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UNIVERSITÀ DEGLI STUDI DI MILANO

Thread Signaling and M2M Communication

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These slides are based on previous versions created by Letizia Bertolaja, Sergio Mascetti, Dario Freni, Claudio Bettini, Gabriele Civitarese, Riccardo Presotto and Luca Arrotta

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Some slides for this course are partly adapted from the ones distributed by the publisher of the reference book for this course (Distributed Systems: Principles and Paradigms, A. S. Tanenbaum, M. Van Steen, Prentice Hall, 2007).

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Solutions to last lecture's exercises

- Sums: https://ewserver.di.unimi.it/gitlab/michelefiori/lab1-sums
- Theatre: https://ewserver.di.unimi.it/gitlab/michelefiori/lab1-theatre

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Outline

- Thread Signaling – Wait & Notify
- Machine to Machine Communication – XML and JSON

Thread Signaling

- We have different methods to coordinate the executions of more threads
  - *wait()*
  - *notify()*
  - *join()*
  - *sleep()*
  - *…*
- You can see something more in this Java Tutorial

Thread.join()

- The *join()* method is used to wait until the end of a thread
  - The thread that called the *join()* method stops until the end of the thread associated with the object on which the method is called
- It can be invoked with an optional parameter that represents the timeout (in milliseconds)
  - In this case, even if the thread does not end before the timeout, the calling thread go on with its next instruction
- The state of a thread can be controlled with the *isAlive()* method
  - It returns *true* if the thread is active, *false* if the thread is ended

Thread.join( )

```java
public class Main {
    public static void main(String arg[]) throws Exception {
        Random r = new Random();
        ArrayList<Thread> threads = new ArrayList<Thread>();

        //create some threads
        for (int i=0; i<100; i++) {
            MyThread mt = new MyThread(r);
            threads.add(mt);
        }

        //start all the threads
        for (Thread t: threads) {
            t.start();
        }

        //wait all the thread to finish
        for (Thread t : threads) {
            t.join();
        }

        System.out.println("...All thread finished!");
    }
}
```

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Thread.sleep()

- The *sleep()* method temporarily stops the execution of the current thread
  - When should we use it?
    - To perform periodic actions
    - To allow the execution of other threads (useful for debugging)
  - It is a static method, usually it is called directly from the *Thread* class
    - It has a time parameter expressed in milliseconds
    - `Thread.sleep(10000); // wait for 10 seconds`

Object.wait( ) and Object.notify( )

- They are methods of the *Object* class, so they can be applicable to any object
- To any object is associated a list of waiting threads
  - Each thread that calls a *wait()* on a specific object waits until another thread awakens it by calling a *notify()* on the same object
- These methods are used to coordinate two or more threads
- Also the *wait()* method can be invoked with an optional timeout parameter
  - Useful to avoid deadlocks (e.g., a node of a network crashed, we don't want to wait for its answer forever)

Observations on wait( ) and notify( )

- More threads can be waiting on the same object
- Calling *notify()* will awaken only **one** thread
  - **Be careful**: it is not granted that the order in which the threads are awakened is the same order in which they have called the *wait()* method!
- *notifyAll()* awakens **all** the waiting threads

The Use of wait( ) and notify( )

- We create a class to allow two threads to wait for each other before going on with the execution

- Why the *meetUp()* method is *synchronized*?

- How to adapt this code to more than two threads?

```
2  public class CheckPoint {
3      boolean hereFirst = true;
4
5      synchronized void meetUp () {
6          if (hereFirst) {
7              hereFirst = false;
8              wait();
9          } else {
10             notify();
11             hereFirst = true;
12         }
13     }
14 }
```

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wait( ) and Intrinsic Lock

- But…the last example should not work! Why?
  - The first thread enters in the critical region, acquires the lock and calls *wait()*
  - The second thread could not take the lock on the object → Deadlock!

