Online Match-Making Recommendation using Case Based Reasoning and K-Nearest-Neighbors

by

Mehrnaz Bayaki
BSc., Azad University of Mashhad, 2009

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Supervisory Committee

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Dr. Issa Traore, Department of Electrical and Computer Engineering
Supervisor

Dr. Kin Li, Department of Electrical and Computer Engineering
Departmental Member

Abstract

Supervisory Committee
Dr. Issa Traore, Department of Electrical and Computer Engineering
Supervisor

Dr. Kin Li, Department of Electrical and Computer Engineering
Departmental Member

In this project a new approach that uses case-based reasoning (CBR) in match-making for online recommendations is developed. The proposed CBR model uses K-nearest neighbor (KNN) classification for effective and efficient case retrieval. The proposed recommendation system is used to match students with potential employees, based on students' qualifications and interests, and available projects. The project report outlines the algorithm design, and corresponding architectural model and implementation.

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Dedication

I would like to dedicate my thesis to my parents Hossein Bayaki and Marzieh Kashani for their endless love, support and encouragement in all stages of my life.

Chapter 1 Introduction

1.1 Context and Overview

Online recommendation systems play a critical role in the success of many current e-commerce organizations such as NetFlix, Amazon, and so on. The project presented in this report was a collaboration with a local startup company to develop an online recommendation system for match-making between companies and students looking for projects or internship positions.

The previous online matchmaking platform allowed collecting information related to individuals (i.e. students) and organizations (e.g. companies) using traditional search engines. The collected information was then manually analyzed by experts to extract entities (i.e. company or students) profiles and then perform matchmaking between students and companies. Students can follow and request to do a project with a specific company and an email will be sent out to that company to tell them to join the match-making site and fill out their profile and submit projects descriptions for interested students.

The goal of the MENG project has been to fully automate the previous platform by researching and developing efficient data extraction and structuring mechanisms and the matchmaking algorithms that will match users to one another based on data inputted through their profiles.

In this project, a case-based reasoning model based on the K-nearest-neighbor (KNN) algorithm is used in order to recommend suitable job opportunities to students. This is a decision making system which uses *K*NN classification algorithm for pattern classification.

1.2 Report Outline

The rest of the report is structured as follows.

Chapter 2 summarizes background knowledge on case-based reasoning and *K*NN classification.

Chapter 3 introduces the proposed match-making algorithm.

Chapter 4 presents the algorithm design and implementation.

Chapter 5 makes some concluding remarks.

Chapter 2 Background

2.1 Overview of Case-Based Reasoning

Case-Based Reasoning (CBR) is the procedure of solving a problem based on the solutions of similar past problems. A case typically comprises of two main parts: the existing problem description and a solution to solve it. In addition to that, the case might indicate the consequences of the given solution (success or failure). The CBR process is defined as following [3]:

1. *Retrieve*: Given a case, CBR system tries to retrieve the most similar cases to the problem case.
2. *Reuse*: Mapping a solution from the previous similar cases to the objective problem.
3. *Revise*: Test the new solution for the target problem and review it to adapt to the target problem if required.
4. *Retain*: After the successful adjustment of solution to the objective problem, store the case as a new case in the memory.

CBR performance is dependent on two factors: precision and swiftness of retrieval and reuse algorithms.

2.2 Background on KNN Classification

Machine learning techniques are categorized into two groups: supervised and unsupervised methods [7, 8]. Supervised learning is the procedure of learning a mapping between a set of *input* variables and an *output* variable and applying this mapping to predict the outputs for unseen data. Supervised learning is the most common methodology in machine learning. Classification and regression data mining methods are classified as supervised machine learning procedures. Unsupervised learning attempts to find unseen structure in unmarked data. Clustering and association mining are placed in this group [1, 2].

Classification is a classic data mining technique based on machine learning. Mainly, classification is used to categorize each item in a set of data into one of predefined, distinct set of classes or groups. As it is a supervised method, the categories (or classes) need to be previously defined and known for the data that is used as the training set (i.e. each instance of data needs to be associated with a "class label", representing which class the instance belongs to).

