Corona Developers Guide

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Contents

Chapter 1

Getting started with Corona development in Eclipse

1.1 Prerequisites

Before we can start developing for Corona, two things must happen. Firstly, the SunSPOT SDK must be installed, as well as all the required environmental variables established as per the instructions provided from Sun in the SunSPOT kits. Corona is developed for the **Blue** SDK, so this version should be installed and used for development. Once this has happened, you need to obtain the source code for Corona, which can be located at the downloads page on the Corona website.

From this point onwards we assume you have the Blue SDK installed at `SDK_DIRECTORY`, and the source code checked downloaded and extracted to `CORONA_DIRECTORY`.

See the User Guide section on "Installing Corona" for more details on running Corona.

1.2 Setting up Eclipse Libraries

Before we load the Corona source code into Eclipse, we first need to setup Eclipse to be able to use the SunSPOT SDK. To do this, we create what is called in Eclipse, a *User Defined Library* for both the SPOT environment and the basestation (host) environment.

To access the User Library settings within Eclipse, open up `Eclipse Preferences -> Java -> Build Path -> User Libraries`. Here we need to create two custom libraries: "SunSPOT Blue SPOT" and "SunSPOT Blue Host".

Firstly, to setup the SPOT user library:

- Click on "New" and create the "SunSPOT Blue SPOT" user library
- Select the new library and click on the "Add JAR's..." button
- Browse to `${SDK_DIRECTORY}/lib`

- Add the following JAR files to the library:
  - `multihop_common.jar`
  - `spotlib_common.jar`
  - `spotlib_device.jar`
  - `squawk_common.jar`
  - `squawk_device.jar`
  - `transducer_device.jar`

Once you have done this, you can then create the "SunSPOT Blue Host" user library. To do this, follow the same steps as above, except instead choose the following JAR files to be added to the library:

- `multihop_common.jar`
- `spotclient_host.jar`
- `spotlib_common.jar`
- `spotlib_host.jar`

Following this, click the "Ok" button in the preferences window to save these user libraries.

Note: if you so desire, you can also setup these JARs associated source code and Javadoc within Eclipse by clicking the arrow to the left of each of these JARs in the User Library menu, and clicking on either the "Source attachment" or the "Javadoc location" items. The source code JAR files are located in `${SDK_DIRECTORY}/src` and the Javadoc in `${SDK_DIRECTORY}/doc/javadoc`.

1.3 Setting up Eclipse Projects

Now that Eclipse knows about the SunSPOT SDK, we can import the Corona source code and start development. Each corona module uses the standard Java folder structure; a folder called `src` containing the source code for the project, a folder `lib` containing JAR files of 3rd party libraries, and a folder `build` which is where the project is compiled into. Eclipse will recognise this folder structure and assist you in setting up the projects.

1.3.1 Corona SPOT

This projects contains the code that is actually executed on the SunSPOTS themselves. This code needs use only the SunSPOT SDK as its standard library as opposed to the default Java SDK you have installed on your local machine.

Create a Java project in Eclipse ("Corona SPOT") that points to the folder `${CORONA_DIRECTORY}/src/spot`. Make sure that the `src` folder is listed as a source folder upon clicking "Next".

Once this has been created, a large number of compile errors will appear; this is because we need to tell Eclipse to use the SunSPOT SDK rather than the system default Java SDK. Right click the project and click on `properties`. Under the "Libraries" tab, remove the Java SDK library, and then click on `Add Library -> User Library -> SunSPOT Blue SPOT`. Once this library has been added to the project, select the "Java Compiler" option on the side of the properties window. Enable "Project Specific Settings", and change the "Compiler Compliance Level" from the default to "1.3". Finally click on "OK" and let the project recompile; there should now be no compile errors.

1.3.2 Corona Server

This projects contains the code that is executed on a computer connected to the basestation node. This code needs use the Java 5 SDK, as well as the "SunSPOT Blue Host" library we created before.

Create a Java project in Eclipse ("Corona Server") that points to the folder `${CORONA_DIRECTORY }/src/server`. Make sure the the `src` folder is listed as a source folder upon clicking "Next". Once this has been created, right click the project and click on `properties`. Under the "Libraries" tab, click on `Add Library -> User Library -> SunSPOT Blue Host`. Once this library has been added to the project, select the "Java Compiler" option on the side of the properties window. Enable "Project Specific Settings", and change the "Compiler Compliance Level" from the default to "1.5". Under the "Projects" tab, tick the "Corona SPOT" project. Finally click on "OK" and let the project recompile; there should now be no compile errors.

1.3.3 Corona GUI

This projects contains the code for the default RMI client interface we provide; a GUI written in Swing/AWT.

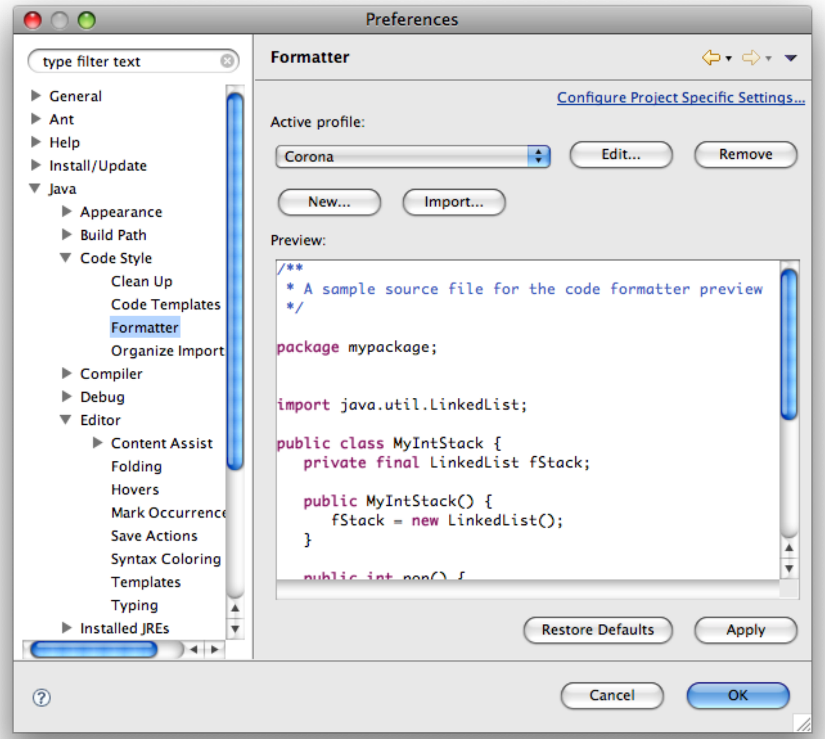
Create a Java project in Eclipse ("Corona GUI") that points to the folder `${CORONA_DIRECTORY }/src/gui`. Make sure the the `src` folder is listed as a source folder upon clicking "Next". Once this has been created, right click the project and click on `properties`. If there are any compile errors upon loading up this project, it probably means that you are using Java 6 rather than Java 5. Set the projects target compiler version to be "1.5" as described in the previous projects, and try again.

Chapter 2

Code Style Guidelines

2.1 Eclipse Code Formatting

During the development of Corona, we have used a common set of style guidelines to help the code look consistent. Eclipse has a useful feature of being able to export and import a set of style guidelines that it auto-corrects for you. We suggest that you import our Eclipse style guidelines file also to help the codes look and feel to be consistent. The file is called `eclipse-code-style-format.xml` and is located in the root directory of the Corona project you downloaded (`${CORONA_SOURCE}/eclipse-code-style-format.xml`).



