A COMPARATIVE EVALUATION OF

TEXT REPRESENTATION TECHNIQUES

FOR CONTENT-BASED JOB RECOMMENDATION SYSTEM

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# List of Abbreviations

**RS** Recommendation System

**JRS**  Job recommendations System

**CBF** Content Based Filtering

**CF** Collaborative Filtering

**HF** Hybrid Filtering

**BoW** Bag of Words

**NLP** Natural Language Processing

**TF** Term Frequency

**IDF** Inverse Document Frequency

**TF-IDF** Term Frequency Inverse Document Frequency

**IR** Information Retrieval

**IF** Information Filtering

**DL** Deep Learning

NN Neural Network

**DNN** Deep Neural Networks

**FNN** Feedforward Neural Networks

**PNN** Probabilistic Neural Networks

**GloVe** Global Vectors for Word Embeddings

**RBO** Rank Biased Overlap

**ANN**  Artificial Neural Networks

**CV** Curriculum Vitae

**BERT** Bidirectional Encoder Representations from Transformers

**WMD** Word Mover's Distance

# Chapter 1. Introduction

## Introduction

Matching human resources effectively with specific job roles is of great significance to the sustainable and healthy development of human resources management and contemporary enterprises (Ni, 2022). However, the rapid growth of online job portals and the adoption of e-recruitment in the current global panorama, along with the massive digital data they contain, has directed to a notable issue of information overload, affecting both individuals seeking employment opportunities and recruiters who are presented with an abundance of options and choices, thereby making the decision-making process more complex. In addition, the ongoing advancement of technology and shifts in industries are continually generating novel employment prospects that demand a wide range of skills, sometimes leading to a realignment of individuals' career paths and contributing to a misalignment between job seekers and the available job market. In response to these challenges, there have been numerous developments in state-of-the-art technology and systems in the field of online talent management. One notable achievement in this domain is the Job Recommendation System (JRS), which falls under the broader category of Recommendation Systems (RS)—algorithms engineered to offer personalized suggestions to users across diverse content or items (Isinkaye et al., 2015). JRS was introduced as a bidirectional technology-driven solution for job recruiting (Yu et al., 2011), designed to match or rank candidates with relevant job openings via online job portals while considering their profiles, employment histories, and behavioural patterns. As Farber et al. recognized in 2003, JRS represented a tremendous leap forward in this capacity when compared to the traditional and limited Boolean search strategy commonly used in talent management.

Over the last decade, JRS has been studied from various perspectives, and it continues to be one of the hot topics in RS that requires specific attention (Mashayekhi et al., 2022). A large number of research publications have delved into a wide spectrum of algorithms, all with the ultimate goal of developing the most effective structure in the JRS domain. This endeavour has resulted in the development of various technical approaches, each designed to fulfil a diverse need across a range of scenarios and continuously adapting to technological advancements. Even though the classification and ideas are changing swiftly, the foundational principles of most JRS, including the entire RS, have remained relatively consistent, predominantly centred around Collaborative Filtering (CF) and Content-Based Filtering (CBF) recommendations (Guo et al., 2017). CF, in particular, has achieved notable success in various domains of traditional RS in terms of accuracy and has demonstrated its effectiveness in handling different situations where both users (also later referred to as 'job seekers' in JRS) and items (also later referred to as 'jobs' in JRS) undergo daily updates. However, this method comes with inherent limitations in JRS, with CF struggling to address cold-start problems where job seekers have yet to encounter job ads on many occasions, making collaborative methods inapplicable (Su and Khoshgoftaar, 2009).

On the other hand, CBF has proven to be a valuable solution for addressing this challenge, mainly when user and item features and profiles are known and its fundamental concept centres on recommending items with shared contextual similarities (Tran et al., 2017). A noteworthy real-world application of these techniques in JRS can be observed from the 2017 ACM RecSys Conference Recommender Systems Challenge (Abel et al., 2016). This challenge was specifically focused on the task of the job recommendations, with the goal of identifying users interested in job advertisements and matching them with suitable job openings. The challenge attracted a total of 262 participating teams from all over the world, who collectively submitted over 6,100 solutions. The winning system for this challenge was proposed by a team of researchers who advocated for the Content-Based Neighbor Model (Volkovs et al., 2017) as the most effective approach for addressing the challenge in JRS.

