



UNIVERSITY OF HUDDERSFIELD

MENG GROUP PROJECT

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## Cryptic Crossword Solver

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DESIGN DOCUMENT

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# **Chapter 1**

## **Design**

This chapter will describe the various design decisions that were taken in order to allow for the system to be developed. The chapter will present a number of artefacts that are expressed using the the Unified Modelling Language (UML).

Additional non-UML diagrams will also be presented to describe the database and user requirement design decisions.

## 1.1 Primary Path

Before being able to correctly design a large, complex system a good understanding of the main scenario through the system will be required. The main scenario is “a sequence of event or actions” (Lunn, 2003) in which many smaller scenarios may occur.

The main scenario of the proposed cryptic crossword solver system is outlined below:

1. Input the cryptic clue to be solved
2. Input the pattern of the solution
3. Process the data based upon a number of algorithms
4. Output the most confident results

Based upon the previously given main scenario, the primary path of the entire system can be proposed. The primary path is defined as the most commonly used ‘route’ though a system with as few variances as possible (Lunn, 2003).

The proposed primary path for the cryptic crossword solver system is outlined below:

1. Input the cryptic clue to be solved
2. Input the solution length
3. Input the pattern of the solution
4. Determine the type of clue that has been given (e.g. anagram)
5. Run the given clue type algorithm
6. Rank each of the results based upon a pre-defined criteria
7. Output the top ranking results

The primary path outlined above takes a relatively generic approach with regards to how a clue should be solved. Ideally the clue would be categorised into a certain type of clue, thus requiring that particular solver to be run.

However the primary path does not illustrate the steps that are required to be taken if the clue can not be categorised — does the system simply stop or would it try an alternative approach?

These additional steps may often be ‘optional’, and hence are described as alternative paths. The alternative path will contain small and subtle changes to the primary path (Lunn, 2003).

If the system is unable to determine the type of clue that has been given then an alternative approach is to be used. In this instance, the primary path would house the following additions and changes:

3 Determine the type of clue that has been given (e.g. anagram)

3.1 Start a new instance of each solver

4 Run the each of the solvers separately

The above alternative path shows that if the clue can not be categorised, then the system will attempt to solve the clue utilising a brute force approach. The above alternative path, could also be regarded as a ‘worst case scenario’.

The outlined primary and alternative paths are a simple way of illustrating the the general ideas behind the system. These paths will be actively referred to throughout the design process.

## 1.2 Activity Diagrams

Within the Primary Path section a primary path analysis was conducted, ensuring that common paths throughout the proposed system are identified. Within this section a number of activity diagrams will be presented that will break the primary path into a number of simple processes.

An activity is a task in a process that allows for small meaningful work to happen. A process may have a number of activities linked together to form a work flow (Lunn, 2003).

Figure 1.1 on page 8, illustrates the main activity diagram for the complete system. The activity diagram follows what was discussed within the Primary Path section, and expands upon some of the generalised points. Over the following subsections key parts of the main activity diagram will be discussed in more detail.

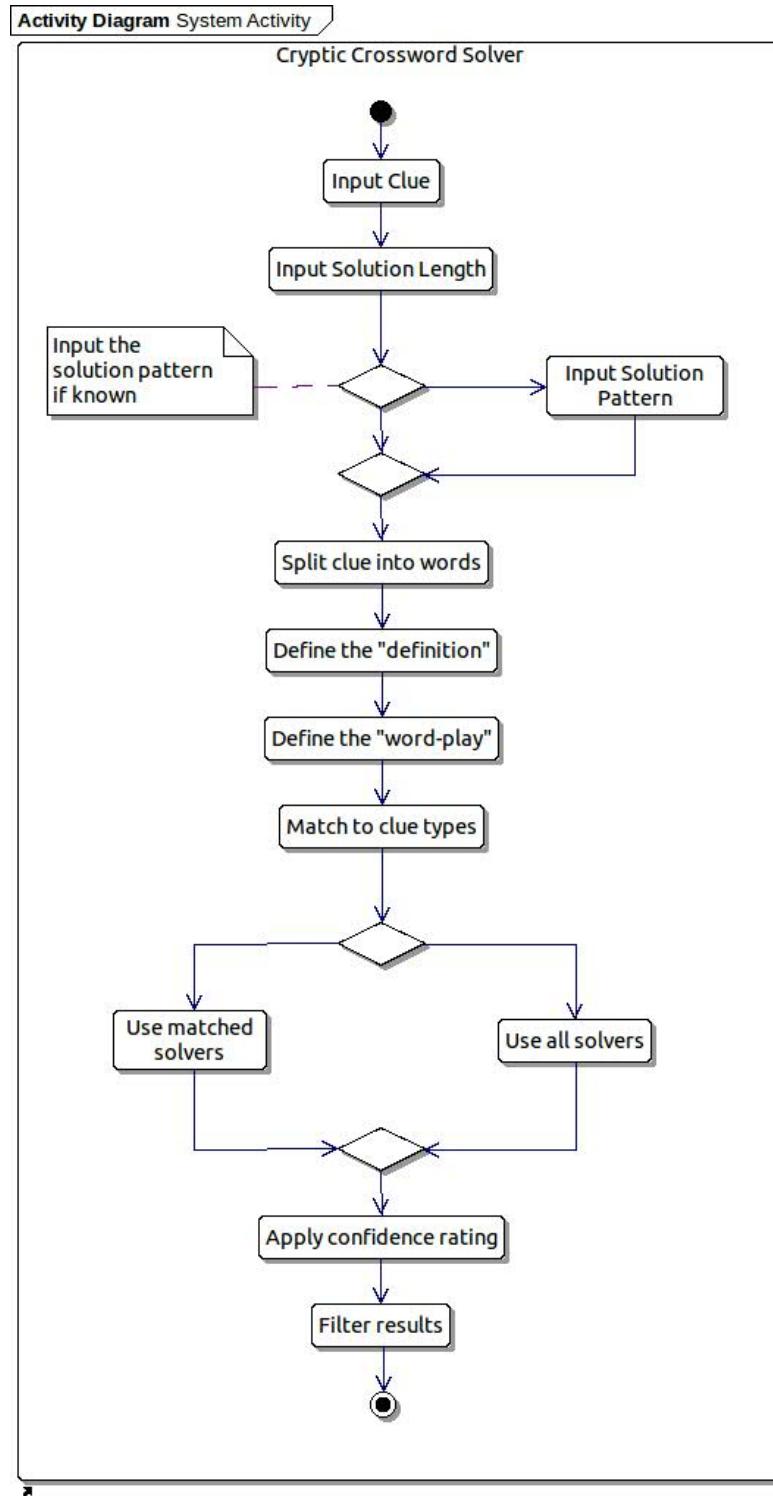


Figure 1.1: The complete Activity diagram

### 1.2.1 Clue Input

Figure 1.2 illustrates how the data should be input into the system. In order for the system to solve a given clue it requires the following three inputs:

- the clue
- the solution length
- the solution pattern

At first it may seem that the solution length is unnecessary, as it could be computed from the solution pattern. The reason for including the solution length is that it provides an additional validation element — much like having to type in a password twice when creating a new online account.

The solution pattern allows a user to predefine the required answer, based upon a number of characters. The solution pattern will accept all letters as well as three predefined ‘special characters’, as outlined below:

- ? ⇒ wild card character
- ⇒ hyphenated word
- , ⇒ word separator

For example, the pattern “????e?-???” could match to “mother-in-law” or “father-in-law”, just as “?????? d?????” could match to “sitting ducks”. As previously mentioned, a user may simply present the correct number of wild card characters to denote an unknown pattern.

