On Design and Implementation of Distributed Modular Audio Recognition Framework
Requirements and Specification Design Document

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August 12, 2006

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Chapter 1

Executive Summary

This chapter highlights some details for the inpatient readers, while the rest of the document provides a lot more details.

1.1 Brief Introduction and Goals

- An open-source project – MARF (http://marf.sf.net [Gro06]), which stands for Modular Audio Recognition Framework – originally designed for the pattern recognition course.

- MARF has several applications. Most revolve around its recognition pipeline – sample loading, preprocessing, feature extraction, training/-classification. One of the applications, for example, is Text-Independed Speaker Identification Application. The pipeline and the application, as they stand, are purely sequential with even little or no concurrency when processing a bulk of voice samples.

- The classical MARF’s pipeline is in Figure 2.1. The goal of this work is to distribute the shown stages of the pipeline as services as well as stages that are not directly present in the figure – sample loading, front-end application service (e.g. speaker identification service, etc.) and implement some disaster recovery and replication techniques in
the distributed system.

- In Figure 2.2 the design of the distributed version of the pipeline is presented. It indicates different levels of basic front-ends, from higher to lower which client applications may invoke as well as services may invoke other services through their front-ends while executing in the pipeline mode. The back-ends are in charge of providing the actual servant implementations as well as the features like primary-backup replication, monitoring, and disaster recovery modules through delegates.

1.2 Implemented Features So Far

- As of this writing the following are implemented. Most, but not all modules work:

- Out of the following six services:

  1. SpeakerIdent Front-end Service (invokes MARF)
  2. MARF Pipeline Service (invokes the remaining four)
  3. Sample Loader Service
  4. Preprocessing Service
  5. Feature Extraction Service (may invoke Preprocessing for preprocessed sample)
  6. Classification (may invoke Feature Extraction for features)

all the six work in the stand-alone and pipelined modes in CORBA, RMI, and WS.

At the demo time, the RMI and as a consequence in Web Services implementation of the Sample Loader and Preprocessing stages were not functional (other nodes were, but could not work as a pipeline) because of the design flaw in the MARF itself (the Sample class data
structure while itself was `Serializable`, one of its members, that inherits from a standard Java class, has non-serializable members in the parent) causing marshalling/unmarshalling to fail. This has been addressed until after demo.

- There are three clients: one for each communication technology type (CORBA, WS, RMI).
- MARF vs. CORBA vs. RMI object adapters to convert serializable objects understood by the technologies to the MARF native and back.

1.3 Some Design Considerations

- For WS there are no remote object references, so a class was created called `RemoteObjectReference` encapsulating nothing but a type (`int`) and an URL (`String`) as a reference that can be passed around modules, which can later use it to connect (using `WSUtils`).

- All communication modules rely on their delegates for business and most of the transaction logic, thus remapping remote operations to communication-technology independent logic and enabling cross-technology communication through message passing. There are two types of delegates – basic and recoverable. The basic delegates just merely redirect the business logic and provide basis for transaction logs while not actually implementing the transaction routines. They don’t endure the transactions overhead and just allow to test the distributed business logic. The recoverable delegates are extension of the basic with the transactional on top of the basic operations.

- All modules also have utility classes like `ORBUtils`, `RMIUtils`, and `WSUtils`. These are used by the distributed modules for common registration of services and their look up. Due to the common design, these can be looked up at run-time through a reflection by loading the requested module classes. The utility modules are also responsible for
1.4 Transactions, Recoverablity, and WAL Design

- Write-Ahead Log (WAL) consists of entries called “Transactions”. The idea is that you write to the log first, ahead of committing anything, and once write call (dump) returns, we commit the transaction.

- A Transaction is a data structure maintaining transaction ID (long), a filename of the object (not of the log, but where the object is normally permanently stored to distinguish different configurations), the Serializable value itself (a Message, TrainingSet, or an entire Serializable business-logic module), and timestamps.

- The WAL’s max size is set to empirical 1000 entries before clean up is needed. Advantage of keeping such entries is to allow a future feature called point-in-time recovery (PITR), backup, or replication.

- MARF-specific note: since MARF core operations are treated as kind of a business logic black box, the “transactions” are similar to the “before” and “after” snapshots of serialized data (maybe a design flaw in MARF itself, to be determined).

- Checkpointing in the log is done periodically, by default every second. A checkpoint is set to be a transaction ID latest committed. Thus, in the event of a crash, to recover, only committed transactions with the ID greater than the checkpoint are recovered.

1.5 Configuration and Deployment

All CORBA, RMI, and WS use a `dmarf-hosts.properties` file at startup if available to locate where the other services are and where to register themselves.
Web Services have Tomcat context XML files for hosting as well as web.xml and related WSDL XML files.

All such things are scripted in the GNU Make Makefile and Ant dmarf-build.xml makefiles.