While CBF offers its advantages in the field of JRS, it is not without its drawbacks. One major limitation is the hand-engineering of features for job and job seeker profiles, which demands substantial domain knowledge. Consequently, the system's performance depends on the quality of these hand-crafted features (Google, 2023). The second major challenge is the absence of a definitive method for constructing the optimal person-job matching architecture. This challenge is closely tied to the domain's nature, which essentially presents a text mining problem, alternatively addressable as a Natural Language Processing (NLP) challenge. Currently, researchers and enterprises have proposed a plethora of different NLP techniques for CBF, primarily focusing on text representations approaches. This encompasses not only traditional statistical techniques such as Term Frequency - Inverse Document Frequency (TF-IDF) (Bansal et al., 2017), Bag-of-Words (BoW) (Guo et al., 2014), and well-established embedding methods like GloVe (Brahushi and Ahmad, 2022), Word2Vec (Gugnani and Misra, 2020), ELMo (Kurdija et al., 2020), but also transformer-based models like BERT (Panchasara et al., 2023), XLNET (Nguyen et al., 2022), along with large language models (LLM) such as LLaMa and ChatGPT (Salinas et al., 2023), implying their suitability for person-job matching tasks. Unfortunately, the existing body of literature in the field of JRS has inadequately addressed this matter, as there is a notable absence of a comprehensive comparative analysis of the most frequently employed approaches for matching in the content-based e-recruitment domain.

Consequently, a pivotal research questions arise: ‘Which NLP’s text representation architecture for person-job ranking in the content-based job RS domain demonstrates the highest level of effectiveness?', ‘Can novel approaches outperform intermediary and conventional approaches?’. To answer these questions and bridge this research gap, my study aims to pursue a review of academic papers and conduct a comprehensive comparative evaluation experiment, with a particular focus on assessing the performance of the most commonly used NLP techniques for person-job matching or ranking based systems. Through this research undertaking, I aim to make a minor contribution to the realm of JRS by enhancing the current state of research concerning automating job markets and career opportunities in the digital era.

## 1.2 Research Question and Research Objectives

The research aims to address the following *research question*:

***Can the application of Transformer’s encoders, known for their state-of-the-art performance across various NLP tasks, outperform distributed word embeddings or traditional statistical representation methods in improving the accuracy of person-job ranking within job recommendation systems?***

*Research Hypothesis:*

To address the research question raised by this study, it is necessary to formulate it as a set of hypotheses. Depending on the outcomes of the experiment, these hypotheses will either be rejected or accepted. Following the execution of statistical tests to assess differences between the models, if the difference is statistically significant (p<0.05), we reject the null hypothesis and accept the alternate hypothesis.

*H0 (null hypothesis):* A job recommendation system utilising Transformer's encoders for text representation in its person-job ranking algorithm will not show significantly improved accuracy outcomes compared to systems that rely on distributed word embeddings or traditional statistical representations.

*H1 (alternate hypothesis):* A job recommendation system utilising Transformer’s encoders for text representation in its person-job ranking algorithm will show significantly improved accuracy outcomes compared to systems that rely on distributed word embeddings or traditional statistical representations*.*

In addition to the primary hypothesis, this research integrates several supportive objectives. These additional objectives are purposefully crafted to enhance the study, offering greater depth of understanding and supplementary evidence:

* Objective 1: *To conduct a comparative model evaluation experiment among different text representation architectures.* The first objective of the study focuses on conducting a thorough comparative analysis through an experiment. This involves using both a validated benchmark dataset from secondary sources and primary collected data. The experiment will deploy the designed architectures to assess their effectiveness in ranking individuals for jobs. The objective is to identify the strengths and weaknesses of the employed methods and how well they perform in real-world situations.
* Objective 2: *To conduct a comparative human evaluation experiment among different text representation architectures in real-life situations.* The secondary objective of the research entails conducting a detailed comparative experiment involving human evaluation. This experiment utilises primary collected data as well as data obtained through web scraping. It involves implementing the created architectures to test their effectiveness in ranking and matching people with jobs under real-world conditions. The objective also includes determining the strengths and drawbacks of the techniques used, as well as evaluating their practical performance in real-life scenarios.
* Objective 3: *To draw knowledgeable conclusions and formulate evidence-based recommendations.* The third and final concluding objective of the study is focused on integrating the results of the research. The primary aim here is to draw informed conclusions from the results of the comparative evaluation studies. These conclusions are intended to lay the groundwork for recommendations based on evidence, offering key insights to researchers, practitioners, and decision-makers working within the dynamic landscape of JRS. The overarching purpose of this research is to enrich the field by providing data-driven guidance, enhancing the precision and efficiency of person-job ranking, and contributing to the evolving domain of JRS.

## 1.3 Thesis Organization

The flow of the thesis goes in following manner:

*Chapter 1:* Consists of introduction and research question with its objectives.

*Chapter 2*: Describes the background study for the research and the summary of related works by different authors.

*Chapter 3:* Includes the overview of the methodology will detail the experiment proposed address the research questions. It will define the methods, libraries and tools that is used to test the hypothesis as well as the metrics required to evaluate the experiment results and ultimately answer the research questions.

