Java-based Distributed Architectures for Intensive Computations related to Electrical Grids

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Introduction 1/4

- On-line power systems security analysis (OPSSA) is one of the most relevant assessments made to assure the optimal control and management of electrical networks

- There are many phenomena (contingencies) that can compromise power systems operation
  - an unexpected variation in the power system structure
  - a sudden change of the operational conditions
- OPSSA deals with the assessment of the security and reliability levels of the system under any possible contingency

Introduction 2/4

Three main steps:

1. **Screening of the most "credible" contingences**

2. **Predicting their impact on the entire system operation**
   - **the contingencies analysis is performed according to the *(n-1) criterion***
   - **for each credible contingency, the simulation of the system behaviour and the verification of operational limits violations**
   - **the system behavior is verified finding the solution of the system state equations (power flow or load flow equations)**

3. **Preventive and corrective controlling**
   - **identification of proper control actions able to reduce the risk of system malfunctioning**

Introduction 3/4

- **Focus: on-line prediction (step 2)**
  - computation times should be less than few minutes for information to be useful
- **Unfortunately OPSSA is computing and data intensive**
  - structure of modern power systems
  - computational complexity of algorithms
  - number of contingencies to analyze
- **New methodologies to reduce computational times**
  - parallel processing on supercomputers and then on cluster and network of workstations (to reduce costs) has been employed (i.e. PVM)

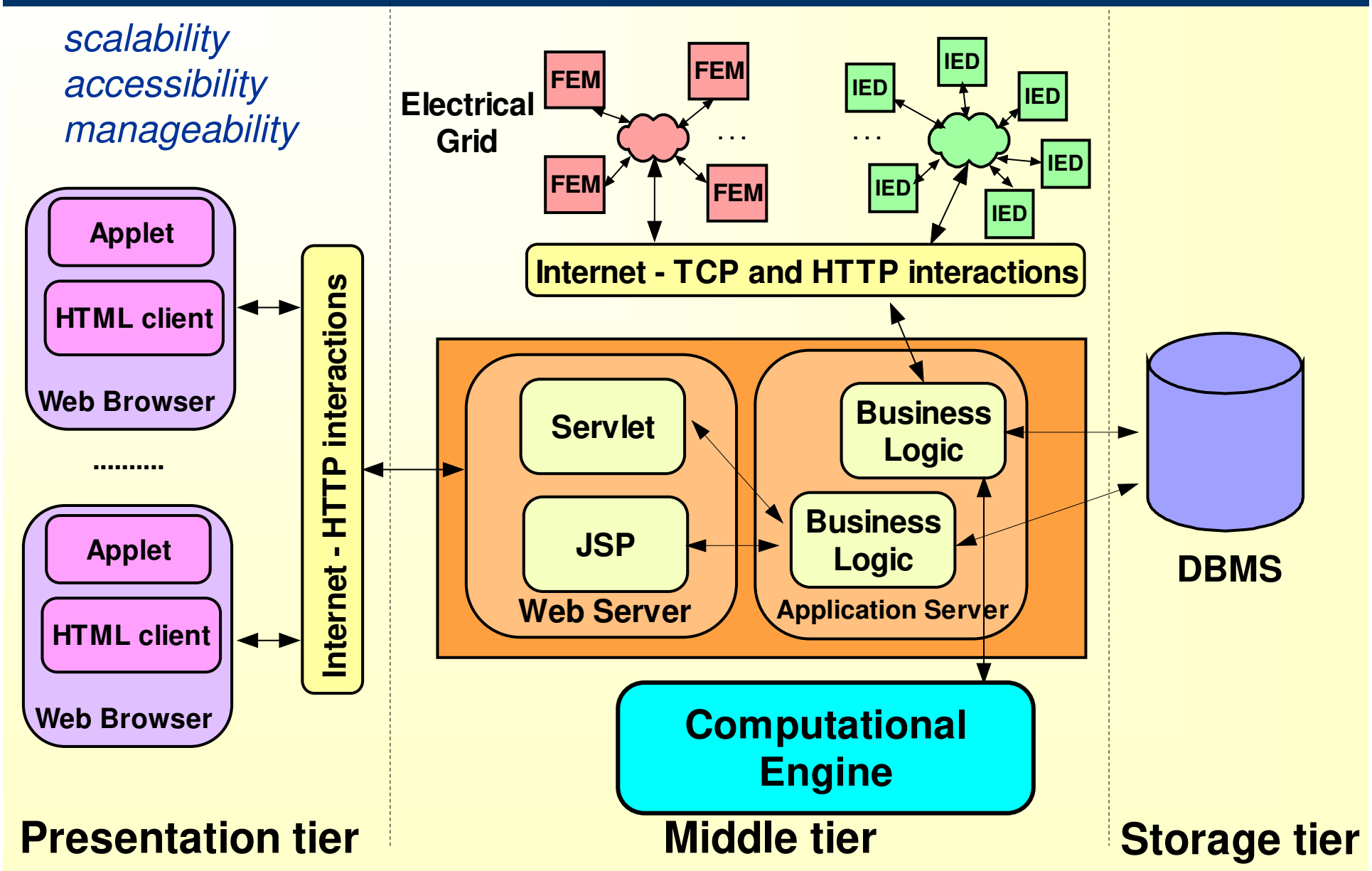
Introduction 4/4

- **Our proposal:**
  - A java-based distributed architecture instead of PVM
- **Advantages:**
  - Programming is easier
  - Portability is assured on each architecture implementing a JVM
  - Better integration with Web technologies
  - Object-Oriented programming allows for adopting architectural and design patterns
- **Disadvantages:**
  - Efficiency is reduced due to Java communication overheads
  - Execution time is higher due to interpretation