1.6 Testing

A Makefile target marf-client-test for a single wave file and a batch.sh shell script test mostly CORBA pipeline with 295 testing samples and 31 testing wave samples x 4 training configs x 16 testing configs.

The largest demo experiment involved only four machines in two different buildings running the 6 services and a client (a some machines ran more than one service of each kind). Killing any of the single services in batch mode and then restarting it, recovered the ability of a pipeline to operate normally.

1.7 Known Issues and Limitations

- After long runs of all six CORBA services on the same machine runs out of file (and socket) descriptors reaching default kernel limits. (Probably due to large number of log files opened and not closed while the containing JVM does not exit and which accumulate over time after lots of rigorous testing).

- Main MARF’s design flaws making the pipeline rigid and less concurrent (five-layer nested transaction, see startRecognitionPipeline() of MARFServerCORBA, MARFServerRMI, or MARFServerWS for examples.

- Transaction ID “wrap-around” for long-running system and transactions with lots of message passing and other operations. MARF does a lot of writes (dumps) and long-running servers have a potential to have their transaction IDs be recycled after an overflow. At the time of this writing, there is no an estimate of how log it might take when this happens.
CHAPTER 1. EXECUTIVE SUMMARY

- All services are single-threaded in the proof-of-concept implementation, so the concurrency is far from being fully exploited per server instance. This is to be overcome in the near future.

1.8 Partially Implemented Planned Features

- WAL logging and recovery.
- Message passing (for gossip, TPC or UDP + FIFO) is to be added to the basic delegates.
- Application and Status Monitor GUI – the rudiments are there, but not fully integrated yet.

1.9 NOT Implemented Planned Features

- Primary-backup replication with a “warm stanby”.
- Lazy, gossip-based replication for Classification training sets.
- Two-phase commit for nested MARF Service transactions (covering the entire pipeline run.
- Distributed System-ware NLP-related applications.
- Thin test clients and their GUI.

1.10 Conclusion

This proof-of-concept implementation of Distributed MARF has proven a possibility for the pipeline stages and not only to be executed in a pipeline and stand-alone modes on several computers. This can be useful in providing any of the mentioned services to clients that have low computational power or no required environment to run the whole pipeline locally or cannot afford long-running processing (e.g. collecting samples with a laptop or any
mobile device and submitting them to the server). Additionally, there were discovered some show-stopping design flaws in the classical MARF itself that have to be corrected, primarily related to the storage and parameter passing among modules.

1.11 Future Work

Address the design flaws, limitations, and not-implemented features and release the code (for future improvements). You may volunteer to help to contribute these ;-) as well as addressing the bugs and limitations when there is a time and desire. Please email to mokhov@cse.concordia.ca if you are interested in contributing to the Distributed MARF project.
Chapter 2

Introduction

Revision : 1.3

This chapter briefly presents the purpose and the scope of the work on the Distributed MARF project with a subset of relevant requirements, definitions, and acronyms. All these aspects are detailed to some extent later through the document. The application ideas in small part are coming from [CDK05, WW05, Mic04, Mic05b, Mic06, Gro06, Mok06b].

2.1 Requirements

I have an open-source project – MARF (http://marf.sf.net [Gro06]), which stands for Modular Audio Recognition Framework. Originally designed for the pattern recognition course back in 2002, it had addons from other courses I’ve taken and maintained and released it relatively regularly.

MARF has several applications. Most revolve around its recognition pipeline – sample loading, preprocessing, feature extraction, training/classification. One of the applications, for example is Text-Independed Speaker Identification. The pipeline and the application as they stand are purely sequential with even little or no concurrency when processing a bulk of voice samples. Thus, the purpose of this work is to make the pipeline distributed and run on a cluster or a just a set of distinct computers to compare with
CHAPTER 2. INTRODUCTION

The classical MARF’s pipeline is in Figure 2.1. The goal of this work is to distribute the shown stages of the pipeline as services as well as stages that are not directly present in the figure – sample loading, front-end application service (e.g. speaker identification service, etc.) and implement some disaster recovery and replication techniques in the distributed system.

In Figure 2.2 the distributed version of the pipeline is presented. It indicates different levels of basic front-ends, from higher to lower, which a client application may invoke as well as services may invoke other services through their front-ends while executing in a pipeline-mode. The back-ends are in charge of providing the actual servant implementations as well as the features like primary-backup replication, monitoring, and disaster recovery modules.

There are several distributed services, some are more general, and some are more specific. The services can and have to intercommunicate. These include:
Figure 2.2: The Distributed MARF Pipeline
• General MARF Service that exposes MARF’s pipeline to clients and other services and communicates with the below.

• Sample Loading Service knows how to load certain file or stream types (e.g. WAVE) and convert them accordingly for further preprocessing.

• Preprocessing Service accepts incoming voice or text samples and does the requested preprocessing (all sorts of filters, normalization, etc.).