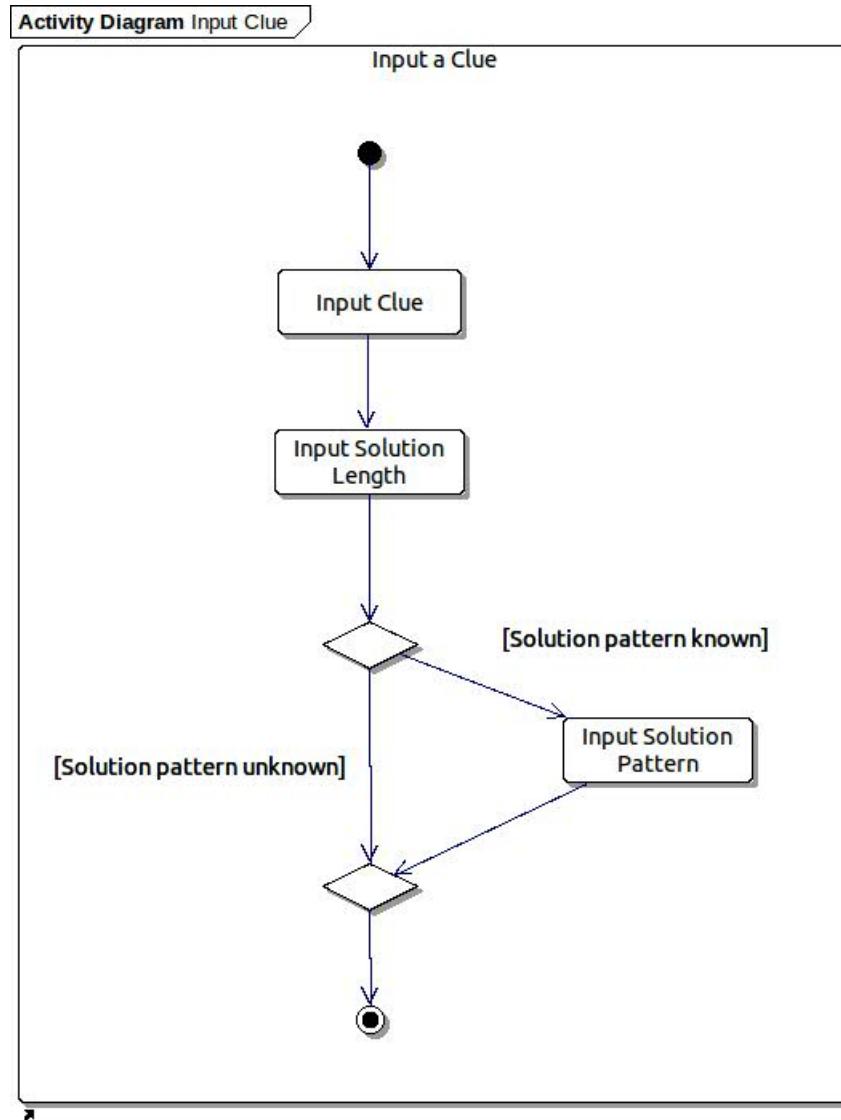


Figure 1.2: Activity diagram showing how a user would input a clue

### 1.2.2 Choosing a Solver

Once the user has successfully input the three variables, the system will then try to determine the type of clue. There are a number of actions that must be performed in order to deduce the type of clue, as shown in figure 1.3.

The system will try to match the given clue to a list of properties that each clue has. For example spoonerism clue types, will have the word “spooner” within the clue.

If the match is successful then the system will bump the ranking of that particular clue type. Once the system has finished applying the categorisation ‘tests’ to the clues, it will select

the top solver to try to solve the clue.

If the chosen solver is unable to solve the clue, then the next ranking solver will try to solve the clue. This process will continue until a set of results have been returned, or if all solvers have been used.

If the categorisation fails for some reason, then the system will try to brute force it's way to answer, by using all solvers.

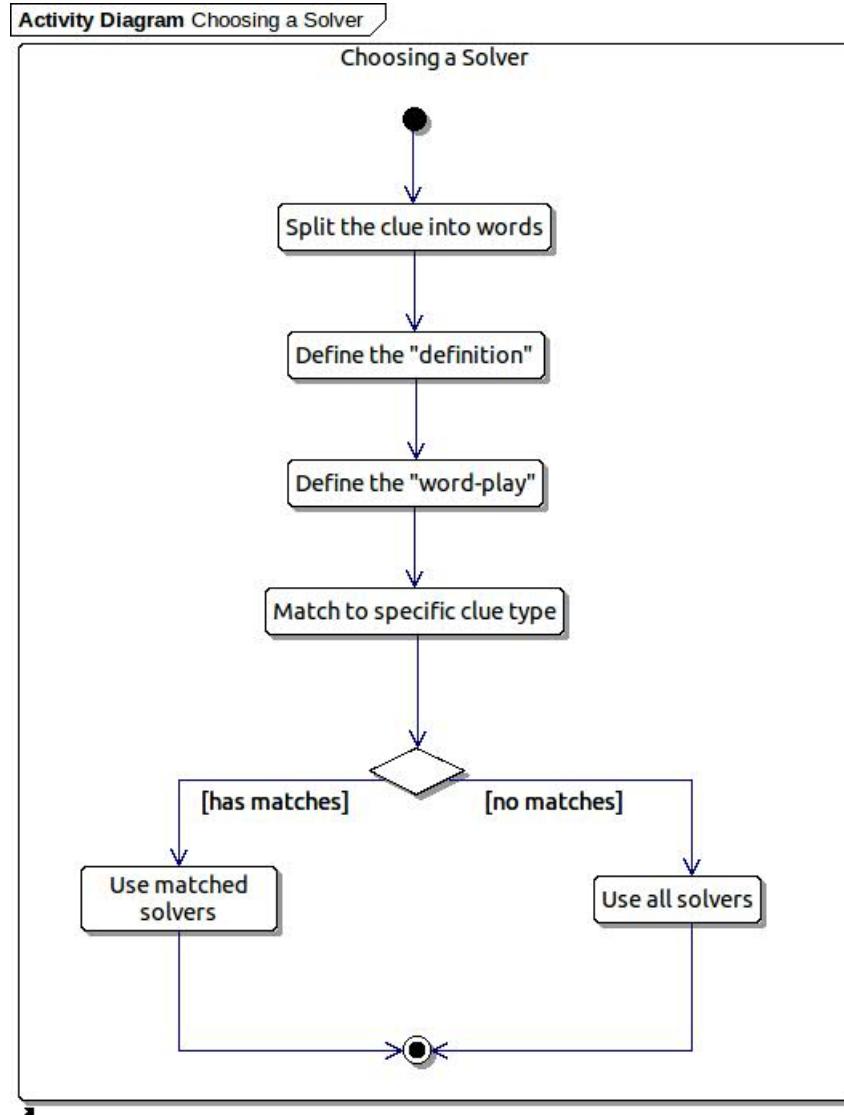


Figure 1.3: Activity diagram showing how a solver is to be chosen

### 1.2.3 Handling Results

Once the solving process has finished, the system will then attempt to apply a ‘confidence rating’. The confidence rating of a solution is how close the system ‘thinks’ the solution is to the correct answer.

For example, if a solution had a confidence rating of 100% it would be deemed as the only answer, whilst 0% would indicate there is no chance of the solution being correct.

It is intended that if there are a large number of results, then the system may choose to filter the results down. For example if thousands of results are generated, then the system may choose to only return results that have a confidence rating higher than 70%.

Figure 1.4 shows the handling of results as an activity diagram.

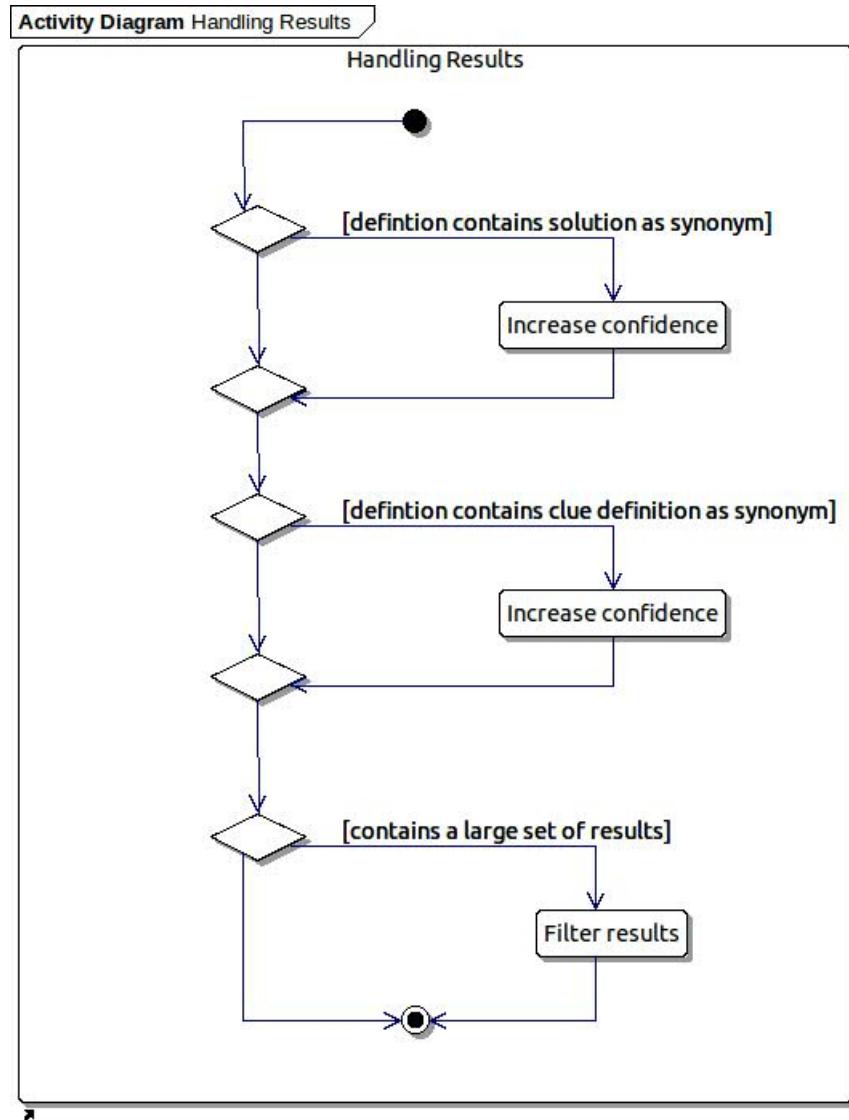


Figure 1.4: Activity diagram showing how results should be handled

## 1.3 Use Case

A Use Case diagram illustrates “a meaningful interaction with a computer system”, and provides various approaches to analysing system design requirements (Lunn, 2003). Within this section the use case of the entire proposed system will be presented and discussed. The use case has been split into two diagrams to increase the readability of the diagram.