We used in this project a CBR model that is based on *K*NN, which is a popular classification algorithm. *K*NN is one of the simplest lazy learning algorithms. It has been frequently used in pattern classification due to its simplicity and effectiveness [4]. Let us assume we have *N* training instances which are labeled $\{Xi, Ci\}$. The algorithm stores all of the training instances in the memory. Class prediction for a new instance x_0 is done by finding its *k* nearest neighbors based on a similarity metric, and then assigning a label using majority vote of its *k* nearest neighbor class labels. Typically, Euclidean distance is used as the similarity metric for measuring the distances between instances. According to the studies on pattern classification algorithms, the performance of *K*NN is comparable with most sophisticated algorithms in this area. Although *K*NN is moderately precise and simple for implementation, it may result in low efficiency if some algorithm parameters are selected inadequately. Likewise, determining an optimum value for k is a great challenge since the efficiency of the algorithm is directly affected by the value selected for *k*.

Normally, the performance of *K*NN is affected by the following parameters and factors: number of nearest neighbors (*k*), size of training instances (*N*) and selection of similarity metric. The choice of k is very critical in this algorithm. Classically, picking larger values for *k* can be more resilient to noise, but that is more expensive in terms of computation cost. Specifying the value of *k* is still a challenge and determining optimum values for *k* is dissimilar in different applications [5, 6].

In *K*NN, selecting a high value for the number of instances (*N*) can result in better performance of the algorithm. For the reason that picking large quantities for *N* helps

finding more similar *k* nearest neighbors for each new instance, although a large training set can be costly in terms of computation and memory space [5, 6, 9].

Chapter 3 Proposed Match-making Algorithm

3.1 Algorithm Design

The goal of the project is to develop a match-making algorithm that connects individuals (i.e. students) and organizations based on their preferences in collaborating on specific projects. For recommending appropriate matches (organizations and their projects) to students, we have made use of a CBR system which employs *K*NN as its retrieval algorithm. We use case-based reasoning to retrieve previously successful matches. A successful match here is defined as following: the organization was satisfied by the student performance, the student has gained experience and knowledge and the project was successful. This is a classification algorithm in which our instances are stored in the case base and are labeled with two classes: positive feedback and negative feedback. Positive feedback indicates a successful match, while negative feedback specifies a failed match between the student, organization and the project.

Our goal is to recommend a suitable match to the student based on previous successful matches. The match making procedure will consist of comparing a new case, defined in terms of the student, the organization and the project, to previous cases in the CBR system. As mentioned above, we use *K*NN as retrieval algorithm in the CBR system.

Table 2.1: Match making data samples

Student
S1
S2
S3
S4

Organization
O1
O2
O3

Project
P1
P2
P3
P4
P5
P6
P7

Organizations/Projects	
O1	P1
O2	P7
O1	P3
O1	P2
O3	P6
O1	P4
O2	P5

Case-base				
Case ID	Student	Organization	Project	Feedback
1	Sx01	Ox11	Px11	Positive
2	Sx02	Ox12	Px12	Negative
3	Sx04	Ox07	Px05	Positive
4	Sx08	Ox11	Px11	Negative
5	Sx03	Ox07	Px05	Positive
6	Sx06	Ox09	Px01	Positive
7	Sx07	Ox12	Px12	Positive
8	Sx09	Ox07	Px05	Negative
9	Sx11	Ox11	Px10	Negative
10	Sx05	Ox09	Px66	Positive
11	Sx10	Ox11	Px77	Negative
12	Sx12	Ox12	Px33	Positive
13	Sx17	Ox07	Px54	Positive
14	Sx22	Ox11	Px17	Negative

In order to give an overview of our proposed match making system, let us consider the example database depicted by Table 2.1. This involves lists of students, organizations, projects, and a sample case base. Now, let us say we want to find a job opportunity for the student S2 in the student table. For doing that, we generate a job opportunity query list as follows. For each organization and project pair in the Organization/Project table we create a JOB Opportunity Query that consists of the student, the organization and project pair. In Table 2.2 below, we have created the job opportunity query list for student S2:

Table 2.2: Query List Example

Query ID	Student	Organization	Project
Q1	S2	O1	P1
Q2	S2	O2	P7
Q3	S2	O1	P3
Q4	S2	O1	P2
Q5	S2	O3	P6
Q6	S2	O1	P4
Q7	S2	O2	P5