• Feature Exraction Service accepts data, presumably preprocessed, and attempts to extract features out of it given requested algorithm (out of currently implemented, like FFT, LPC, MinMax, etc.) and may optionally query the preprocessed data from the Preprocessing Service.

• Classification and Training Service accepts feature vectors and either updates its database of training sets or performs classification against existing training sets. May optionally query the Feature Extraction Service for the features.

• Natural Language Processing Service accepts natural language texts and performs also some statistical NLP operations, such as probabilistic parsing, Zipf’s Law stats, etc.

Some more application-specific front-end services (that are based on the existing currently non-distributed apps) include but not limited to:

• Speaker Identification Service (a front-end) that will communicate with the MARF service to carry out application tasks.

• Language Identification Service would communicate with MARF/NLP for the similar purpose.

• Some others (front-ends for Zipf’s Law, Probabilistic Parsing, and test applications).
The clients are so-called “thin” clients with GUI or a Web Form allowing users to upload the samples for training/classification and set the desired configuration for each run, either for individual samples or batch.

Like it was done in the Distributed Stock Broker [Mok06b], the architecture is general and usable enough to enable one or more services using CORBA, RMI, Web Services (WS), Jini, JMS, sockets, whatever (well, actually, Jini, JMS were not implemented in either applications, but it is not a problem to add with little or no “disturbance” of the rest of the architecture).

2.2 Scope

In the Distributed MARF, if any pipeline stage process crashes access to information about the pending transactions and computation in module is not only lost while the process remains unavailable but can also be lost forever.

Use of a message logging protocol is one way that a module could recover information concerning that module’s data after a faulty processor has been repaired. A WAL message-logging protocol is developed for DMARF. The former is for the disaster recovery of uncommitted transactions and to avoid data loss. It also allows for backup replication and point-in-time recovery if WAL logs are shipped off to a backup storage or a replica manager and can be used to reconstruct the replica state via gossip or any other replication scheme.

The DMARF is also extended by adding a “warm standby”. The “warm standby” is a MARF module that is running in the background (normally on a different machine), receiving operations from the primary server to update its state and hence ready to jump in if the primary server fails. Thus, when the primary server receives a request from a client which will change its state, it sends the request to the backup server, performs the request, receives the response from the backup server and then sends the reply back to the client. The main purpose of the “warm standby” is to
minimise the downtime for subsequent transactions while the primary is in disaster recovery. The primary and backup servers communicate using either the reliable TCP protocol (over WAN) or a FIFO-ordered UDP on a LAN. Since this is a secondary feature and the load in this project will be more than average, we simply might not have time to do and debug this stuff to be reliable over UDP, so we choose TCP do it for us, like we did in StockBroker Assignment 2. IFF we have time, we can try to make a FIFO UDP communication.

- Design and implement the set of required interfaces in RMI, CORBA, and WS for the main MARF’s pipeline stages to run distributedly, including any possible application front-end and client applications.

- Assuming that processor failures are benign (i.e. crash failures) and not Byzantine, analysis of the classical MARF was done to determine the information necessary for the proper recovery of a MARF module (that is, content of the log) and the design of the “warm standby” replication system.

- Modify MARF implementation so that it logs the required information using the WAL message-logging protocol.

- Design and implement a recovery module which restarts a MARF module using the log so that the restarted module can process subsequent requests for the various operations.

- Design and implement the primary server which receives requests from clients, sends the request to the backup server, performs the request, and sends the response back to the client only after the request has been completed correctly both in the primary and the backup servers. When the primary notices that the backup does not respond within a reasonable time, it assumes and informs the MARF monitor that the backup has failed so that a new backup server can be created and initialized.
• Design and implement a monitor module which periodically checks the module process and restarts it if necessary. This monitor initializes the primary and backup servers at the beginning, creates and initializes a backup server when the primary fails (and the original backup server takes over as the primary), and creates and initializes a backup server when the original backup server fails.

• Design and implement the backup server which receives requests from the primary, performs the request and sends the reply back to the primary. If the backup server does not receive any request from the primary for a reasonable time, it sends a request to the primary to check if the latter is working. If the primary server does not reply in a reasonable time, the backup server assumes that the primary has failed and takes over by configuring itself as the primary so that it can receive and handle all client requests from that point onwards; and also informs the broker monitor of the switch over so that the latter can create and initialize another backup server.

• Integrate all the modules properly, deploy the application on a local area network, and test the correct operation of the application using properly designed test runs. One may simulate a process failure by killing that process from the command line while the application is running.

2.3 Definitions and Acronyms

**API**  Application Programmers Interface – a common convenience collection of objects, methods, and other object members, typically in a library, available for an application programmer to use.