The primary intended use of the system is to be able to submit a clue to be solved, which requires the clue, solution length and solution pattern. Figure 1.5 illustrates the three parameter requirements in order to submit a clue to be solved.

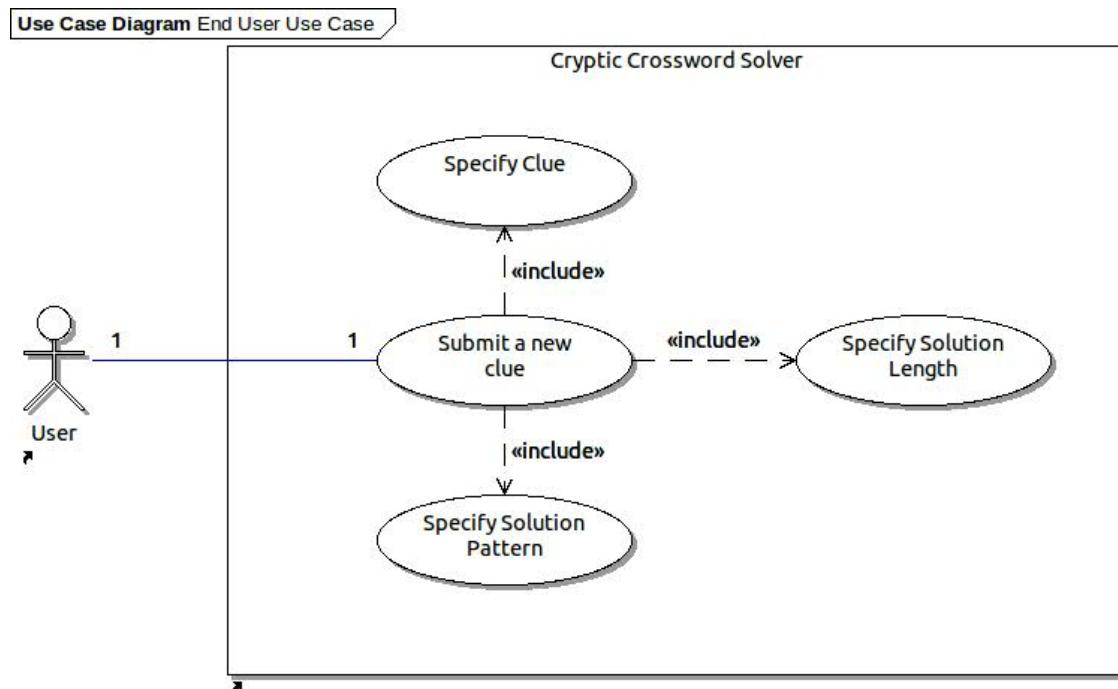


Figure 1.5: Use case illustrating the actor's range of possibilities

It must be stated that the solution pattern could be unknown. In this instance a set wild card characters must be given to the system. This was previously shown in figure 1.2 on page 10.

The remainder of the Use case is shown in figure 1.6. Once the user has input the various data elements the system will then attempt to solve the clue.

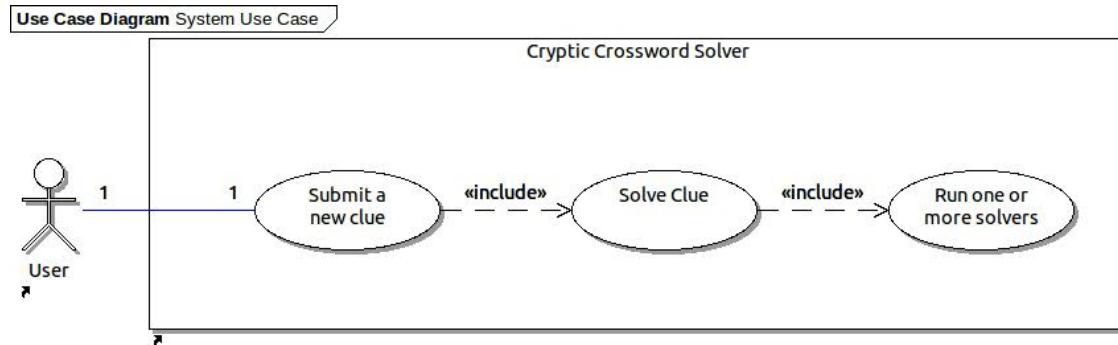


Figure 1.6: System Use Case

The use case demonstrates that there is very little user input required, and once the data parameters have been entered there will be no additional user interaction required.

A design decision has been taken so that there is minimal user interaction with the service. This will be particularly useful for those who are using a mobile device, as inputting data can be laborious in comparison to a desktop machine.

## 1.4 Sequence Diagrams

Within the previous Use Case section a number of key, generic functions were identified. In order for a sequence diagram to be developed, the generic functions will be converted into a set of objects and interactions. Each of the objects and interactions will eventually form the classes that will be used to build the system. Therefore a sequence diagram can be described as a “way of describing a journey through a system” (Lunn, 2003).

The two sequence diagrams that will be described within this section focus upon submitting a clue and solving a clue.

### 1.4.1 Submitting a Clue

Figure 1.7 illustrates a user sending data to the web service (servlet). Within this diagram a number of key elements such as how a clue will be solved have been removed. This is to ensure that the diagram is as simple as possible, as this diagram will only be focusing upon how a user sends and receives data.

The Solving a Clue subsection on page 17 describes in detail how a solver will solve the clue.

To simplify the diagram the user is submitting a ‘block’ of data, which in fact would be the three main parameters — the clue, the solution length and the solution pattern. This has been shown upon the diagram as a ‘block’ of data, because all three parameters will be sent to the system at the same time.

Once the data has arrived at the servlet, the data will be validated. If the data is deemed to be invalid, the servlet will send an error response back, finishing the current instance.

If the data is deemed to be valid, then the system will try to categorise the clue, and solve the clue using the required solver(s). This is will be discussed in more detail in the Solving a Clue subsection on page 17.

Once a set of solutions have been generated, the the in-memory set will be converted to either JSON or XML depending upon the client’s request. Once converted the data is returned as part of the response, satisfying the client’s request.

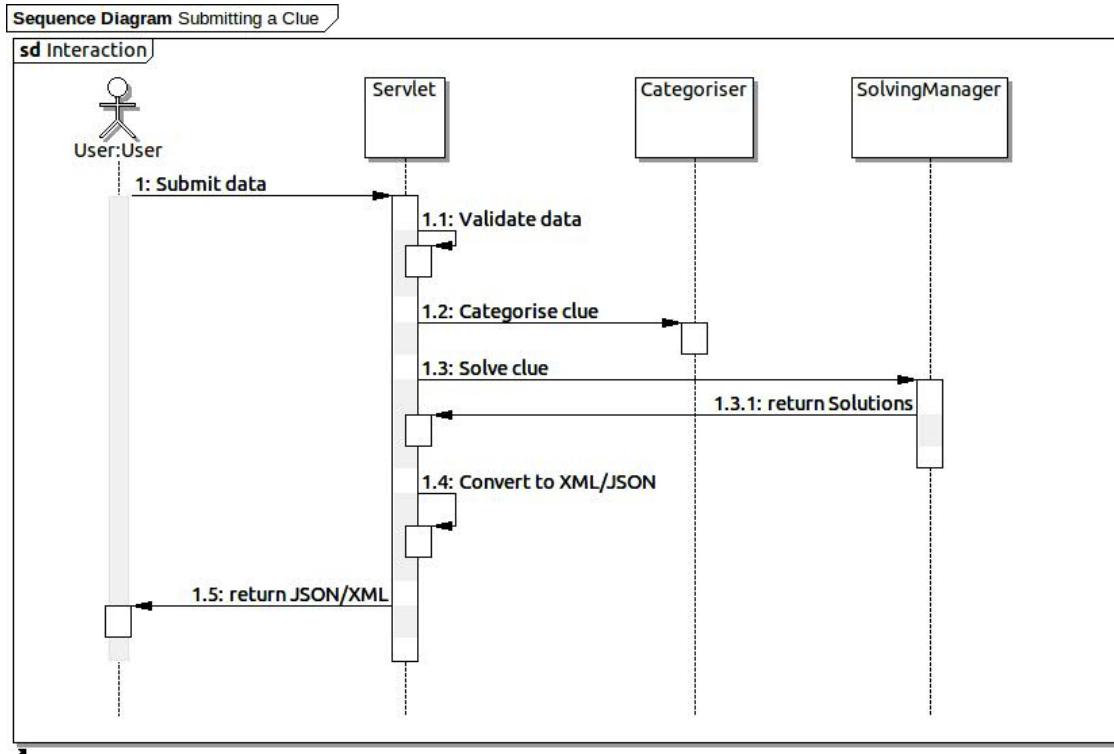


Figure 1.7: Sequence diagram illustrating a user submitting a clue

#### 1.4.2 Solving a Clue

Figure 1.8 illustrates how a given clue will be solved. This sequence diagram assumes that valid data has been passed to the ‘SolvingManager’. This process was described in the previous subsection entitled ‘Submitting a Clue’ on page 16.