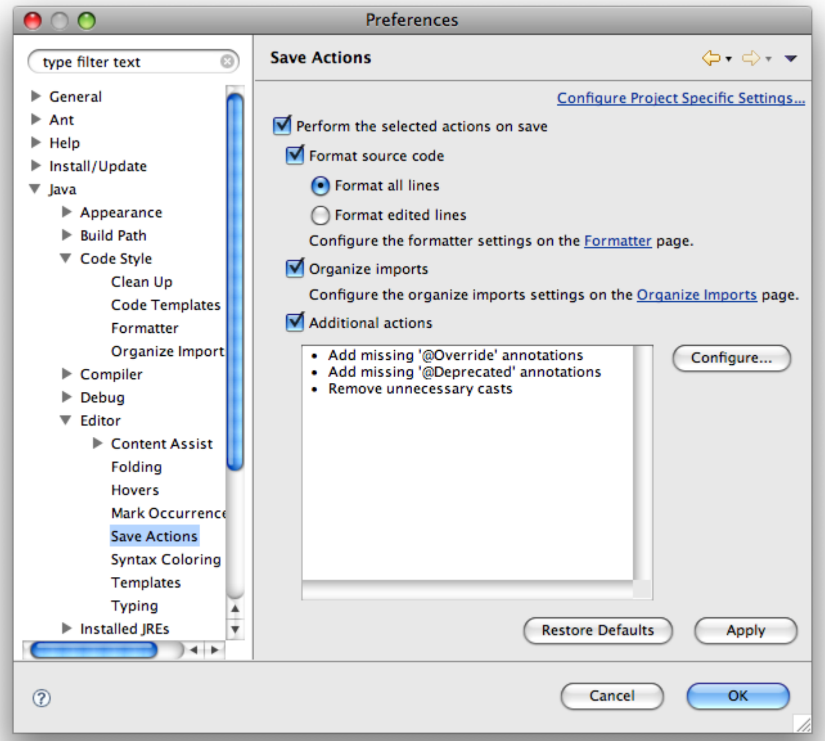
Active profile: Corona

```
/**
 * A sample source file for the code formatter preview
 */

package mypackage;


import java.util.LinkedList;

public class MyIntStack {
   private final LinkedList fStack;

   public MyIntStack() {
      fStack = new LinkedList();
   }

   public int pop() {
```

To import this file into Eclipse, open `Eclipse Preferences -> Java -> Code Style -> Formatter`, and click on the Import button. Navigate to the `eclipse-code-style-format.`

`xml` file, and load it in. Once you have done this, the active profile should state “Corona”.

Also, you should set Eclipse to apply this style formatting upon save. To do this, still in the preferences, go to `Java -> Editor -> Save Actions` and make sure you have the “Format source code” option selected.



Save Actions

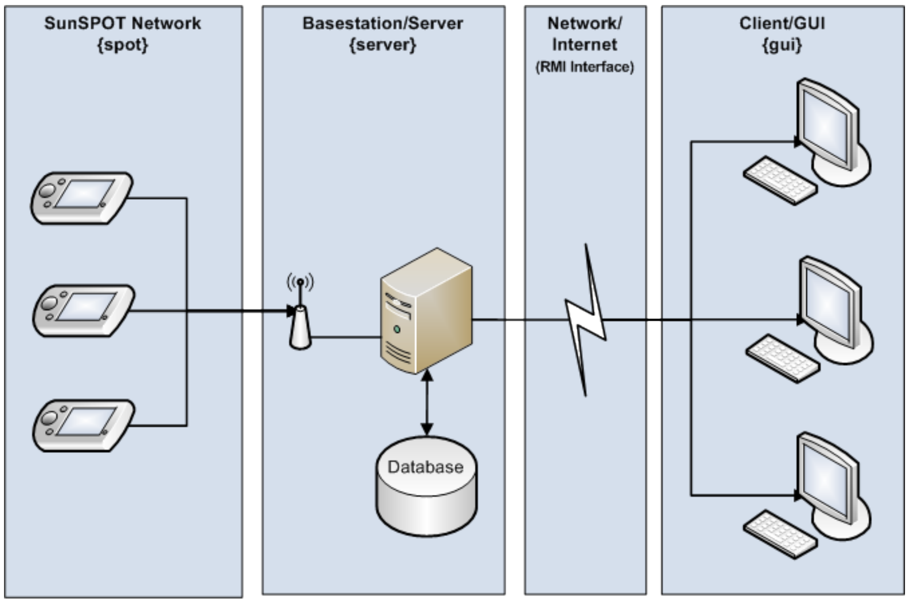
- [✓] Perform the selected actions on save
  - [✓] Format source code
    - [✓ Format all lines]
    - Format edited lines
  - Configure the formatter settings on the Formatter page.
  - [✓] Organize imports
  - Configure the organize imports settings on the Organize Imports page.
  - [✓] Additional actions
    - Add missing '@Override' annotations
    - Add missing '@Deprecated' annotations
    - Remove unnecessary casts

Click on “Ok” to save the preferences.

Chapter 3

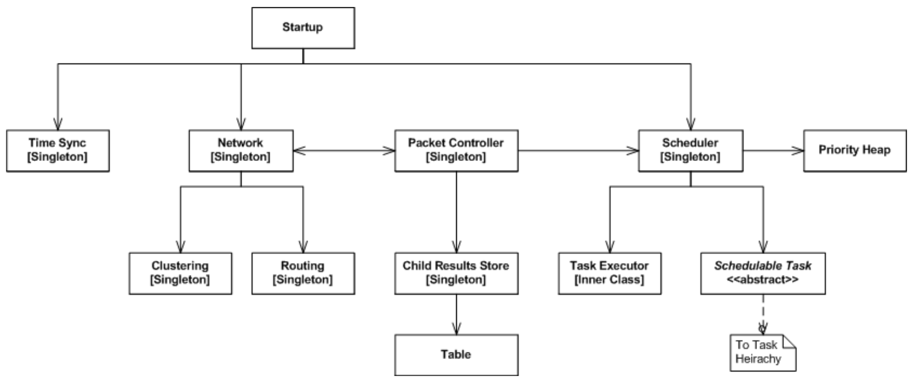
System Overview

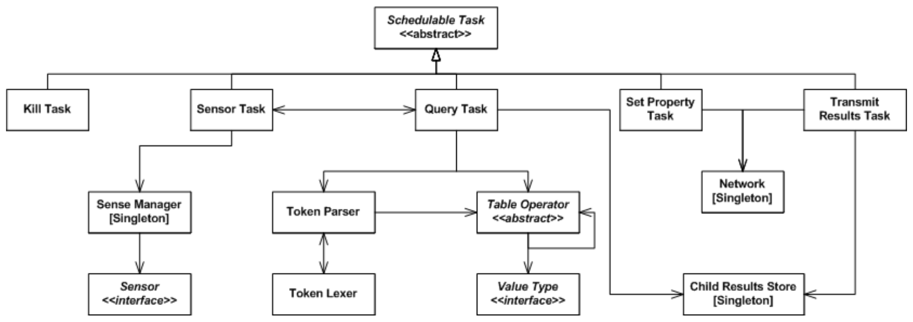
Corona has three main modules; `spot`, `server`, and `gui`.



3.1 The `spot` module

The `spot` module is deployed to each individual SunSPOT. It runs a scheduler that manages the execution of all tasks on the SunSPOTs. When a query is executed on the `server` a set of tasks are generated to do the work of the query, which are disseminated into the network. When a task is received by a SunSPOT, it is scheduled to execute at the specified time. Then when the task executes, the appropriate sensors are activated which produce a single result row on that node (with one column for each sensed value). A relational expression tree (which is contained within the task) then executes to produce the result table that the user specified in their query. On each node, this expression tree takes as inputs the table containing the newly sensed row, as well as all tables from child nodes. It outputs a single table which is forwarded onto the parent node. This result will continue to be aggregated with results further up the tree and eventually forwarded to the `server` module running on the basestation which persists the final result table for later access.