**CORBA**  Common Object Request Broker Architecture – a language model independent platform for distributed execution of applications possibly written in different languages, and, is, therefore, heterogeneous type of RPC (unlike Java RMI, which is Java-specific).
CHAPTER 2. INTRODUCTION

**HTML** HyperText Markup Language – a tag-based language for defining the layout of web pages.

**IDL** Interface Definition Language – a CORBA interface language to “glue” most common types and data structures in a specific programming language-independent way. Interfaces written in IDL are compiled to a language specific definitions using defined mapping between constructs in IDL and the target language, e.g. IDL-to-Java compiler (idlj) is used for this purpose in this assignment.

**CVS** Concurrent Versions System – a version and revision control system to manage source code repository.

**DSB** Distributed Stock Broker application.

**DMARF** Distributed MARF.

**J2SE** Java 2 Standard Edition.

**J2EE** Java 2 Enterprise Edition.

**JAX-RPC** Java XML-based RPC way of implementing Web Services.

**JAX-WS** The new and re-engineered way of Java Web Services implementation as opposed to the older and being phased-out Java XML-RPC.

**JDK** The Java Development Kit. Provides the JRE and a set of tools (e.g. the javac, idlj, rmic compilers, javadoc, etc.) to develop and execute Java applications.

**JRE** The Java Runtime Environment. Provides the JVM and required libraries to execute Java applications.

**JVM** The Java Virtual Machine. Program and framework allowing the execution of program developed using the Java programming language.

**MARF** Modular Audio Recognition Framework [Gro06] has a variety of useful general purpose utility and storage modules employed in this work, from the same author.
CHAPTER 2. INTRODUCTION

**RMI** Remote Method Invocation – an object-oriented way of calling methods of objects possibly stored remotely with respect to the calling program.

**RPC** A concept of Remote Procedure Call, introduced early by Sun, to indicate that an implementation certain procedure called by a client may in fact be located remotely from a client on another machine.

**SOAP** Simple Object Access Protocol – a protocol for XML message exchange over HTTP often used for Web Services.

**STDOUT** Standard output – an output data stream typically associated with a screen.

**STDERR** Standard error – an output data stream typically associated with a screen to output error information as opposed to the rest of the output sent to STDOUT.

**WS** Web Services – another way of doing RPC among even more heterogeneous architectures and languages using only XML and HTTP as a basis.

**WSDL** Web Services Definition Language, written in XML notation, is a language to describe types and message types a service provides and data exchanged in SOAP. WSDL’s purpose is similar to IDL and it can be used to generate endpoint interfaces in different programming languages.
Chapter 3

System Overview

Revision : 1.2

In this chapter, we examine the system architecture of the implementation of the DMARF application and software interface design issues.

3.1 Architectural Strategies

The main principles are:

Platform-Independence where one targets systems that are capable of running a JVM.

Database-Independent API will allow to swap database/storage engines on-the-fly. The appropriate adapters will be designed to feed upon required/available data source (binary, CSV file, XML, or SQL) databases.

Communication Technology Independence where the system design evolves such that any communication technologies adapters or plugins (e.g. RMI, CORBA, DCOM+, Jini, JMS, Web Services) can be added with little or no change to the main logic and code base.

Reasonable Efficiency where one architects and implements an efficient system, but will avoid advanced programming tricks that improve the efficiency at the cost of maintainability and readability.
Simplicity and Maintainability where one targets a simplistic and easy to maintain organization of the source.

Architectural Consistency where one consistently implements the chosen architectural approach.

Separation of Concern where one isolates separate concerns between modules and within modules to encourage re-use and code simplicity.

3.2 System Architecture

3.2.1 Module View

Layering

The DMARF application is divided into layers. The top level has a front-end and a back-end. The front-end itself exists on the client side and on the server side. The client side is either text-interactive, non-interactive client classes that connect and query the servers. The front-end on the server side are the MARF pipeline itself, the application-specific frontend, and pipeline stage services. All pipeline stages somehow involved to the database and other storage management subfunctions. At the same time the services are a back-end for the client connecting in.

3.2.2 Execution View

Runtime Entities

In the case of the DMARF application, there is hosting run-time environment of the JVM and on the server side there must be the naming and implementation repository service running, in the form of orbd and rmiregistry. For the WS aspect of the application, there ought to be DNS running and a web servlet container. The DBS uses Tomcat [Fou05] as a servlet container for MARF WS. The client side for RMI and CORBA clients just requires a JRE (1.4 is the minimum). The WS client in addition to JRE may require
a servlet container environment (here Tomcat) and a browser to view and submit a web form. Both RMI and CORBA client and server applications are stand-alone and non-interactive. A GUI is projected for the client (and possibly server to administer it) in one of the follow up versions.