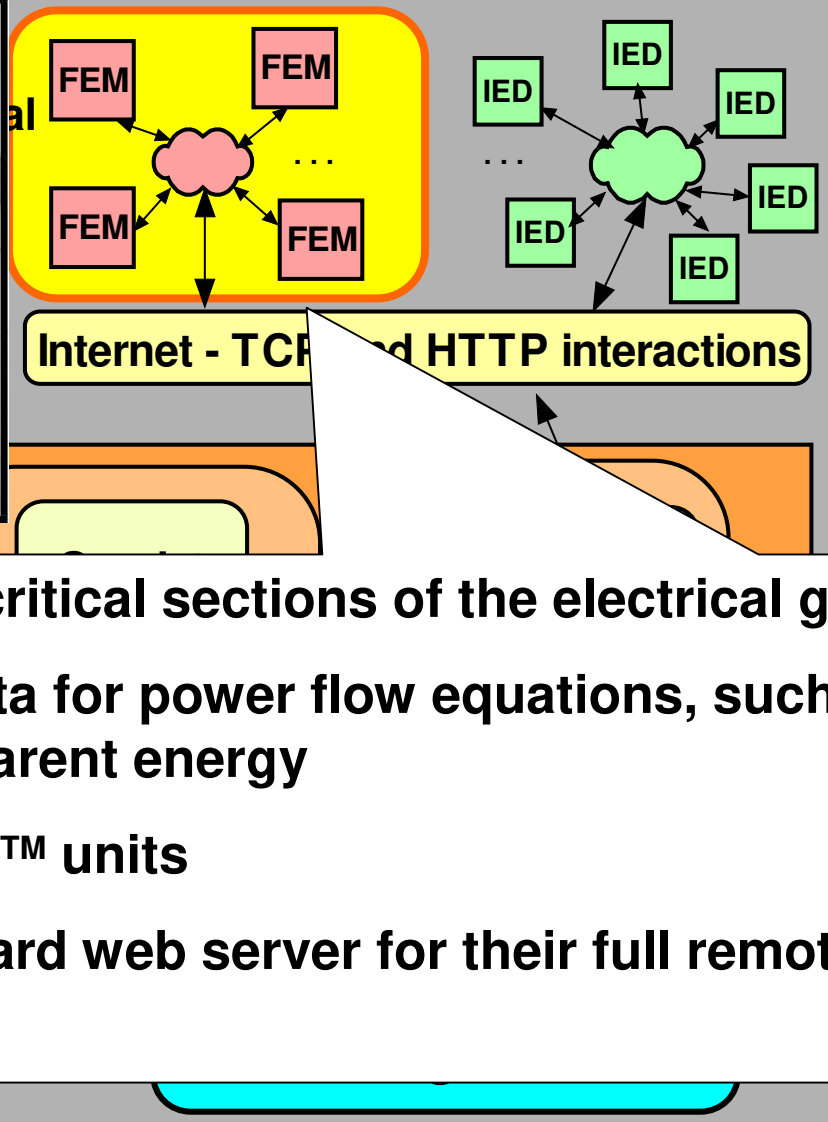
Contents

- The overall distributed architecture
- Computational engine
  - Algorithms
  - Design goals
  - RMI based implementation
  - ProActive based implementation
- Deployment on a testbed
- Conclusions and future work

The overall distributed architecture

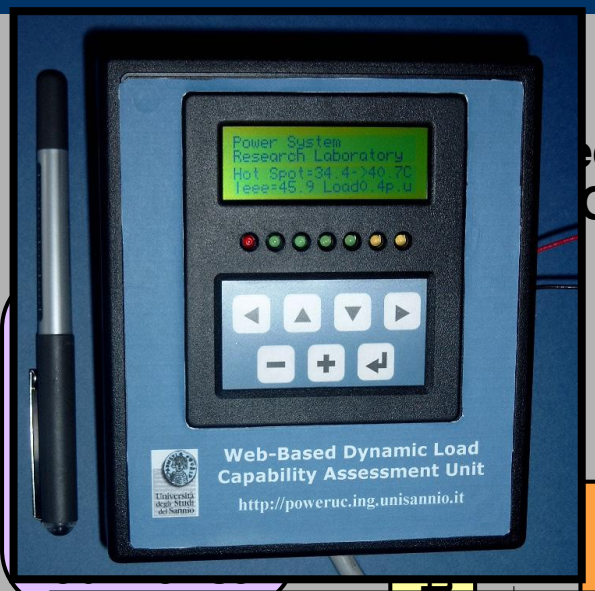


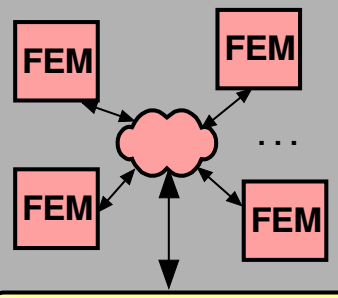
A network of field power meters (FEMs)

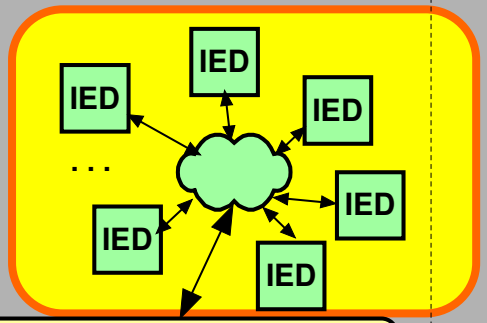


- distributed in the most critical sections of the electrical grid
- to provide input field data for power flow equations, such as active, reactive and apparent energy
- based on ION 7330-7600™ units
- equipped with an on-board web server for their full remote control

A network of distributed Intelligent Electronic Devices (IEDs)