- Why does it work?

wait( ) and Intrinsic Lock

- *wait()* releases the intrinsic lock associated with the object on which it is called
  - The lock must be acquired before calling *wait()*, otherwise an exception will be raised
- So, the second thread can execute the method
  - and then it awakens the first thread
- When the first thread is awakened, it has to acquired again the lock before going on
  - So it has to wait until the second thread leaves the method

The Use of wait() and notifyAll()

- In this case, we want to coordinate 10 threads

```
21  public class CheckPoint {
22      int n_threads = 10;
23      int counter = 0;
24
25      synchronized void meetUp () {
26          if (counter < n_threads-1) {
27              counter++;
28              wait();
29          } else {
30              notifyAll();
31              counter = 0;
32          }
33      }
34  }
```

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Busy Waiting

- This is an example of Busy Waiting

```
...
while (true) {
    if (eventHappened){
        doSomething();
    }

    Thread.sleep(SOME_TIME_IN_MILLISECONDS);
}
...
```

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Busy Waiting

- **This is evil!**
- The CPU is busy for nothing while it could be used for the computations of other threads
- This happens even if we use the *sleep* method!
- The solution is to use *wait()* and *notify()*

DO NOT USE BUSY WAITING IN YOUR PROJECT

```
...
while (true) {
    if (eventHappened){
        doSomething();
    }

    Thread.sleep(SOME_TIME_IN_MILLISECONDS);
}
...
```

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Busy Waiting

- To avoid the Busy Waiting
  - Instead of continuing to iterate waiting for the event, the thread calls the *wait()* method
  - Another thread will *notify()* the first thread when the event occurs, awakening it

```
...
while (!eventHappened) {
    wait();
    if(eventHappened)
        doSomething();
}
...
```

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Wait, Notify, and Synchronized Statements

- The *wait* and *notify* methods are always related to the synchronization object

- You should always think in terms of the intrinsic lock!

```
...
synchronized(obj){
    ...
    obj.wait();
    ...
}
...
synchronized(obj){
    ...
    obj.notify();
    ...
}
```

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Exercise – The Veterinarian

- A veterinarian has a waiting room that can contain only dogs and cats
  - A cat can't enter in the waiting room if there is already a dog or a cat
  - A dog can't enter in the waiting room if there is a cat
  - There can't be more than four dogs together
- The animals stay in the waiting room for a random interval of time
- The animals that can't enter in the waiting room have to wait as necessary
- The problem must be solved by using *synchronized*, *wait* and *notify*
  - You have to develop two methods: *enterRoom* and *exitRoom*
  - Each animal is represented by a randomly generated thread from which you will call these methods

The java.util.concurrent Library

- Java provides useful libraries to make the concurrent programming easier
- There are several tools
  - High-level synchronization primitives (semaphores, locks, …)
  - Data structures that support concurrency
  - Atomic data types (e.g., *AtomicInteger*)
- You **CANNOT** use these tools in the project!
  - The purpose of this lab is to learn in depth how concurrency works in Java

Producer-Consumer Pattern

- It’s a multi-process communication pattern
- The Producer is the entity (in our case, a thread) that sends some data
- The Consumer is the entity (another thread) that receives these data
- Data are transmitted through a shared memory buffer, typically a queue
- It is possible to consider more producers and/or consumers
- What’s the main problem?

The Consumer shouldn’t periodically check if there are data in the buffer

Queue Implementation Example

Demo

Exercise – The Chat Service

- Build a *chat* service through sockets
- Each user writes the messages to be sent with the keyboard
- The communication is asynchronous: each user can send messagges indipendently from the other users
- The threads must communicate through a shared buffer
- Two variations:
  1. Chat between only two users (one is the server, the other is the client)
  2. Chat-room: a server receives connections from several users and forwards the messages to all the participants

Machine to Machine Communication

- In a distributed system, processes that runs on different machines connected through a network have to communicate
- The communication occurs through messages exchange
- The coordination between processes in a network consists of two operations:
  - Messages transmission
  - Messages reception
- Messages are exchanged through sockets

How to Represent Messages?

- At the Application Layer, data are stored in proper data structures
- At the Network Layer, data are transmitted as streams of bytes
- The problem: the processes can be heterogeneous and store data in different ways (Big Endian vs Little Endian, different float representations, ASCII vs Unicode, …)
- It is necessary to agree on a common format to represent data!