Communication Paths

It was resolved that the modules would all communicate through message passing between methods. CORBA is one of the networking technologies used for remote invocation. RMI is the base-line technology used for remote method calls. Further, a JAX-RPC over SOAP is used for Web Services (while a more modern JAX-WS alternative to JAX-RPC was released, this project still relies on JAX-RPC 1.1 as it’s not using J2EE and the author found it simpler and faster to use given the timeframe and more accurate tutorial and book material available). All: RMI, CORBA, and WS influenced some technology-specific design decisions, but it was possible to abstract them as RMI and CORBA “agents” and delegate the business logic to delegate classes enabling all three types of services to communicate in the future and implement transactions similarly. Communication to the database depends on the storage manager (each terminal business logic module in the classical MARF is a StorageManager). Additionally, Java’s reflection \cite{Gre05} is used to discover instantiation communication paths at run-time for pluggable modules.

Execution Configuration

The execution configuration of the DMARF has to do with where its data/ and policies/ directories are. The data/ directory is always local to where the application was ran from. In the case of WS, it has to be where Tomcat’s current directory is; often is in the logs/ directory of $\text{catalina.base}$. The data directory contains the service-assigned databases in the XXX.gzbin (generated on the first run of the servers). The “XXX” corresponds to the either training set or a module name that saved their state. Next, orb keeps
its data structures and logs in the orb.db/ directory also found in the current directory. Additionally, the RMI configuration for application’s (both client and server) policy files is located in allow.policy (testing with all permissions enabled). As for the WS, for deployment two directories META-INF/ and WEB-INF/ are used. The former contains the Tomcat’s context file for deployment that ought to be placed in ${catalina.base}/conf/Catalina/localhost/ and the latter typically goes to local/marf as the context describes. It contains web.xml and other XML files produced to describe servlet to SOAP mapping when generating .war files with wscompile and wsdeploy.

The build-and-run files include the Ant [Con05] dmarf-build.xml and the GNU make [SMSP00] Makefile files. The Makefile is the one capable of starting the orbd, rmiregistry, the servers, and the clients in various modes. The execution configuration targets primarily Linux FC4 platform (if one intends to use gmake), but is not restricted to it.

A hosts configuration file dmarf-hosts.properties is used to tell the services of how to initialize and where to find other services initially. If the file is not present, the default of host for all is assumed to be localhost.

### 3.3 Coding Standards and Project Management

In order to produce higher-quality code, it was decided to normalize on Hungarian Notation coding style used in MARF [Mok06a]. Additionally, javadoc is used as a source code documentation style for its completeness and the automated tool support. CVS (cvs) [BddzzP+05] was employed in order to manage the source code, makefile, and documentation revisions.

### 3.4 Proof-of-Concept Prototype Assumptions

Since this is a prototype application within a timeframe of a course, some simplifying assumptions took place that were not a part of, explicit or implied, of the specification.
1. There is no garbage collection done on the server side in terms of fully limiting the WAL size.

2. WAL functionality has not been at all implemented for the modules other than Classification.

3. MARF services does not implement nested transaction while pipelining.

4. Services don’t intercommunicate (TCP or UDP) other than through the pipeline mode of operation.

5. No primary-backup or otherwise replication is present.

### 3.5 Software Interface Design

Software interface design comprises both user interfaces and communication interfaces (central topic of this work) between modules.

#### 3.5.1 User Interface

For the RMI and CORBA clients and servers there is a GUI designed for status and control as time did not permit to properly integrate one. Therefore, they use a command-line interface that is typically invoked from a provided Makefile GUI integration is projected in the near future. See the interface prototypes in Figure 3.1 and in Figure 3.2.

#### 3.5.2 Software Interface

Primary communication-related software interfaces are briefly described below. A few other interfaces are omitted for brevity (of storage and classical MARF).
CHAPTER 3. SYSTEM OVERVIEW

RMI
The main RMI interfaces the RMI servants implement are ISpeakerIdentRMI, IMARFServerRMI, ISampleLoaderRMI, IPreprocessingRMI, IFeatureExtractionRMI, and IClassificationRMI. They are located in the marf.server.rmi.* and marf.client.rmi.* packages. There also are the generated files off this interface for stubs with rmic and the servant implementation.

CORBA
The main CORBA IDL interfaces the servants implement are ISpeakerIdentCORBA, IMARFServerCORBA, ISampleLoaderCORBA, IPreprocessingCORBA, IFeatureExtractionCORBA, and IClassificationCORBA. The IDL files are located in the marf.server.corba.* package and are called MARF.idl and Frontends.idl. There also are the generated files off this interface definition for stub, skeleton, data types holders and helpers with idlj and the servant implementation and a data type adapter (described later).

WS
The main WS interface the WS “servants” (servlets) implement is ISpeakerIdentWS, IMARFServerWS, ISampleLoaderWS, IPreprocessingWS, IFeatureExtractionWS, and IClassificationWS. They are located in the marf.server.ws.* There are also the generated files off this interface for stub and skeleton serializers and builders for each method and non-primitive data type of Java with wscompile and wsdeploy and the “servant” implementations. There are about 8 files generated for SOAP XML messages per method or a data type for requests, responses, faults, building, and serialization.