The ‘SolvingManager’ object will manage the process of solving a given clue. In order to do this it will have to house several processes, including distributing the clue out to one or more solvers, and merging all results.

Figure 1.8 illustrates the distributing and solving of the clue as a synchronous process, however this was used for illustrative purposes only. The system will in fact distribute and solve the clue upon an asynchronous basis. This will mean that each solver will be running at the same time, and thus reducing the total amount of time needed to solve the clue.

The system will wait however, for all solvers to finish, ensuring that all solutions can be returned to the user. The merging of the results will simply remove any duplicate solutions, upon a first come basis. So if a solution is already in the list, it will not be re-added because a different solver has managed to find the same solution.

Finally the confidence ratings will be adjusted. The adjustments are made upon a number

of factors, and were described in figure 1.4 on page 13.

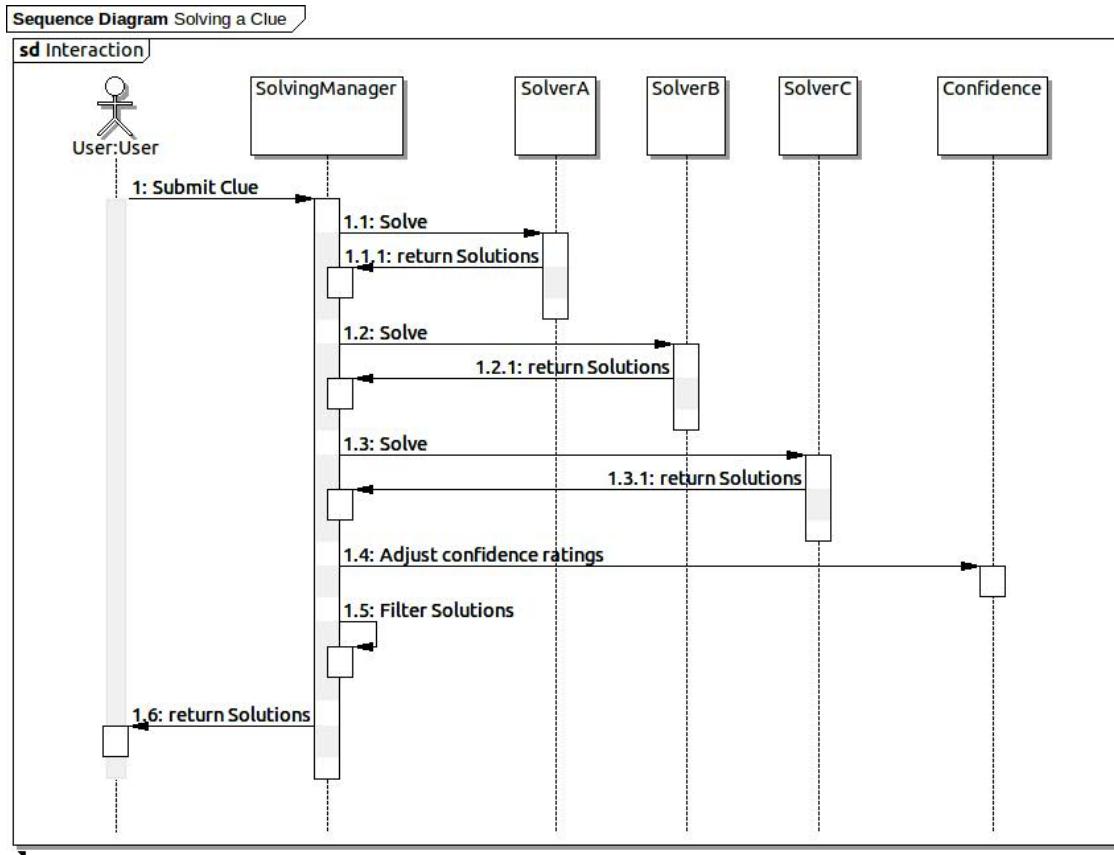


Figure 1.8: Sequence diagram illustrating the system solving a clue

## 1.5 Class Diagrams

Within this section a range of class diagrams will be presented and discussed. “A class diagram describes the structure of a system by highlighting the system’s classes, attributes, methods, and relationships with other classes” (Lunn, 2003).

Figure 1.9 illustrates the seven packages that make up the cryptic crossword solver. Over the following subsections, each of the packages will be described in more detail.

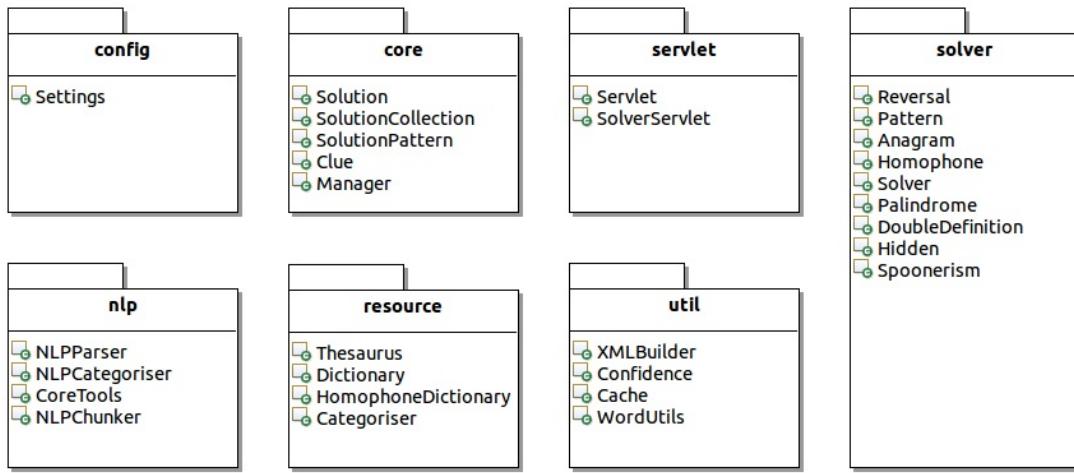


Figure 1.9: Package overview of the Cryptic Crossword Solver system

The architecture of the system will utilise a ‘plug and play’ approach. This approach, will allow for various numbers of solvers to be added at run time, rather than a compile time.

From a development point this will allow for the underlying system to be developed and tested utilising a limited number of solvers. Once the underlying system has been completed, solvers can then be added at any time, without having to alter any previously written code.

### 1.5.1 Config

The configuration class only contains one class, Settings. The Settings class is designed to hold all application specific settings, and each setting can be altered based upon the mode it is being run under — for example development, testing or production.

The Settings class follows the Singleton design pattern which ensures that the class will have only one instance (Gamma, 1995). This prevents various numbers of the same Settings objects being used in memory, and thus wasting valuable space.

Figure 1.10 illustrates the config package, containing the Settings class.

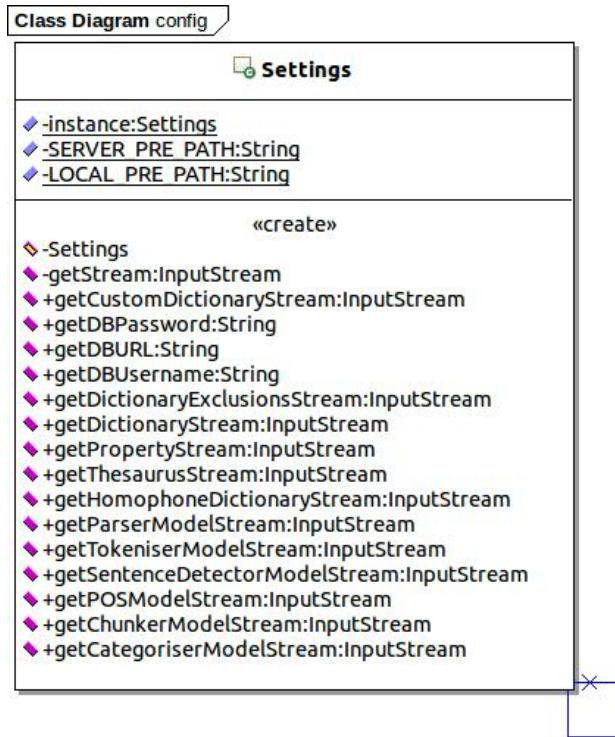


Figure 1.10: Config package class diagram

### 1.5.2 Core

The core package contains the various classes that are deemed to be at the heart of the system. A class has been devoted to the clue, a solution and a solution pattern providing various specific functionalities.