*Chapter 4:* Provides a comprehensive description of the implementation processes undertaken to execute the experiments, along with a presentation of various experimental results and evaluation findings.

*Chapter 5:* Conclusion.

# Chapter 2. Background Study and Related Works

## 2. 1 Information Overload:

According to Wu et al. (2022), the rapid expansion of digital technology and rising internet usage have led to a substantial information overload issue, where customers face an excessive number of options and decisions. Finding relevant and distinctive items and content among the abundance of similar online possibilities has become a pervasive challenge (Roy and Dutta, 2022). As a result, it has necessitated the expansion of one of today's powerful digital tools known as RS. RS are advanced technologies that aid in determining the ranking or user preference for specific items. They have been developed to address the challenge of information overload, sifting through vast and constantly changing data (Konstan and Riedl, 2012), based on the user's preferences, interests, or observed behaviour regarding the product (Karypis, 2001; Pan and Li, 2010). In the present day, RS have evolved into a distinct field of research and stand as one of the most successful web applications, catering to billions of users daily by providing recommendations for diverse content such as news feeds, videos, e-commerce products, music, movies, books, games, friends, jobs, and more (Dong et al., 2022). Their extensive use spans various industries and platforms, including e-commerce websites, streaming services, social media platforms, and content platforms. Prominent e-commerce websites like Amazon (Ha et al., 2017), Netflix (Gomez-Uribe et al., 2016), YouTube (Davidson et al., 2010), Spotify (Millecamp et al., 2018), Facebook (Shapira et al., 2013), LinkedIn (Kenthapadi et al., 2017), Airbnb (Mauro et al. 2021), and Tinder (Bartlett et al., 2023) all leverage recommendation engines to enhance their user experiences. In recent years, there has been an upsurge of different methodologies and approaches for building RS, each varying in the problem domain, the type of information used, and the recommendation algorithm employed for making predictions with the most commonly used methods, such as CF, CBF, and Hybrid Filtering (HF)

## 2.2 Recommendation as a Problem

According to Celma (2010), the issue of making recommendations is divided into two distinct problems: predicting and recommending. The prediction part deals with guessing how likely it is that a user will favor certain items, while the recommendation part concerns with suggesting a list of N items to the user, which also can be reduced as listing of top N items once the system is capable of ranking items in a complete order.

Sarwar and his colleagues in 2001 described the prediction challenge by identifying a group of *m* users and a set of *n* items that could be recommended. Each user has a list of items they have provided feedback on, either directly or indirectly. This list of items for a user is a subset of the total items and could even be empty. They also introduced a function to estimate how likely it is that an active user would prefer an item not already familiar to them.

Furthermore, Sarwar and his team in 2001 explained the recommendation problem as the process of creating a list of N items, chosen from the total set of items, that the user is most likely to enjoy. Specifically, these are the N items ranked highest in terms of the user's estimated preference. This list is carefully ordered and excludes items the user has already shown interest in. Considering the vast number of potential items and users, this process can be quite complex.

## 2.3 Job Recommendation System:

Long before the internet, Vega (Vega, 1990) proposed a novel approach that would connect job seekers with open employment. This system was available via the Minitel terminal, a precursor to the internet, by dialling 3615 and browsing to the LM/EMPLOI service. It allowed users to enter search queries and submit digital resumes via text messaging over the phone line. The system would then match the input against a database using a predefined job taxonomy, identifying a list of job vacancies that could potentially interest the applicant. But it was a complex task that was urging for innovation. Then in the early stages of information systems, the focus of human resource management was largely on the storage and tracking of applicant data through applicant management systems. These systems facilitated internal workflows and communications between the HR department and other departments, as noted by Al-Otaibi and Ykhlef (2012). Initially, elementary methods such as posting job advertisements on the career pages of corporate websites were employed. However, as experience with these initial systems grew, the realization of their potential led to the development of more sophisticated e-recruitment platforms, marking an evolution from simple job posting to more complex job matching solutions. In recent times, job recommendation has gained significant attention and importance on online recruiting platforms (Mashayekhi et al., 2022). Unlike traditional RS that suggest items to users, JRS focus on recommending job applicants to recruiters where the contexts of user and item are likely to be symmetrical. These systems aim to deliver personalized lists of job descriptions to applicants based on their preferences or present recruiters with a curated list of potential candidates who match the job requirements. In order to enhance the quality of recommendations, various recommendation approaches have been devised and incorporated into JRSs.