Delegate
The DMARF is flexible here and allows any delegate implementation as long as IDelegate in marf.net.server.delegates is implemented. A common implementation of it is also there provided with the added value
benefit that all three types of servants of the above can use the same delegate implementations and therefore can share all of functionality, transactions, and communication.

3.5.3 Hardware Interface

Hardware interface is fully abstracted by the JVM and the underlying operating system making the DMARF application fully architecture-independent. The references to STDOUT and STDERR (by default the screen or a file) are handled through the System.out and System.err streams. Likewise, STDIN (by default associated with keyboard) is abstracted by Java’s System.in.
Figure 3.1: SpeakerIdenApp Client GUI Prototype
Figure 3.2: MARF Service Status Monitor GUI Prototype
Chapter 4

Detailed System Design

Revision : 1.2

This chapter briefly presents the design considerations and assumptions in the form of directory structure, class diagrams as well as storage organization.

4.1 Directory and Package Organization

In this section, the directory structure is introduced. Please note that Java, by default, converts sub-packages into subdirectories, which is what we see in Figure 4.1. Please also refer to Table 4.1 and Table 4.2 for description of the data contained in the directories and the package organization, respectively.
### Directory Structure Table

| Directory   | Description                                                                                                                                 |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| bin/        | compiled class files are kept here. The sub-directory structure mimics the one of the src/.                                                   |
| data/       | contains the database as well as stocks file.                                                                                               |
| logs/       | contains the client and server log files as “screen-shots”.                                                                                 |
| orb.db/     | contains the naming database as well as logs for the orbd.                                                                                  |
| doc/        | project’s API and manual documentation (well and theory as well).                                                                            |
| lib/        | meant for libraries, but for now there is none                                                                                              |
| src/        | contains the source code files and follows the described package hierarchy.                                                                  |
| dist/       | contains distro services .jar and .war files.                                                                                               |
| policies/   | access policies for the RMI client and server granting various permissions.                                                                     |
| META-INF/   | Tomcat’s context file (and later manifest) for deployment .war.                                                                               |
| WEB-INF/    | WS WSDL servlet-related deployment information and classes.                                                                                  |

Table 4.1: Details on Main Directory Structure
## Table 4.2: DMARF’s Package Organization

| Package                  | Description                                                                 |
|--------------------------|-----------------------------------------------------------------------------|
| marf                     | root directory of the MARF project; below are the packages mostly pertinent to the DMARF |
| marf.net.*.*             | MARF’s directory for the some generic networking stuff                      |
| marf.net.client          | client application code and subpackages                                      |
| marf.net.client.corba.*  | Distributed MARF RMI clients                                                |
| marf.net.client.ws.*     | Distributed MARF WS clients                                                 |
| marf.net.messaging.*     | Reserved for message-passing protocols                                      |
| marf.net.protocol.*      | Reserved for other protocols, like two-phase commit                         |
| marf.net.server.*        | main server code and interfaces is placed here                              |
| marf.net.server.rmi.*    | RMI-specific services implementation                                        |
| marf.net.server.corba.*  | CORBA-specific services implementation                                      |
| marf.net.server.ws.*     | WS-specific services implementation                                         |
| marf.net.server.delegates.* | service delegate implementations are here                                      |
| marf.net.server.frontend.* | root of the service front-ends                                                 |
| marf.net.server.frontend.rmi.* | RMI-specific service front-ends                                                |
| marf.net.server.frontend.corba.* | CORBA-specific service front-ends                                               |
| marf.net.server.frontend.ws.* | WS-specific service front-ends                                                 |
| marf.net.server.frontend.delegates.* | service front-ends delegate implementations                                      |
| marf.net.server.gossip   | reserved for the gossip replication implementation                           |
| marf.net.server.gui      | server status GUI                                                            |
| marf.net.server.monitoring | reserved for various service monitors and their bootstrap                   |
| marf.net.server.persistence | reserved for WAL and Transaction storage management                            |
| marf.net.server.recovery | reserved for WAL recovery and logging                                       |
| marf.Storage             | MARF’s storage-related utility classes                                       |
| marf.util                | MARF’s general utility classes (threads, loggers, array processing, etc.)    |
| marf.gui                 | general-purpose GUI utilities that to be used in the MARF apps, clients, and server status monitors |
CHAPTER 4. DETAILED SYSTEM DESIGN

Figure 4.1: Package Structure of the Project
4.2 Class Diagrams

At this stage, the entire design is summarized in five class diagrams representing the major modules and their relationships. The diagrams of the overall architecture and its storage subsystem are in Figure 4.3 and Figure 4.4 respectively. Then, some details on CORBA, RMI, and WS implementations are in Figure ??, Figure ??, and Figure ?? respectively. Please locate the detailed description of the modules in the generated API HTML off javadocs or the javadoc comments themselves in the `doc/api` directory. Some of the description appears here as well in the form of interaction between classes.