For example the solution pattern provides methods that allow for words to be computed, without having to work out the length of each word every time. The clue class is able to deduce the best solutions, based upon a collection of solutions.

The SolutionsCollection provides a simple interface to handle any number of solutions. The SolutionsCollection uses the HashSet as it's base class, which prevents duplicate solutions to be stored within the same set. It also provides a faster lookup, in comparison to List based structures.

Finally the manager class is the heart of the system and was originally illustrated in the subsection Solving a Clue on page 17. It will be able distribute a clue and it's solution pattern to the various solvers asynchronously. It also handles the merging of results within the `distributeAndSolve` method.

Figure 1.11 illustrates the core package, containing the various core classes.

Class Diagram core

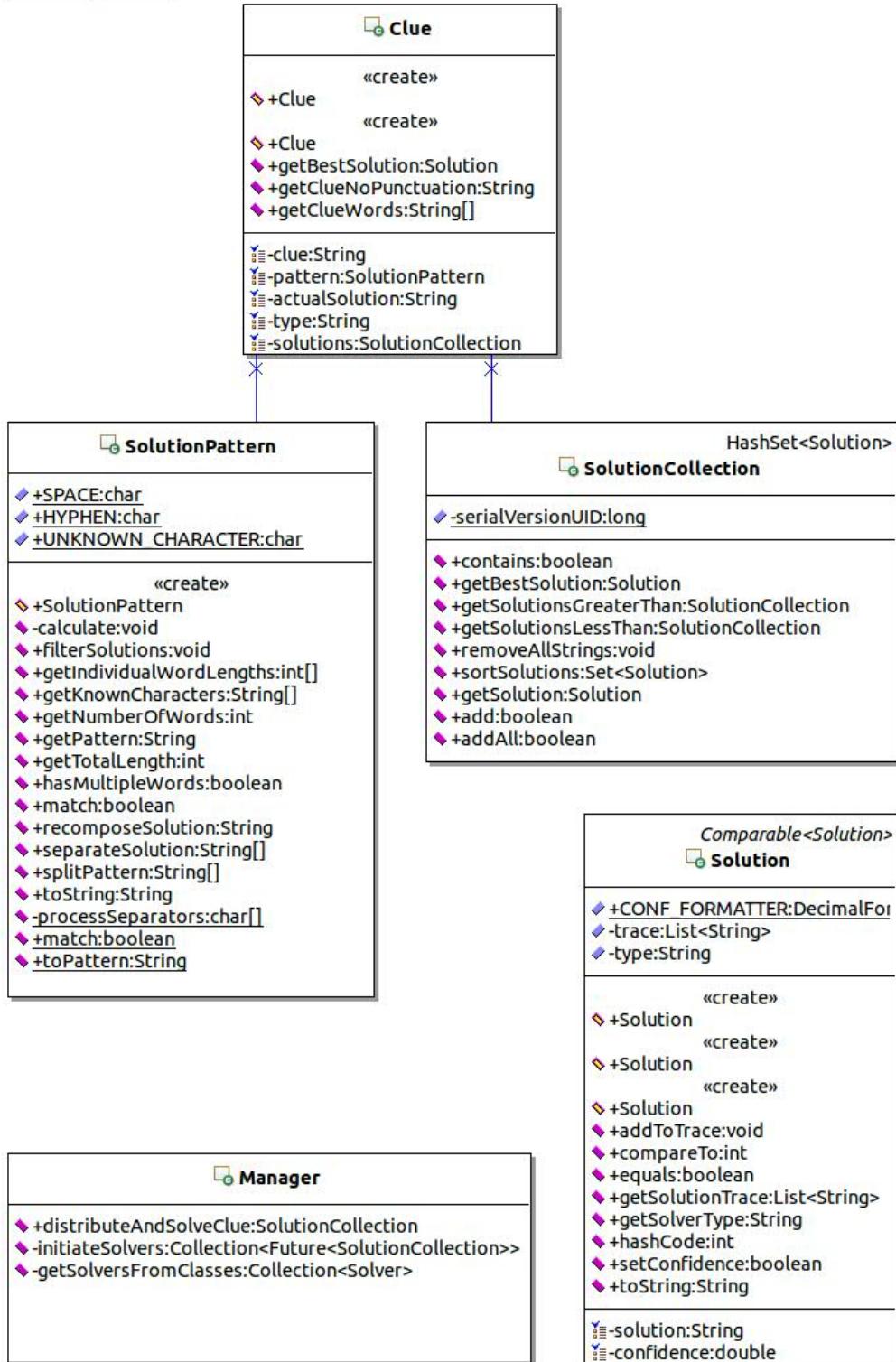


Figure 1.11: Core package class diagram

### 1.5.3 NLP

The NLP package contains the various classes that focus on providing the system with an interface to the Apache OpenNLP library. This will allow the system to be able to use natural language processing techniques from within the application.

Figure 1.12 illustrates the NLP package, containing the various NLP related classes.

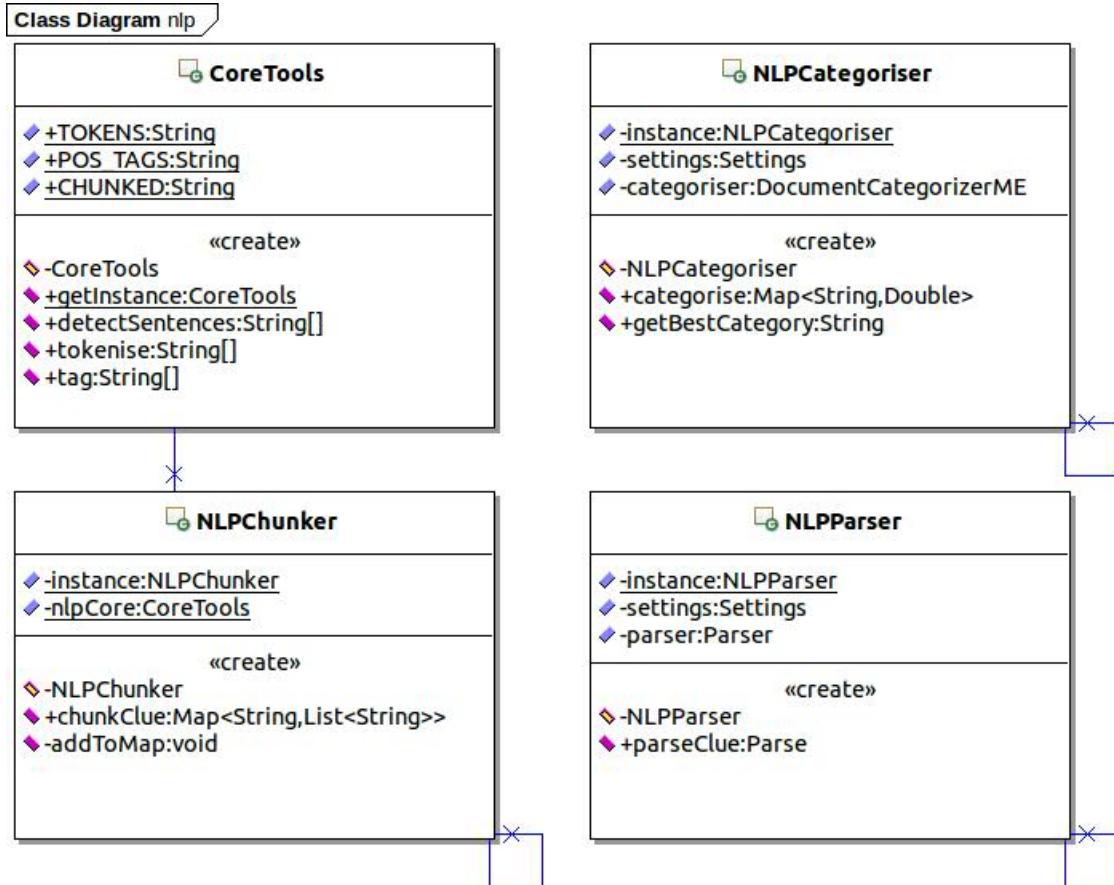


Figure 1.12: NLP package class diagram

### 1.5.4 Resource

The resource package contains various classes that provide interfaces to the array of resources that the system will use. As with the config package, all classes utilise the Singleton design pattern.

The reason for this is that it is to be expected that these classes will be used multiple times throughout the life of the system. To prevent multiple objects being created and being left

in memory, the singleton design pattern was selected. The pattern will “ensure that a class only has one instance, and provide a global point of access to it” (Gamma, 1995).

The Dictionary, Thesaurus and HomophoneDictionary classes provide the functionality that would be expected. For example the Dictionary has the ability to check to see if a given word is a ‘real word’. Whereas the Thesaurus class has the ability to find synonyms of a given word.

