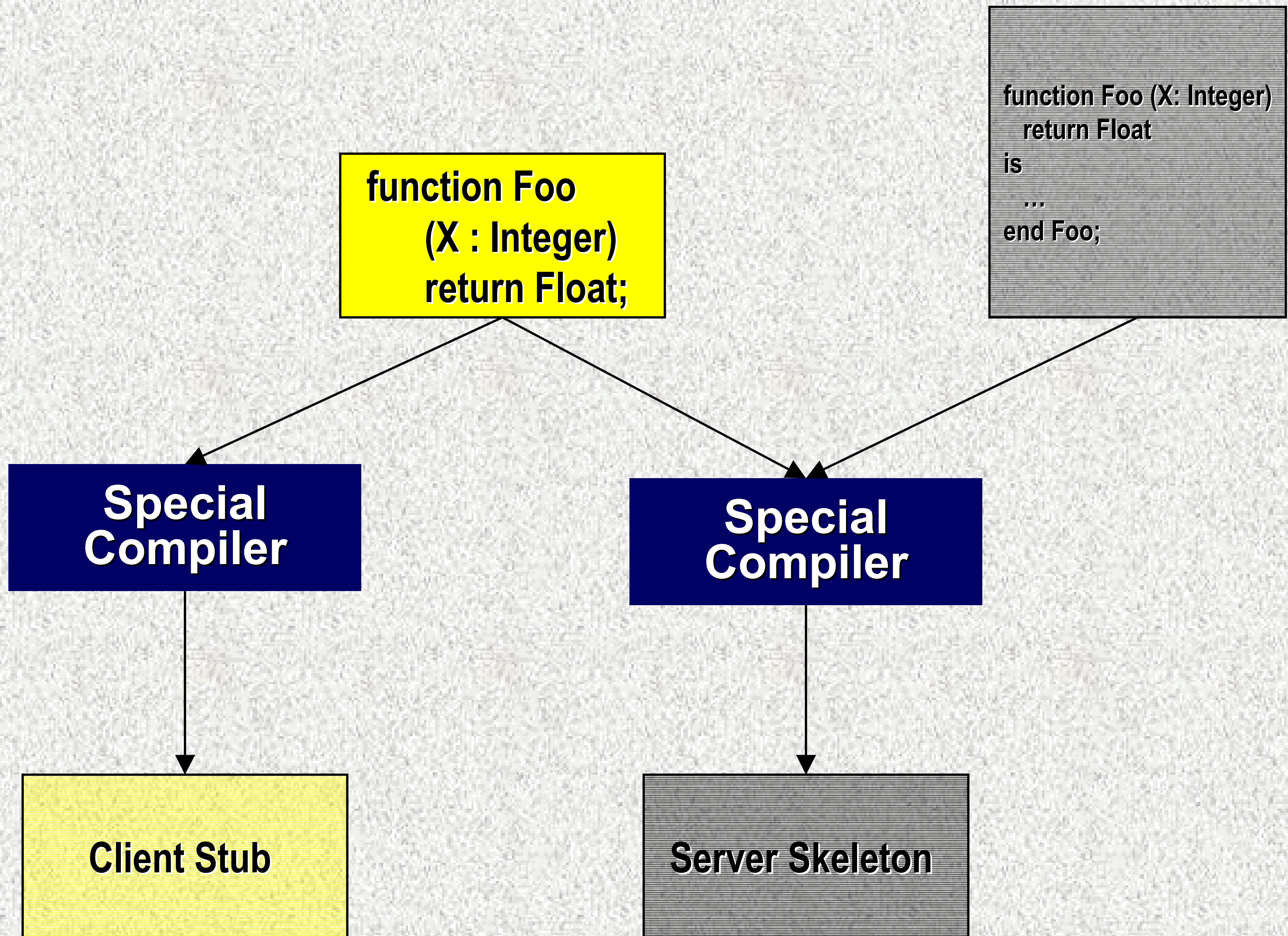
Stubs & Skeletons



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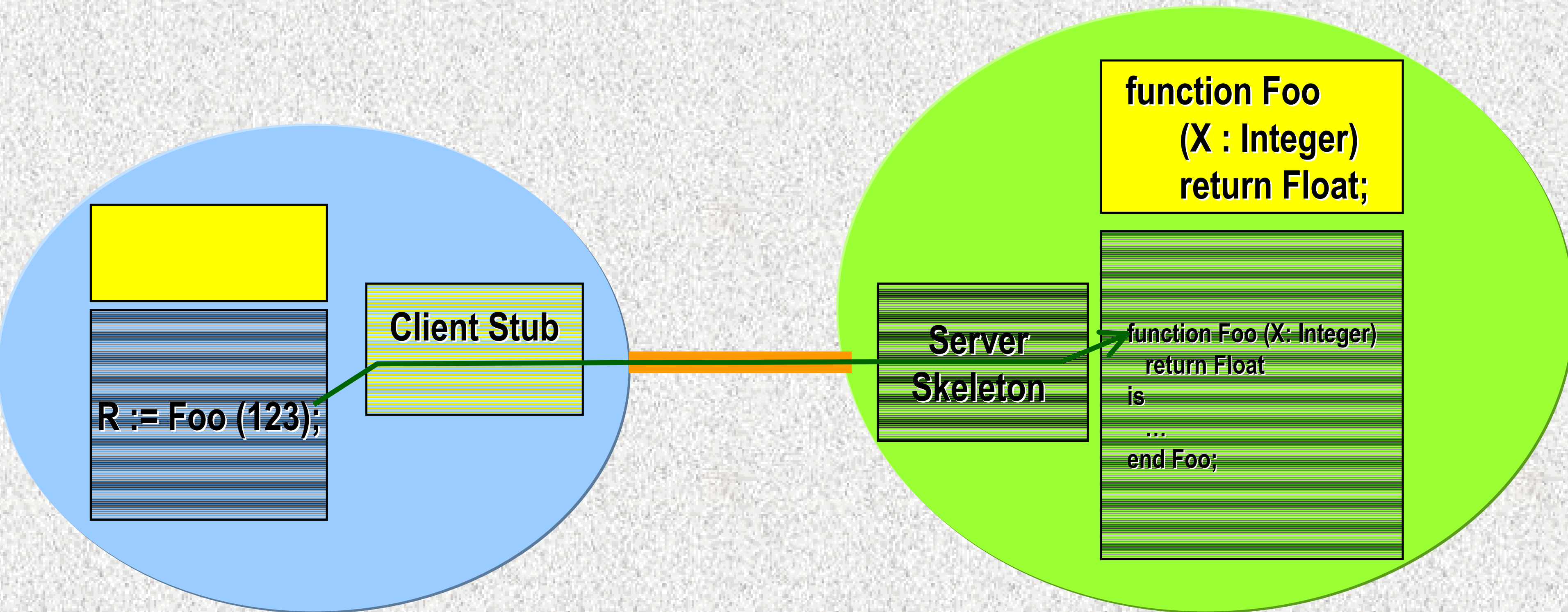

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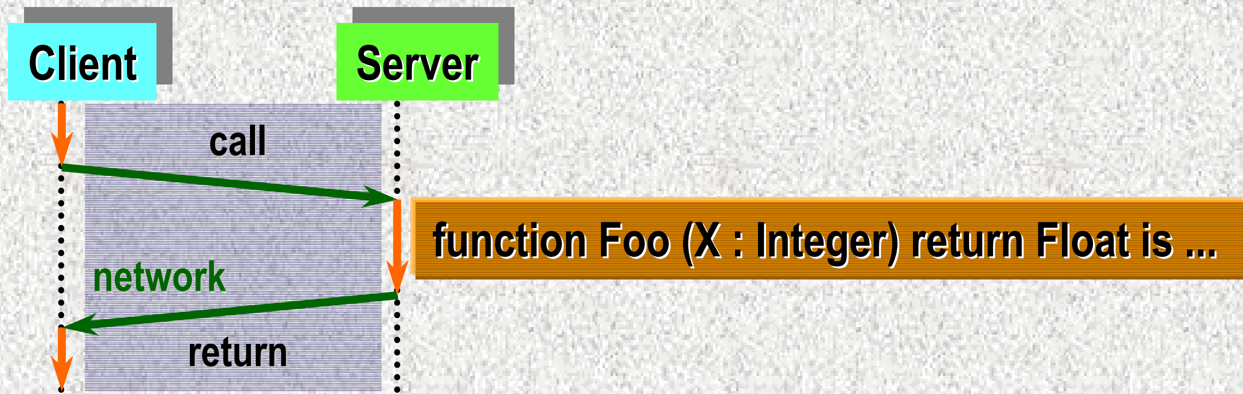

Client
Client Stub
Server Skeleton
Server
call
parameter
marshalling
result
unmarshalling
call
function Foo
network
result
marshalling
return
result
unmarshalling
return

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Enhancing RPCs

- **Exceptions**
  - exceptions raised in the callee canbe transmitted to the caller over the network
- **Asynchronous calls**
  - the caller does not need to wait for the result from the callee (one way procedure calls)
- **Pointers on remote procedures**
  - RPC through a pointer. At the point of call the spec of the callee is known but not its location or identity

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Service Related to RPCs: Naming

- Records the location of the various processes
  - location of client stubs and server skeletons

- This service is called via RPC

- To solve the circularity problem the naming service is at a known machine address