In this part, we want to predict which job opportunity will most probably have a positive feedback (i.e. will be a positive experience for the student and the company). For doing that, we will make our decision based on the previous cases stored in our case base. For each query in the query list (in this case Q1, Q2, Q3... Q7) we will search the case-base looking for the *k* nearest/similar cases. This *k* should be an odd number (e.g. 1, 3, 5, 7, 9, etc.). Then we predict the expected feedback for the query using majority voting over the *k* nearest/similar cases. To illustrate, let us assume that we are using $k = 5$ and after running the *K*NN search over the case-base, we got the 5 similar cases to each query listed in Table 2.3.

Table 2.3: K-Nearest-Neighbors Examples

Query ID	Similar Cases	Predicted Feedback
Q1	3, 4, 9, 11 and 14	Negative
Q2	1, 3, 4, 9 and 14	Negative
Q3	1, 4, 5, 8 and 9	Negative
Q4	3, 4, 8, 11 and 14	Negative
Q5	2, 4, 5, 6, 9 and 11	Negative
Q6	3, 5, 6, 11 and 14	Positive
Q7	3, 6, 7, 10 and 11	Positive

Based on the (k = 5) similar cases to each job opportunity query, the most likely job opportunity suitable for student S2 are the ones in Q6 and Q7. This is because 3 similar cases to Q6 had positive feedback and 4 similar cases to Q7 had positive feedback. The system at the end should recommend the student to apply to work for organization O2 on project P5.

At this time, the proof-of-concept software implementation is designed by using k = 1. Hence for each query in the query list the similar cases to the query are retrieved from the case-base, however, the feedback of the most similar case among similar cases will be assigned to the feedback feature of the query. For more illustration, assume that we are searching the case base using *K*NN algorithm, we will find out that Q6 has 5 similar cases (3, 5, 6, 11 and 14), but case 3 has the highest similarity to Q6 compared to the 4 other cases. So, the feedback for Q6 would be positive. This indicates we can recommend to student S2 to work for organization O1 on project P4.

The steps of our proposed match-making algorithm are defined as follows:

1. Create ***JobOpportunities*** as an empty List.
2. For each ***organization*** with some ***open project*** in the system database (DB) read the organizations and their open projects.
    - 2.1. Extract useful organization and project features/attributes and create organization and project objects.
    - 2.2. Set each organization object and project object as a job opportunity JO.
    - 2.3. Add JO to the JobOpportunities list.
3. From ***DB*** read one student profile.
4. Extract useful student feature/attributes from the student's profile and create a student object.
5. Create ***Q*** as an empty queries list.
6. For each **JO** in the **JobOpportunities**:

6.1. If the ***JO*** not suitable for the student drop this ***JO.***

6.2. Create a query ***q***, where ***q*** consists of the student object and the ***JO.***

6.3. Add ***q*** to the ***Q*** list.

7. Create R as an empty result list.

8. For each ***q*** in the ***Q*** list:

8.1. Use *K*NN search to find the nearest ***K*** cases to ***q*** in the case base.

8.2. Use majority voting with ***K*** voters to predict the feedback (good or not good) of ***q.***

8.3. Add ***q*** and the result to the Results list

9. From the Result list select the top ***m*** positive feedback and display it to the students

3.2 Initial Case Base and Dataset

The sample dataset provided by the company was stored in PostgreSQL database containing different tables storing information for students, businesses and projects. The number of the records for students, businesses, and projects are 12, 10, and 41, respectively. The considerable point to mention is that each organization has one or more projects. As per of the company's request, some of the attributes for each of the students, businesses and projects were taken from the dataset tables to use for matching.

The attributes that were taken for matching from the student_profiles table in the dataset are the following:

1. Student year of study
2. Student major
3. Student education level id

Student's industry was taken from sectors table that was inner join to the sectorizations table in the database using a SQL script.

Student's skills were taken form taggings table which was inner join to the tags table in the database using a SQL script.

The attributes that were taken for matching organizations from the business_profiles table in the database are:

1. OrgTypeId: indicates the organization type
2. OrgSizeId: indicates organization size.

Project attribute that was taken from the projects table in the database is:

1. Project Funding available

Project (required) skills are taken from sectors and sectorizations table, and represented as a set of strings.