Schedulable Task <<abstract>>
Kill Task
Sensor Task
Query Task
Set Property Task
Transmit Results Task
Network [Singleton]
Sense Manager [Singleton]
Token Parser
Table Operator <<abstract>>
Sensor <<interface>>
Token Lexer
Value Type <<interface>>
Child Results Store [Singleton]

3.2 The `server` module

The `server` module runs on a single computer and connects wirelessly to the SunSPOT network. The `server` module establishes a network topology among the SunSPOTs and coordinates time synchronization. It also disseminates queries to the wireless sensor network (which have been issued from the `gui`) and then collects and stores results such that the `gui` may access on demand. Code in this module has dependencies on code in the `spot` module; the `server` is a superset of the `spot` module so to speak.

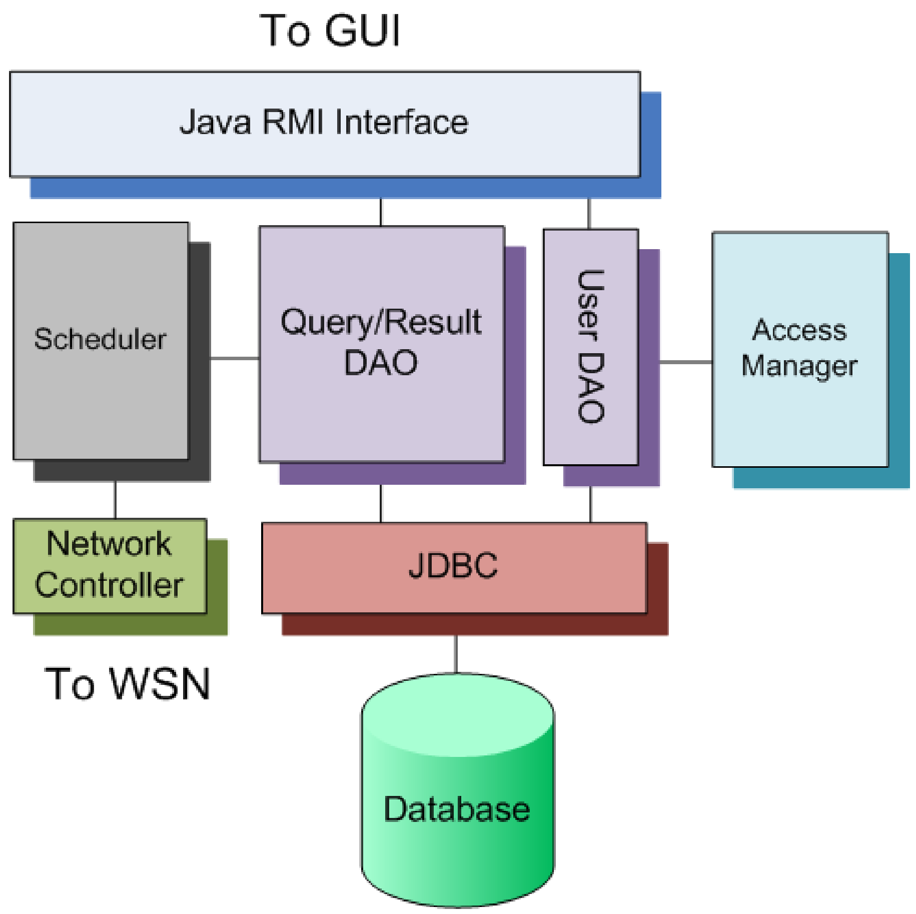
This module has a persistence layer (in the form of a database) to store queries, result tables and user details. It also provides access control which only allows authorized users to access the system. We introduce two levels of access, namely the privileged "administrator" and the standard "user".

The communications layer between the `server` and its clients (e.g. the `gui`) is implemented using an RMI interface, which securely exposes the functionality of the system to clients.

The diagram below gives an indication of the major components of the `server` module.

3.3 The `gui` module

The `gui` module is the users interface to the system. It connects remotely to a Corona server using the RMI interface. Multiple `gui`'s can concurrently access the system. The GUI provides a visual Query Builder which allows queries to be constructed by a user without the need to know SQL. It also contains features for graphing and visualising results in a more meaningful way.



The code in this package can have no direct dependencies upon code in either the `spot` or `server` modules, but can have dependencies on code in the `server` module which is in the `corona-rmi.jar` file (see Modifying the RMI Interface and Developing an RMI FrontEnd for more details). This GUI is designed to run on Java 5.

Chapter 4

Package Outline

For the best package outline, see the package description page of the generated Javadoc for Corona. The Javadoc for Corona can be downloaded form the Corona website, or alternatively, viewed online here.

4.1 SPOT Module: `au.edu.usyd.corona.*`

The SPOT module can be broken down into three main sections; the networking layer, the scheduler layer, and the relational database layer.

The networking layer consists of all the code needed for the sustaining of the networking tree, the global time synchronization, and the transmitting of application layer packets between the nodes. The packages that are involved in this are:

Package	**Description**
`compression`	Provides compression classes used to help minimize the amount of data sent via wireless
`io`	Stream wrappers and other misc IO related classes used in the transporting of data
`middleLayer`	Contains all of the code for the networking tree and the global time synchronization

The scheduler layer consists of the code necessary for the periodic time-triggered execution of "tasks" on the nodes in a Corona network. These tasks include things such as sensing data from the sensors, requesting the transmitting data to other nodes, requesting that a time synchronization occurs, etc (see the Adding New Tasks guide for mode details). The packages involved in this layer are:

Package	**Description**
`grammar`	Used for processing the token grammar language that SQL queries are compiled down to
`scheduler`	The main system scheduler, as well as the implementation of time-triggered tasks
`sensing`	The implementation classes which obtain data from sensors on the SunSPOT

The relational database layer contains the code required for the relational database processing that is performed on the results of queries inside a Corona network. In network data processing occurs on each node in the network tree as the results are transmitted back to the root (the basestation). For more information, see the Adding a new Table Attribute and Adding a new Type guides. The packages involved in this layer are:

Package	**Description**
`srdb`	Stands for SunSPOT Relational DataBase, and contains our implementation of a relational database used throughout Corona
`types`	The implementation of the different data types used in `srdb` and throughout Corona—

4.2 Server Module: `au.edu.usyd.corona.server.*`

The `server` module can also be broken down into three logical sections; the SQL grammar layer, the persistence layer, and the RMI layer.

The SQL grammar layer contains all of the code which deals with compiling and processing SQL queries executed by users of the server. This process involves converting the SQL string into the appropriate token grammar tokens and/or executable tasks to be run on the scheduler. This process is partially handled by the ANTLR grammar file. For more information on the SQL compiling process, see the Modifying the SQL Grammar and adding new Query Types section. The packages involved in this layer are:

Package	**Description**
`grammar`	Contains the compilers for the different types of queries, using the ANTLR generated lexer and parser

The persistence layer is responsible for persisting the results of queries into a database, whereby the underlying database is abstracted away from the application layer code. The `persistence.DAOInterfaces` package provides the interfaces that the application layer interacts with. We provide one default implementation of these interfaces in Corona which uses a JDBC compatible database, and this implementations can be found in `persistence.JDBCDAO`. For more information on this persistence layer, see the Modifying the Persistence Layer guide. The packages involved in this layer are:

Package	**Description**
`persistence.*`	Contains the interfaces and implementation of the objects being persisted in a database

The RMI layer contains all the code for handling clients connecting to a Corona server. This consists of creating classes to interact with the RMI server, and providing efficient means for connected users to obtain data from the server. For more information on the RMI interface code, see the Modifying the RMI interface guide. The packages involved in this layer are:

Package	**Description**
`session.*`	Code that manages a users logged in session via the RMI interface
`user`	Manages the users in the Corona server

4.3 GUI Module: `au.edu.usyd.corona.gui.*`

The GUI is included in Corona as an example of how to write an RMI front end to a Corona server, and to provide basic interaction with the server. We have left the GUI relatively undocumented as we do not expect people to necessarily modify it.