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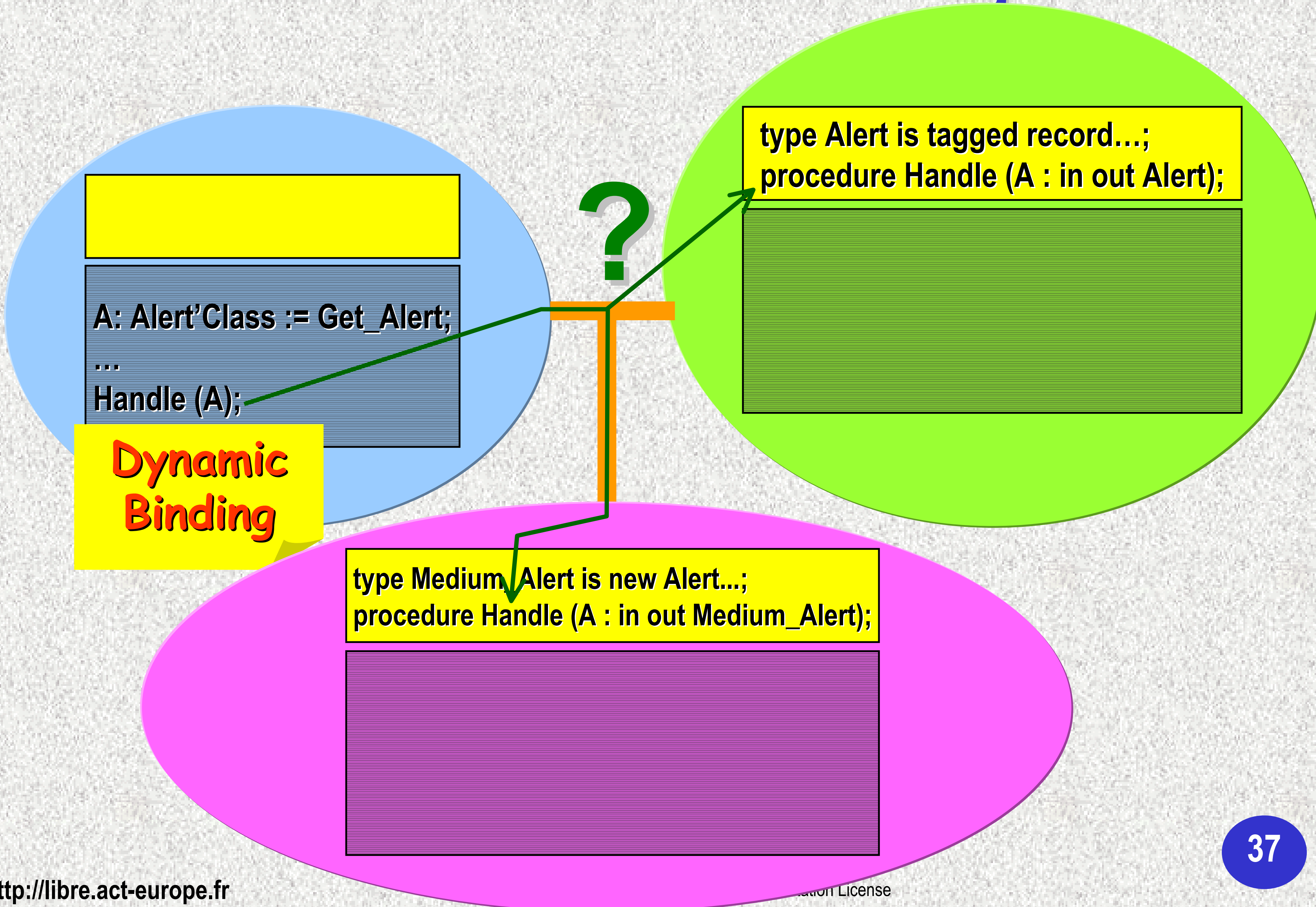
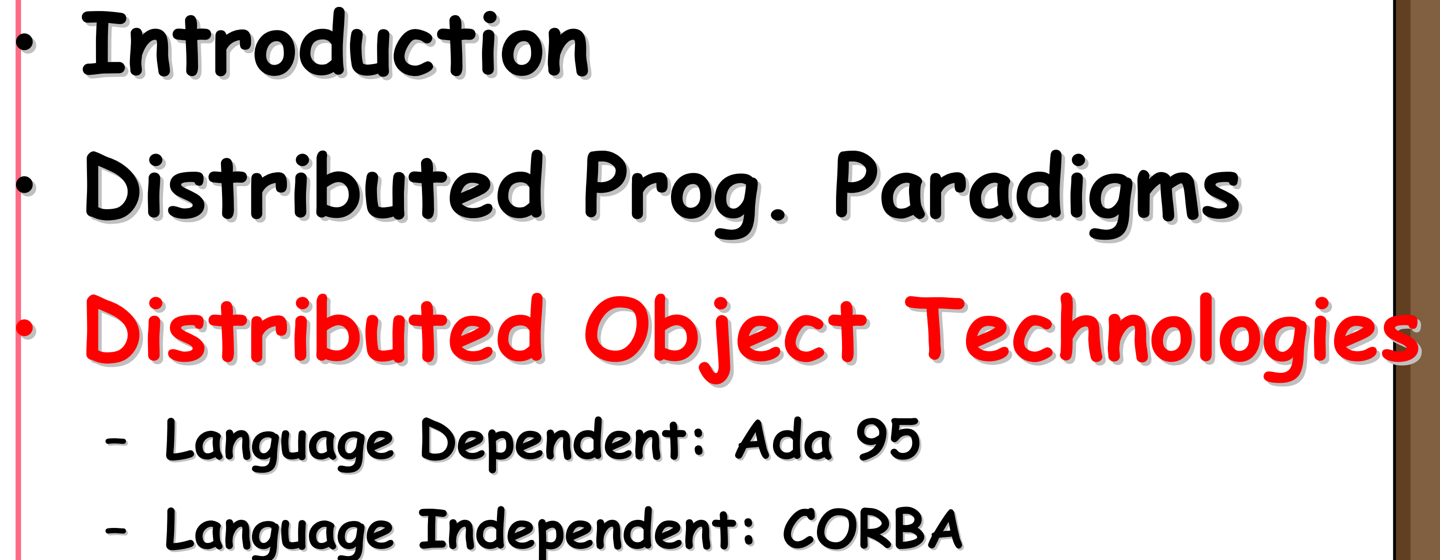
Answer 3: Distributed Objects





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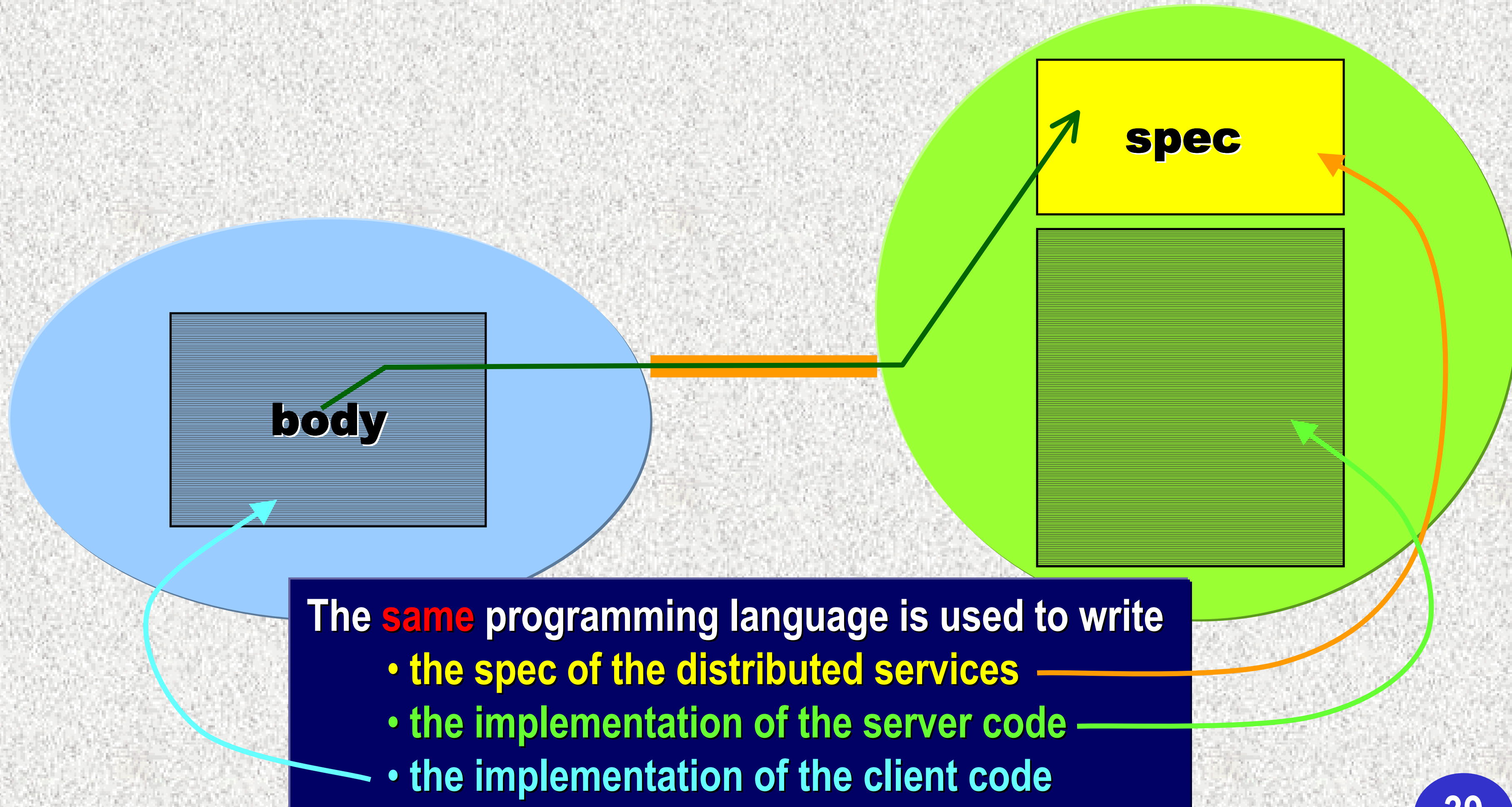
Language Dependent Distributed Objects Paradigm