Project industry is an array of strings that indicates the industry areas of the project and is taken from taggings and tags table.

Other tables were also defined in the database. The tables that were used for this project from the dataset are:

1. student_profiles
2. business_profiles
3. projects

4. sectorizations
5. sectors
6. taggings
7. tags

We created the initial case for the system based on expert advice and the business practice of the sponsoring company. The case base is written as an XML file containing 10 cases. Each case contains student, organization, and project information.

Student Attributes

The student information are *major* which is a string value, *year of study,* which is an integer value and *education_level_id* as an integer; *education_level_id* can have the following values:

- 1 for a high school student
- 2 for an undergraduate student
- 3 for a master student
- 4 for a PhD student
- 5 for a post-doc fellow.

Furthermore, *student _industry,* which is a string type, specifies student's industry and at last s*tudent_skill,* that is an array of strings represents student's skills.

Organization Attributes

Organization information consists of *Org_type_id* and *Org_size_id.*

Org_type_id is an integer, which can have the following different values:

- 0 for private
- 1 for government
- 2 for non-profit.
- 3 for educational

Org_size_id is an integer that refers to the number of employees in the organization; it can have the following possible values:

- 0 for the size of 1-5
- 1 for the size of 6-20
- 2 for the size of 20-50
- 3 for the size of 50+

Project attributes

Project attributes are skills, industry and Funding_available. Funding_available is defined as follows:

Funding_available: a Boolean value that specifies whether the project has fund (true value) or no fund (false value) for the student that will work on it.

3.3 Evaluation/ Testing:

The number of queries is 240. The system failed to find matches for 4 queries out of 240.

We evaluated the system using the test samples provided by the sponsoring company.

The similar cases to each query were printed on the screen using KNN algorithm (as per of the company request here $k = 1$, and it might be larger later, but an odd number should be taken for the value of *k)*. In order to calculate similarity between each query and all the 10 cases, an instance of the caseRetriever class is created to do the comparison. The caseRetriever class will create an instance of similarityMetric class to do the calculation according to the formulas shown below. The final similarity is the sum of similarities between students, organizations and projects. The following formulas are shown for illustration:

$$similarity = studentSimilarity + organizationSimilarity + projectSimilarity$$

$$\begin{aligned} studentSimilarity = {} & similarity\ in\ yearOfStudy + similarity\ in\ major \\ & + similarity\ in\ education\_level\_id + similarity\ in\ skills \\ & + similarity\ in\ industry \end{aligned}$$

$$\begin{aligned} & organizationSimilarity \\ & = similarity\ in\ organization\ type + similarity\ in\ organization\ size \end{aligned}$$

$$\begin{aligned} & projectSimilarity \\ & = similarity\ in\ project\ skills + similarity\ in\ project\ industry \\ & + similarity\ in\ available\ funding \end{aligned}$$

If the similarity is more than a specific threshold, then that case would be counted as a similar case to our query and will be stored along with the similarity measure and the value of its feedback which is either positive or negative. In case, none of the cases were

similar to our query, a message will be printed on the screen: “No similar cases found for this query”. Then the similarity measures between the different cases for each query are compared, and the case with the highest similarity will be selected ($k = 1$) as the nearest neighbor to our query and if the feedback is positive, then the query feedback is marked as positive (shows a suitable match) otherwise it will be marked as negative (specifies that the matching between this student, organization and project will not be successful).

At last we only printed out the matches with positive feedback (successful matches to recommend to the students) for each student in the queryList.

Chapter 4 System Design and Implementation

We designed and documented the match-making software architecture using the UML. Figure 2.1 illustrates the UML class diagram for the system.