Marshalling and Unmarshalling

- Who transmits the data performs the **marshalling** process: the data to be transmitted are assembled in a proper format, suitable for the transmission
- Who receives the data performs the **unmarshalling** process: the received data are translated in proper data structures
- The processes have to agree on a common external data format to grant interoperability
- We will see three formats
  - XML
  - JSON
  - Protocol Buffers

XML (eXtensible Markup Language)

- An encoding information standard
- A generalized markup language (it's possible to create dialects)
- Both human- and machine-readable
- There are several tools for validation (*XMLSchema*) and query (*XPath/XQuery*)

XML (eXtensible Markup Language)

```xml
<actor>
    <name>Christian</name>
    <surname>Bale</surname>
    <filmography>
        <movie>
            <title>The Prestige</title>
            <year>2006</year>
        </movie>
        <movie>
            <title>The Dark Knight</title>
            <year>2008</year>
        </movie>
    </filmography>
</actor>
```

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JSON (JavaScript Object Notation)

- A more recent standard
- Born for Javascript, but independent of it
- Both human- and machine- readable
- More compact and readable than XML
- Can encode arrays
- The transmission is quicker for a given message
- It has almost replaced XML for network communications

JSON (JavaScript Object Notation)

```
{
    "name": "Christian",
    "surname": "Bale",
    "filmography": [
        {"title": "The Prestige", "year": 2006},
        {"title": "The Dark Knight", "year": 2008}
    ]
}
```

More details about JSON objects definition here

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JSON: Encoding with Java

```
public class Actor {
...
    public String toJSONString() throws JSONException {
        JSONObject actor = new JSONObject();
        actor.put(" name ", this.name);
        actor.put(" surname ", this.surname);
        JSONArray movies = new JSONArray()
        for (Movie m : this.filmography) {
            JSONObject movie = new JSONObject();
            movie.put(" title ", m.getTitle());
            movie.put(" year ", m.getYear());
            movies.put(movie);
        }
        actor.put(" filmography ", movies);
        return actor.toString()
    }
...
```

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JSON: Decoding with Java

```
public class Actor {
...
    public Actor(String jsonString) throws JSONException {
        JSONObject input = new JSONObject(jsonString);
        this.setName(input.getString(" name "));
        this.setSurname(input.getString(" surname "));
        JSONArray array = input.getJSONArray(" filmography ");
        for (int i=0; i<array.length(); i++) {
            JSONObject current = array.getJSONObject(i);
            String title = current.getString(" title ");
            int year = current.getInt(" year ");
            Movie m = new Movie(title, year);
            this.filmography.add(m);
        }
    }
...
```

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The Gson Library

- A Google library used to convert Java objects into JSON representations and vice versa
- It works with any type of pre-existing Java object (even objects we don't have the code of)
- It doesn't require annotations and supports generic types
- Easy to use:
  - *toJson()* method to convert an object to a JSON string
  - *fromJson()* method to convert a JSON string to an instance of an object
- More info here

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How Data are Transmitted?

- Data are represented in their text-based coding
  - No problem with strings, numbers and booleans
- We need a proper coding for binary data. For example, **Base64**
  - Used to convert a string of bits in a string of ASCII characters
  - The string of bits is divided into 6-bits blocks
  - Each block can contain a value from 0 to 63, and so it can be represented through an ASCII character

Exercise – Students Stats with JSON

- Build a server application *University* that receives data from a client about a *Student*
- The client sends through sockets to *University* data related to a specific *Student*:
  - Personal details: Name, Surname, Year of Birth, Place of Residence (multi-attributes field)
  - List of passed exams: for each exam, store Exam Name, Mark and Date of Verbalization
- The *University* receives the message from the socket and prints the student's stats
- The solution must be built by using JSON as data interchange format (you can use the GSON library!)

References

- Code Examples: https://ewserver.di.unimi.it/gitlab/michelefiori/lab2-examples.git

- Exercises Setup: https://ewserver.di.unimi.it/gitlab/michelefiori/setup_test_dps.git

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Contact

- You can contact me via email for any clarification or meeting:

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Queue Implementation Example

```java
public class Queue {
    public ArrayList<String> buffer = new ArrayList<String>();

    public synchronized void put(String message) {
        buffer.add(message);
        notify();
    }

    public synchronized String take() {
        String message = null;

        while(buffer.size() == 0) {
            try { wait(); }
            catch (InterruptedException e) { e.printStackTrace(); }
        }

        if(buffer.size() > 0) {
            message = buffer.get(0);
            buffer.remove(0);
        }
        return message;
    }
}
```

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