Chapter 5

Adding a new Table Attribute

If you have added your own sensors to the SunSPOT, or for what ever other reason you would like to support another attribute in the result tables, this is the guide for you. Here we will go through step by step how to add a new table attribute to the system.

To guide us through this example, I will be adding a new sensor to the system called "random", which when sensed, will return a pseudorandom integer number.

5.1 Creating a Sensor Class

The first step in adding a new table attribute to the system is to create a Sensor class for this attribute, whereby Sensor class I mean it has to implement the `au.edu.usyd.corona.sensing.Sensor` interface. So, I am going to create the class `au.edu.usyd.corona.sensing.RandomSensor` and make it implement `Sensor`.

```java
package au.edu.usyd.corona.sensing;

import au.edu.usyd.corona.types.ValueType;

class RandomSensor implements Sensor {
   public String getSensorName() {

   }

   public ValueType sense() throws IOException {

   }
}
```

As per the Javadoc description of `Sensor`, the `getSensorName()` method should return the name of the sensor (case insensitive). This name is used in the "`SELECT <sensor>`" syntax in the query language, as well as in the list of results returned for a query. The `sense()` method is called every time a query which requests that sensor as part of its data is executed. This method should return the value that was "sensed" by the sensor. The return type should be a `ValueType`. If you need to create your own new database type to suite your needs (the provided ones are not enough), then see the Adding a new Database Type guide as to how to do this.

For our example though, we are going to make the `sense()` method return a random integer number. The completed `RandomSensor` class thus looks like this:

```java
package au.edu.usyd.corona.sensing;


import java.io.IOException;
import java.util.Random;

import au.edu.usyd.corona.types.IntType;
import au.edu.usyd.corona.types.ValueType;

class RandomSensor implements Sensor {
   private final Random random = new Random();

   public String getSensorName() {
      return "random";
   }

   public ValueType sense() throws IOException {
      return new IntType(random.nextInt());
   }

}
```

5.2 Registering the Sensor

Once you have created your sensor class, it is time to register the class in the system. Doing this is very simple. Open up the class `au.edu.usyd.corona.sensing.SenseManager` and look in its constructor. Here you will see a list of sensor objects being created and being added to a vector. At the end of this list, add a new instance of your sensor to this vector.

```java
sensors.addElement(new RandomSensor());
```

5.3 Compile and Run

Thats it! Now compile the SPOT code, and then the server code, deploy it out into the network and watch your new sensor in action.

```
SELECT node, time, light, random
START IN 25 seconds
EPOCH 40 seconds
RUNCOUNT 12
```

Chapter 6

Adding a new Database Type

If the standard set of data types we provide are not enough for your needs, then you can implement your own data type and add it into Corona simply enough. This data type can theoretically then interact with any of the other data types in the system.

The standard set of data types that come with corona are:

- Integer (`au.edu.usyd.corona.types.IntType`)
- Long (`au.edu.usyd.corona.types.LongType`)
- Byte (`au.edu.usyd.corona.types.ByteType`)
- Boolean (`au.edu.usyd.corona.types.BooleanType`)
- Float (`au.edu.usyd.corona.types.FloatType`)
- IEEE Address (`au.edu.usyd.corona.types.IEEEAddressType`)

As as example, we will be adding a 2x2 Matrix (of integers) type into the system.

6.1 Adding a "Token Grammar" Token

Firstly, we need to modify the tokens that are used in the Token Grammar, and allocate one of the remaining data type tokens to our new class. Open up the interface `au.edu.usyd.corona.grammar.TokenGrammarTokens`. This interface provides all of the unique identifiers for anything in the token language. Find the first unused `T_DATA_TYPE_` variable, which in our case, is `T_DATA_TYPE_7`. You will want to rename this constant to be something meaningful for your type.

```
public static final char T_DATA_TYPE_MATRIX_2x2 = 'g';
```

6.2 Creating the Type Class

The next step is to create a class for this new data type. This class has to implement the au.edu .usyd.corona.types.ValueType interface. If you are going to place your class in that package, there is an abstract base class there to extends from for convenience, called AbstractValueType . The class you create **must** be public, and **must** have a default constructor. It may have other constructors also, but it at least has to have a default constructor (no arguments).

So I will create my au.edu.usyd.corona.types.Matrix2By2 class and make it extend AbstractValueType .

```java
package au.edu.usyd.corona.types;


import java.io.DataInput;
import java.io.DataOutput;
import java.io.IOException;

public class Matrix2By2Type extends AbstractValueType {

   public Matrix2By2Type() {
   }

   protected void _decode(DataInput b) throws IOException {

   }

   protected void _encode(DataOutput b) throws IOException {

   }

   public ValueType add(ValueType v) throws InvalidOperationException {

   }

   public boolean equals(ValueType v) throws InvalidOperationException {

   }

   public boolean less(ValueType v) throws InvalidOperationException {

   }

   public ValueType multiply(ValueType v) throws InvalidOperationException {

   }

   public ValueType divide(ValueType v) throws InvalidOperationException {

   }

   public ValueType negate() throws InvalidOperationException {

   }

   public Object toJDBCObject() {

   }

   public String toString() {

   }

   public String toTokens() {

   }
}
```

The next step is to flesh out the class. See the Javadoc for au.edu.usyd.corona.types.

`ValueType` for a description of what each of these methods should be doing (however the method names are pretty self-documenting ...)

My completed `Matrix2By2` class is the following:

```java
package au.edu.usyd.corona.types;


import java.io.DataInput;
import java.io.DataOutput;
import java.io.IOException;

import com.sun.spot.util.Utils;

public class Matrix2By2Type extends AbstractValueType {
   private int a, b, c, d;

   public Matrix2By2Type() {
   }

   public Matrix2By2Type(int a, int b, int c, int d) {
      this.a = a;
      this.b = b;
      this.c = c;
      this.d = d;
   }

   protected void _decode(DataInput b) throws IOException {
      this.a = b.readInt();
      this.b = b.readInt();
      this.c = b.readInt();
      this.d = b.readInt();
   }

   protected void _encode(DataOutput b) throws IOException {
      b.writeInt(this.a);
      b.writeInt(this.b);
      b.writeInt(this.c);
      b.writeInt(this.d);
   }

   public ValueType add(ValueType v) throws InvalidOperationException {
      if (v instanceof Matrix2By2Type) {
         Matrix2By2Type m = (Matrix2By2Type) v;
         return new Matrix2By2Type(a + m.a, b + m.b, c + m.c, d + m.d);
      }
      else
         throw new InvalidOperationException("Cannot add types", this, v);
   }

   public boolean equals(ValueType v) throws InvalidOperationException {
      if (v instanceof Matrix2By2Type) {
         Matrix2By2Type m = (Matrix2By2Type) v;
         return a == m.a && b == m.b && c == m.c && d == m.d;
      }
      else
         throw new InvalidOperationException("Cannot compare types", this, v);
   }

   public boolean less(ValueType v) throws InvalidOperationException {
      throw new InvalidOperationException("Type has no concept of 'less than'", this, v);
   }

   public ValueType multiply(ValueType v) throws InvalidOperationException {
      int value;
      if (v instanceof Matrix2By2Type) {
         Matrix2By2Type m = (Matrix2By2Type) v;
         return new Matrix2By2Type(a * m.a + b * m.c, a * m.b + b * m.d, c * m.a + d * m.c, c
             * m.b + d * m.d);
      }
      else if (v instanceof IntType)
         value = ((IntType) v).getVal();
      else if (v instanceof LongType)
         value = (int) ((LongType) v).getVal();
      else if (v instanceof ByteType)
```

```
            value = ((ByteType) v).getVal();
        else if (v instanceof BooleanType)
            value = ((BooleanType) v).getVal() ? 1 : 0;
        else
            throw new InvalidOperationException("Cannot multiply types", this, v);
        return new Matrix2By2Type(value * a, value * b, value * c, value * d);
    }

    public ValueType divide(ValueType v) throws InvalidOperationException {
        throw new InvalidOperationException("Types can not be divided", this, v);
    }

    public ValueType negate() throws InvalidOperationException {
        return new Matrix2By2Type(-a, -b, -c, -d);
    }

    public Object toJDBCObject() {
        final byte[] out = new byte[4 * Utils.SIZE_OF_INT];
        Utils.writeBigEndInt(out, 0 * Utils.SIZE_OF_INT, a);
        Utils.writeBigEndInt(out, 1 * Utils.SIZE_OF_INT, b);
        Utils.writeBigEndInt(out, 2 * Utils.SIZE_OF_INT, c);
        Utils.writeBigEndInt(out, 3 * Utils.SIZE_OF_INT, d);
        return out;
    }

    public String toString() {
        return "[[" + a + "," + b + "] , [" + c + "," + d + "]]";
    }

    public String toTokens() {
        return T_DATA_TYPE_MATRIX_2x2 + "" + T_GROUP_OPEN + a + " " + b + " " + c + " " + d + ""
            + T_GROUP_CLOSE;
    }
}
```