### 2.3.1 Content-based job recommendation system:

The core idea behind a content based JRS is to suggest jobs or positions to users by comparing the content of job listings to the user's profile, focusing on how similar they are. The definition of ‘content’ varies widely, depending on the specific field the system is applied to, resulting in a variety of variables that can be utilized for this purpose (Gao et al., 2012). Within JRSs, the content-based approach mainly depends on measuring the semantic similarity between the user's profile and job descriptions to generate recommendations. This similarity estimation helps in determining the relevance of each job opening to the job seeker. The fundamental process involves gathering content details from both job seekers and job descriptions, followed by evaluating their similarities. This typically involves selecting relevant features to use and converting this information into formats understandable by computational devices for subsequent analysis. Various methods have been employed for this conversion, including the Bag-of-Words (BoW) model with TF-IDF weighting (Mpela and Zuva, 2020), Latent Dirichlet Allocation (Bansal, Srivastava & Arora, 2017), along with more modern approaches like Word2vec (Gugnani and Misra, 2020; Vaverde-Rebaza et al., 2018; Janusz et al., 2018) and BERT (Vanetik, 2023). Despite the emergence of new techniques, content-based recommendation's contributions have remained notably consistent over the past decade, with ongoing recommendations from researchers for its use in JRSs. The key steps in CB methods typically involve:

1. *[u1, u2 … um] ∈ U, [ j1, j2 … jm] ∈ J*
2. Begin
3. Modelling *jobs j ∈ J, Content(j)*
4. Modelling user’s preference *u ∈ U, UserProfile(u)*
5. Estimate utility value of job *j* for user *u*.

*fcb(u, j) = Sim(user profile(u), content(j))*

1. Return *Top-N* of jobs based on value of *f(u,j)*
2. End.

*Where: Input:*

* *U = {u},* set of users
* *J = {j},* set of all available jobs

*Output:*

* *[u1, u2 … um] ∈ U,* return a ranked list (*Jto pn*) of potential jobs to recommend for *u*.

## 2.4 Text representation:

Human language is characterized by its intricate complexity and variability, featuring a broad spectrum of words, grammatical constructions, phrases, and subtle linguistic distinctions. For computers to interpret and handle these complexities effectively, text needs to be converted into a structured, numerical form that is accessible to algorithms. This conversion is achieved through text representation, a key element of NLP, enabling the transformation of textual information into a machine-readable format (Szymański, 2014). For a given set of text documents *D = {di, i=1, 2..., n},* where each di stands for a document, the problem of text representation is to transform each *di* of *D* as a point *si* in a numerical space *S*, where the distance or similarity between each pair of points in space *S* is well defined. Various methods exist for representing text features, each offering unique benefits and limitations.

### 2.4.1 Bag of Words (Bow):

BoW is the simplest form of statistical representation of text and one of the earliest (Baeza-Yates and Ribeiro-Neto, 1999). This approach views each document as a bag containing words, ignoring the sequence and grammatical structure of the text. It constructs a fixed-length vector, with each dimension representing a distinct word from the overall text collection. The value in each dimension reflects the occurrence frequency of the corresponding word within the document. While BoW is straightforward and effective for basic tasks, its major drawback is the lack of contextual understanding; it cannot grasp the semantics of words or phrases. BoW simplifies the transformation of unstructured text into a structured, numerical format suitable for machine learning algorithms. In the BOW model, a text document is represented as a collection of unordered terms. Given the document collection <*D = {di, i=1, 2..., n}>,* suppose there are m unique terms appeared in this collection. Mathematically, this corpus of documents can be represented by a *m* by *n* matrix <*S ∈ Rm\*n>*. Each text document is denoted by a column vector <*si, i = 1, 2 …, n>* and each term is denoted by a row vector. The *jth* entry of *si*is denoted by <*sji , j = 1, 2, …, m> (Liu and Özsu, 2009).*

Because of its simplicity and speed, BoW is often used as a preprocessing stage in more advanced statistical methods. However, the major drawback of it is that it only retains the frequency of the words in the document and loses the sequence information, disregarding grammar, and word order.

### 2.4.2 Term Frequency - Inverse Document Frequency

BoW can be extended by using weighting schemes that relate documents with words. One of the most popular extensions is TF-IDF. It enhances its predecessor model by considering the importance of words in a document relative to their frequency across the entire corpus (Aizawa, 2003). It operates on the principle of assigning weights to words based on their occurrence rate within a specific document (term frequency) and their rarity or commonality across the entire corpus (inverse document frequency). To determine the weight of any given word, TF-IDF calculates both the term frequency (TF) and inverse document frequency (IDF) and then multiplies these two values, as demonstrated in the following formula:

*TF (t, d) =*

*IDF(t) = log*

*TF-IDF (t, d) = TF (t, d)\*IDF (t)*

Where:

* TF refers to the ratio of the count of a specific word in a document to the total number of words in that document.
* IDF refers logarithm of the quotient of the total number of documents in the corpus by the number of documents containing the term T.