At the beginning of the hierarchy are the `IClient` and `IServer` are independent of a communication technology type of interfaces that “mark” the would-be classes of either type. This is design of a system where one will be able to pick and choose either manually or automatically which communication technologies to use. These interfaces are defined in the `marf.net` and used in reflection instantiation utils.

Next, the hierarchy branches to the CORBA, RMI, and WS marked-up sever and client interfaces, `ICORBAServer`, `ICORBAClient`, `IRMIServer` and `IRMIClient`, `IWSServer` and `IWSClient`. The specificity of the `IRMIServer` that it extends the `Remote` interface required by the RMI specification. The `ICORBAServer` allows to set and get the root POA. And the `IWSServer` allows setting and getting an in-house made `RemoteObjectReference` (which isn’t true object reference as in RMI or CORBA, but incapsulates the necessary service location information).

Then, the diagram shows only the CORBA details (and RMI and WS are similar, but the diagram is already cluttered, so they were omitted). Then the diagram shows all six servants and their relationships with the interfaces as well as blending in WAL logging and transaction recovery. There some monitoring modules designed as well.

The clients for the respective technologies are in the `marf.net.client.corba` `marf.net.client.rmi` and `marf.net.client.ws` packages.
Figure 4.2: Sequence Diagram of the Pipeline Of Invocations
Figure 4.3: General Architecture Class Diagram of marf.net
When implementing the CORBA services, a data type adapter had to be made to adapt certain data structures that came from \[\text{MARF.idl}\] to the common storage data structures (e.g. \text{Sample}, \text{Result}, \text{CommunicationException}, \text{ResultSet}, etc.). Thus, the \text{MARFObjectAdapter} class was provided to adapt these data structures back and forth with the generic delegate when needed.

The servers for the respective technologies are in the \text{marf.net.server.corba}, \text{marf.net.server.rmi} and \text{marf.net.server.ws} packages.

Finally, on the server side, the \text{RecoverableClassificationDelegate} interacts with the \text{WriteAheadLogger} for transaction information. The storage manager here serializes the WAL entries.

More design details are revealed in the class diagram of the storage-related aspects in Figure 4.4. The \text{Database} contains stats of classification and is only written by the SpeakerIdent front-end. All, \text{Database}, \text{Sample}, \text{Result}, and \text{ResultSet} and \text{TrainingSet} implement \text{Serializable} to be able to be stored on disk or transferred over a network.

The serialization of the WAL instance into the file is handled by the \text{WALStorageManager} class. The \text{IStorageManager} interface and its most generic implementation \text{StorageManager} also come from my MARF’s \text{marf.Storage} package. The \text{StorageManager} class provides the implementation of serialization of classes in plain binary as well as compressed binary formats. (It also has facilities to plug-in other storage or output formats, such as CSV, XML, HTML, and SQL, which derivatives must implement if they wish.

### 4.3 Data Storage Format

This section is about data storage issues and the details on the chosen underlying implementation and ways of addressing those issues. For the details on the classical MARF storage subsystem please refer to the Storage chapter in \[\text{Gro06}\].
Figure 4.4: Storage Class Diagram
4.3.1 Log File Format

The log is saved in the `module-technology.log` files for the server and client respectively in the application’s current directory. As of this version, the file is produced with the help of the `Logger` class that is in `marf.util`. (Another logging facility that was considered but not yet only used in WS with Tomcat is the Log4J tool [AGS+06], which has a full-fledged logging engine.) The log file produced by `Logger` has a classical format of “[ time stamp ]: message”. The logger intercepts all attempts to write to STDOUT or STDERR and makes a copy of them to the file. The output to SDTOUT and STDERR is also preserved. If the file remains between different runs, the log data is appended.

4.4 Synchronization

The notion of synchronization is crucial in an application that allows access to a shared resource or a data structure by multiple clients. This includes our DMARF. At the server side the synchronization must be maintained when the `Database` or `TrainingSet` objects are accessed through the server possibly by multiple clients. The way it is implemented in this version, the `Database` class becomes its own object monitor and all its relevant methods are made synchronized, thus locking entire object while it’s accessed by a thread thereby providing data integrity. The whole-instance locking maybe a bit inefficient, but can be careful re-done by only marking some critical paths only and not the entire object.

Furthermore, multiple server keep a copy of their own data structures, including stock data, making it more concurrent. On top of that, the WS, RMI, and CORBA brokers act through a delegate implementation allowing to keep all the synchronization and business logic in one place and decouple communication from the logic. The rest is taken care of by the WAL.
4.5 Write-Ahead Logging and Recovery

The recovery log design is based on the principle of the write-ahead logging. This means the transaction data is written first to the log, and upon successful return from writing the log, the transaction is committed.