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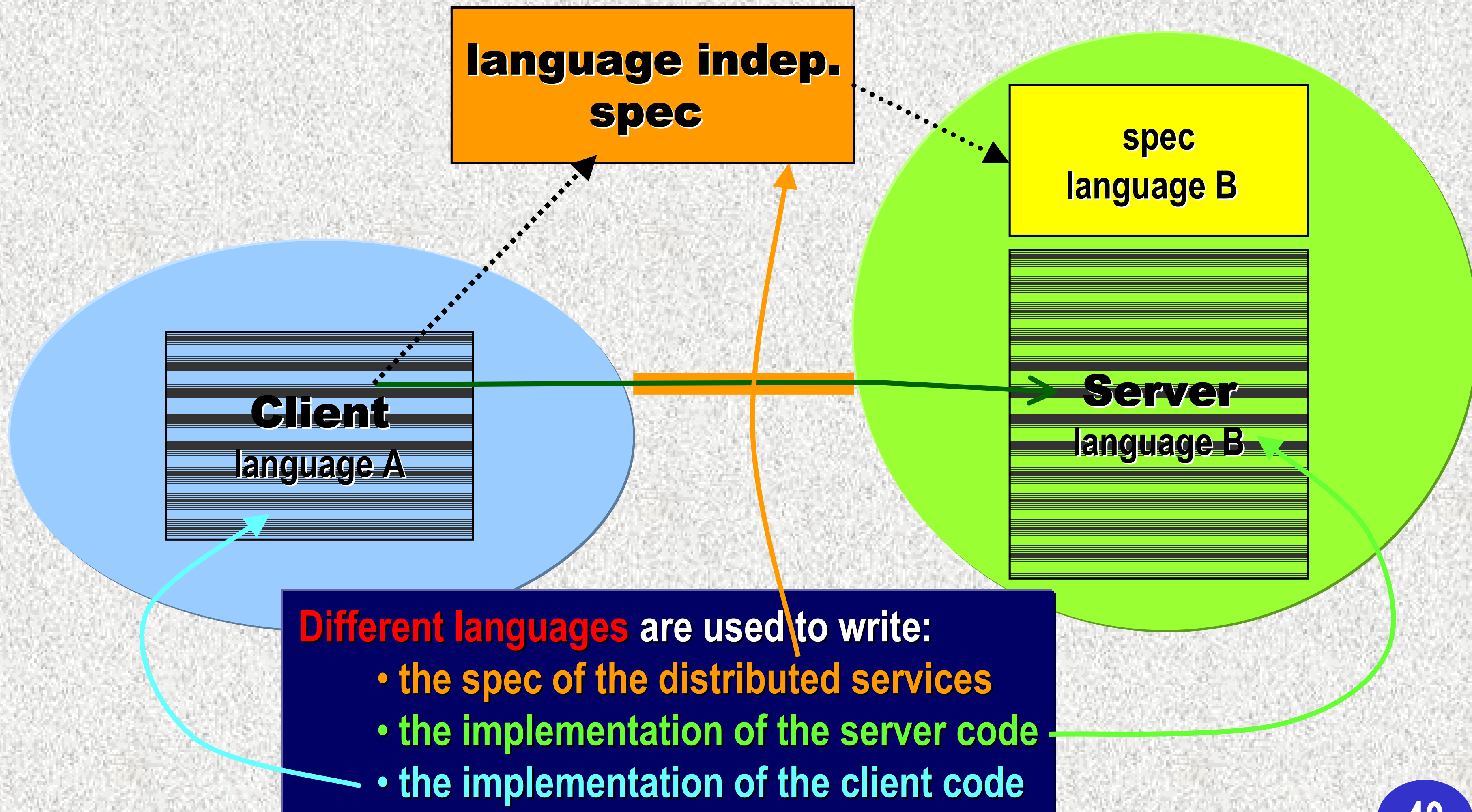
Language Independent Distributed Objects Paradigm



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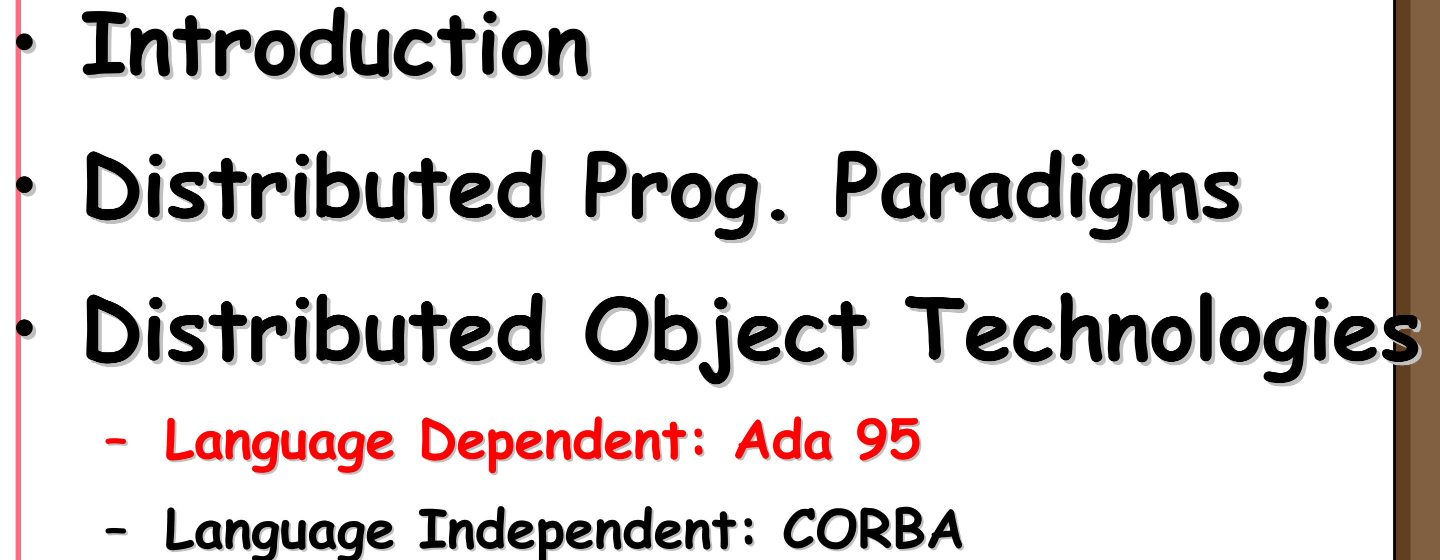

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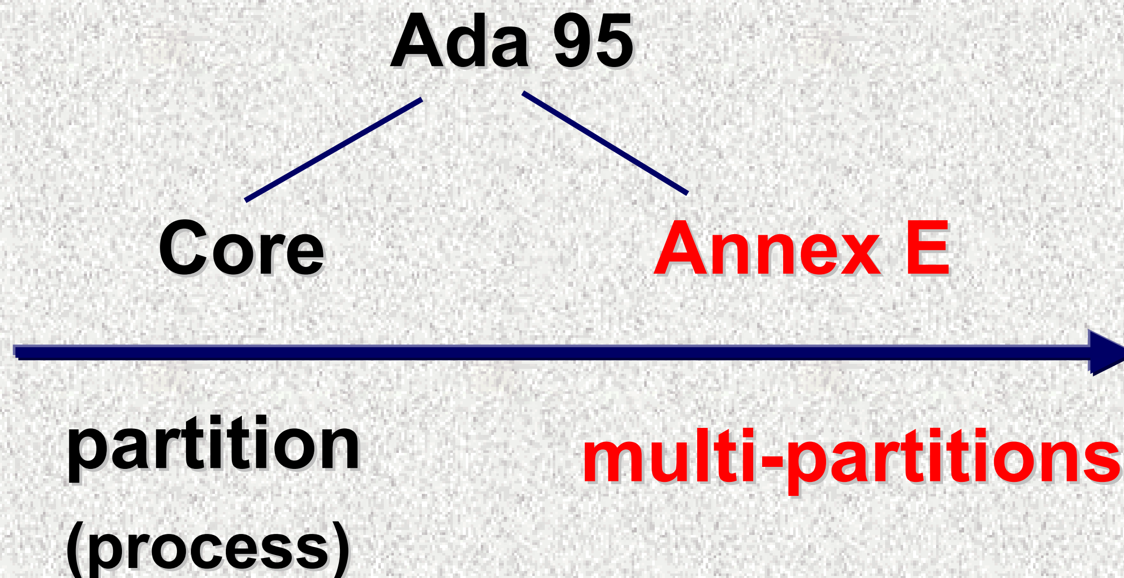
Ada 95
Distributed Systems Annex

Ada 95 Distributed Programming



A partition comprises one or more Ada packages

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Supported Paradigms

- Client/Server Paradigm (RPC)
  - Synchronous / Asynchronous
  - Static / Dynamic
- Distributed Objects
- Shared Memory

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Ada Distributed Application

- No need for a separate interfacing language as in CORBA (IDL)
  - Ada is the IDL

- Some packages categorized using pragmas
  - Remote_Call_Interface (RCI)
  - Remote_Types
  - Shared_Passive (SP)

- All packages except RCI & SP duplicated on partitions using them

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Remote_Call_Interface (RCI)

- Allows subprograms to be called remotely
  - Statically bound RPCs
  - Dynamically bound RPCs (remote access to subprogram)

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Remote_Types

- Allows the definition of a remote access types
  - Remote access to subprogram
  - Remote reference to objects
    (ability to do dynamically dispatching calls across the network)

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Shared_Passive

- A Shared_Passive package contains variables that can be accessed from distinct partitions
- Allows support of shared distributed memory
- Allows persistence on some implementations

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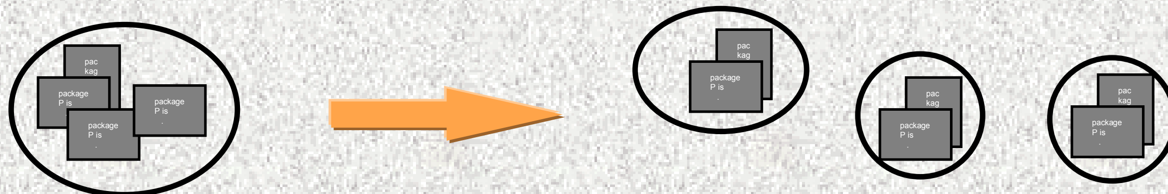
Building a Distributed App in Ada 95

1. Write app as if non distributed.
2. Identify remote procedures, shared variables, and distributed objects & categorize packages.
3. Build & test non-distributed application.
4. Write a configuration file for partitionning your app.
5. Build partitions & test distributed app.