6.3 Updating the Token Grammar Parser

Open up the `au.edu.usyd.corona.grammar.TokenParser` file and go to the `_parseValueType()` method. Here there will be a switch statement with a case for each potential data type token. Update the token that you renamed earlier to be the new name.

Before:

```
case T_DATA_TYPE_7:
    throw new TokenParseException("Custom data type 7 not accounted for");
```

After:

```
case T_DATA_TYPE_MATRIX_2x2:
    throw new TokenParseException("Matrix type parsing not written");
```

For the minute this is fine. This method is only called if you want users to be able to hard code items of your new type in the query language. For example with the matrix type, we could want to allow users to have syntax like `SELECT * WHERE matrix_sensor == [[1, 2], [9, 12]]`. Adding this support is non-trivial and is explained in the chapter Modifying the SQL Grammar and adding new Query Types.

6.4 Registering the Class

Open up the class `au.edu.usyd.util.ClassIdentifiers`. There is an instance variable in this class called `classes` which is an array of `java.lang.Class` objects. Add the class object for your new type into this array, and then save and close the file.

6.5 Compile and Run

That should be it in terms of writing code to get your new data type to work in Corona.

6.6 Adding a Renderer in the Corona GUI for Your Type (Optional)

Seeing as the GUI was provided as an implementation of the server API, rather than as a module to extend from, we normally do not offer any coding support for the inner workings of the GUI. However if you do wish to use the Corona GUI and want to have your new data type rendered correctly, this is a very brief set of instructions on how to do so.

Open the class `au.edu.usyd.corona.gui.util.FormattingUtils`. Add a new named inner class that extends from `CoronaCellRenderer`.

```java
public static class Matrix2By2Renderer extends CoronaCellRenderer {
   @Override
   public void setValue(Object value) {
      setHorizontalAlignment(JLabel.LEFT);
      setText(convert(value));
   }

   @Override
   public String convert(Object value) {
      byte[] bytes = (byte[]) value;
      int a = readInt(bytes, 0);
      int b = readInt(bytes, 4);
      int c = readInt(bytes, 8);
      int d = readInt(bytes, 12);
      return "[[" + a + "," + b + "] , [" + c + "," + d + "]]";
   }

   private static int readInt(byte[] bytes, int offset) {
      int result = 0;
      for (int i = 0; i < 4; i++)
         result = (result << 8) | (bytes[offset + i] & 0xFF);
      return result;
   }
}
```

The convert method has to take in a `java.lang.Object` which is what is returned from the database for this result, and it has to convert it to a `java.lang.String`. This code here is decoding the encoding of the `Matrix2By2` class, and converting it to a String representation.

Add a public static final instance of this `CoronaCellRenderer` subclass to the top of the `FormattingUtils` class.

```java
public static final Matrix2By2Renderer MATRIX_2x2_RENDERER = new Matrix2By2Renderer();
```

Lastly, add a mapping from the sensor name to your newly created renderer in the static initializer of `FormattingUtils`. In this case, a sensor which returns a `Matrix2By2` type is called `zebra`.

```
ATTRIBUTES.put("ZEBRA", MATRIX_2x2_RENDERER);
```

Sensed attributes which do not have a renderer defined in this map will be rendered throughout the GUI using their `toString()` method instead.

Chapter 7

Adding new Tasks

A "task" in Corona is something that can be executed on the `Scheduler` that runs on each node. A query that is executed in the system generates one or more tasks which do the work of that query. These tasks are generally transmitted down the network tree so that nodes can do the work of the query. For example, executing a query such as `SELECT *` will cause a single `QueryTask` to be generated on the server which contains the relation expression tree for that query. This task will be transmitted from the basestation, down the network tree. When it arrives at each node, it will be scheduled there. Scheduling the task on the node also triggers the generation of another task on that node, a `SensorTask` which will activate the sensors to produce a table with a single row which will act as input to the `QueryTask`.

Tasks are the only thing that the application layer of the system transmits (i.e. everything must be encoded as a task). This means that results coming back up the network tree to the basestation are encoded as a `TransmitResultsTask` which contains the result table from that node. Execution of this task on the receiving node simply causes that table to be made available to the corresponding `QueryTask` executing the relational expression tree on that node.

Because we need a way of accessing individual tasks in the Scheduler, each task must have a unique ID. This requires the unique ID to be unique across the entire network. In order to achieve this, we use the following ID structure for tasks:

```
Task ID = (Query ID, Node ID, Local ID)
```

The `Query ID` is the ID of the query that the task is associated with. The `Node ID` is the IEEE address of the node that the task originated on. The `Local ID` is a unique number for the task, local to the node that the task originated on.

In this walk through we will be creating a task which either changes the colour of a given LED to be red, green, or blue, or instead, turns off the LED. In the section Modifying the SQL Grammar and adding new Query Types we will show you how this task can be used to turn LEDs on or off by simply executing a SQL-like query.

7.1 Create the Task

All tasks have to be a subclass of `au.edu.usyd.corona.scheduler.SchedulableTask`. They also **must** have a default constructor; they may (and probably will) have additional constructors, but they must have a default one also. So lets create our basic subclass of `SchedulableTask` that we will call `LEDTask`.

```java
public class LEDTask extends SchedulableTask {
   public static final byte LED_RED = 0;
   public static final byte LED_GREEN = 1;
   public static final byte LED_BLUE = 2;
   public static final byte LED_OFF = 3;

   private byte number;
   private byte value;

   public LEDTask() {
      super();
   }

   public LEDTask(TaskID taskID, byte number, byte value) {
      super(taskID);
      this.number = number;
      this.value = value;
   }

   protected void _execute() {
   }

   protected void _deconstruct() {
   }

   protected void _reschedule() {
   }

   protected void _encode(DataOutput data) throws IOException {
   }

   protected void _decode(DataInput data) throws IOException {
   }

   public void baseInit() throws IOException {
   }

   public void nodeInit() {
   }
}
```

The description of all of these methods is somewhat self-documenting, but a proper description can be found in the Javadoc for `SchedulableTask`. Now, we want our `LEDTask` to execute once on every node apart from the base station (the base has no LEDs). This means we need to implement the following methods:

- `_execute()`: called to execute the task
- `_encode()` and `_decode()`: used when the task needs to be sent via wireless to package and unpackage the task into a byte array (a form of serialization so to speak)
- `baseInit()`: called when the task is first run on the base station. This is used to distribute the task down to the spots in the network.

```java
public class LEDTask extends SchedulableTask {
   public static final byte LED_RED = 0;
   public static final byte LED_GREEN = 1;
   public static final byte LED_BLUE = 2;
   public static final byte LED_OFF = 3;

   private byte number;
   private byte value;

   public LEDTask() {
      super();
   }

   public LEDTask(TaskID taskID, byte number, byte value) {
      super(taskID);
      this.number = number;
      this.value = value;
   }

   protected void _execute() {
      if (Network.getInstance().getMode() == Network.MODE_SPOT) {
         final ITriColorLED led = EDemoBoard.getInstance().getLEDs()[number];
         led.setOn();

         if (value == LED_RED)
            led.setColor(LEDColor.RED);
         else if (value == LED_GREEN)
            led.setColor(LEDColor.GREEN);
         else if (value == LED_BLUE)
            led.setColor(LEDColor.BLUE);
         else if (value == LED_OFF)
            led.setOff();
      }
   }

   protected void _deconstruct() {
   }

   protected void _reschedule() {
   }

   protected void _encode(DataOutput data) throws IOException {
      data.writeByte(number);
      data.writeByte(value);
   }

   protected void _decode(DataInput data) throws IOException {
      number = data.readByte();
      value = data.readByte();
   }

   public void baseInit() throws IOException {
      Network.getInstance().send(this, Network.SEND_MODE_CHILDREN, true, true);
   }

   public void nodeInit() {
   }
}
```

7.2 Register the Class

You need to add the class you just created to the “classes” array in the top of the `au.edu.usyd.corona.util.ClassIdentifiers` class. Doing this allows the class to be transmitted in the network more efficiently.

```
private static final Class[] classes = new Class[]{/* everything else */, LEDTask.class};
```

Chapter 8

Modifying the SQL Grammar and adding new Query Types

This walk through on how to add query types presumes you already know how to use ANTLR, and that you know how to modify an ANTLR grammar file.

For this walk through, we will be adding query syntax to support the turning on and off of the LEDs on the SunSPOT, and setting their colour. The syntax we would like to support in the SQL grammar is of the form

```
LED <number> = <value>
```

where `<number>` is an integer in the range 0 - 7 (there are only 8 LEDs on the SunSPOT), and `<value>` is one of `RED`, `GREEN`, `BLUE`, or `OFF`.

8.1 Modifying the ANTLR Grammar

The ANTLR grammar file is located in `${CORONA_HOME}/src/server/grammar/` and is called `CoronaQL.g`. This is a plain text file, and is in the ANTLR grammar format.

The first step is to edit the list of special tokens at the top of the file, and add a new token type for your new query type. Here I will add `TYPE_LED` to the list of tokens:

```
tokens {
   ALL_ATTRIBS;
   AGGREGATION;
   TYPE_KILL; TYPE_SYNC; TYPE_ROUTE; TYPE_QUERY; TYPE_SET; TYPE_LED;
}
```

Next, we scroll down to the definition of the `statement2` rule, and add support for our new query type's rule. I am going to call my LED query types rule "led".

```
statement2
    : kill
    | sync
    | route
    | set
    | led
    | data_query ;
```

Now, add the definition of the syntax of your rule. Make sure that you rewrite the tree to have the `TYPE_LED` token as the root of the tree, and any needed data as the children of the tree.

```
LED: 'LED' ;

led
   : LED WHITE_SPACE NUMBER_INT WHITE_SPACE? '=' WHITE_SPACE? WORD -> ^(TYPE_LED NUMBER_INT
      WORD)
   ;
```

8.2 Recompiling the ANTLR Grammar

Once you are happy with your grammar definition, it is time to compile it into executable Java source code. Open a terminal in the directory `${CORONA_HOME}/src/server`. Here you want to execute the `generate_grammar.sh` shell script. A successful compile will output only one line of output as follows:

```
$ ./generate_grammar.sh
ANTLR Parser Generator  Version 3.1 (August 12, 2008)  1989-2008
$
```

If you get compile or parse errors upon compiling, to back to step 1 and edit the file until ANTLR is happy.

8.3 Writing the Corresponding Task

Instructions on how to add Tasks to Corona is discussed in the Adding Tasks guide. This guide has a walk through on how to add the LED task that we are going to use here.

8.4 Writing the Compiler

The next step is to write the compiler for your new query type. This compiler class should be in the package `au.edu.usyd.corona.server.grammar` and should extend the abstract base class `au.edu.usyd.corona.server.grammar.QLPacketTypeCompiler<T extends SchedulableTask >`. The generic parameter should be the name of the class you created in Step 3. Your compiler class should have a 2 argument constructor as shown below, which you directly pass up to the superconstructor.

```java
class LEDCompiler extends QLPacketTypeCompiler<LEDTask> {
   public LEDCompiler(Tree root, int queryId) {
      super(root, queryId);
   }

   @Override
   public LEDTask compile() throws QLCompileException {
   }
}
```

The `compile` method should process the `Tree` and validate its semantics. If there is an error, a `QLCompileException` should be thrown. If the semantics are valid, a new `LEDTask` instance should be created and returned.

```java
class LEDCompiler extends QLPacketTypeCompiler<LEDTask> {
   private final TaskID taskId;

   public LEDCompiler(Tree root, int queryId) {
      super(root, queryId);
      this.taskId = new TaskID(queryId);
   }

   @Override
   public LEDTask compile() throws QLCompileException {
      int number = Integer.parseInt(root.getChild(0).getText());
      String value = root.getChild(1).getText().toUpperCase();
      byte val;

      // check the validity of number
      if (number < 0 || number > 7)
         throw new QLCompileException("The LED number has to be in the range 0 to 7 inclusive"
             );

      // check the validity of value
      if (value.equals("RED"))
         val = LEDTask.LED_RED;
      else if (value.equals("GREEN"))
         val = LEDTask.LED_GREEN;
      else if (value.equals("BLUE"))
         val = LEDTask.LED_BLUE;
      else if (value.equals("OFF"))
         val = LEDTask.LED_OFF;
      else
         throw new QLCompileException("Unknown value '" + value + "'; expected ('RED', 'GREEN
             ', 'BLUE', 'OFF')");

      return new LEDTask(taskId, (byte) number, val);
   }
}
```

8.5 Register the Compiler

Open up the the class `au.edu.usyd.corona.server.grammar.QLCompiler` and go to the `createCompiler` method. Edit the `switch` statment to account for your new token type, and return your new compiler:

```java
case CoronaQLLexer.TYPE_LED:
   return new LEDCompiler(root, queryId);
```

8.6 Compile and Run

Clean and deploy the code to the SunSPOTs, and then also to the base station. Fire up the GUI and have a go at using your new syntax. For our example, firing off the query

```
LED 0 = red
```

causes the first LED to turn red. Firing off the query

```
LED 0 = fish
```

causes a compiler error message to pop up, saying that 'FISH' is not a valid value.

Chapter 9

Modifying the Persistence Layer

The Data Access Object (DAO) pattern is a standard pattern from separating data sources and their access implementations from business logic. More information about this pattern can be found at:

- Java blueprints
- J2EE Patterns
- `http://www.javapractices.com/topic/TopicAction.do?Id=66`

The system implements this pattern to achieve this separation and to allow new data sources to be easily swapped in without any code modifications. First we provide a description of our implementation of the pattern, then we provide a description of the default implementation of the DAOFactory and finally a description of how completely custom DAO can be implemented.