While TF-IDF reduces the influence of common words, thereby enhancing the contribution of more significant terms to a document's representation, the method remains straightforward and scalable, which is advantageous for analyzing large volumes of text. However, it shares a limitation with the BoW model in that it does not capture the positional context of words within the document (Ramos, 2003). Additionally, TF-IDF's effectiveness is highly dependent on the specific corpus it's applied to. For instance, a matrix representation derived from football data would not be applicable to tennis or basketball data. This underscores the importance of using high-quality training data for the model to be effective (Zhang et al., 2011).

Word embedding:

## 2.2 Related Works

Recognising the broad and varied scope of this domain, the review of related works is systematically divided into three distinct subsections. Each subsection is dedicated to a specific category of embedding methods in the RS: the classic TF-IDF, the more advanced Word2Vec, and the latest transformer encoders, BERT. This structure allows for a comprehensive exploration of the embedding landscape, from the foundational techniques to the latest advanced techniques. The decision to cover a broad spectrum of RSs arises from the observation that comparative experiments specifically tailored to the job recommendation domain are scarce.

### 2.2.1 TF-IDF in Comparative Experiments for Recommendation Systems

Romadon et al. (2020) reported that combining TF-IDF with ANN for RS classification problems works better than Word2Vec embeddings because TF-IDF has a higher average accuracy rate of 80.55% compared to 71.22% for Word2Vec. The study suggests that TF-IDF's enhanced capability in extracting relevant features for the task of classifying job applicant texts contributes to its better performance. It is proposed that augmenting the dataset and concentrating on high-accuracy criteria could further enhance results. Similarly, in 2021, Zhu developed a system for recommending scholarly articles from PubMed that are relevant to public datasets from the Gene Expression Omnibus (GEO). This system utilises and evaluates various methods for text representation. The results showed that methods based on term frequency, like BM25 and TF-IDF, worked better than all the others. This included well-known NLP embedding models like Doc2Vec, ELMo, and BERT.

The utilization of TF-IDF for categorizing CVs in relation to job openings was highlighted as a significant advancement. This method proved instrumental in assisting employers to find suitable candidates whose skills and experiences aligned with the job criteria, specifically within targeted geographic locations. According to Apaza et al. (2021), the success of TF-IDF in parsing and analyzing CV data underscored its importance as a powerful tool in the development of RS for job matchmaking.

Brahushi and Ahmad (2022) conducted a study to evaluate the efficacy of a hybrid two-way RS compared to the rankings of resumes and job descriptions by human experts. The research devised four distinct scenarios—matching resumes to resumes, jobs to jobs, resumes to jobs, and jobs to resumes—using a dataset of 400 documents to create a standard based on human rankings derived from content similarity. GloVe (Global Vectors for Word Embeddings) and TF-IDF methods were used to calculate cosine similarity scores across all scenarios and see how well the system matched these human-generated rankings. The comparison of system-generated rankings to human rankings utilised the Rank Biased Overlap (RBO) similarity score as the evaluation metric. The results showed that both GloVe and TF-IDF had median RBO scores above 0.5, but TF-IDF generally did better than GloVe, especially when comparing resumes to resumes, where the difference was very clear. This indicates that although both embedding approaches are capable of reflecting human judgement in the ranking of resumes and job descriptions, TF-IDF demonstrates a slightly superior congruence with human rankings in the majority of the scenarios.

### 2.2.2 Word2Vec in Comparative Experiments for Recommendation Systems

The comparison between TF-IDF and Word2Vec vectors in the context of job postings was done by Elsafty et al. (2018). The study revealed that Word2Vec models significantly outperform the TF-IDF baseline. The precision at the P@10 score for TF-IDF was only 8.69%, while Word2Vec models achieved scores ranging from 54.84% to 56.22%. Further enhancements using Word2VecF and Doc2VecC, particularly when combined with TF-IDF weights, led to even higher precision scores, reaching up to 64.23%. Compared to sparse representations of TF-IDF, this shows that dense vector representations are better at finding semantic similarities between job descriptions.

Shrestha (2020), in her study, highlights the comparison between TF-IDF and Word2vec (including Word Mover's Distance, WMD) techniques for JRS. The study found that Word2vec offers better recommendations due to its ability to capture the semantic meanings of words in job profiles, which TF-IDF lacks. Word2vec showed an accuracy increase of 7% over TF-IDF, and even when further refined with WMD, it showed promising results with a precision and recall increase of 4% over TF-IDF. Despite the promising results, the study acknowledges the limitations due to the size and specificity of the dataset used, suggesting that a larger dataset could improve the accuracy of these models. This conclusion underlines the potential for Word2vec and similar techniques to enhance the effectiveness of JRSs, recommending further research with larger, real-world datasets and online experiments with many users for comprehensive evaluation.