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Remote_Call_Interface

An Example

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Write App

```
package Types is
    type Device is (Furnace, Boiler,…);
    type Pressure is …;
    type Temperature is …;
end Types;
```

```
with Types; use Types;
package Sensors is
    function Get_P (D: Device) return Pressure;
    function Get_T (D: Device) return Temperature;
end Sensors;
```

```
with Types; use Types;
with Sensors;
procedure Client_1 is
    P := Sensors.Get_P (Boiler);
```

```
with Types; use Types;
with Sensors;
procedure Client_2 is
    T := Sensors.Get_T (Furnace);
```


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Categorize

```
package Types is
   pragma Pure;
   type Device is (Furnace, Boiler,...);
   type Pressure is ...;
   type Temperature is ...;
end Types;
```

```
with Types; use Types;
package Sensors is
   pragma Remote_Call_Interface;
   function Get_P (D:Device) return Pressure;
   function Get_T (D:Device) return Temperature;
end Sensors;
```

```
with Types; use Types;
with Sensors;
procedure Client_1 is
   P := Sensors.Get_P (Boiler);
```

```
with Types; use Types;
with Sensors;
procedure Client_2 is
   T := Sensors.Get_T (Furnace);
```


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Build & Test

```
package Types is
    pragma Pure;
    type Device is (Furnace, Boiler,...);
    type Pressure is ...;
    type Temperature is ...;
end Types;
```

```
with Types; use Types;
package Sensors is
    pragma Remote_Call_Interface;
    function Get_P (D:Device) return Pressure;
    function Get_T (D:Device) return Temperature;
end Sensors;
```

```
with Types; use Types;
with Sensors;
procedure Client_1 is
   P := Sensors.Get_P (Boiler);
```

Build & Test

```
package Types is
   pragma Pure;
   type Device is (Furnace, Boiler,…);
   type Pressure is …;
   type Temperature is …;
end Types;
```

```
with Types; use Types;
package Sensors is
   pragma Remote_Call_Interface;
   function Get_P (D:Device) return Pressure;
   function Get_T (D:Device) return Temperature;
end Sensors;
```

```
with Types; use Types;
with Sensors;
procedure Client_2 is
   T := Sensors.Get_T (Furnace);
```

Partition

```
configuration Config_1 is
   Node_A : Partition := (Sensors);
   Node_B : Partition := (Client_1);
   Node_C : Partition := (Client_2);
end Config_1;
```


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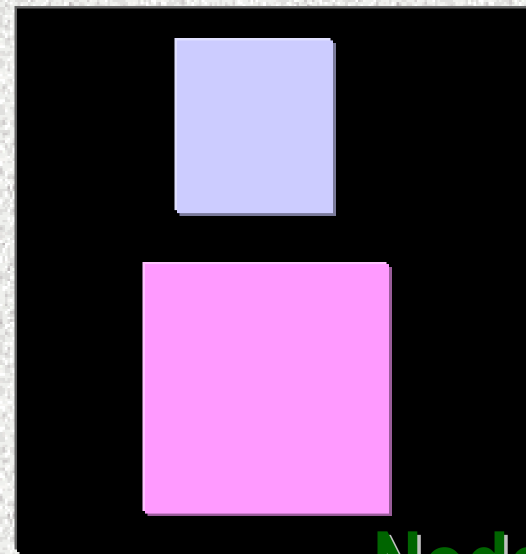
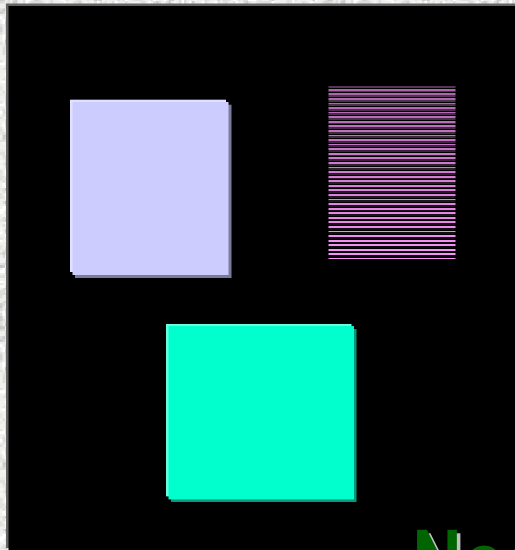
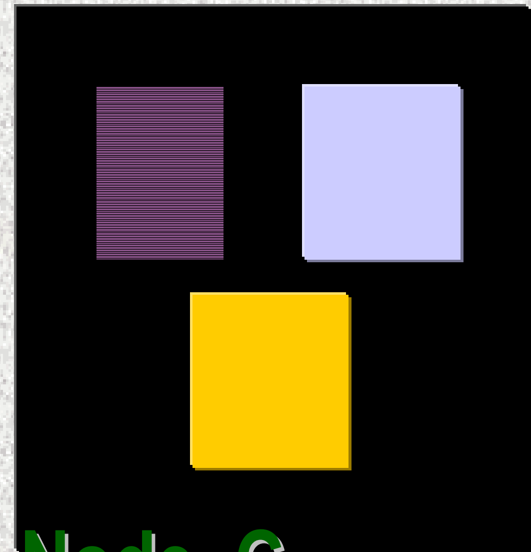
Partition







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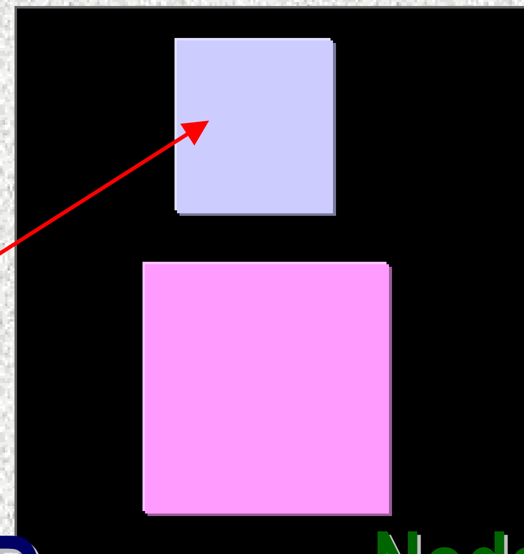
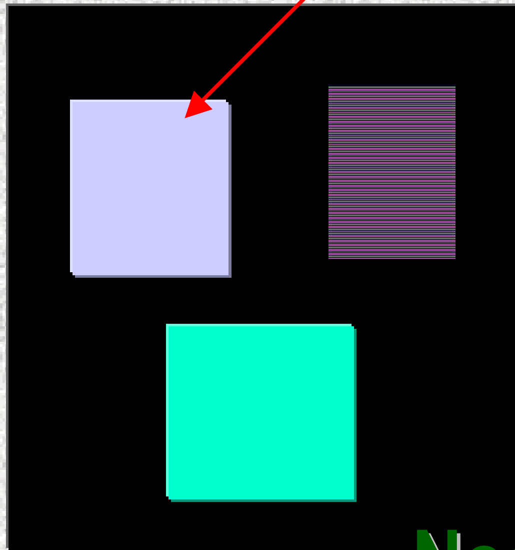
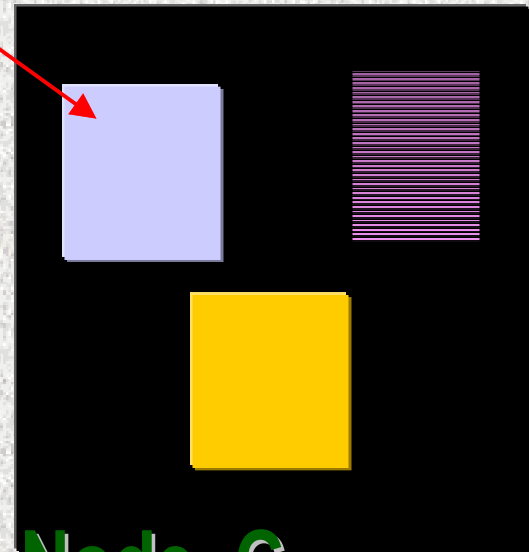
```
package Types is
   pragma Pure;
   type Device is ...;
   type Pressure is ...;
   type Temperature is ...;
end Types;
```