9.1 DAO Pattern Implementation

Our DAO Implementation has a `DAOFactory` (`au.edu.usyd.corona.server.persistence.DAOinterface.DAOFactory`) which gives access to DAO objects which can ultimately be used to access the underlying data source. The `DAOFactory` implements the Abstract Factory and Singleton patterns. At runtime it dynamically loads a DAO implementation that is specified in the `config/dao.properties` file in the server module, e.g.:

```
# DAO Factory implementation to use
dao.factory.class = au.edu.usyd.corona.server.persistence.JDBCDAO.JDBCDAOFactory
```

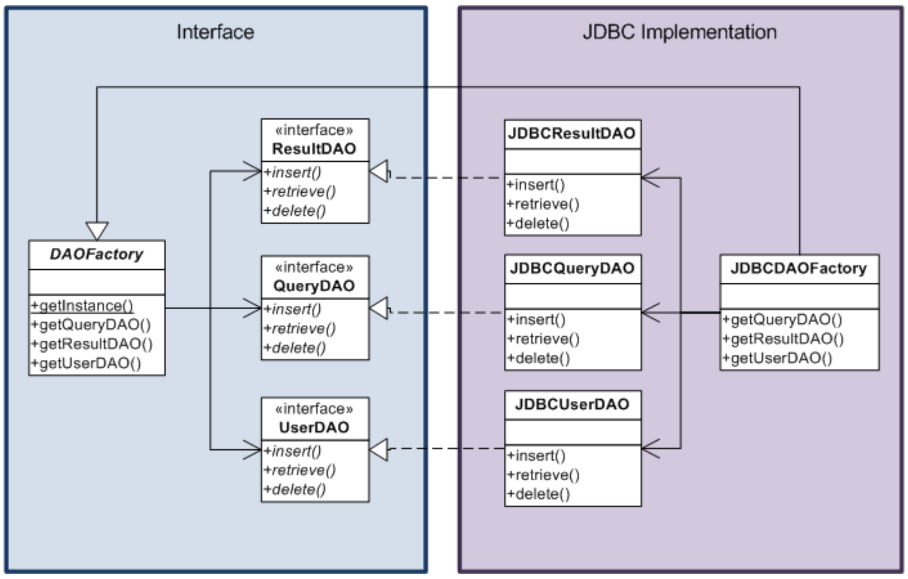
When clients of the `DAOFactory` call the static `getInstance()` method on `DAOFactory`, it returns a specific implementation of that factory which provides access to the corresponding implementations of DAO objects.

Our DAO Implementation has 3 DAO interfaces:

- `au.edu.usyd.corona.server.persistence.DAOinterface.ResultDAO`

- `au.edu.usyd.corona.server.persistence.DAOinterface.QueryDAO`
- `au.edu.usyd.corona.server.persistence.DAOinterface.UserDAO`

`ResultDAO` provides storage and retrieval of Result tables. `QueryDAO` provides storage and retrieval of Query details. `UserDAO` provides storage and retrieval of User information.



9.2 JDBC DAO

We provide a single implementation of the DAO interface for use with JDBC databases. Since we are storing tables of results from the sensor network, it is natural to store them in a DBMS. It also means we can allow SQL queries to be re-executed over historic tables and filter out necessary information rather than having to deal with large tables that may have been retrieved from the network.

As mentioned, the JDBC DAO implementation is the default one and is loaded by the DAO-Factory at runtime as long as the `JDBCDAOFactory` class is specified in the dao configuration file (`config/dao.properties`).

9.2.1 Configuring the DBMS Used

The details of the particular DBMS that is used by JDBC are also specified in a configuration file, located at config/jdbc-dao.properties.

The properties file looks like:

```
# Database settings
database.driver = org.hsqldb.jdbcDriver
database.url = jdbc:hsqldb:file:data/db;shutdown=true
database.username = sa
database.password =
database.name = hsqldb
database.sql.filename = config/jdbc-sql.xml
```

In order to alter the DBMS used by Corona, only these properties must be changed.

Here is a description of the properties:

Property	**Description**
database.driver	The fully qualified class name of the JDBC driver that your database vendor provides. The library containing this class must be linked at compile time.
database.url	The JDBC url of the database to connect to. This will depend on the DBMS you are using, check the instruction manual for further details.
database.username	The username to gain access to the specified database.
database.password	The password to gain access to the specified database.
database.name	A descriptive name for the database system. This name can be invented by the user of the system. It must correspond to the name of the database used in the corresponding SQL XML file.
database.sql.filename	The filename of the XML file containing the SQL for the specific DBMS you have chosen (details below).

9.2.2 Configuring DBMS SQL

Unfortunately, every DBMS has slightly different SQL syntax for performing certain operations. We account for this in the system by externalising SQL into an XML file. When a new DBMS is specified in the `jdbc-dao.properties file`, an XML file must be created which contains the SQL required to perform the DAO operations. The location of this XML file is specified by the `database.sql.filename` property in the `jdbc-dao.properties` file. By default, we provide SQL for HSQLDB, a lightweight in-process DBMS. Here is a sample of the structure of the XML file:

```
<DAOConfiguration>
    <DAOStatements database="hsqldb">
   <SQLStatement method="COUNT_TABLE">
            <SQLFragment>
                SELECT count(*) FROM ({query})
            </SQLFragment>
        </SQLStatement>

        <SQLStatement method="CHECK_TABLE">
            <SQLFragment>
                SELECT count(*) FROM {table} WHERE 1=2
            </SQLFragment>
        </SQLStatement>
    </DAOStatements>
</DAOConfiguration>
```

DAOConfiguration is the root tag.

DAOStatements tags specify a block of XML containing SQL for an individual database system, in this case HSQLDB. The database property in this tag must correspond to the database.name property specified in the `jdbc-dao.properties` file – "hsqldb" in this example. Following this are SQLStatement blocks. These have a single property called "method" which specifies a name for that particular SQL statement. Inside these blocks are SQLFragment blocks which specify sections of the SQL which are appended to give the final executed SQL inside Corona.

Textual substitutions are made into the SQL by Corona. Markers like "{query}" denote that the text "{query}" will be substituted by the system with an actual SQL query. This is necessary as Corona allows certain raw SQL queries to be executed over existing databases. Note that the utmost care is taken to prevent injection attacks (in particular we pre-parse user SQL and check its structure before performing substitutions).

SQL fragments have an optional "excludeIfNamedParamEmpty" property which has a value "TRUE" or "FALSE" (default). If this value is "TRUE", that SQLFragment will not be included in the final SQLStatement if any of the named parameters (e.g. {query}) have an empty string value. This allows, for example, a WHERE clause to be excluded if there are no conditions in it.

All of the SQLStatements given in the HSQLDB implementation must have equivalent implementations for an alternative DBMS.

9.3 Alternative DAO Implementations

Alternative DAO implementations can be provided as long as they implement the required interfaces. There may be several reasons for doing this - either one wants to use a data source other than a JDBC database (not recommended) or one wants to use a JDBC database but the provided JDBCDAO implementation in not sufficient.

A DAOFactory implementation must be written which inherits from the abstract DAOFactory class and implements its given methods. This means that implementations of the ResultDAO, QueryDAO and UserDAO interfaces must also be written (as a DAOFactory gives access to these). Once these classes have been written and compiled, they must be added to the classpath of Corona when compiling. Furthermore, the fully qualified class name of the new DAOFactory implementation must be specified in the `config/dao.properties` file.

Chapter 10

Modifying the RMI interface

10.1 Updating the `RemoteSessionInterface`

To edit the RMI interface, you need to edit the `au.edu.usyd.corona.server.session.RemoteSessionInt` interface to include your new method signature, and then also update the `au.edu.usyd.corona.server.session.RemoteSession` class with the implementation of this new method signature. As you should know from RMI basics, all objects returned from an RMI method need to either be Serializable (implement `java.io.Serializable`), or be an RMI Remote Object (extends `java.rmi.server.UnicastRemoteObject`).

10.2 Updating the Ant `build.xml` File

The naming convention we have used is that any RMI remote object classes should start with “Remote”, and any RMI remote interfaces should start with “Remote” and end in “Interface”. If your remote object does not fit these guidelines, or you need a new Serializable object to be returned from a new RMI method, then you might need to modify the `build.xml` file, so that these things are accounted for when creating the `corona-rmi.jar` file.