Checkpointing is done periodically of flushing all the transactions to the disk with the record of the latest committed transaction ID as a checkpoint. In the even of crash, upon restart, the WAL is read and the object states are recovered from the latest checkpoint.

The design of the WAL algorithm in DMARF is modified such that the logged transaction data contains the “before” and “after” snapshots of the object in question (a training set, message, or the whole module itself). In part this is due to the fact that the transactions are wrapped around classical business logic, that does alter the objects on disk, so in the even of a failure the “before” snapshot is used to revert the object state on disk the way it was back before the transaction in question began.

WAL grows up to a certain number of committed transactions. Periodic garbage collection on WAL and checkpointing are performed. At the garbage collection oldest aborted transactions are removed as well as up to a 1000 committed transactions. WAL can be periodically backed up, shipped to another server for replication, or point-in-time recovery (PITR) and there are timestamps associated with each serialized transaction.

In most part, WAL is pertinent to the Classification service as this is where most of writes are done during the training phase (in the classification phase it is only reading). Sample loading, preprocessing, and feature extraction services can also perform intermediate writes if asked, but most of the time they crunch the data and pass it around. The classification statistics is maintained at the application-specific front-end for now, and there writes are serialized.
4.6 Replication

The replication is done by either the means of WAL (ship over WAL to another host and “replay” it along certain timeline). Another way is lazy update though the gossip architecture among replica. Delegates broadcast “whoHas(config)” requests before computing anything themselves; if shortly after no response received, the delegate issuing the request starts to compute the configuration itself, else a transfer is initiated from another delegate that have computed an identical configuration.
Chapter 5

Testing

The conducted testing of (mostly CORBA) pipeline including single training test and a batch training on maximum four computers in separate buildings. `Makefile` and `batch.sh` serve this purpose. If you intend to use them, make sure you have the server jars in `dist/` and properly configured `dmarf-hosts.properties`.

The tests were quite successful and terminating any of the service replicas and restarting it resumed normal operation of the pipeline in the batch mode. There more thorough testing is to be conducted as the project evolves from a proof-of-concept to a cleaner solution.
Chapter 6

Conclusion

Revision: 1.2

Out of the three main distributed technologies learnt and used through the course (RMI, CORBA, and Web Services) to implement the MARF services, I managed to implement all three.

The Java RMI technology seems to be the lowest-level of remote method invocation tools for programmers to use. Things like Jini, JMS tend to be more programmer-friendly. Additional limitation that RMI has as the requirement of the remote methods to throw the RemoteException and when generating stubs RMI-independent interface hierarchy does work.

A similar problem exists for CORBA, which generates even CORBA-specific data structures from the struct definitions that cannot be easily linked to the data structures used elsewhere throughout the program through inheritance or interfaces.

The WS implementation from the Java-endpoint provided interface and and a couple of XML files was a natural extension of RMI implementation but with somewhat different semantics. The implementation aspect was not hard, but the deployment within a servlet container and WSDL compilation were a large headache.

However, highly modular design allowed swapping module implementations from one technology to another if need be making it very extensible by
the means of delegating the actual business logic to the a delegate classes. As an added bonus of that implementation, RMI, CORBA, WS services can communicate through TCP or UDP and do transaction. Likewise, all the synchronization efforts are undertaken by the delegate and the delegate is the single place to fix is there is something broken. Aside from the delegate class, a data adapter class for CORBA also contributes here to translate the data structures.

6.1 Summary of Technologies Used

The following were the most prominent technologies used throughout the implementation of the project:

- J2SE (primarily 1.4)
- Java IDL [Mic04]
- Java RMI [WW05]
- Java WS with JAX-RPC [Mic06]
- Java Servlets [Mic05a]
- Java Networking [Mic05b]
- Eclipse IDE [ec+04]
- Apache Ant [Con05]
- Apache Jakarta Tomcat 5.5.12 [Fou05]
- GNU Make [SMSP00]

6.2 Future Work and Work-In-Progress

Extend the remote framework to include other communication technologies (Jini, JMS, DCOM+, .NET Remoting) in communication-independent fashion and transplant that all for use in MARF [Gro06]. Additionally, complete
application GUI for the client and possibly server implementations. Finally, complete the advanced features of distributed systems such as disaster recovery, fault tolerance, high availability and replication, and others with great deal of thorough testing.

6.3 Acknowledgments

- The authors of the Java RMI [WW05], Java IDL [Mic04], Java Web Services [Mic06] reference material from Sun.
- The authors of the textbook [CDK05].
- Dr. Rajagopalan Jayakumar for the Distributed Systems Design Course
- Dr. Peter Grogono for \LaTeXe\ introductory tutorial [Gro01]
- Nick Huang, the TA
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