### 2.2.3 Bert in Comparative Experiments for Embedding

In the exploration of novel text representation techniques for comparison in RS, several studies have made significant contributions. In 2021, Lavi et al. created ConSultantBERT, a BERT model that has been fine-tuned and built on top of the Siamese SBERT framework. It performed better than both unsupervised and supervised baselines that use TF-IDF features and pre-trained BERT embeddings. The innovation demonstrated superior capability in handling multilingual and cross-lingual matching, making it a powerful tool for feature representation in JRS. The success of ConSultantBERT is attributed to its fine-tuning on a large-scale, real-world dataset, optimising cosine similarity in embeddings for precise resume-vacancy matching. Singh et al. (2023) explored the domain of social networking, focusing specifically on LinkedIn, to enhance the site's post-recommendation mechanism. They created content-based RS using machine learning, GPT-2, and BERT to provide more personalised content to users. Their research revealed that BERT outperformed other models in identifying similarities between the content users generate and the posts recommended to them, highlighting its capability to significantly improve user engagement and satisfaction on LinkedIn.

Neelima and Mehrotra (2023) offered a thorough examination of word embedding techniques, organising them into traditional, static, and contextualised categories. They emphasized the efficiency of BERT in generating contextualized word embeddings, which, when integrated with NN models, improved accuracy in diverse NLP tasks like sentiment classification and text categorization. Their study highlighted the dynamic development of word embeddings and their vital contribution to replicating human cognitive functions within computational models. Focusing on the critical issue of Islamophobia, the study by Saeed et al. (2023) employs text data mining and NLP techniques to identify Islamophobic content on social media platforms. The study shows that transformer-based algorithms like BERT and GPT are good at classifying texts by using Latent Dirichlet Allocation for topic modelling and Word2Vec and GloVe for feature extraction. The empirical analysis conducted reveals that these advanced techniques, particularly when used in conjunction with traditional textual features, offer a solid strategy for detecting Islamophobic narratives, with the BERT and GPT models achieving notable F1 scores.

## 2.3 Research Gaps

The existing literature on the comparison of text representation techniques within JRS is somewhat limited. A detailed analysis of the available papers reveals that each embedding method, including traditional and novel techniques, has its own unique advantages and limitations, and their effectiveness can vary widely based on the specific application scenario. For example, comparisons between TF-IDF and Word2Vec have been made in the context of JRS, yet the outcomes of their effectiveness differ greatly, influenced by the system's architecture and its various components. There are instances where TF-IDF has shown superiority, while in other scenarios, Word2Vec embeddings have been more effective. This inconsistency makes it challenging to draw definitive conclusions on the preferable choice of text representation technique for JRS, given the countless configurations and possibilities available for system design. Recent studies have highlighted BERT's impressive capabilities in numerous NLP tasks, including RSs, by leveraging its encoding features. Yet, the direct comparison of these three embedding models—TF-IDF, Word2Vec, and BERT—within the same JRS framework has not been explored. This oversight represents a current gap in the literature, particularly in evaluating the performance of JRSs using the vector representations provided by these techniques.

This research seeks to address this gap by conducting a thorough comparative analysis of these prominent embedding techniques within a self-designed JRS architecture. It is crafted to evaluate the embeddings through tests including classification accuracy, job ranking efficiency, and human-centric evaluation. By doing so, this study aims to provide a clear, empirical basis for selecting embedding techniques in the development of more effective and nuanced JRS, thus contributing subtle insights to the field.

# Chapter 3. Research Methodology

To address the primary research question, it is essential to conduct an evaluation procedure, and the evaluation of the system is the cornerstone of research methodology in RS, which evolved from experimental practice in Machine Learning (ML) and IR (Castells and Moffat, 2022). Both RS and JRS are typically assessed either online or offline manner. Online assessment involves the real-time evaluation and testing of the recommendation algorithms and models while they are actively being used by users in a live or production environment. This approach is used to measure the system's performance and efficiency under real-world conditions. While it is deemed effective in measuring experimental outcomes, it is a costly and time-consuming approach, generally favoured by only industry experts (Peska and Vojtas, 2020). On the other hand, offline evaluation and offline metrics are most commonly used in academic settings due to their ease of execution, repeatability, speed, and flexibility in accommodating various recommendation models (Gilotte et al., 2018). An offline experiment is conducted using a pre-existing dataset of users and items. Its objective is to closely replicate the data that the system is anticipated to encounter when it is deployed online (Gunawardana and Shani, 2015). And for this research, the offline evaluation and online evaluation are conducted to access and compare three different text representation models in JRS. In addition, it is important to mention that this study employs a unique methodology similar to online evaluations used by industry but diverges by integrating real, volunteer participants who remotely participate in the experiment. This approach allows to combine the scalability and accessibility of online evaluations with the authenticity and commitment of volunteer participants who have proactively agreed to contribute to our research.