The `-post-host-compile` and `-rmic` targets are the ones to pay attention to. They are defined to be as follows:

```xml
<!-- Override to create a Corona repos JAR file for the desktop project -->
<target name="-post-host-compile" depends="-rmic">
   <!-- create the secondary RMI interface project jar -->
   <jar destfile="${corona.repos}/${rmi.jar.file}" >
      <fileset dir="${build.dir}" includes="**/Remote*.class" />
      <fileset dir="${build.dir}" includes="**/_Stub.class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/grammar/Query.class"
          />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/persistence/JDBCDAO/
          JavaToJDBCTypes.class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/session/*Exception.
          class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/session/notifier/
          NotifierID.class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/session/notifier/
          NotifierID$NotifierType.class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/session/notifier/
          NotifierInterface.class" />
      <fileset dir="${build.dir}" includes="au/edu/usyd/corona/server/user/*.class" />
```

```
        </jar>
    </target>

    <!-- compiles rmi stubs -->
    <target name="-rmic">
        <rmic base="${build.dir}" includes="**/Remote*.class" excludes="**/antlr/** **/Remote*
            Interface.class" />
    </target>
```

The files listed in the `-post-host-compile` target are the remote objects as well as the Serializable objects used by any publicly exposed RMI method. You may need to add your new classes here.

10.3 Updating the Clients

All clients connecting to a Corona server have a copy of the `corona-rmi.jar` file, which contains the RMI stub files needed to make RMI work correctly. After you have modified the RMI definition on the server, all clients need a copy of the new `corona-rmi.jar` JAR file. This file is located in the `${HOME}/.corona_repos/` directory after an `ant host-compile`.

Chapter 11

Developing a front-end using the RMI Interface

Corona provides an RMI API for anyone to connect to. This RMI API is the only means of clients connecting to the Corona server, and the GUI which we provide uses this API. These instructions assume you know roughly how RMI works and what it is.

After you have `ant host-compile`'d the `server` module of Corona, a JAR file will be created in your `${HOME}/.corona_repos/` directory called `corona-rmi.jar`. This is the only thing you need to develop a front end to Corona.

In your new front end project, ensure that you include this `corona-rmi.jar` file in the classpath.

Connecting to a Corona server via RMI is very simple. The code needed to connect to a Corona server running at `example.com` would be as follows:

```java
import au.edu.usyd.corona.server.session.RemoteSessionManagerInterface;
import java.rmi.Naming;

RemoteSessionManagerInterface rmiManager = (RemoteSessionManagerInterface) Naming.lookup("//
    example.com/SessionManager");
```

The name "SessionManager" is important, and is the unique identifier for the RMI listener created by the Corona server. The `RemoteSessionManagerInterface` interface is an interface defined in the `corona-rmi.jar` file. Having an instance of this allows you to login to the Corona server you specified in the host name part of the URL (in our case, `example.com`).

To log into this server with the username `john` and the password `smith`, the code would be as follows:

```java
import au.edu.usyd.corona.server.session.RemoteSessionInterface;
import au.edu.usyd.corona.server.session.RemoteSessionManagerInterface;
import java.rmi.Naming;

RemoteSessionManagerInterface rmiManager = (RemoteSessionManagerInterface) Naming.lookup("//
    example.com/SessionManager");
RemoteSessionInterface rmi = rmiManager.login("john", "smith");
```

An instance of a `RemoteSessionInterface` is all you need to interact with a Corona server. This interface defines all of the API methods the Corona server exposes. For a description of what this interface defines, look at the Javadoc for this interface.

For example, if we have already logged into a server as above, and we wish to execute the query "`SELECT * RUNCOUNT 60`", this is a simple API call.

```
import au.edu.usyd.corona.server.grammar.Query;

Query query = rmi.executeQuery("SELECT * RUNCOUNT 60");
```

Chapter 12

Some improvements that can be made to Corona

Some modifications that we believe might be nice additions to Corona are listed below.

12.1 Routing and Network Improvements

- The routing protocol is quite tedious to debug and could undergo some furthering testing and debugging.
- Currently when a node in the routing tree is disconnected, all child nodes will also become disconnected. An optimisation that could be implemented is to allow subtrees to be stay connected so that only the root of the disconnected subtree is unrouted. This, however, requires one to be careful that loops do not form in the routing tree as we do not want the root of the disconnected subtree to become routed to a descendant.
- Currently we base the choice of a routing parent node only on the shortest path to the basestation. This can lead to routing trees where single nodes can have very large numbers of children and other nodes have no children. This puts a large strain on that node. It may be interesting to investigate this.
- Currently we do application level aggregation of results. That is, all results from children for a single query are first collected and then combined before sending to the parent node, which can reduce the number of transmissions. It would be interesting to investigate aggregating unrelated results for transmission, if 2 results must be transmitted at similar times. This may also provide an improvement to transmission.

12.2 Asynchronous Result Forwarding and Forwarding after Disconnection

- Currently, a node will wait a set period of time for all of its children to send it results, based on the height of the subtree rooted at that node. After this period, it will execute the relational expression tree with the results it does have and forward them on. Any results from children received after this timeout will be ignored. To improve the number of results received, it would be interesting to allow forwarding of results after this time. Care would have to be taken with how this is done. For example, if calculating the average of an attribute in the network, one could not use results that come in after the relational expression tree has been executed on the basestation, as we discard the count information that is required to calculate the average (when aggregating).

- Related to this idea is the notion of storing results on disconnected nodes or sub-trees. A node that is disconnected from the network (and hence cant forward its results at the set time) could store its results temporarily in flash memory and then forward the results when it regains connection to the network.

12.3 Query Optimisation

- Currently no attempt is made to optimise a query. The relational expression tree is generated in a very straightforward way. It would be interesting to look at ways to optimise this expression tree. One particular example is that to evaluate conditional expressions (such as `WHERE` clauses), we only have a `NAND` operator, multiple of which can be combined to form `AND`, `OR` and `NOT` operations. Doing this, however, increases the size of the representation of the relational expression tree (for transmission) and also increases the amount of computation done on a node. Hence, implementing these as separate operators would improve performance. This is also the case for comparison operators (we only implement the `<` operator).

- Currently, when performing a `SENSE` operation in the relational expression tree, we run all of the sensors on a node. A nice optimisation would be to only run sensors that are required for that query.

12.4 User Access

- Currently, user access is implemented in a very simplistic way. We only have 2 levels of user, privileged and normal. After a query has been compiled, the resultant tasks are checked manually to ensure the user has the the required privileges to execute them (if the query requires that). It would be nicer to separate this logic into an Access Manager and to expand on the number of user levels and the abilities each user has.

12.5 Task Persistence

- Currently superficial information about every Task generated or received on the basestation is stored in a TaskDAO. This allows the status of tasks (and hence queries to be tracked). Because we do not serialise the entire task, however, it means that the basestation cannot recover tasks that were in the middle of executing when the basestation crashed. An improvement might be to serialise the entire task with all of its state and then if the basestation crashes, we can recover the contents of the scheduler.

12.6 Node Efficiency

- Even though Corona has been written with some important research concepts in mind to improve efficiency, we have also written it with stability and simplicity in mind. This means that some design choices are not wise in terms of node resource efficiency. For example, we create many ValueType and Task objects which are thrown away very quickly meaning the node has to do more work garbage collecting. One improvement here would be to investigate using Object pools to reduce the number of objects that we garbage collect and then re-create.
- The nodes make use of the shallow sleep mode automatically to conserve power when all threads are blocked. This allows the radio to continue receiving packets, which is required by the system. It would be interesting to investigate utilising the deep sleep mode available to conserve more power in the SunSPOTs. When deep sleeping, the nodes cannot receive radio packets. Hence, this should only be for a short, determinable interval, when a user of the system knows that their query will not be executed.
- It would be interesting to consider the notion of "Data Freshness". If we have recently issued a query to activate the sensors, we may not need to activate them again, instead using slightly out of date data.

12.7 Language Independent Interface

- Currently we use RMI to provide an interface for application programmers. This, however, requires that the applications be written in Java. It would be nice to add a layer on top of the current RMI interface which allows communication through a language independent remote procedure call (RPC) technology such as SOAP.