DUPLICATED







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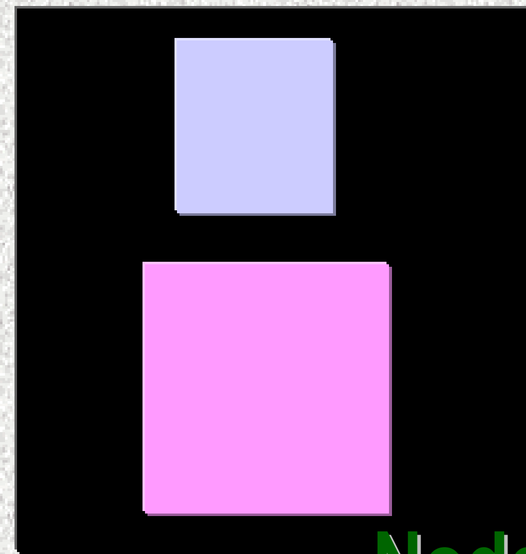
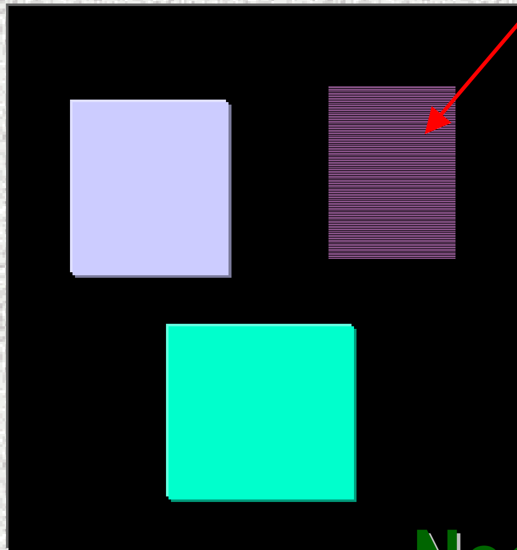
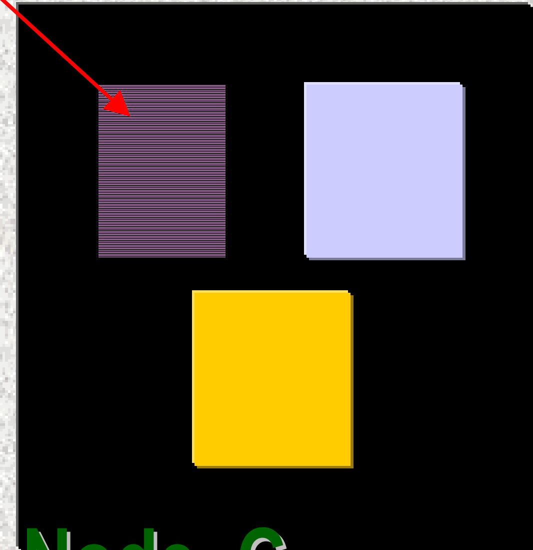
```
with Types; use Types;
package Sensors is
   pragma Remote_Call_Interface;
   function Get_P(...) return Pressure;
   function Get_T(...) return Temperature;
end Sensors;
```



STUBS





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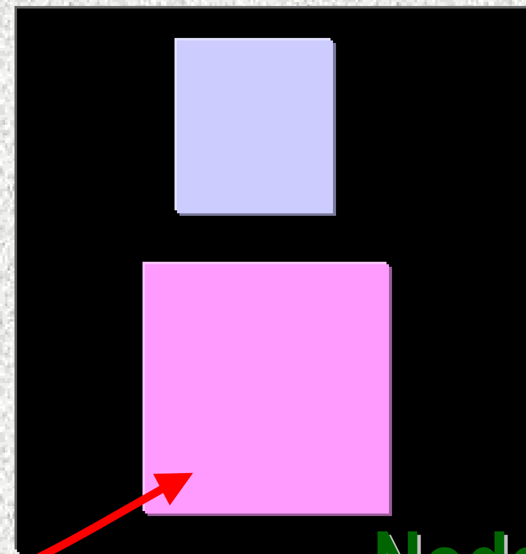
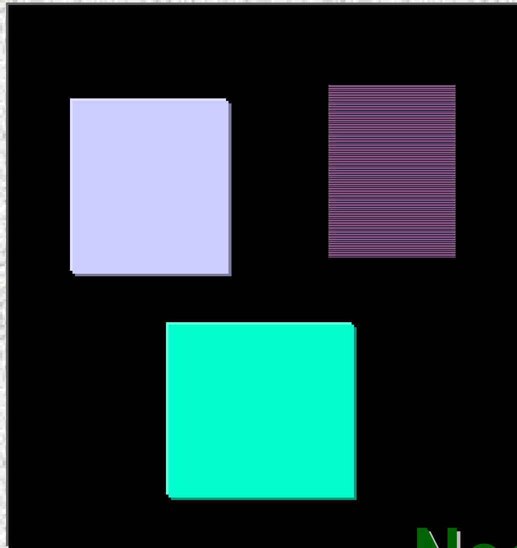
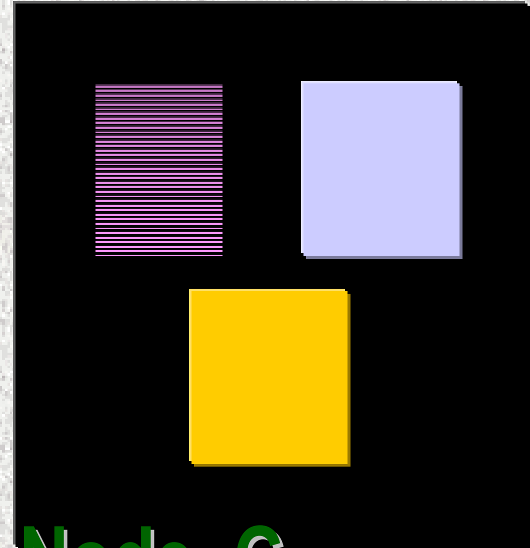
```
with Types; use Types;
package Sensors is
    pragma Remote_Call_Interface;
    function Get_P(...) return Pressure;
    function Get_T(...) return Temperature;
end Sensors;
```



SKELETON
+ BODY





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…..:= Sensors.Get_P (Boiler);

Sensors.Get_P **Stub**

Marshal Arguments

Send

Node_B

Sensors.Get_P **body**

Select body

Skeleton

Unmarshal Arguments

Receive

Node_A

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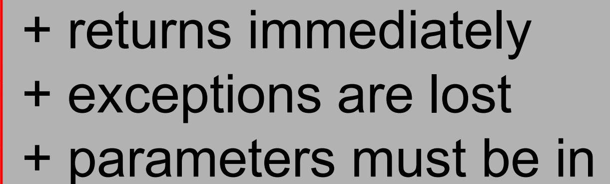
Asynchronous Calls

```
with Types; use Types;
package Sensors is
   pragma Remote_Call_Interface;
   …
   procedure Log (D : Device; P : Pressure);
   pragma Asynchronous (Log);

end Bank;
```



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Remote_Types

An Example

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Write App

```
package Alerts is
    type Alert is abstract tagged private;
    type Alert_Ref is access all Alert'Class;
    procedure Handle (A : access Alert);
    procedure Log      (A : access Alert) is abstract;
private
    ...
end Alerts;
```

```
package Alerts.Pool is
    procedure Register (A : Alert_Ref);
    function   Get_Alert return Alert_Ref;
end Medium;
```

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
    loop
        Handle (Pool.Get_Alert);
    end loop;
end Process_Alerts;
```


©

```
package Alerts.Low is
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

```
with Alerts.Pool; use Alerts.Pool;
package body Alerts.Low is
    ...
begin
    Register (new Low_Alert);
end Alerts.Low;
```


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```
package Alerts.Medium is
     type Medium_Alert is new Alert with private;
     procedure Handle (A : access Medium_Alert);
     procedure Log      (A : access Medium_Alert);
private
     ...
end Alerts.Medium;
```

```
with Alerts.Pool; use Alerts.Pool;
package body Alerts.Medium is
     ...
begin
     Register (new Medium_Alert);
end Alerts.Medium;
```


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Categorize

```
package Alerts is
    pragma Remote_Types;
    type Alert is abstract tagged private;
    type Alert_Ref is access all Alert'Class;
    procedure Handle (A : access Alert);
    procedure Log     (A : access Alert) is abstract;
 private
```

```
package Alerts.Pool is
    pragma Remote_Call_Interface;
    procedure Register (A : Alert_Ref);
    function   Get_Alert return Alert_Ref;
end Medium;
```

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
    loop
        Handle (Pool.Get_Alert);
    end loop;
end Process_Alerts;
```


©

```
package Alerts.Low is
    pragma Remote_Types;
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

```
package Alerts.Medium is
    pragma Remote_Types;
    type Medium_Alert is new Alert with private;
    procedure Handle (A : access Medium_Alert);
    procedure Log    (A : access Medium_Alert);
private
    ...
end Alerts.Medium;
```


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Build & Test

```
package Alerts is
    pragma Remote_Types;
    type Alert is abstract tagged private;
    type Alert_Ref is access all Alert'Class;
    procedure Handle (A : access Alert);
    procedure Log      (A : access Alert) is abstract;
 private
    ...
end Alerts;
```

```
package Alerts.Low is
    pragma Remote_Types;
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

```
package Alerts.Medium is
    pragma Remote_Types;
    type Medium_Alert is new Alert with private;
    procedure Handle (A : access Medium_Alert);
    procedure Log      (A : access Medium_Alert);
private
    ...
end Alerts.Medium;
```

```
package Alerts.Pool is
    pragma Remote_Call_Interface;
    procedure Register (A : Alert_Ref);
    function    Get_Alert return Alert_Ref;
end Medium;
```

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Partition

```
configuration Config_2 is
   Node_AL  : Partition := (Alerts.Low);
   Node_AM : Partition := (Alerts.Medium);
   Node_B    : Partition := (Alerts.Pool);
   Node_C    : Partition := (Process_Alerts);
end Config_2;
```


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What Happens When Executing the Distributed Program ?