A close-up of a sign

Description automatically generatedFigure provides an overview of the main structure of the custom architecture for JRS. The operation of this architecture follows a left-to-right sequence. The process begins by taking input data from job seekers and job listings, then passes through a series of iterative processing units to generate output data containing recommended profiles and job listings. These three components can be considered as the core and central components of the entire system. It’s where the text representation techniques will be applied to and rank the jobs or candidates based on the conditions and details they provided. The subsequent sections will interpret niceties of the design and experimental procedures for each segment of the system. Additionally, it will cover the sampling strategies employed, the ethical guidelines adhered to, and the configuration of the experimental setup.

## Sampling Strategy

Careful selection of an appropriate sampling approach plays a crucial role in achieving the objectives of the study, as emphasized by Stratton in 2021. For this particular experiment, it is essential to have two distinct, well-structured datasets: one for individuals seeking employment and another for available job listings. As mentioned in previous section, the job seeker dataset acts as a representation of the experiment's participants, mirroring the demographic characteristics from which the subjects are drawn. Conversely, the job listings dataset represents the 'job listing pool.' These datasets provide the context within which participants engage in the matching and ranking process, employing content based JRS and various text representation methods.

Below, an overview of the selected sampling strategies for each dataset is provided, including specific considerations and underlying rationales informing these choices.

### 3.2.1 Job Seekers’ Dataset

Before selecting participants to represent the job seeking population, it is critical to consider the following sampling limitations:

1. Difficulty in defining the complete job searchers population*,* whether it refers to an entire nation or a smaller geographical region. This complication arises from the multitude of job seeker’s categories, including those who are actively seeking, passively looking, monitoring, or transitioning between these states due to their dynamic nature (Bortnick, 1992).
2. Unlike other populations such as voters, licensed professionals etc., there is often no unified registry or database that encompasses the complete information of all job seekers, which collectively contribute to the limited accessibility of this population.
3. In this situation, the information provided by participants will only be used to evaluate and compare system architectures and interact with the data in the job listing pool. Any findings and conclusions drawn from the use of the sample won’t be used for generalization of the entire population (Yin, 2009).

A circular network with many circles

Description automatically generated with medium confidenceGiven the limitations indicated above, the convenience technique was the most suitable option for selecting participants in the experiment. In addition, it is important to point out that the limitations, as mentioned earlier, fit  *Figure . Advantages of convenient sampling.*

A screenshot of a cell phone

Description automatically generated precisely the qualities defined by Etican et al. in 2016. They describe convenience sampling as a non-probabilistic technique in which participants are chosen based on their accessibility and proximity. It is a convenient and cost-effective method that allows researchers to quickly collect data from voluntarily available individuals ready to engage in the experiment (refer to Figure 4).

Furthermore, they underscore the common use of this method in situations where obtaining a random or representative sample is challenging. However, it is essential to acknowledge that convenience sampling comes with its own set of limitations, as the samples obtained may not precisely mirror the broader population, necessitating caution when interpreting and generalising results derived from convenience sampling.

As for the recruitment of volunteers, the online social media platform, more specifically Facebook, is used due to its cost-effectiveness and faster sample acquisition (Antoun et al., 2016). A Google Form, which I constructed beforehand for the experiment (Bulgan, 2024), along with a well-articulated post that clearly explained the objectives of the research and the anticipated time *Figure. Screen shot of the Google Form.*

commitment, was posted on the local Facebook communities known for daily postings of job offers and job seeker ads (refer to Figure \*). These groups are ‘[Ireland Job Vacancies And Employment](https://www.facebook.com/groups/1618183571730254/)’ (162.9K members), ‘[Jobs Ireland](https://www.facebook.com/groups/jobsearchireland/)’ (128K members), ‘[DUBLIN JOBS](https://www.facebook.com/groups/1415280002101858/)’ (49.0K members) and ‘[Ирланд дахь ажлын зар](https://www.facebook.com/groups/2017664791841533/)’ (6.6K members). Once potential volunteers were attracted, detailed information about participation requirements, risks, benefits, and the rights of participants was provided through personal messages.