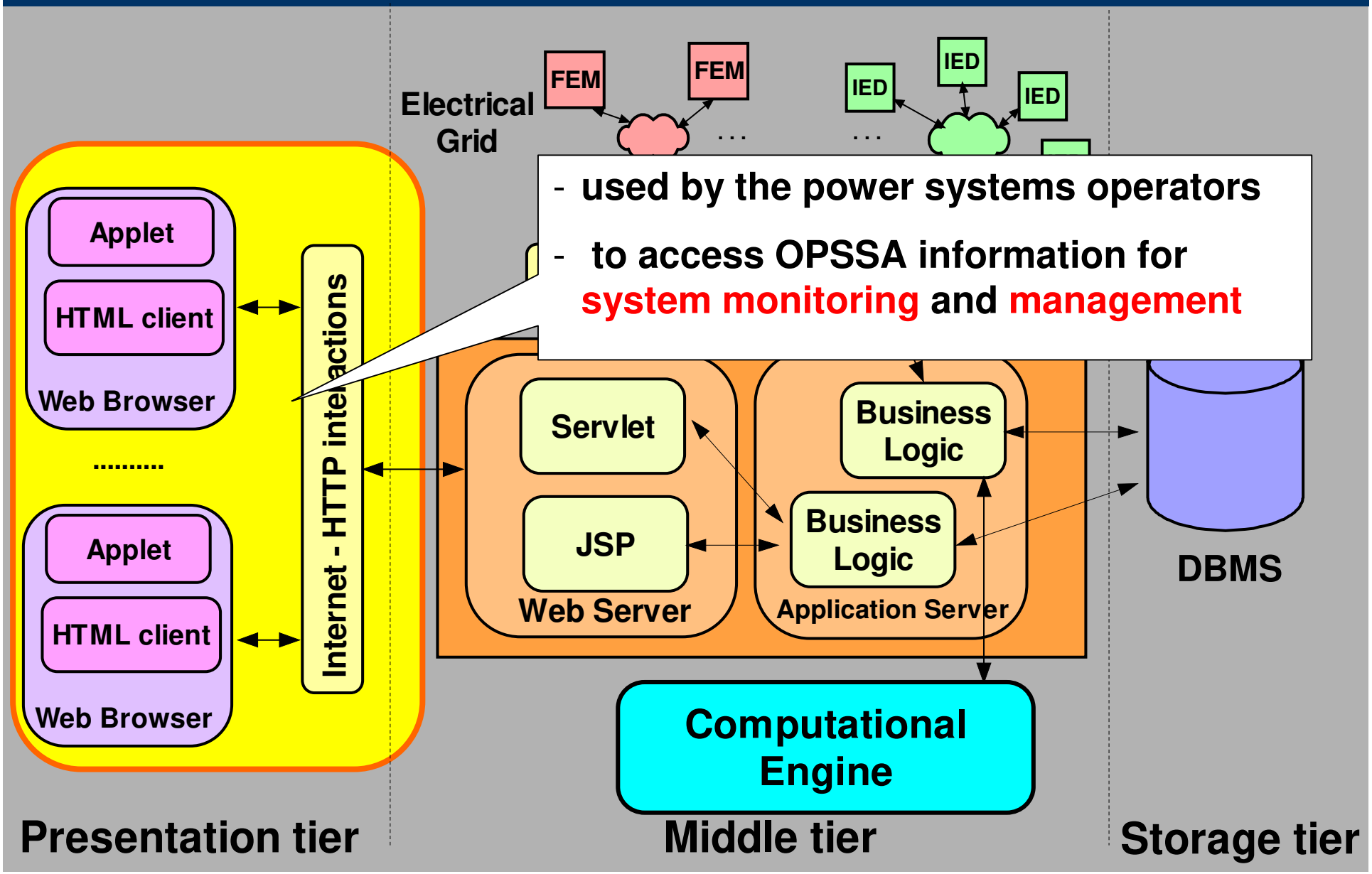


Internet - TCP and HTTP interactions

- distributed in the most critical sections of the electrical grid
- to monitor continuously the thermal state of critical sections of the electrical grid
- to analyse system behavior
  - to verify limits violations (such as load capability)
- remote controlled by the TCP/IP protocol

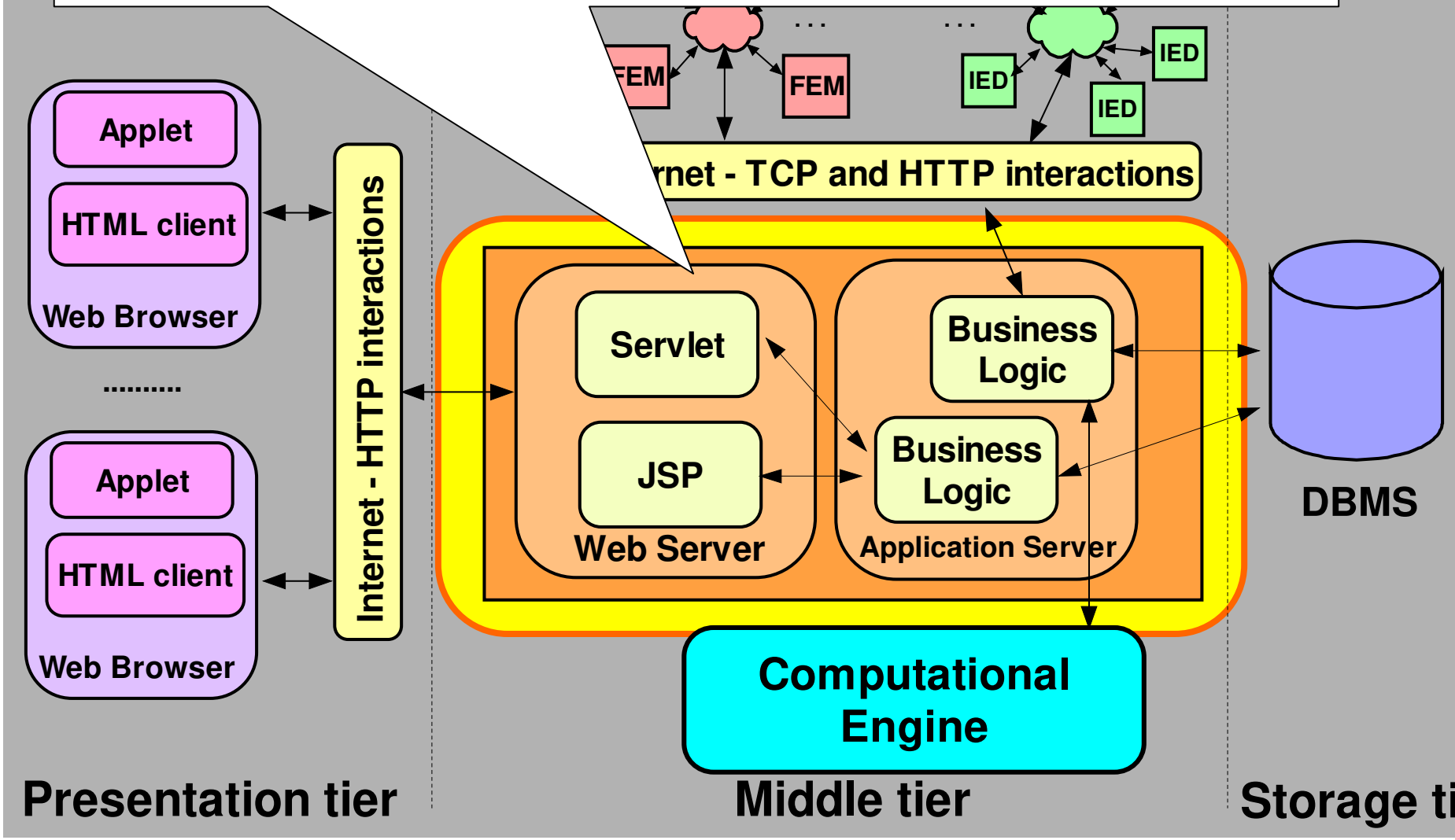
Presentation tier | Middle tier | Storage tier

Clients


Electrical Grid
FEM
FEM
IED
IED
IED
- used by the power systems operators
- to access OPSSA information for system monitoring and management
Applet
HTML client
Web Browser
.....
Applet
HTML client
Web Browser
Internet - HTTP interactions
Servlet
JSP
Web Server
Business Logic
Business Logic
Application Server
DBMS
Computational Engine
Presentation tier
Middle tier
Storage tier