All of the classes are able to utilise the SolutionPattern class (as found in the core package), which allows for words to be matched upon various known and unknown character combinations.

The Categoriser class will map a given clue and solution combination to various lists of clue type indicators. If an indicator is found, then the confidence rating of the solution will be increased. This will form part of the overall ranking of a solution.

Figure 1.13 illustrates the resource package, containing the various resource classes.

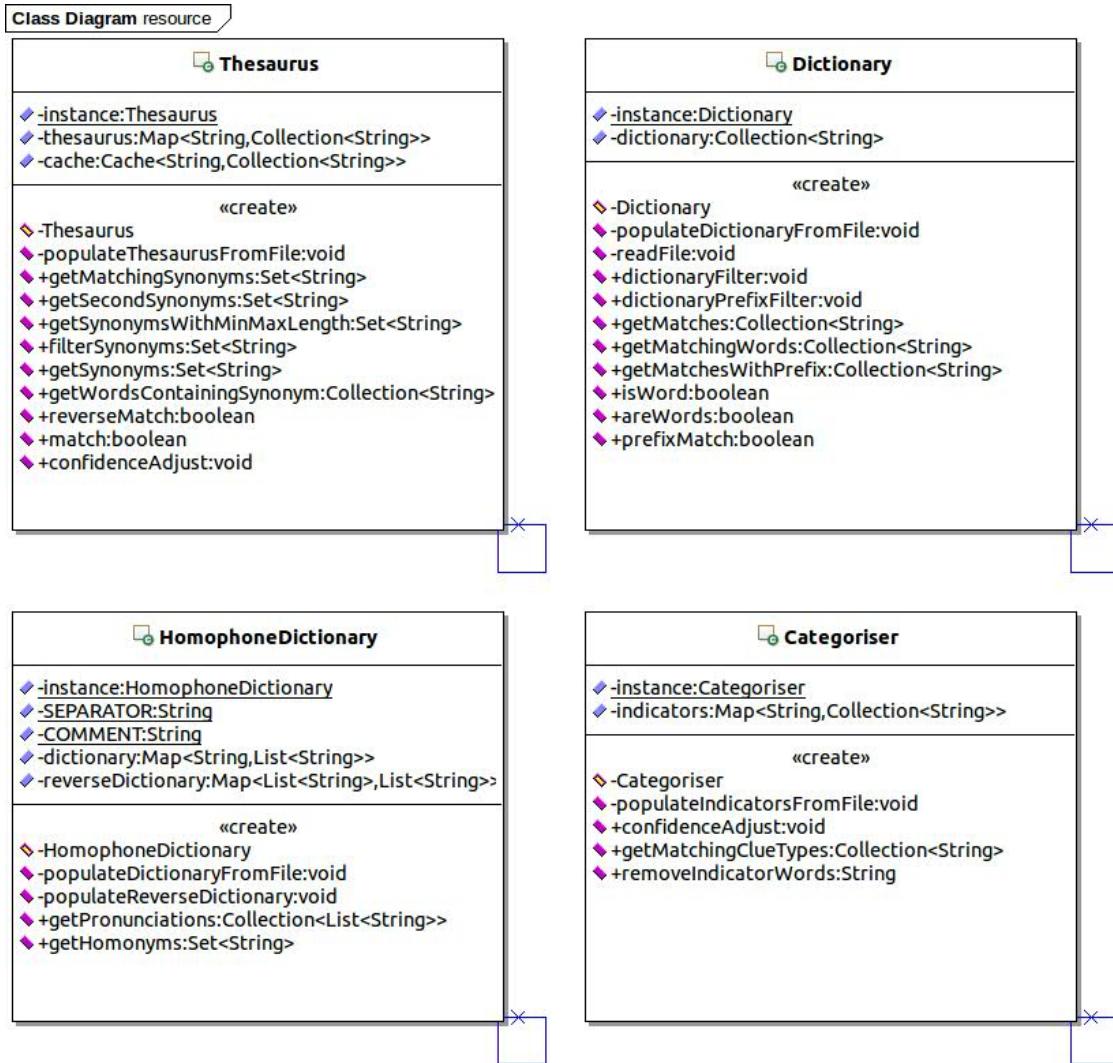


Figure 1.13: Resource package class diagram

### 1.5.5 Servlet

The servlet package contains two classes that provide the web service interface. Both classes tie into the Tomcat system, which provides a container for the web service to sit in.

The Servlet class is a customised base class that provides various levels of common functionality, that other specific classes will utilise. This functionality includes converting XML into JSON, and determining if a reject was made via AJAX.

The Solver class extends the Servlet class, and provides the functionality required for handling solver related queries. All GET and POST requests to the Solver class made via AJAX will be treated as a request over the web.

However all GET and POST requests that do not pass the AJAX flag, will be treated as if the user intended on viewing a website. All non-AJAX posts will be redirected to the Solver's default HTML page, which will allow users to enter the various parameters via a web form.

It is intended that the solver class will listen upon all requests upon the /solver URL path — for example www.example.com/solver.

Figure 1.14 illustrates the servlet package, containing the public web service related classes.

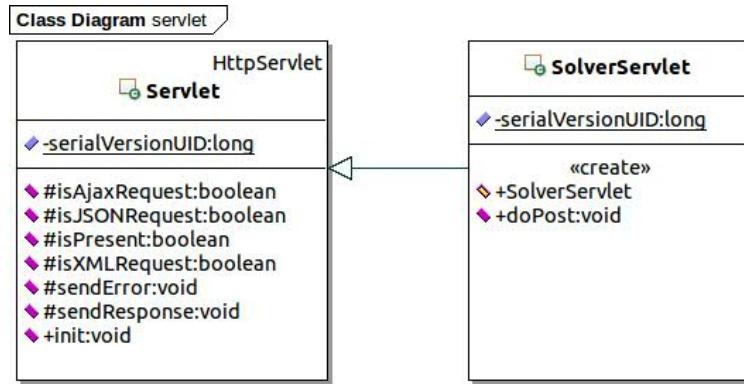


Figure 1.14: Servlet package class diagram

### 1.5.6 Solver

The solver package contains the all of the solver algorithm classes that are used as part of the over all solving process. Each solver extends a main Solver class which provides a number of base methods, as well as some additional methods that require each solver to override.

The Solver class implements the Callable interface, which provides functionality to run a class in it's own thread. A design decision was taken that the Callable interface was to be used, as once it has finished executing it is able to return an object unlike similar interfaces such as Runnable.

Each of solver classes implement the Abstract Factory design pattern via the base class Solver. This pattern “provides an interface for creating families of related objects without specifying their concrete class” (Gamma, 1995).

Each of the solvers is able to return a concrete product, which in this instance is a a SolutionCollection object. The SolutionCollection will contain all the solutions that the given solver has managed to compute.

Figure 1.15 illustrates the solver package, containing the various solving algorithms used by the system.