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```
package Alerts.Low is
    pragma Remote_Types;
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

Node_AL

```
package Alerts.Medium is
    pragma Remote_Types;
    type Medium_Alert is new Alert with private;
    procedure Handle (A : access Medium_Alert);
    procedure Log      (A : access Medium_Alert);
private
    ...
end Alerts.Medium;
```

Node_AM

Step 1: A Low_Alert object in Node_AL registers itself with Node_B

```
package Alerts.Pool is
    pragma Remote_Call_Interface;
    procedure Register (A : Alert_Ref);
    function    Get_Alert return Alert_Ref;
end Medium;
```

Node_B

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Node_C

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```
package Alerts.Low is
   pragma Remote_Types;
   type Low_Alert is new Alert with private;
   procedure Log (A : access Low_Alert);
private
   ...
end Alerts.Low;
```

Node_AL

```
package Alerts.Medium is
   pragma Remote_Types;
   type Medium_Alert is new Alert with private;
   procedure Handle (A : access Medium_Alert);
   procedure Log    (A : access Medium_Alert);
private
   ...
end Alerts.Medium;
```

Node_AM

Step 2: A Medium_Alert object in Node_AM registers itself with Node_B

```
package Alerts.Pool is
   pragma Remote_Call_Interface;
   procedure Register (A : Alert_Ref);
   function   Get_Alert return Alert_Ref;
end Medium;
```

Node_B

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Node_C

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```
package Alerts.Low is
    pragma Remote_Types;
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

Node_AL

```
package Alerts.Medium is
    pragma Remote_Types;
    type Medium_Alert is new Alert with private;
    procedure Handle (A : access Medium_Alert);
    procedure Log     (A : access Medium_Alert);
private
    ...
end Alerts.Medium;
```

Node_AM

Step 3: Process_Alerts in Node_C does an RPC to Get_Alert in Node_B

```
package Alerts.Pool is
    pragma Remote_Call_Interface;
    procedure Register (A : Alert_Ref);
    function   Get_Alert return Alert_Ref;
end Medium;
```

Node_B

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Node_C

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```
package Alerts.Low is
   pragma Remote_Types;
   type Low_Alert is new Alert with private;
   procedure Log (A : access Low_Alert);
private
   ...
end Alerts.Low;
```

Node_AL

```
package Alerts.Medium is
   pragma Remote_Types;
   type Medium_Alert is new Alert with private;
   procedure Handle (A : access Medium_Alert);
   procedure Log    (A : access Medium_Alert);
private
   ...
end Alerts.Medium;
```

Node_AM

Step 4: Get_Alert returns a pointer to an Alert object (Low_Alert or Medium_Alert)

```
package Alerts.Pool is
   pragma Remote_Call_Interface;
   procedure Register (A : Alert_Ref);
   function  Get_Alert return Alert_Ref;
end Medium;
```

Node_B

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Node_C

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```
package Alerts.Low is
    pragma Remote_Types;
    type Low_Alert is new Alert with private;
    procedure Log (A : access Low_Alert);
private
    ...
end Alerts.Low;
```

Node_AL

```
package Alerts.Medium is
    pragma Remote_Types;
    type Medium_Alert is new Alert with private;
    procedure Handle (A : access Medium_Alert);
    procedure Log    (A : access Medium_Alert);
private
    ...
end Alerts.Medium;
```

Node_AM

?

Step 5: Node_C performs a dispatching RPC. It calls Handle in Node_AL or Node_AM

```
package Alerts.Pool is
    pragma Remote_Call_Interface;
    procedure Register (A : Alert_Ref);
    function  Get_Alert return Alert_Ref;
end Medium;
```

Node_B

```
with Alerts, Alerts.Pool; use Alerts;
procedure Process_Alerts is
begin
   loop
      Handle (Pool.Get_Alert);
   end loop;
end Process_Alerts;
```

Node_C

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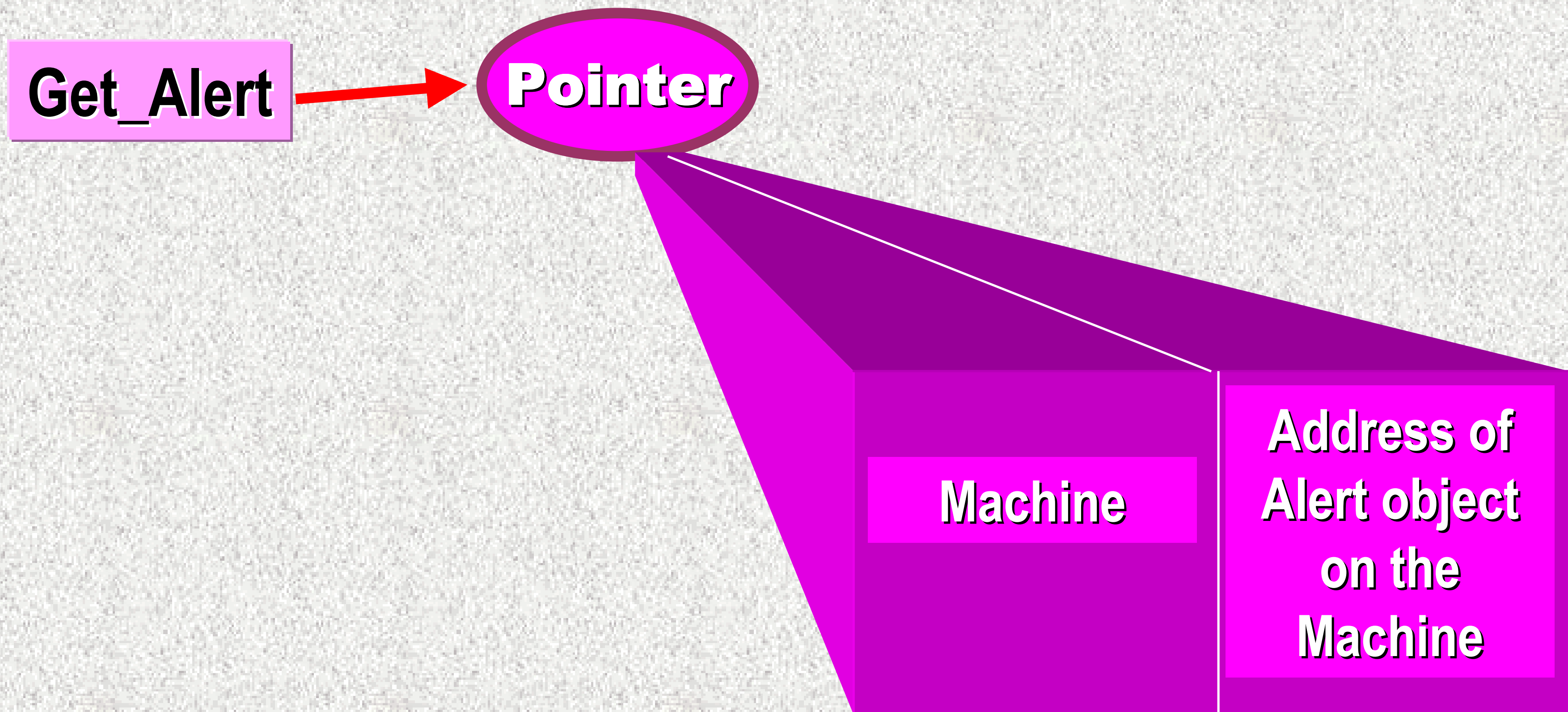
What Does Get_Alert Return ?



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Remote Access to Class Wide Type

- At compile time:
  - You do not know what operation you'll dispatch to
  - On what node that operations will be executed on

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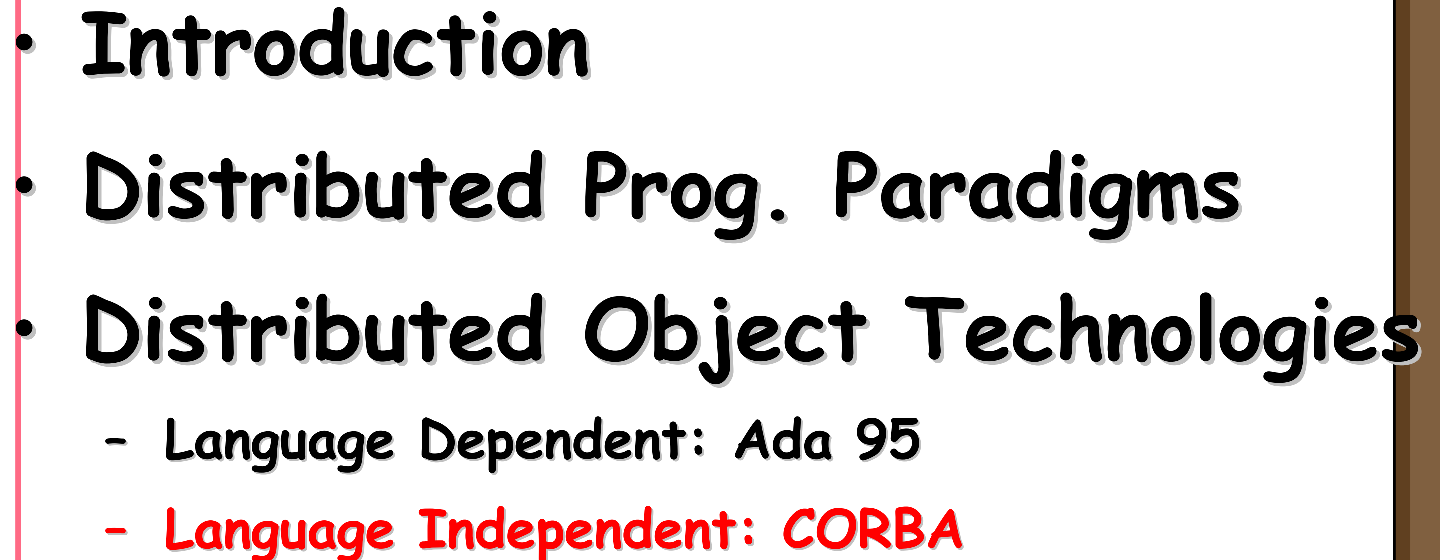

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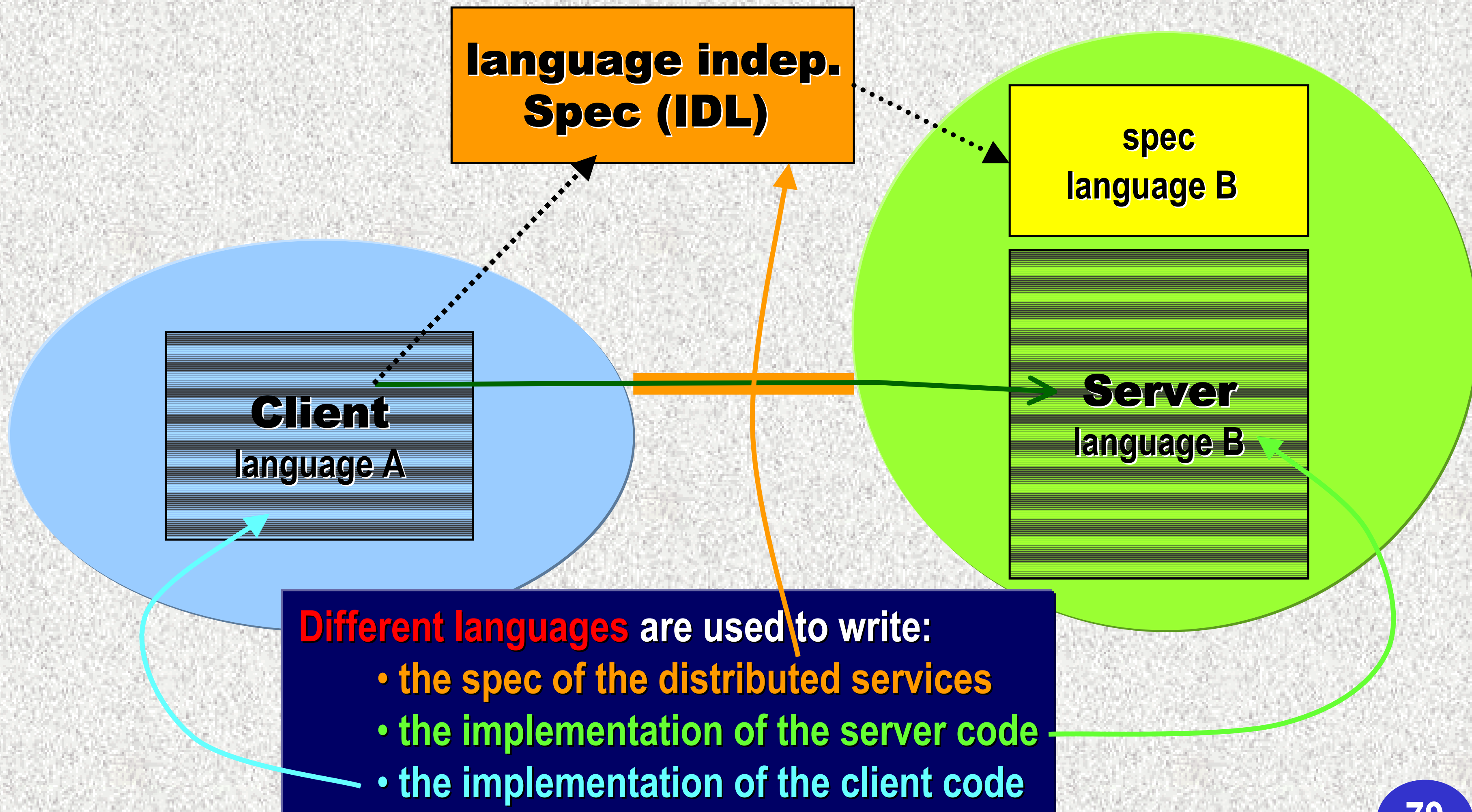
Language Independent Distributed Objects Paradigm



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CORBA Interfaces

- In Corba interfaces are described in IDL
  - (Interface Description Language)
- The IDL is independent of programming languages
- Each interface is translated in
  - Language A used for the client (client stub)
  - Language B used for the server (server skeleton)
- To implement the server the programmer completes the skeleton in language B
- To implement the client the programmer uses the services provided by th estub in language A

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The CORBA Architecture

- RPC go through the ORB
  - (Object Request Broker)
- The ORB is a software bus
- ORBs communicate with a set of standardised protocols
  - IIOP, GIOP

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The IDL

- Syntax similar to C++ with some Ada additions
- IDL must be translatable in various prog. Languages
  - Ada, C, C++, Java, …
- There are limitations in what you can write in the IDL
- Programmer must understand how the IDL is translated in the host language
  - to complete the server skeleton
  - to use the client stub

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Example