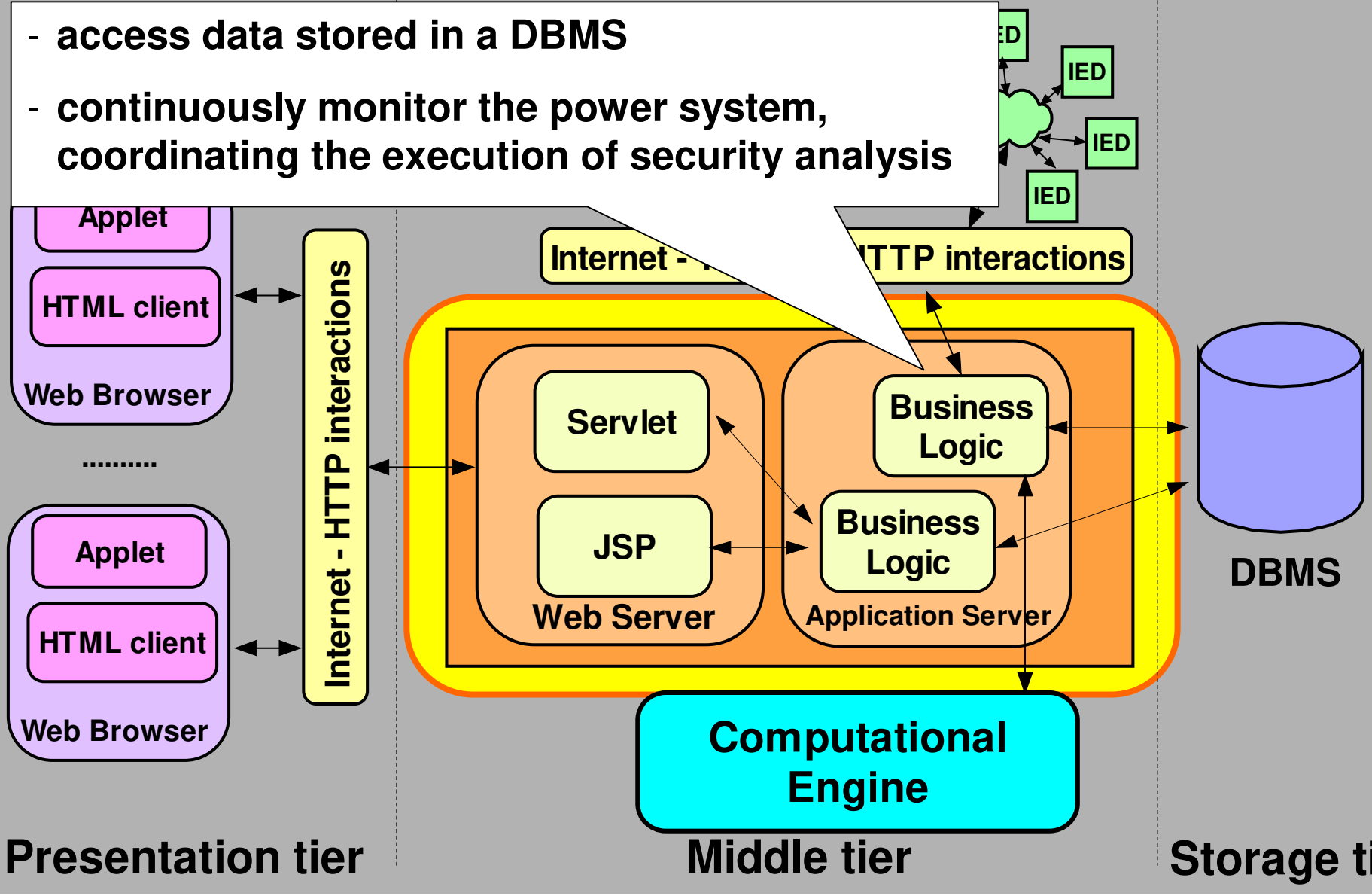
Web components

- handle the presentation at the server-side

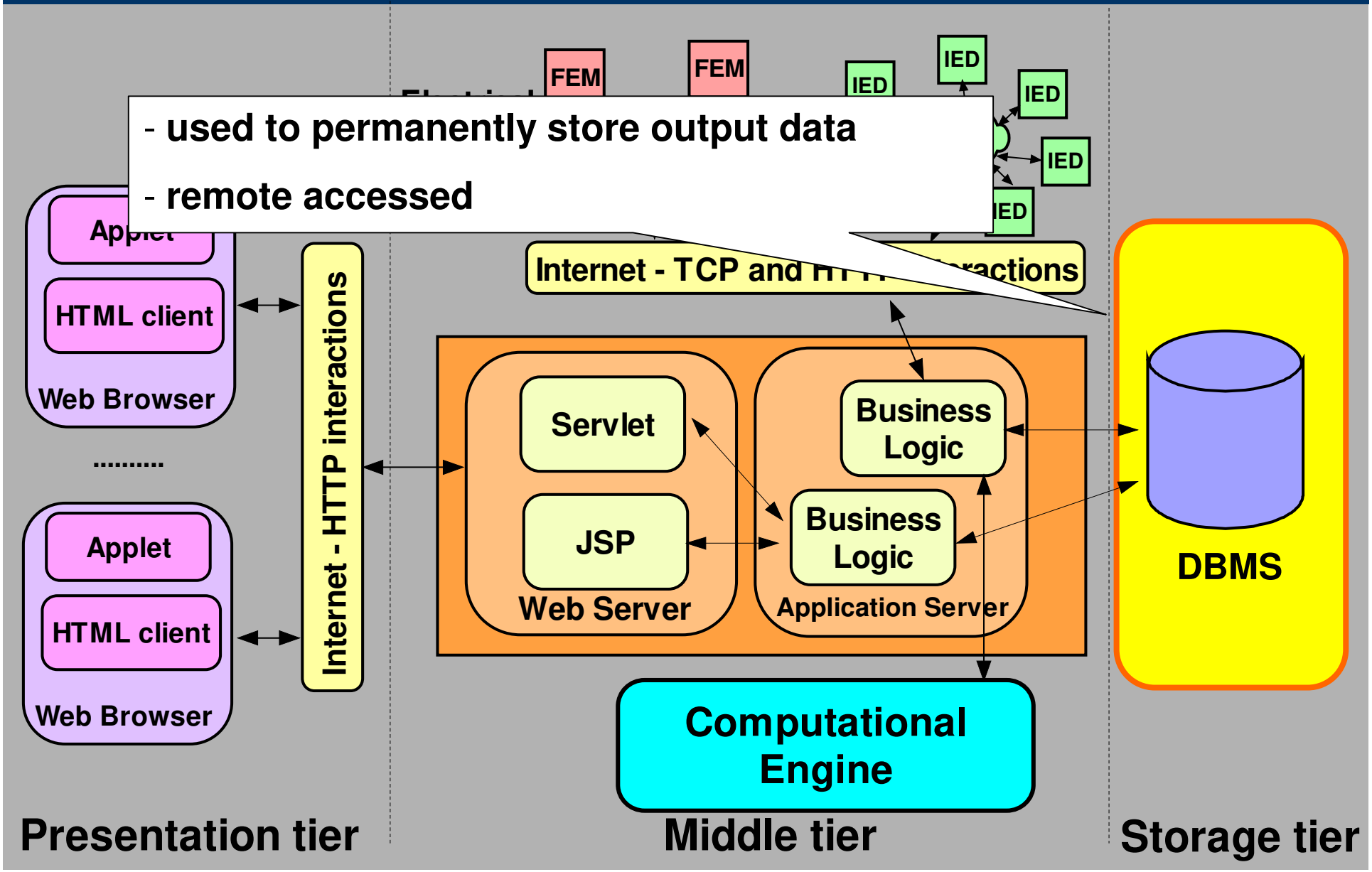


Business Logic Components

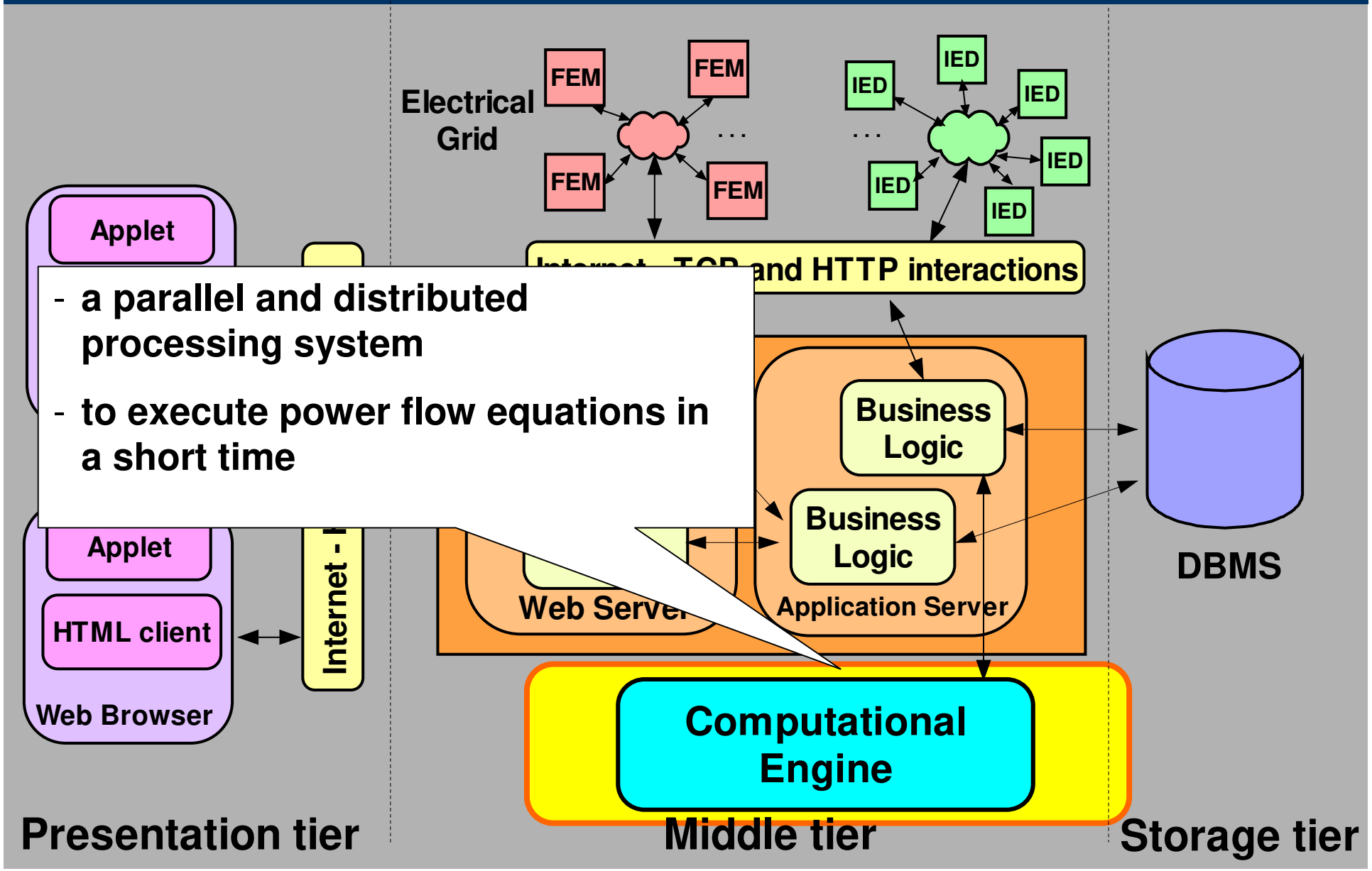
- access data stored in a DBMS
- continuously monitor the power system, coordinating