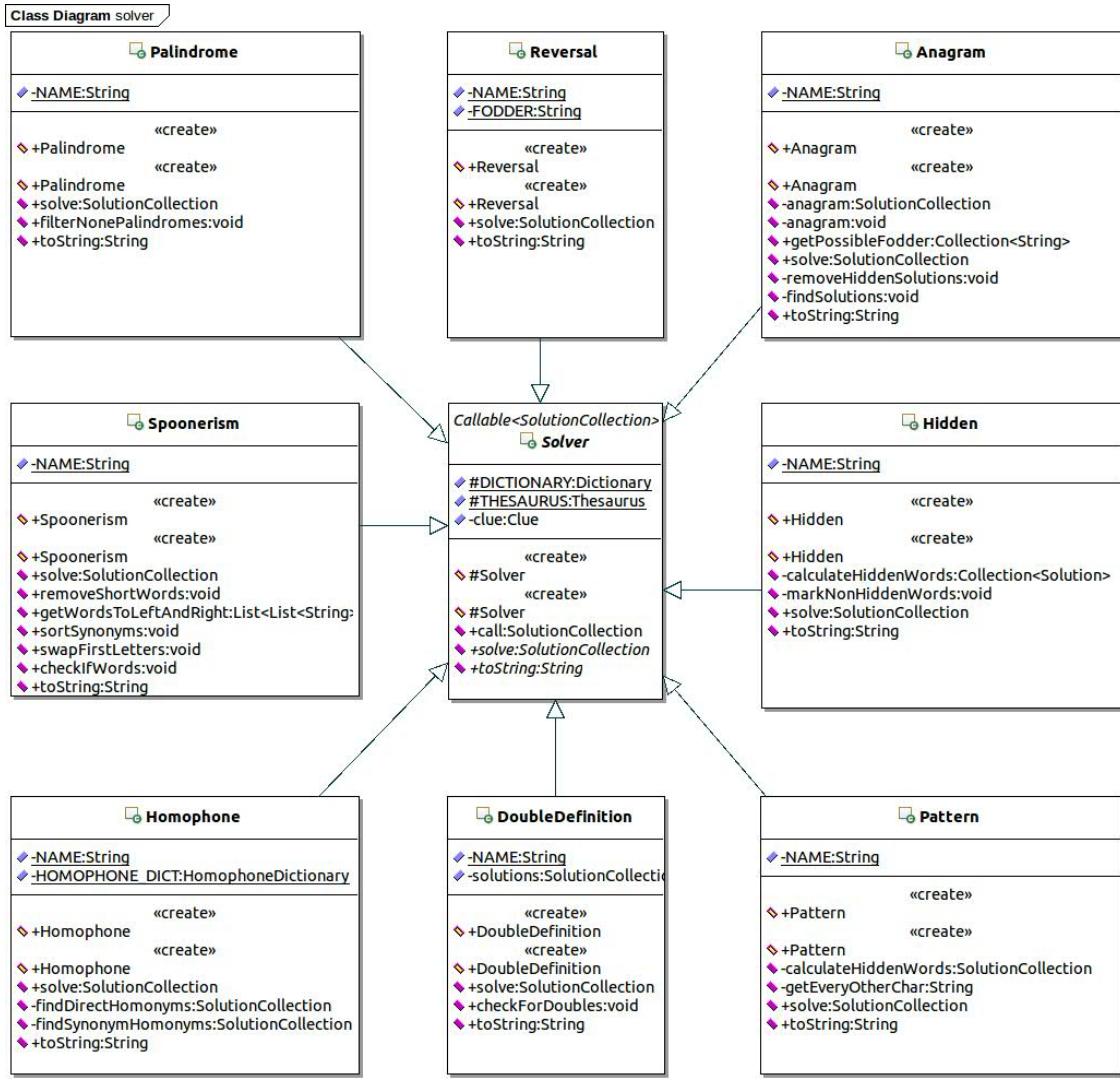


Figure 1.15: Solver package class diagram

### 1.5.7 Util

The util package contains a number of classes that are unrelated with each other, but provide functionality that is required throughout the system.

The XMLBuilder class provides a data encapsulation layer around an XML library. This class is able to build well-formed XML documents that are suitable for the system's output.

The WordUtils class provides a number of generic methods that are used to manipulate strings as words. This functionality is particularly useful, as the system will be dealing with large amounts of natural language (English) sentences.

The confidence class provides a number of rules, that when applied to a solution is able to deduce it's overall 'correctness'. This value is directly reported back to the user as the confidence rating.

Figure 1.16 illustrates the util package, containing the a number of additional utility classes.

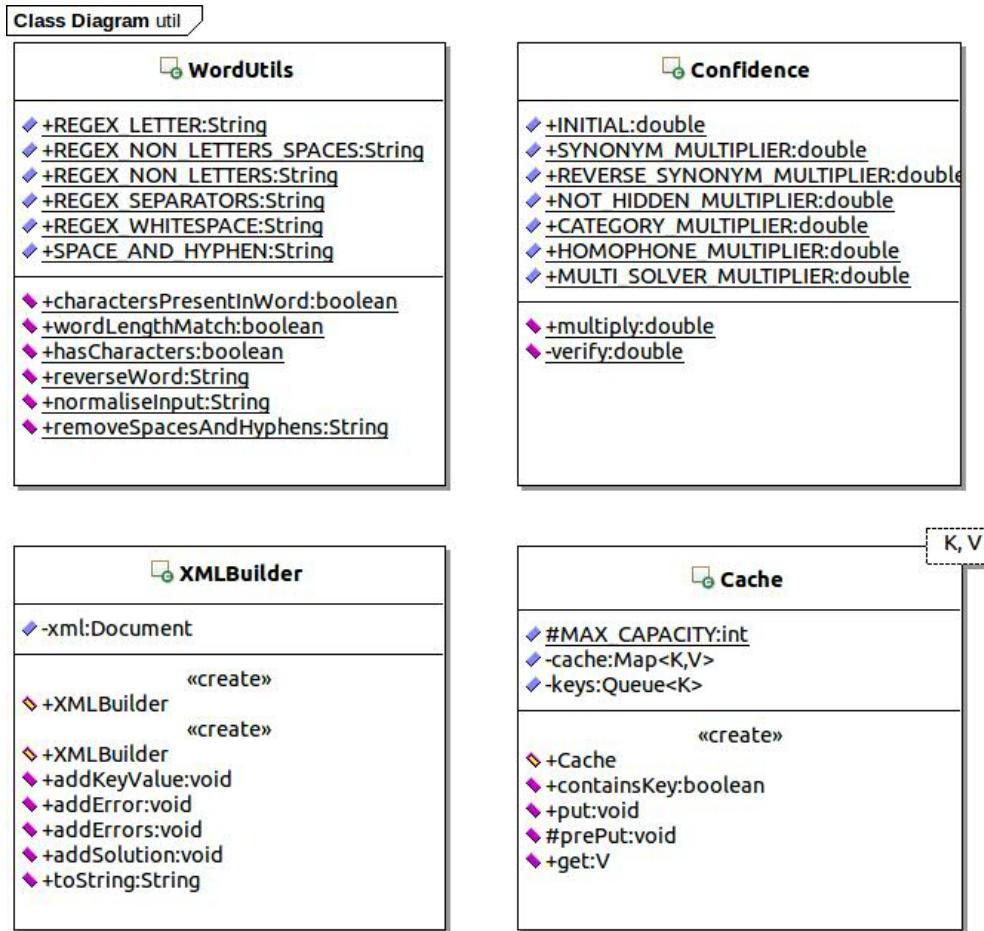


Figure 1.16: Util package class diagram

## 1.6 Database Design

As part of the testing strategy a list of clues and their solutions are required to be stored. In order to accurately store a large amount of training data, a database will be used.

The database design is of a minimalistic approach as it is not intended to hold a large amount of data, nor will it be used within a production environment. Figure 1.17 shows the proposed database design.

Each record will contain a clue, a solution, and the solutions length. The solutions length has been assigned a VARCHAR data type, because solutions can span across more than one word. For example 3,4 would relate to two words, of three and four characters respectfully. Each of these attributes are required — i.e. not null.

The orientation attribute is an ENUM that contains either ‘down’ or ‘up’, indicating the direction that the solution is arranged. The orientation may be useful for certain clue types, such as reversal, where by the clue references the direction — e.g. north-to-south, or east-to-west.

The clue number attribute stores the number of clue, as some clues use the clue number in obtaining the solution answer. Although this is uncommon, it will be taken into consideration.

The clue type attribute is an ENUM that holds the various types of clues, such as ‘purely cryptic’ or ‘anagram’. It is intended that these values will be ‘mapped’ to the system code, so that clues can be used automatically when training.

cryptic_clues	
• <b>id</b>	<b>INT(10)</b>
•clue	VARCHAR(255)
•solution	VARCHAR(32)
•length	VARCHAR(32)
◦orientation	ENUM
◦clue_number	TINYINT(3)
◦type	ENUM

Figure 1.17: Testing database entity-relationship diagram

## 1.7 User Interface

The previous sections have presented a number of system designs from a programmatic point of view. Within this section, there will be a focus upon user interface designs, and thus how the end user will interact with the system.

Fundamentally there are two aspects to the user interface design of the system — inputting the clue and retrieving the results. Each of these aspects will be discussed in more detail in the following subsections.

### 1.7.1 Platform Support

One of the main objectives of the project is to develop a system that can be used upon a number of mobile platforms, as well as trying not to neglect ‘traditional’ desktop users.

In order to complete both of these objectives, a responsive design is required. A responsive design is one that is able to dynamically change based upon the screen size.

This means that there will only be one code based for multiple screen sizes, and thus allows for easier maintainability. All of the designs within this section feature a responsive design. Figure 1.18 illustrates the power of responsive designs.

The left-hand side form shows a ‘traditional’ desktop experience, whilst the form upon the right-hand side, shows a mobile experience.

The figure displays two versions of an input form side-by-side, illustrating responsive design. Both versions include three text input fields: 'Clue', 'Solution Length', and 'Solution Pattern'. Below each input field is a descriptive note. At the bottom of each form are two buttons: 'Reset' and 'Solve'.

Input Type	Desktop Version (Left)	Mobile Version (Right)
Clue:	A large rectangular input field.	A large rectangular input field.
Punctuation	Punctuation can also be included.	Punctuation can also be included.
Solution Length:	A medium-sized rectangular input field.	A very small rectangular input field.
Description	Any combination of single words (e.g. 3), multiple words (e.g. 3,5) or hyphenated words (e.g. 3-5) can be entered.	Any combination of single words (e.g. 3), multiple words (e.g. 3,5) or hyphenated words (e.g. 3-5) can be entered.
Solution Pattern:	A medium-sized rectangular input field.	A medium-sized rectangular input field.
Description	Provide any known characters, unknown characters (?), word separators (comma) and hyphens (-).	Provide any known characters, unknown characters (?), word separators (comma) and hyphens (-).
Buttons	Reset, Solve	Reset, Solve

Figure 1.18: The input form to be completed by the end user

## 1.7.2 User Input

In order for the system to solve the clue, it must first be given the clue, along with additional supporting information. The additional information such as the solution length and solution pattern is vital to the system in order for it to compute the correct answer.