```
module M {
   interface T {
      void P ();
   };
};
```

```
package M is
   pragma Remote_Types;
   type T is tagged ...;
   procedure P (O : in access T);
end M;
```


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Exemple

```
module Echo {
    string echoString (in string mesg);
};


 Module foo {
    interface Buffer {
       exception Empty;
       void put (in string content);
       string get() raises (Empty);
    }
 };
```


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Example of IDL translation in Ada

```
with Corba.Object;
package Echo is
   type Ref is new Corba.Object.Ref with null record;
   function To_Echo (Self : in Corba.Object.Ref'Class)
      return Ref'Class;
   function To_Ref (From : in Corba.Any) return Ref;
   function To_Any (From : in Ref) return Corba.Any;
   function echoString (Self : in Ref;
                        msg  : in Corba.String)
                     return Corba.String;
   Null_Ref : constant Ref := (Corba.Object.Null_Ref
                                  with null record);
   Echo_R_Id : constant Corba.RepositoryId :=
      Corba.To_Unbounded_String («IDL:Echo:1.0»);
end Echo;
```


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CORBA Services

- The CORBA core services are very few
- Lot ’s of external services
  - Naming (distributed and hierarchical)
  - Persistance
  - Transaction
  - Security
  - ...

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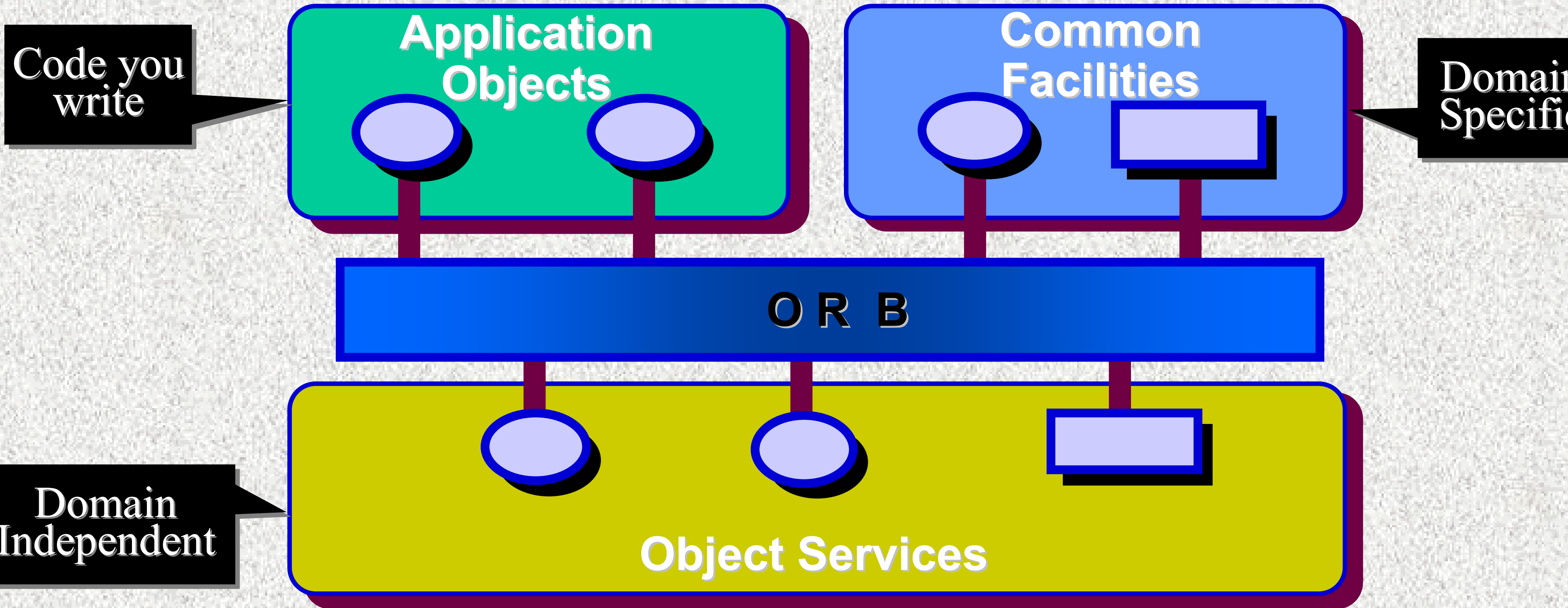