the execution of security analysis



A DataBase Management System (DBMS)



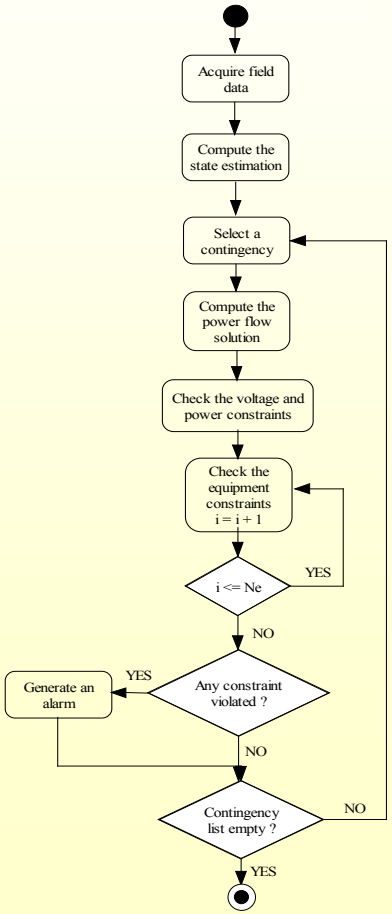
Computational Engine



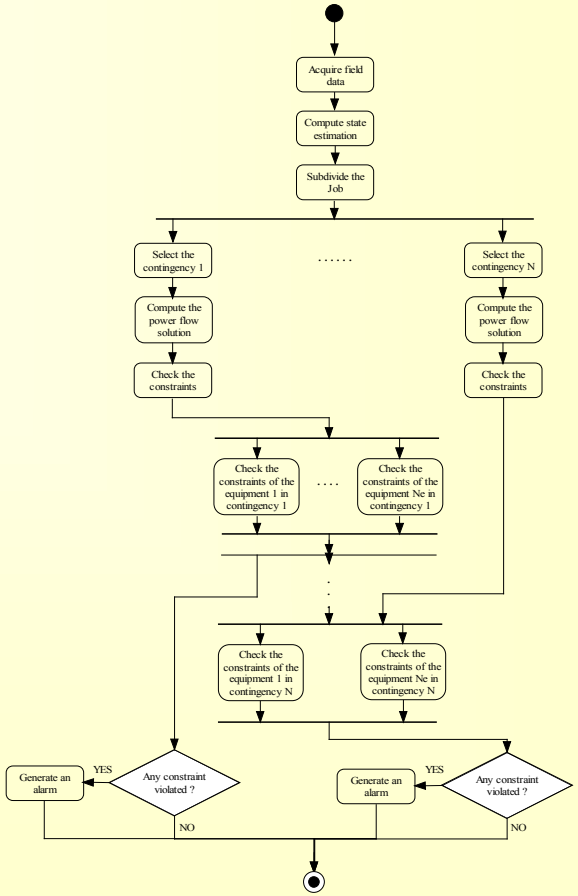
- a parallel and distributed processing system
- to execute power flow equations in a short time