However the intended users of the system are likely to be operating upon some form of mobile device, meaning that a simple and power interface is required. It also means that space will be at a premium, and thus it can not afford to be wasted.

Figure 1.19 illustrates the design of the user input form. One of the most noticeable elements to the form design is how much space has been allocated to the input boxes.

The design of the inputs utilises a bi-column setup using the ratio of 1:3. This means that for every 1 pixel of space allocated to the left-hand labels, there will be 3 pixels of space allocated to the right-hand input boxes. This allows users of mobile devices to quickly select the input box, rather than having to tap a small area several times.

In order to assist the end user additional help blocks will be included, and give useful information to the user, such as describing the solution pattern format required.

**Clue:**   
Punctuation can also be included.

**Solution Length:**   
Any combination of single words (e.g. 3),  
multiple words (e.g. 3,5) or hyphenated  
words (e.g. 3-5) can be entered.

**Solution Pattern:**   
Provide any known characters, unknown  
characters (?), word separators (comma) and  
hyphens (-).

**Reset**    **Solve**

Figure 1.19: The input form to be completed by the end user

As the system is dealing with input from users, it is inevitable that a user will attempt to

input incorrect data. This will require validation to be performed, and if validation has failed then the user should be notified.

As previously mentioned space is a premium upon a mobile device. Therefore displaying a list of validation error messages at the top of the screen would not be utilising limited amount of space wisely.

In order to combat this issue, validation will be displayed ‘inline’ with the form input elements, as seen within figure 1.20. By utilising an ‘inline’ approach it recycles the screen space that has been made available to the form.

For inputs that have passed the validations the outline will change to green, and for validations that have failed the input group will change to red. This will immediately alert the user to the various issues, and thus allows the user to fix the errors in a quicker and more efficient manner.

The image shows a mobile application interface with a light gray background. At the top, there is a green header bar with the text "Solve" in white. Below the header, there is a large white input field with rounded corners. Inside this field, the word "ermine" is written in black. To the left of the input field, the word "Clue:" is written in green. To the right of the input field, the text "Found ermine, deer hides damaged" is displayed in a green box. Below this, the text "Punctuation can also be included." is shown in green. Underneath the input field, the text "Solution Length:" is written in green. To its right, the number "10" is displayed in a green box. Below this, the text "Any combination of single words (e.g. 3), multiple words (e.g. 3,5) or hyphenated words (e.g. 3-5) can be entered." is shown in green. At the bottom of the input field, the text "Solution Pattern:" is written in red. To its right, there is a red-bordered input field containing the text "Provide any known characters, unknown characters (?), word separators (comma) and hyphens (-)." Below the input field, there are two buttons: a "Reset" button on the left and a "Solve" button on the right, both in a light gray color.

Figure 1.20: The input form indicating a validation error

### 1.7.3 Results

The displaying of the results follows on from some of the previous design decisions. Each potential solution is rendered into it’s own panel, and will contain the confidence rating, and the solver type that managed to deduce the solution (as shown in Figure 1.21).

Within an open panel, additional information is displayed — known as the solution trace. A solution trace provides a step by step account of how the solution was able to be computed. The solution trace may help to teach users how a particular type of clue is solved.

The results are ordered by confidence rating in ascending order, and by default the first panel will be ‘open’, showing the solution trace. The reason for this is that the top answer is likely to be the answer the end user is looking for

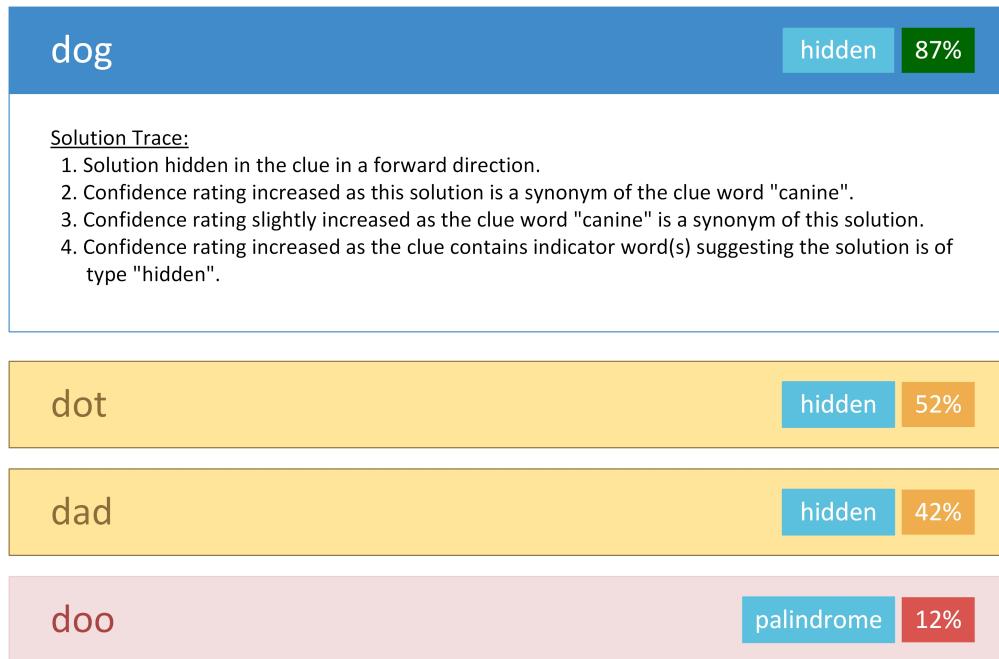


Figure 1.21: Results list displaying the top answer in blue

Each of the panels are “clickable”, meaning that if any given panel is selected then the solution trace will be displayed, whilst previously selected panels will be ‘closed’ (as shown in Figure 1.22). The main reason behind this is to reduce the amount of scrolling a user has to do, especially for those without a mouse.

Each solution is awarded a colour based upon the confidence rating. Blue refers to a top answer, whilst the remaining colours (green, yellow and red) indicate the likelihood of the solution being correct.

This will allow the end user to immediately deduce that ‘green’ results are more likely to be correct in comparison to ‘red results’, and that a ‘blue’ result is likely to be correct.

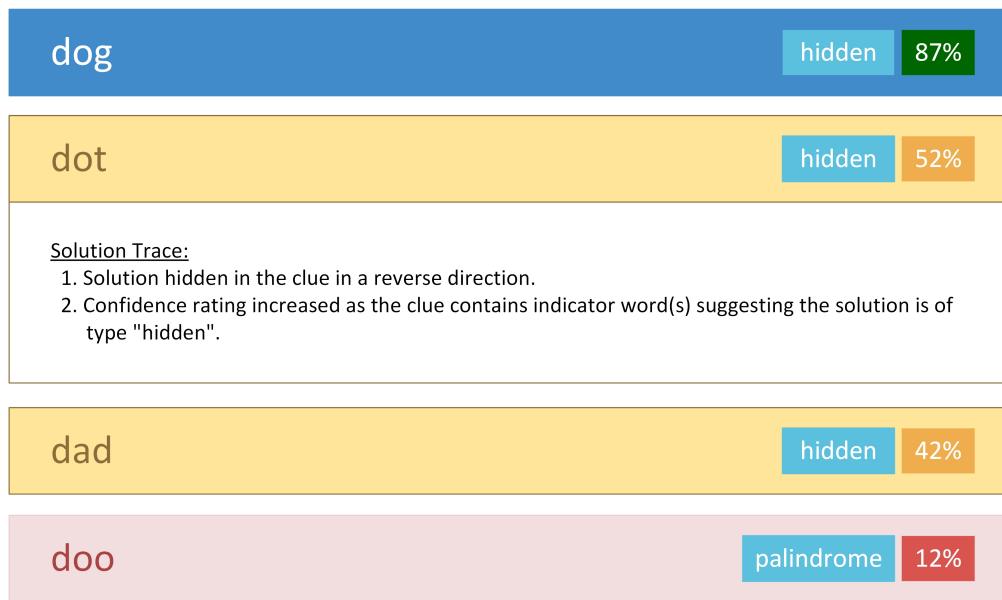


Figure 1.22: Results list displaying alternative solutions

# Glossary of Terms

The following section contains a glossary with the meanings of all names, acronyms, and abbreviations used by the stakeholders.

Term/Acronym	Definition
The Guardian	A national UK newspaper that prints daily cryptic crosswords
Android	A mobile phone software platform by Google Inc.
BlackBerry	A mobile phone hardware and software platform developed by BlackBerry Limited
iOS	A mobile phone software platform developed by Apple Inc.
iPhone	A smart phone developed by Apple Inc.
iPod	A portable digital music player developed by Apple Inc.
iPad	A tablet developed by Apple Inc.
NLP	Natural Language Processing
SRS	Software Requirements Specification
App	Shorthand for application

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- Lunn, K. (2003). *Software development with UML*. Palgrave, first edition.