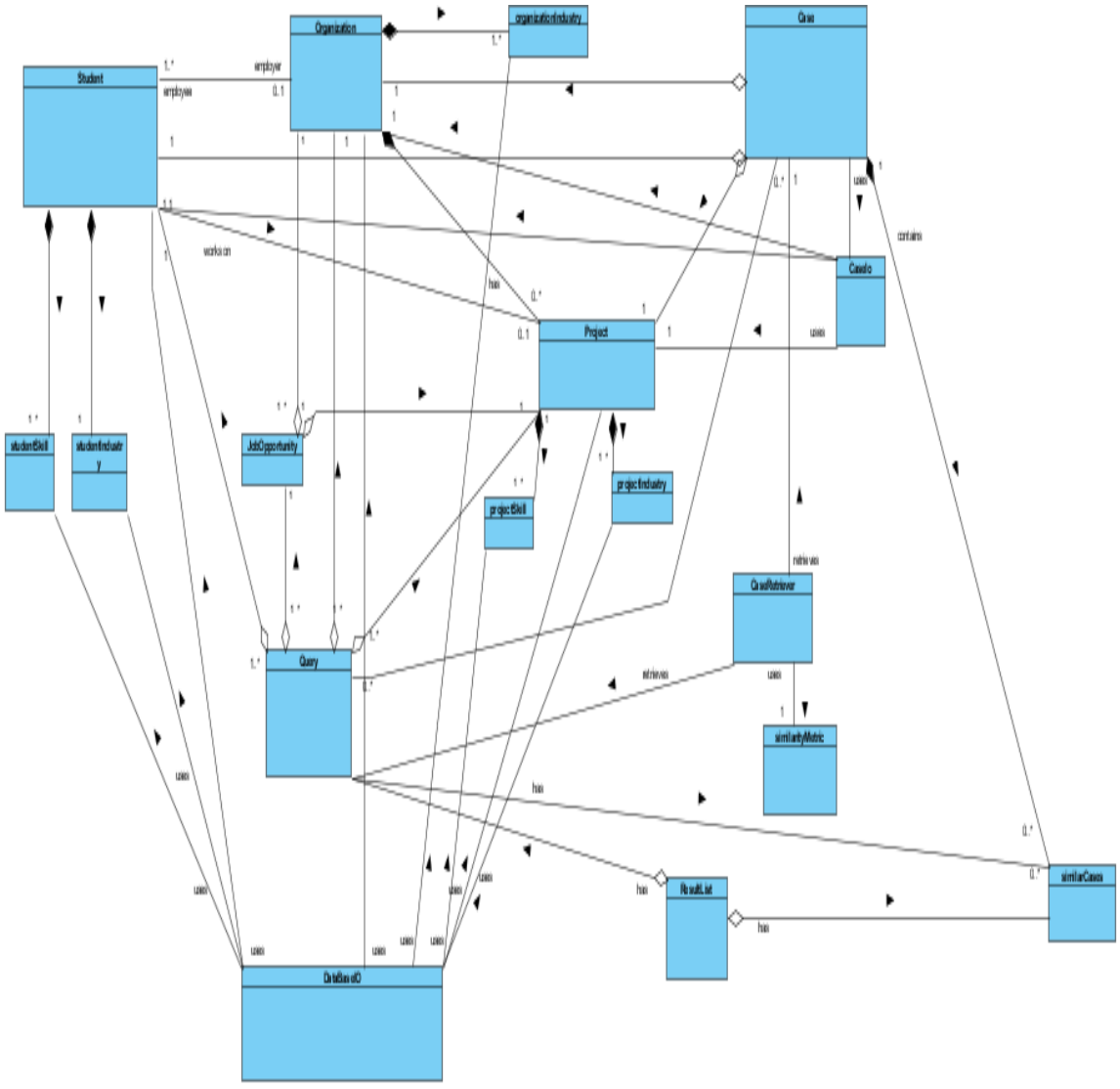
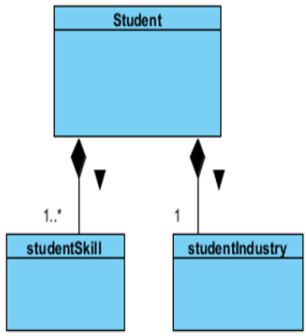


Figure 2.1 Match-making system software architecture

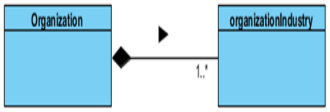
The following brief descriptions of the different classes involved in the match-making system are provided:

1. **Student:** This class describes the student object.
2. **Organization:** This class describes the organization object.
3. **Project:** This class describes the project object.
4. **Case:** This class describes the case object in the case base. Each case object consists of a student object, an organization object, a project object and a variable of string type named *feedback* that can have two values: positive and negative. The feedback variable indicates the relation between the student, organization and project. If the feedback is positive, it shows that the experience of doing the project by the student for the organization was satisfying for both the student and the organization. Otherwise, if the experience was not satisfying, the feedback variable has negative value. The case class has these attributes: case id (integer number), student object, organization object, project object and feedback variable of type string.
5. **Query:** This class describes the query we want to answer; the attributes of this class are Query ID, student object, organization object and project object.
6. **JobOpportunity:** This class is used for matching the organizations with their projects by using business_id attribute common in business_profiles table and projects table. The attributes of this class are organization object and project object that defines a job opportunity.
7. **DataBaseIO:** This class is used for interacting with the database. We use this class to read data from the database.
8. **CaseIO:** This class is used for reading and writing data from/to the case-base.
9. **CaseRetriever:** This class is used for our search process; it implements the search algorithm to find the similar cases in the case-base for our query in the Query list table. In this system *K*NN algorithm is used for finding the nearest neighbours in the case-base.
10. **SimilarityMetric:** This class encapsulates the similarity metric which is used by the CaseRetriever class. Different similarity metrics can be used depending on the type and characteristic of the data.

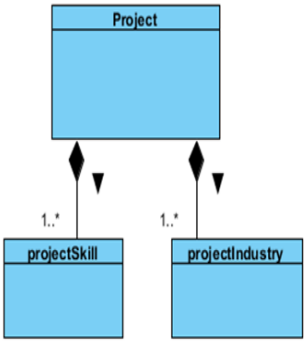
11. **SimilarCases:** This class describes a similar case to the query. The attributes of this class are similarity (Integer number) that shows the value of the similarity between the case and the query in the Query list, and relation (String attribute), which indicates the feedback related to this case.
12. **ResultList:** This class describes the matches found for each query. The attributes of this class are Result ID, student object, organization object, project object, feedback of type string (that indicates that the experience of getting this student to work on the specified project in the company would be a positive experience or a negative experience); the similarity of the nearest neighbour if $k = 1$ is used. If the feedback for this query is calculated according to the number of positive feedbacks and negative feedbacks of the query nearest neighbours, the similarity attribute is null and presents 0.
13. **Main:** This is the main (or process) class that manages the match-making system.
14. **studentSkill:** This class is used to capture student's skills.
15. **studentIndustry:** This class is used to capture industry interest for a student.
16. **organizationIndustry:** This class is used to capture industry information for an organization.
17. **projectSkill**: This class is used for creating skills needed for a particular project.
18. **projectIndustry**: This class is used to capture industry for a project.



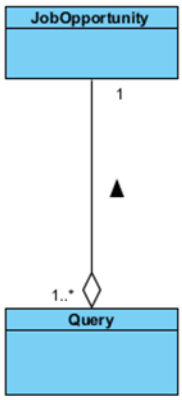
(a) Student subsystem



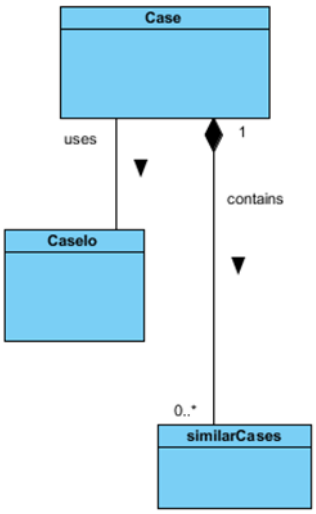
(b) Organization subsystem



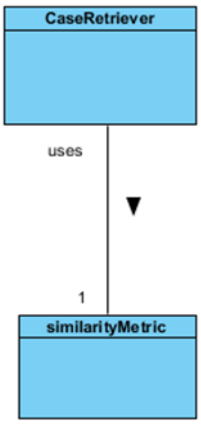
(c) Project subsystem



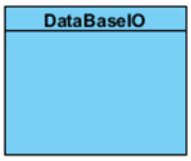
(d) Query subsystem



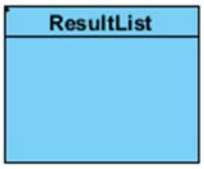
(e) Case subsystem



(f) Retrieve susbsystem



(g) DatabaseIO susbsystem



(h) Result subsystem

Figure 2.2 Subsystems decomposition

As can be seen from Figure 2.1, the class diagram is really large, so we revisit the class structure by grouping them in subsystems, and the subsystems into packages. Finally, the whole system is shown by the relationships between packages which help to analyze the system architecture from a higher-level perspective. We consider 8 subsystems depicted by Figure 2.2.

