Abstract—Online examination system has been developed as per requirement of NASSCOM and DIT. The system can cater to a large number of students for administering multiple choice questions and True-False Questions of various subjects. System offers Dynamic paper generation using 3 parameter model based on Item response theory. Flex, Spring and Hibernate frameworks have been used for development of system and it is highly secure and fail safe. The system uses open source stack in its design and is extensible, reliable and scalable to handle future requirements. The system is further designed to support very large load using cloud computing paradigm. The paper presents the functional description and architectural design of the system along with Adaptive exam conduction model used.

Index Terms—Online examination software, flex, spring, blazeds, terracotta, hibernate, eucalyptus, cloud computing.

I. INTRODUCTION

Development of a National Online Examination System (NOES) within India was a NASCOMM recommendation which, Department of IT (DIT), Ministry of Communication and Information Technology is realizing through C-DAC. The purpose of such an endeavor was to design and develop a robust, fault tolerant, secure & scalable and an adaptive system, through which examinations can be delivered on an “on demand” basis in pre-identified examination centers spread across the country. The project is being carried out in two phases namely, Phase-I wherein the software for conducting the exam was to be designed and developed and Phase -II wherein various colleges and partnering institutions are to be roped in to collaborate in providing questions to the question bank. Phase 1 of the project is nearing its complementation whereas Phase II has been initiated and is on-going.

The system utilizes various open source software framework. The integration of these frameworks to work as a cohesive unit has been one of the major engineering outcome of Phase 1 of the project. This paper presents an architectural perspective of the NOES. The paper also presents various issues faced as per design and implementation perspective.

II. REQUIREMENTS OF EXAMINATION SYSTEM

Online examination system has various user centric provisions and administrative functions. The former include registration of candidates, selection of center, selecting examination time and date, and payment of fee (either through Demand Draft or through Credit Card). The latter include examination setup, admit card generation, verification of fee receipt, question pool management, question paper matrix preparation, creating nodes for different subjects for adding questions, verification of questions for their technical correctness, tagging of questions under different subjects, etc. The Fig. 1 shows the generic process flow of the system.

Some key non functional requirements that had a strong impact on the architecture and the components used in the architecture includes: Open Source Stack to avoid vendor locking, Scale out Vs Scale Up, Ease of Extensibility, Performance/High System Throughput, Reliability, Security/Privacy/Escrow Accounts etc. All these functional and non-functional requirements have been considered, while deciding on technology components in the solution, described in further sections.

III. SYSTEM ARCHITECTURE


Fig. 1. Process flow diagram of online exam system.
JVM Level Clustering for High Availability and better throughput. System uses Eucalyptus for providing cloud computing services such as elastic scaling required for handling varying system loads. Fig 2 shows system components of online examination software at different tiers.

A. Presentation Tier

The software interface is designed and implemented as a Rich Internet Application (RIA). RIA is a web based application that has most of the characteristics of desktop applications. They are typically delivered by standard web browser plug-ins or independently via sandboxes or virtual machines. RIA has interactivity features which are often difficult to implement using normal HTML based applications. Adobe Flex, a framework for designing and developing RIA applications, was used at the Presentation tier. By using Flex, a state full application running on the browser was developed for activities like student registration, payment of fees through online payment gateway, etc.

Use of Flex as a Framework also helps in creating HTTP based applications that run on the user desktop as opposed to the conventional browser. This was required in situations where in a complete “control” of Desktop was required e.g. when a user is giving an examination using the software; he should not be allowed to interact with browsers and any other applications. Adobe AIR framework helped in realizing such requirements.

B. Business Tier

One of the major considerations while designing the system was to ensure a design, agnostic to underlying Application Server. Enterprise Application Technologies like Enterprise Java Beans (EJB), although based on Java, are required to be coded to ensure portability across various applications servers of different vendors. Moreover, EJB’s are considered to be heavy weight as compared to a Plain Old Java Object (POJO).

Our business tier design uses Spring Framework to utilize the simplicity of POJO programming and at the same time relieves the application developer from concerns about issues like Transaction, Persistence etc. These “concerns” are managed by Spring Framework itself. Apart from being a replacement to EJB, Spring also provides aspect orientation to avoid code dangling and to provide modularization of cross-cutting concerns such as logging of users, Role Based Access Control [7] and Transaction management.

Declarative transaction management in Spring, separates transaction management code from the business methods via declarations and uses Transactions as Aspect. Various transactional attributes like propagation behavior, isolation level, rollback rules, transaction timeout etc can be specified using annotations. This helps programmer in concentrating more on developing functional requirements in place of transaction management aspects. However, the development team faced issues while implementing transaction management as discussed later in section IV.