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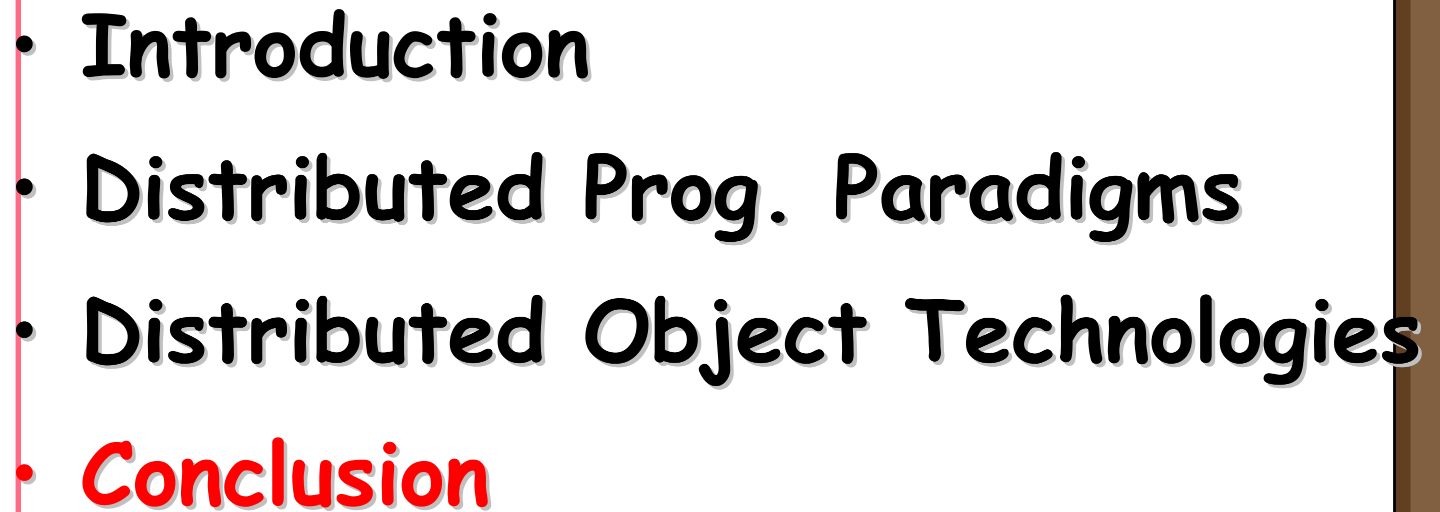

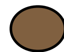

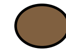

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Developing a Distributed App

- Using network services directly
  - Sockets
- Using middleware
  - CORBA
  - COM/DCOM
- Using a distributed language
  - Ada 95 DSA
  - Java RMI

Similar issues with Tasking

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Impact on Development Phases

General Design

Distributed Design

Coding

Testing

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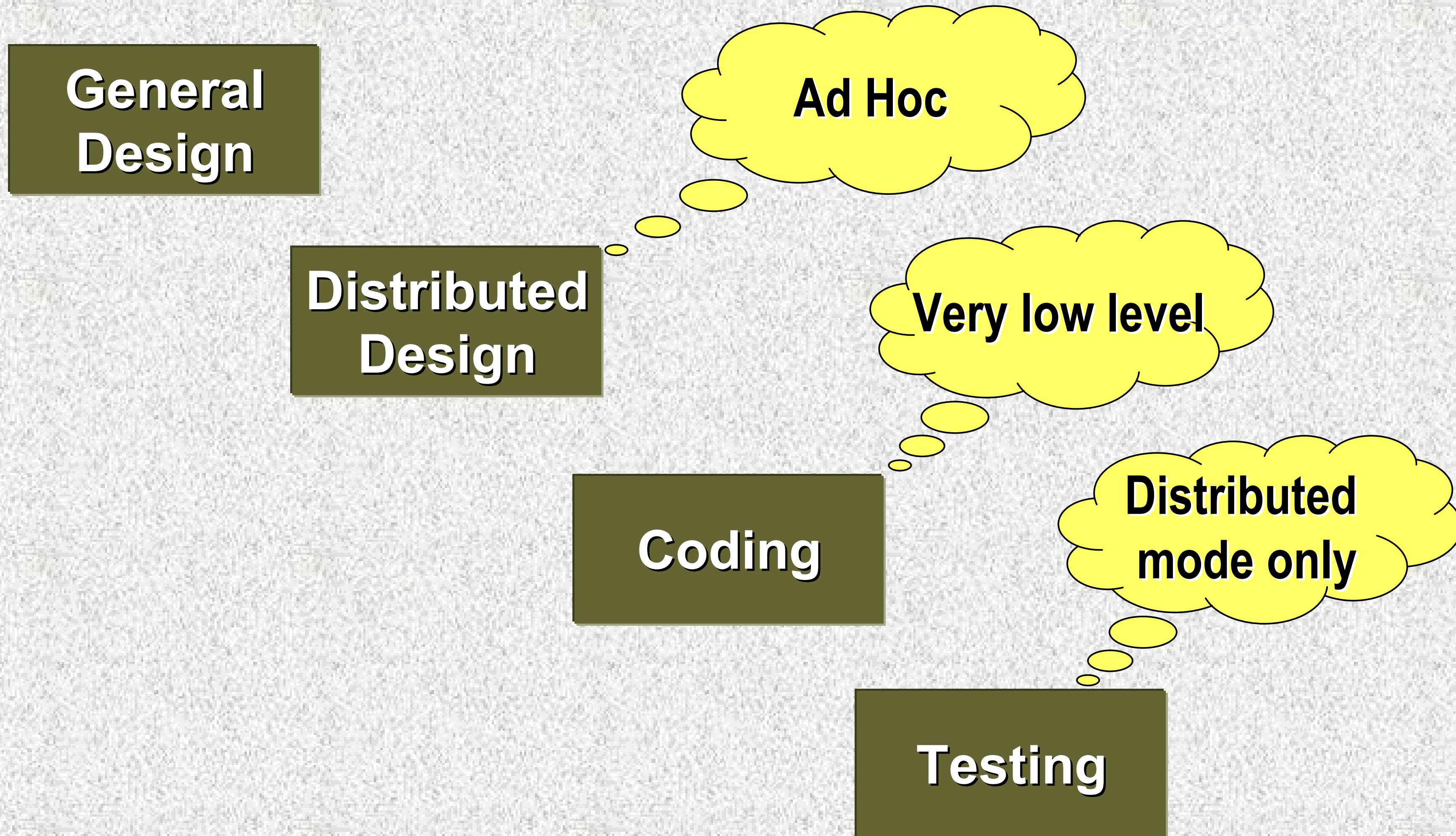
Sockets



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- Everything must be done with sockets
- Data marshaling/unmarshalling
- Handle heterogeneous systems directly

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CORBA

General Design

Distributed Design

Coding

Testing

IDL

Must invoke high-level services directly

Distributed mode only

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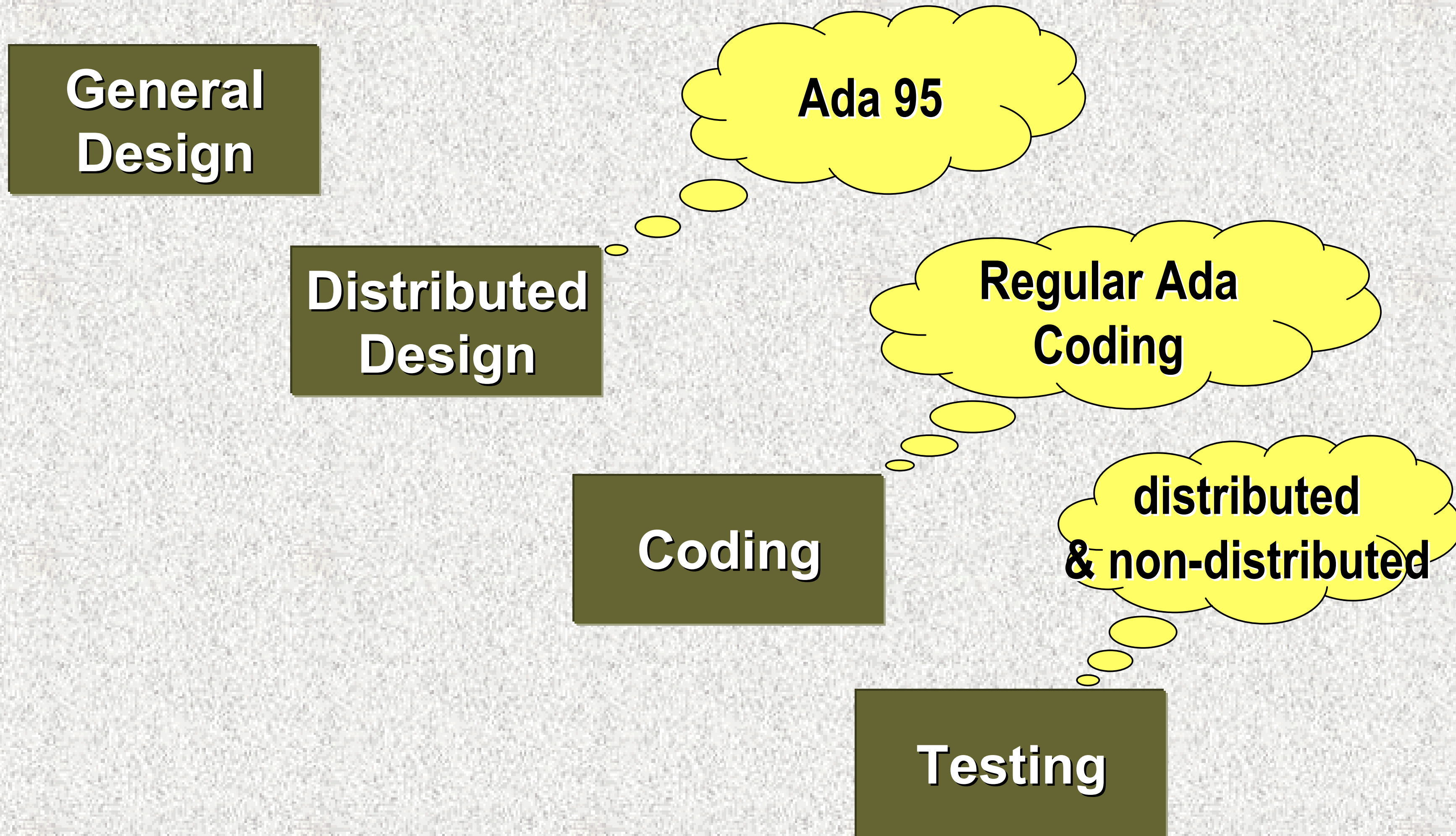
Ada 95 DSA



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Ada 95 DSA & CORBA: Benefits

- Save developer's time, in socket programming:
  - Defining a client/server protocol
  - Defining a message format
  - Marshalling of data
  - Unmarshalling data
- Raise the level of abstraction

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