Computational engine: algorithm

- **Sequential algorithm**



- **Concurrent algorithm**



Adopting a concurrent algorithm based on the domain decomposition

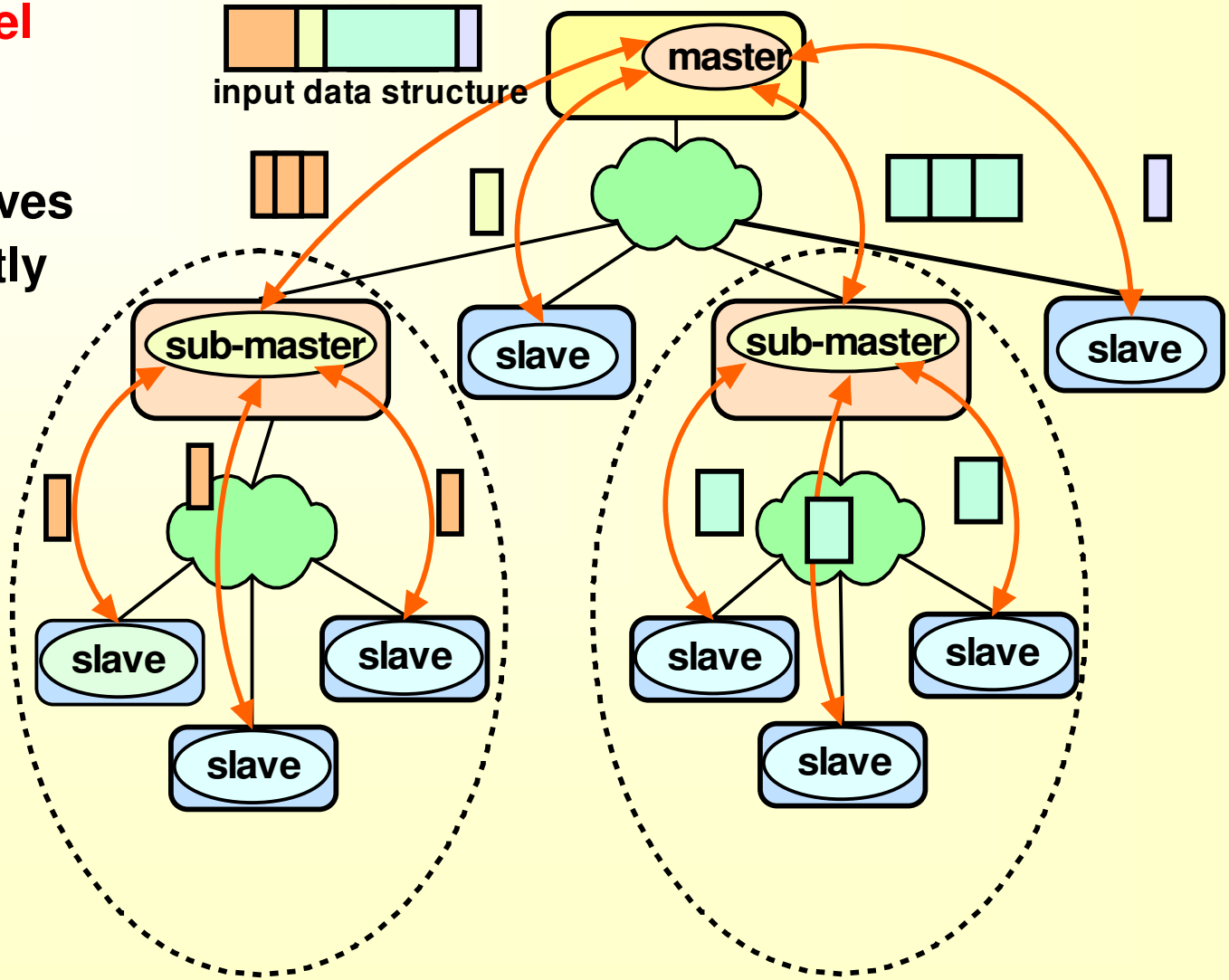
Computational Engine: design goals

- **The computational engine is designed as a framework, whose main goals are:**
  1. **high performance**
     - **The framework is to be able to compute the analysis of each contingency in parallel with the others**
  2. **flexibility and scalability**
     - **The framework is to be able to exploit all the available resources to minimize the computation time**
  3. **hierarchy**
     - **The framework is to be able to exploit clusters of workstations or networks of workstations handled by front-ends**

- **Architectural design solution: hierarchical master/slave model**

The hierachical m/s model 1/3

– **hierarchical master/slave model**
  - **object-level parallelism**
  - **master and slaves are transparently created**



The hierachical m/s model 2/3

- Three implementation problems:
  - Task allocation in order to minimize the execution time
    - Time minimization algorithm
  - Object-oriented design to support a transparent hierarchical master/slave model
    - Hierarchical master/slave pattern
  - Object-oriented implementation to support a distributed and parallel implementation of the hierarchical master/slave pattern
    - RMI based implementation
    - ProActive based implementation

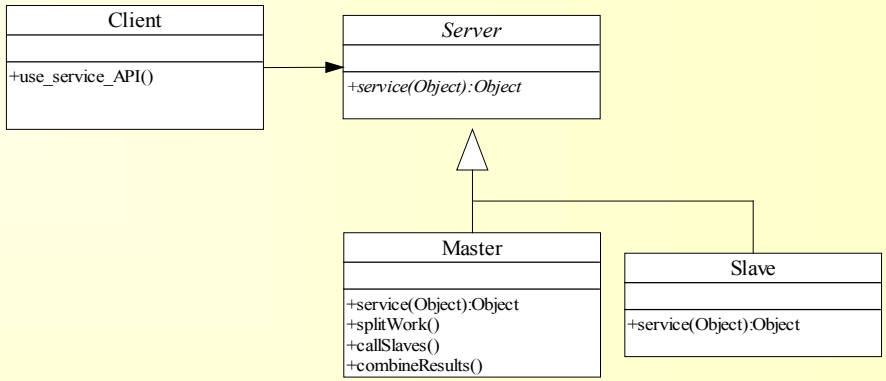
Task allocation: time minimization

- This phase is important and complex due to the heterogeneity of hardware architectures
  - to minimize load imbalance, the workload should be distributed dynamically and adaptively to the changing conditions of resources.
- We consider only static information
  - Defined *N* as the number of independent sub-tasks in which the overall task is divided;
  - *n* as the number of available resources at a certain level;
  - and t_i as the elapsed time that the resource *i* needs to complete a single sub-task;
  - n_i the number of sub-tasks assigned to the resource *i*
  - the problem to minimize the execution time using assigned resources can be formulated as follows:

$$\begin{cases} n_1 \cdot t_1 = n_2 \cdot t_2 = \ldots = n_n \cdot t_n \\ \sum_{i=1}^{n} n_i = N \end{cases}$$

The hierachical m/s pattern

- **M/S pattern:**
  - `splitWork()` is used to create slave objects, to allocate them onto the available resources, and to partition a task into sub-tasks.
  - `callSlaves()` is used to call the method service() on all the slave objects, which perform the same computation with different inputs.
  - `combineResults()` is used to combine the partial results in order to produce the final result.