Security was one of the key non functional requirements of the NOES. The security subsystem of the NOES provides Authorization, Role Based Access Control (RBAC) and cryptographic functions for storing user credentials for authentication; through Spring Security. For providing cryptographic functions like encryption Java Simplified Encryption (Jasypt) was integrated with Spring Security and Hibernate, so that Spring Security uses password encoders etc provided by Jasypt.

Using the Security Subsystem, access control can be provided at the URL level, Method Invocation Level, domain object level and view rendering level. The authorization is implemented with the help of Spring Security as a set of Intercepting Filters as shown in Fig. 3.

For making Access Control Decisions the Spring Security Access Decision manager were used. All these access decision managers use a group of voters to be configured for voting on access control decisions. NOES utilize Role Voters and Authenticated Voters. Role Voters votes for an access control decision based on a user’s role.
The Fig. 4 shows applications running on top of Terracotta. Using Terracotta, application is clustered at the JVM level for high availability and scalability [8], [9]. Terracotta keeps objects with cluster level scope instead of JVM level scope. Since objects are now available across the cluster, there are no single points of failures. Further, Terracotta has been configured in such a way that it persist the object graph. This helps to recover even in situations wherein there is a full cluster restart.

Using Terracotta also allowed us to scale out the application by just increasing the number of JVM's in the setup. Therefore, transparent scaling was achieved without requiring a change in source code for the purpose of scaling. Terracotta is also used to implement various design patterns like Write behind to System of Records (SOR), Asynchronous Commit etc with intent to minimize Database I/O during an examination. The usage of these design patterns are mentioned in TABLE I.

**TABLE I : USE OF KEY DESIGN PATTERNS IN NOES**

<table>
<thead>
<tr>
<th>Design Pattern used</th>
<th>Use in NOES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model View Control</td>
<td>Separation of Presentation Tier with Business Tier</td>
</tr>
<tr>
<td>Proxy Pattern</td>
<td>Used for implementation of Advices when implementing Aspect Orientation in Business Tier</td>
</tr>
</tbody>
</table>

Terracotta also provides a transparent Hibernate 2nd Level Caching which increases the throughput of NOES and further reduces Disk I/O. This results in improving the performance by decreasing the load on the system. The deployment architecture of the system is shown in Fig. 5. The figure shows DNS based load balanced (LB) cluster of Apache mod_proxy based load balancer interacting with Tomcat Servers (TC). TC are clustered at their JVM by Terracotta Mirrored Server Arrays(Tera1..n). Eucalyptus is being used as a cloud platform for providing Elastic Scaling. Whenever the load is increased beyond a threshold limit, Eucalyptus is instructed to spawn, required number of Xen Virtual Machines on available Nodes. Thereafter, a specific Eucalyptus Machine Image (Emi) is deployed on top of Xen to run a particular machine instance.

**TABLE II : MAPPING OF NON-FUNCTIONAL REQUIREMENTS TO VARIOUS TECHNICAL COMPONENTS**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Flex</th>
<th>Spring</th>
<th>Jasypt</th>
<th>Spring Security</th>
<th>Terracotta</th>
<th>Eucalyptus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalability</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>OSS Stack</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Expandability</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transparent Scale Out</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>High Availability</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High Volume Transaction</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Security</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**IV. ISSUES FACED DURING IMPLEMENTATION**

A. Integrating Flex and Spring

Flex can access java object and Spring beans are nothing but java objects therefore ideally integration of Flex and Spring should be simple. However, whenever Flex contacts Spring business tier using BlazeDS, BlazeDS instantiates Java Objects. This default behavior does not fit our architecture as Spring should instantiate the components and inject these components whenever needed. The key to the Flex/Spring integration, therefore, is to configure BlazeDS to let the Spring container take care of instantiating Spring beans by the use of suitable factory classes provided by BlazeDS. In the first version of NOES, we designed and developed a SpringFactory and configured BlazeDS to use this factory class to let Spring instantiate the classes and perform dependency injection when needed. Later the Spring Community came up with Spring BlazeDS Integration Components [10]. The current version of NOES uses this new scheme to integrate Flex and Spring.

B. Integrating BlazeDS Channel Security and Spring Security

BlazeDS has got methods to authenticate Channel sets between Flex Client and the Server Side Code. NOES, however, use Spring Security to implement security functions. This again required that BlazeDS should allow Spring Security to manage security. For this purpose, we extended the functionalities of BlazeDS and designed and developed a Login Command Class which allowed, BlazeDS to use Spring Security functionalities. Later when Spring Integration Components [11] were released, we shifted our code base to use it.