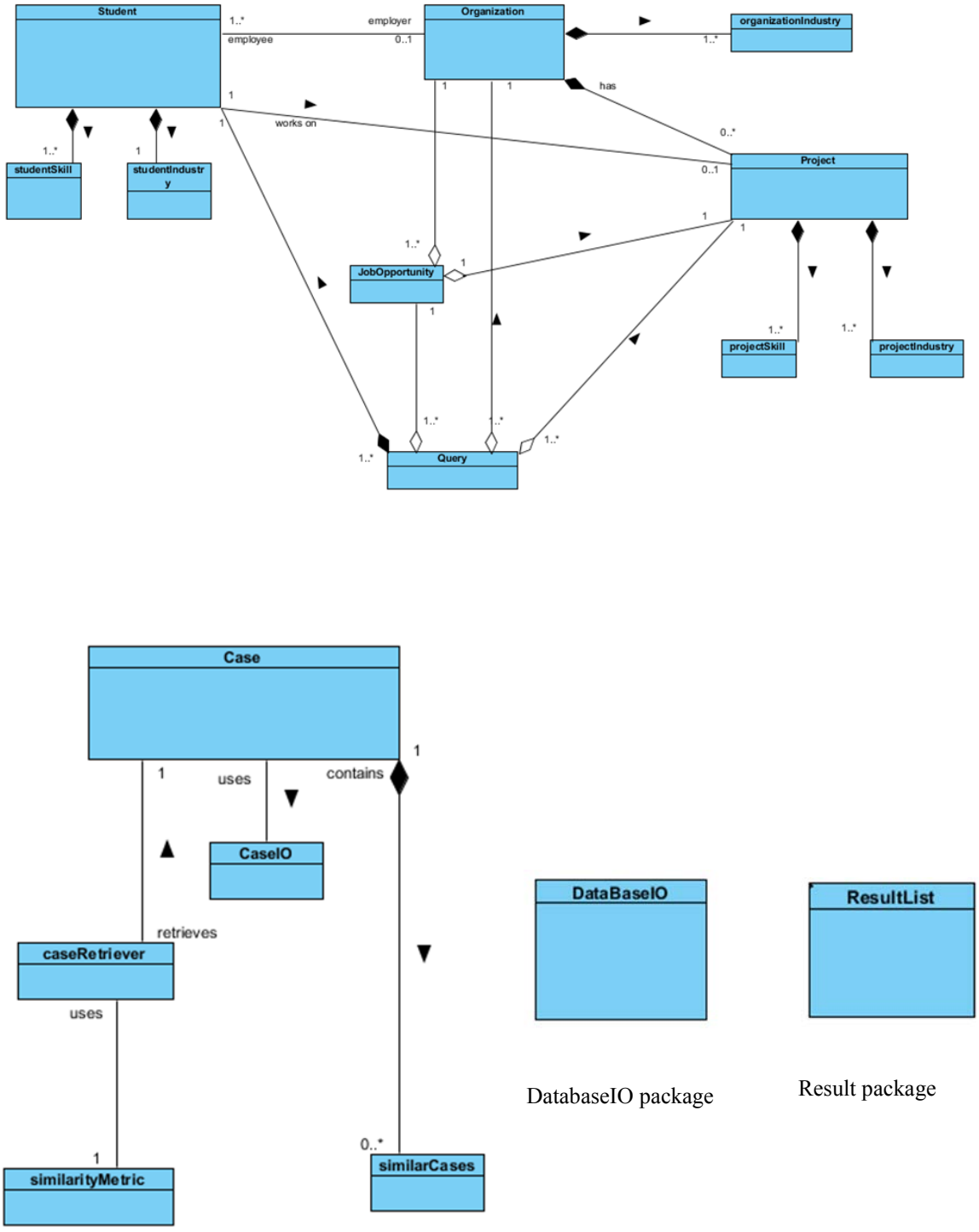


Figure 2.3 Package decomposition

The subsystems are structured into 4 packages depicted by Figure 2.3, and defined as follows:

1. Query package: This package consists of student, Organization, Project and Query subsystems with their relationships in the class diagram.
2. CBR package: This package consists of case and retrieve subsystems.
3. DataBaseIO package: This package contains DataBaseIO class.
4. Result package: This package contains ResultList class.