- **Hierarchical M/S pattern:**
  - An additional class (Server) is introduced
  - `service()` is used to hide the difference between master and slave objects

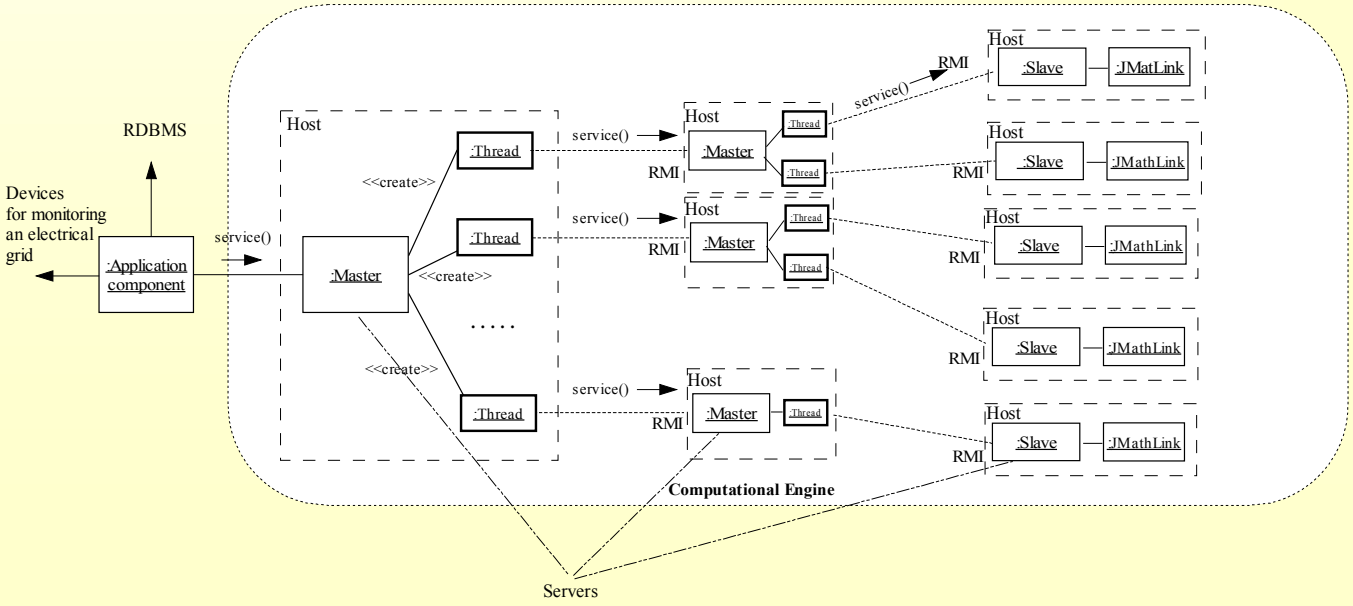
HM/S pattern implementation

- To support distributed and parallel implementation of HM/S pattern
  - `service()` has to be asynchronously invoked
  - Each `service()` method has to be executed by a different computational resources

- Solutions: an object-oriented middleware based on remote method invocations
  - RMI – the well known middleware provided by SUN
  - ProActive - Java library for seamless sequential, concurrent and distributed programming
    - It is based on the active object pattern and allows for invoking a method of an active object respecting the same syntax of local invocations
    - the invocation mechanism is asynchronous, and implemented through future objects
    - It does not require manually stub generation

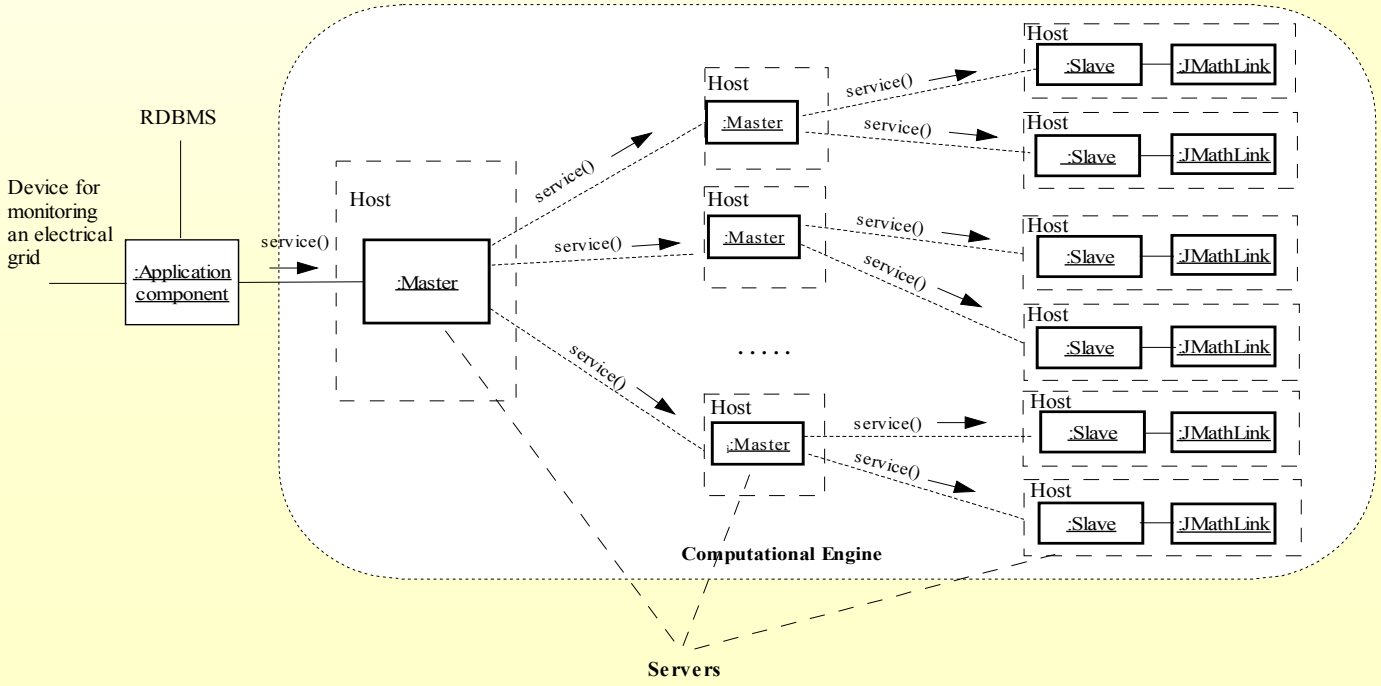
RMI implementation of HM/S pattern

- **Each Server**
  - **is defined as a remote object**
  - **is allocated onto a different computational resource**
  - **its method `service()` has to be asynchronously and remotely invoked by the client**
  - **the asynchronous invocation is implemented by invoking `service()` within a dedicated thread of control**



ProActive implementation of HM/S p.