C. Issue Faced during Implementing Transaction Management using Spring

NOES use MySQL as a database server at present (though the design is agnostic to the database at the backend). The default database engine of MySQL in Linux is MyISAM [12]. Transaction management provided by Spring does not work...
with MyISAM. The solution to this problem was to change the 
database engine from MyISAM to InnoDB[13].

Spring uses the Proxy Pattern to implement Aspect based 
Transaction management. Therefore, methods called using 
Proxy were only advised for transaction management. In our 
service class there were situations when a proxy method (f1) 
called another method (f2). Java calls method f2 using “this” 
pointer. In such cases the method f2 is not advised for 
transaction management. Therefore, if some exception 
happened while execution was in f2, it had to be manually 
handled.

To work around, we have taken a reference of the interface 
type implemented by the service and created a bean post 
processor which assigns the proxy to the reference. This is 
called self reference. Now whenever, a function is called 
inside a method which is advised for transaction, self 
reference is used instead of this pointer.

NOES sends automated E-mails to candidates triggering a 
successful completion of an event such as registration 
successfully done, admit cards generated etc. Most of these 
situations involve a database operation to either Insert, 
Update or Delete records. Such methods are required to 
advise as a Transactional method. In such scenarios, the 
sending of email is typically the last step after a successful 
database operation. However, Spring buffers the database 
operation and performs it at the end of the Transactional 
Method i.e. after sending the mail. This can lead to a situation 
where in the database operation was not successful, however, 
e-mail was sent. To get around this issue, we flush 
Hibernate session right after issuing a command to save, 
update or delete an object. Doing this throws an exception 
immediately on failure of a Database operation and thus 
prevents sending of mails in case of exceptions.

Whenever a Transactional method is called from the Flex 
end and it fails, nothing was returned from the Business tier 
to the presentation tier and the transaction was not rolled 
back. The reason for this was that, Transactional method did 
not throw out an exception to the calling method and the 
Spring Transaction manager only rolls back an exception if 
the transactional method throws out an exception. To solve 
this issue, a service method was introduced such that it was 
not treated as transactional and this method was exposed to 
the presentation tier. The service method internally called a 
Transactional method. This transactional method did not 
handle exceptions and threw out exception to the service 
method. In this case, Spring Transaction Manager rolls back 
the Transaction and the service method can be used to handle 
the exception and send relevant message to the presentation 
tier.

D. Integrating Flex and Terracotta

Terracotta has defined several classes which it treats as 
non-portable. These non-portable classes cannot be used in 
clustered mode across different JVM’s. Flex uses some such 
classes pertaining to HTTPServlets in its messaging session 
thereby making clustering Flex Sessions using Terracotta 
incompatible. Since the application at the front end was a 
state-full one, reliance on sessions was not necessary and 
therefore Terracotta was configured to ignore non-portable 
classes which were used by Flex in its messaging session.

Further, we had used a load balancer based on Apache to use 
sticky sessions. This allowed HTTP request to be routed to 
the same application server where it was first originated, this 
helped in non-sharing of sessions across the cluster. In case of 
a node failure, the user just needs to re-login and he can 
continue from where had left as since his progress is stored 
across cluster using Terracotta.

E. Concurrency Issues with Terracotta Asynchronous Committer

Terracotta AsynCommmiter allows to commit records in a 
 asynchronous manner through configuration of processing 
buckets, present at each application server. When two or 
more processing buckets tries to commit a data element, at 
the same time and the primary key of such a data element is a 
numeric increment, then there will be Data Integrity 
Violations as two data elements may have the same number 
as primary key. Further, the application can enter into an 
infinite loop as in case of an error while committing in the 
database, Terracotta tries to recommit the values. While 
recommitting again the same situation of Data Integrity may 
arise. This situation can go on till a serial schedule is found. 
To overcome this issue, we have used UUID as the primary 
key of data items which are stored asynchronously. This 
prevents Data Integrity Violations in asynchronous commit 
mode.

V. IMPLEMENTATION ADAPTIVE ASSESSMENT SYSTEM IN 
NOES

Item Response Theory (IRT) provides the theoretical 
framework for implementation of Adaptive Testing. The IRT 
algorithm aims to provide information about the functional 
relation between the estimate of the learner’s proficiency in a 
concept and the likelihood that the learner will give the 
correct answer to a given question. The amount of knowledge, 
learning ability, proficiency in a subject of a person, etc., 
cannot be directly measured like height or weight. These are 
generally referred to as the latent traits or “ability” in IRT 
[14]. The aim of IRT is to estimate this ability. IRT rests on 
the postulate that an examine has a definite probability of 
giving a correct answer to the given question, and this 
probability will be high for high ability examinees and low 
for low-ability ones.