The Package diagram of the whole system is depicted by Figure 4.

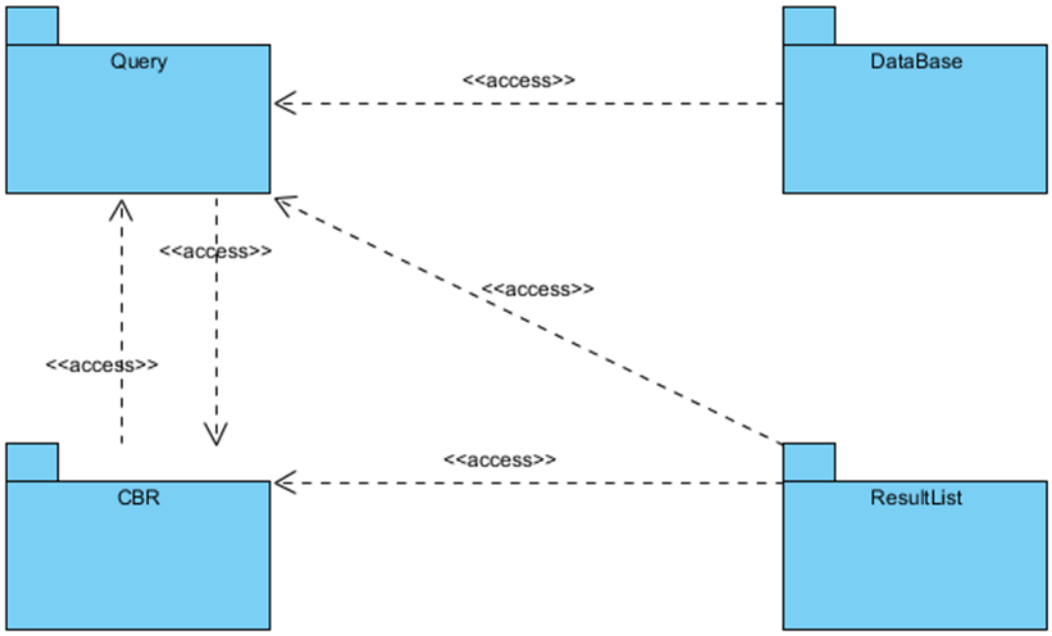


Figure 2.4 Package diagram for the match-making system

The following relationships are defined for the packages listed in Figure 2.4:

1) Query and CBR: Since some of the class elements in Query package have aggregation or association relationships with some class diagrams in CBR

package, there is an access relationship from Query package to CBR package. In contrast, CBR package has also the same relationships with Query Package, hence there is another access relationship from CBR package to Query package.

2) DataBaseIO and Query: DataBaseIO package consists of one class and has association relationship with some of the classes in Query package. This can specify an access relation from DataBaseIO to Query.
3) Result and Query: Result package which contains ResultList class has aggregation relation with one class in Query package; therefore we define an access relationship from Result to Query package.
4) Result and CBR: Result package which contains ResultList class has aggregation relation with one class in CBR package, this defines access relationship from Result to CBR package.

The above system architecture was implemented in Java and deployed on the web portal of the industry partner involved in the project.

Chapter 5 Conclusion

This report presents a match making system using case based reasoning. The case-based reasoning system uses a KNN classifier as its retrieval algorithm in matching students and organizations on projects.

The project was carried out in order to fulfill the requirements set by a Victoria-based e-commerce company. One of the company's critical success factors is their ability to match students with organizations (like what online dating does for singles). However, their previous online matchmaking scheme relied on human experts to manually analyze information from students and companies in order to find adequate matches. Not only our proposed match-making algorithm embodies the existing human expertise, but more importantly, it allows automating the match-making process in more effective way. The proposed algorithm has been fully implemented, and is currently deployed and operating at the company's site.

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