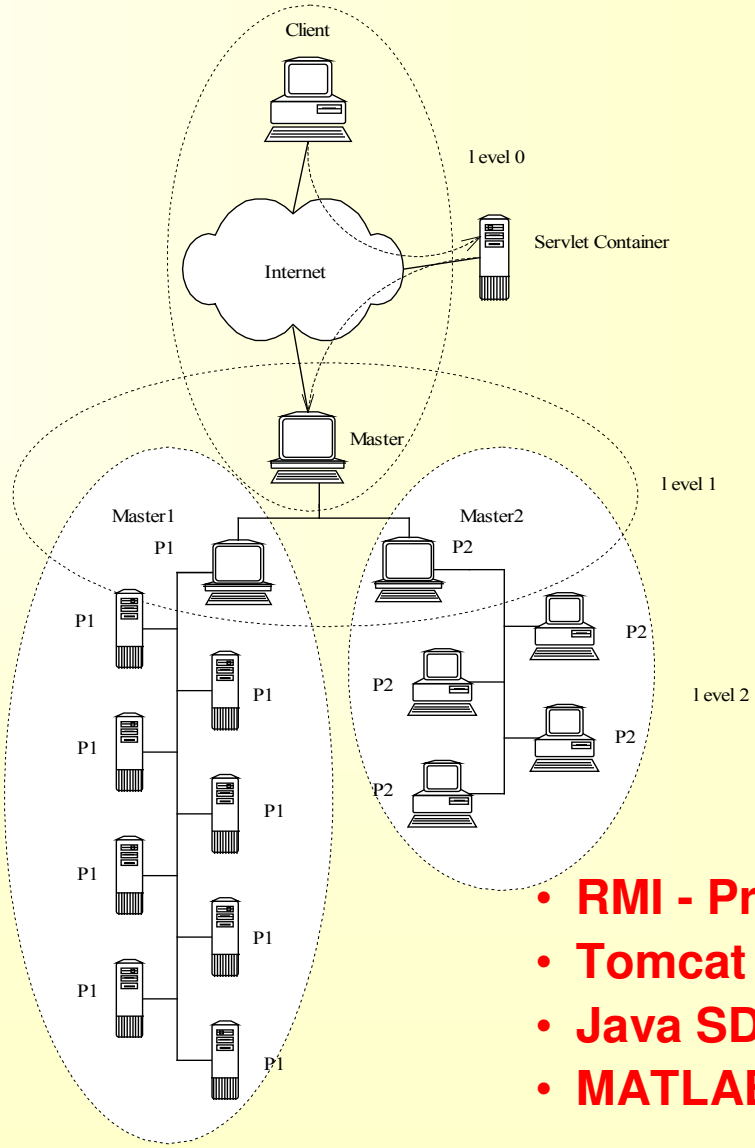
- **Each Server**
  - **is defined as an active object (that can be dynamically created)**
  - **is allocated on a different computational resource (dynamically)**
  - **its method `service()` has to be asynchronously and remotely invoked by the client.**
  - **the asynchronous invocation is directly supported by ProActive**



Software platform evaluation on a testbed 1/2

- **Standard IEEE 118-nodes test network**
  - **electrical network description is local to each computational resource**
- **The experiments refer to 186 contingencies**
- **A COW with P1 proc.**
  - **P1 = Pentium II 350 MHz**
- **A NOW with P2 proc.**
  - **P2 = Pentium IV 2 GHz**

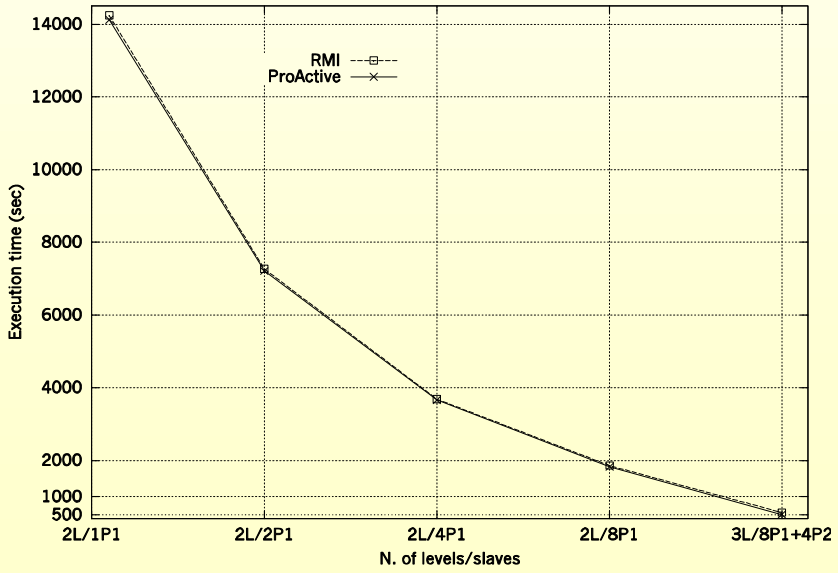
$$\begin{cases} n_1 = n_2 = \ldots = n_8 = 6 & P_1 \\ n_1 = n_2 = \ldots = n_4 = 35 & P_2 \end{cases}$$



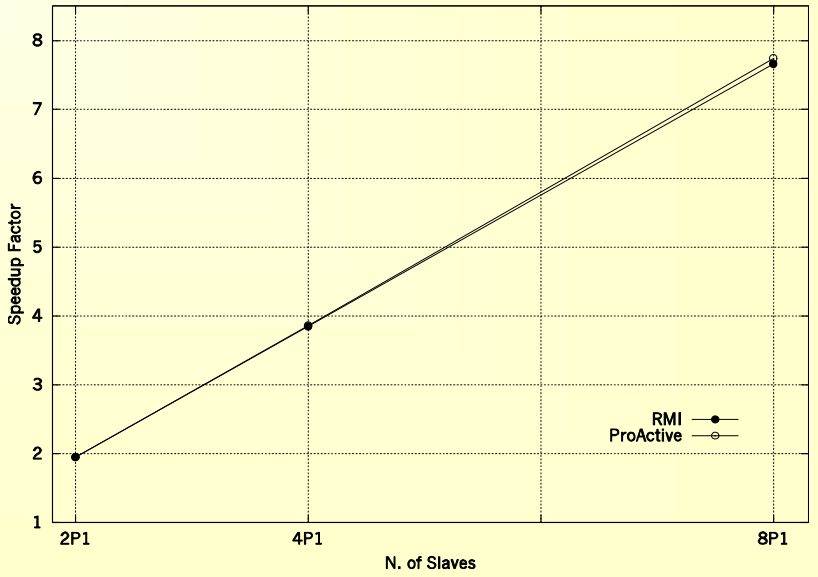
- **RMI - ProActive**
- **Tomcat 4.1**
- **Java SDK 1.4.1**
- **MATLAB 6.5**

Software platform evaluation on a testbed 2/2

- The framework shows good results
- RMI vs ProActive:
  - Exibhit almost the same results (ProActive is based on RMI)
  - ProActive simplifies parallel and distributed programming
  - ProActive enables group communication (not used in this work)



Execution times



Speed up

Conclusions and Future Work

- A distributed Web-based architecture for the OPSSA implemented by using RMI and ProActive middleware, has been presented
- Experimental results demonstrate the validity of the framework and its applicability to obtain results in more and more realistic and useful times

- In a parallel work we are:
  - using ProActive atop HiMM in a Grid Environment
  - adopting a broker-based architecture to automatically acquire resources and split the workload

- In the future we intend:
  - to include the solution of the power flow equations in the dynamic scenario
  - to extend our mapping algorithms in order to consider also communication tasks
  - to employ group communication in order to reduce communication overheads