NOES test an examinee on multiple subjects like Aptitude, 
Programming Language, Data Structures, etc. Therefore, the 
question paper for the examinee needs to have questions from 
all these sections. Further, each section must have enough 
questions of various difficulty levels so as to precisely 
determine the ability of examinee. For the recruitment exam 
conducted using NOES, there were 12 sections for each 
examinee. Being adaptive in nature, each section had to 
contain 30 questions from each of 5 difficulty levels where 
30 is the upper limit of the number of questions that an 
examinee can attempt in a section. So a single question paper 
can contain 30*5*12 or 1800 questions. Major issue was to 
send such a huge set of questions to hundreds of examinees 
simultaneously at the start of the exam. In order to reduce the 
load on the network, the questions were sent to the examinees 
only section wise.
Another design issue relates to calculating the ability estimates of the examinees and administering the next best question corresponding to his/her ability. Ability estimation of an examinee, for a section, takes into account all the responses made by the examinee in that section. This involves a huge amount of calculations as ability estimation and question selection has to be done after each response for each examinee as the process is iterative. In order to relieve server, from the workload of the above calculations, it was decided that the calculations involved for an examinee must be done at the client machine which the examinee is using. RIA client capable of working outside the browser environment helped us in realizing it [15].

At the start of each section the client gets all the question ids corresponding to that section. The client calculates examinee ability, decides the difficulty level of the question to be given next and then sends to server, the question id of the calculated difficulty level. On receiving the id the server sends the question along with its answers and the correct option. The examinee sees the question text along with the question options and makes a response. TABLE III shows calculation being done in a session for a candidate based on the responses. AAS test can be stopped if any of the following criteria are met.

<table>
<thead>
<tr>
<th>Setup Description</th>
<th>Results of load testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Apache Load Balancer:</td>
<td>• Max Load Tested: 5000</td>
</tr>
<tr>
<td>• Tomcat : Max Thread 1500 (One Tomcat instance), Min Spare Thread : 100</td>
<td>• Ramp up Time: 50 sec</td>
</tr>
<tr>
<td>• JVM : Initial 256 MB , Max 2GB , Chunk Size 256 MB</td>
<td>• Idle Time: 5 sec [Presumed Thinking Time]</td>
</tr>
<tr>
<td>• Peak size Reached during load test 400 MB</td>
<td>• Peak CPU Usage: 12 % Response Time:</td>
</tr>
<tr>
<td>• MySQL : max_connections=6000</td>
<td>• Cumulative Avg: 0.9155 Sec</td>
</tr>
<tr>
<td>• Distributed 2nd Level Cache</td>
<td>• Login/Fetch QP: 0.814 sec</td>
</tr>
<tr>
<td>• Caching Policy : Non Restrict Read Write</td>
<td>• SetAnswer: 0.087 sec</td>
</tr>
<tr>
<td></td>
<td>• Clock sync: 0.0075 sec</td>
</tr>
<tr>
<td></td>
<td>• EndExam: 0.0070 sec</td>
</tr>
</tbody>
</table>

- The ability of an examinee has been calculated with desired precision (i.e., the standard error in calculating the ability has fallen below a predefined value).
- The first 'n' numbers of questions is consecutively answered correctly or wrongly. The examinee is given the highest/lowest ability for that subject or examination based on whether all answers are correct or incorrect.
- The maximum number of questions for a particular section or the whole of examination has been administered to the examinee. This case may arise when the computer is unable to precisely predict the ability of examinee.
- The maximum time limit for a particular section in an examination or the total time limit of the examination has been reached.
- The item bank has got exhausted which may be the case when item bank is quite small.

VI. CONCLUSION AND FUTURE WORK

Using the NOES, C-DAC has conducted three PG Entrance Examination and two national level recruitment examination successfully. The question pool of NOES has 97,000 questions on Electronics, Computer Sc & engineering encompassing 400 different Topics along with questions on aptitude.

The National Level recruitment Examination was conducted across 10 centers of C-DAC for a period of 10 days each day having 3 slots. Therefore, more than 500 live runs of the system are already conducted so far. DOEACC has also expressed its interest in conducting CCC examination.

The initial stress testing result shows that we can conduct an exam for 5,000 concurrent users using just 2 Tomcat server instances. We plan to scale the application to support around 1, 00, 000 concurrent users in a single session.

NOES uses Hibernate in its ORM Session. One of the criticism of ORM technologies, is that generates non-optimized SQL Queries for databases. We plan to tweak the ORM layer and use frameworks like AutoFetch to generate Optimized SQL.

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