Two individuals expressed interest in the research by requesting further details through direct messages on Facebook, and another person completed the Google Form via the shared link. At the time of the initial online meeting, all three were actively seeking employment and after receiving more detailed information regarding to the experiment and its aims, all three people agreed to participate in it by sharing relevant personal information. Two of them gave their written consent through Facebook direct messages, while the third individual marked all queries and sections concerning confidentiality, participation, and consent to share personal information on the Google Form by selecting 'yes', which is equivalent to providing written consent. Afterwards, the volunteers were invited to engage in the first phase of their participation in the experiment – the online interview. An online video call was arranged for each participant, during which they were requested to provide information relevant to their job search by answering prepared questionnaires. The formulated questions were:

1. Name or Nickname. Please provide your name or nickname that you want to use in my research. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential. You can provide your actual name or full name if you wish. Alternatively, if you're not comfortable with that, you can choose to go by a nickname or a made-up name.
2. Contact information. Please provide the contact details you prefer, whether it's your mobile number, personal email, or any other social media profile that I can use to contact you throughout my research. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential.
3. Job role of interest. Please provide details about your preferred field of interest or the specific job title you have in mind. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential.
4. Educational information. Please provide your highest level of education and details regarding your major field of study. Additionally, include information on any other degrees or certificates obtained beyond your highest educational achievement. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential. You may choose not to mention the names and graduation year of the institution or educational organisation if you're not comfortable providing those specifics.
5. Skills information. Please provide your personal skills information, encompassing both hard and soft skills acquired through prior work experience or training. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential.
6. Experience information. Please provide your professional experience details. You can mention in this field the length of time spent in previous roles related to your current field of interest. Additionally, highlight any skill-based experiences that are relevant. If there's no relevant experience, feel free to enter <None>. Be assured that the information provided by you will be exclusively used for research purposes only, and any details that could identify you will remain confidential. You may choose not to mention the names of the businesses and organisations where you worked previously if you're not comfortable providing those specifics.

However, the two agreed for a voice call rather than a video session and requested not to record the conversation. Another participant declined all call requests but consented to complete the Google Form. Moreover, all three participants wished to maintain the confidentiality of their age, gender, names, contact details, and any other potentially identifying information. Below, tables present the information gathered from each participant through voice calls and the Google Form. For privacy reasons, participants will henceforth be referred to as 'user\_1', 'user\_2', and 'user\_3' in this experiment.

|  |  |  |  |
| --- | --- | --- | --- |
| **1. participant** | user\_1 | user\_2 | user\_3 |
| **2. data\_collection** | Voice Call | Voice Call | Google Form |
| **3. date** | 2023-12-17T15:30:00.000000 | 2023-12-27T11:50:00.000000 | 2023-12-31T13:39:00.000000 |
| **4. location** | Dublin, Ireland | Dublin, Ireland | Dublin, Ireland |
| **5. preferred\_position** | Registered nurse | Electrician | Data analyst |
| **6. education** | Graduate diploma: Critical care nursing | High school diploma  Vocational electrician certification  Construction safety certification | Degree:  Master of Science in Data Analytics,  Bachelor of Science in BA  Certifications:  Microsoft Certified - Azure Data Scientist Associate,  Google Data Analytics Certificate |
| **7. skill** | patient care  wound care  medical procedures  adult nursing  infection control  diagnostic  time management  communication skills  attention to detail | Circuit testing  Blueprint reading  Fault finding  Electrical wiring  Troubleshooting  Inspection equipment  Installation  Organization  Maintenance  Diagnostic  Independent worker  Safety knowledge | Python  Data Mining and Extraction  Data Analytics and Visualization  ETL Pipeline  Data Reporting  Database Management Systems  SQL and NoSQL  Machine Learning  A/B Testing  Data Governance |
| **8. experience** | Registered Nurse – 3 years | Residential Electrician's Helper 1 year | Entry Level Data Analyst: 1 year  Data Coordinator: 2 years |

*Table . The job seeker’s data*

### 3.2.2 Job Offers’ Dataset

For the data collection of the job offers dataset, the web scraping technique has been used to gather publicly available data from Indeed.com. The domain of web scraping offers various techniques in different formats, each offering unique benefits. In this experiment, the Python library Selenium is chosen as the data collection tool for the job listing pool due to its user-friendliness and robust community support (Chapagain, 2019). The primary aim of employing this tool has been to extract publicly accessible information from the Indeed job platform for use in the experiment. It is crucial to acknowledge that collecting random job listings or the entire job database from the platform is not feasible. Instead, collection was done on the outcomes of a keyword search using the job title information that each participant provided in order to create a validation test that replicates real-world scenarios for our system architectures.

The logic behind the extraction process is as follows: An experiment participant expressed during their interview an interest in nursery-related positions, leading to the collection of all job advertisements from Indeed resulting from a 'nurse' keyword search. On January 10, 2024, a total of 564 job ads related to nursing in Dublin and surrounding areas were gathered from Indeed. Subsequently, on January 20, 2024, an additional 194 jobs were collected using the same search criteria to enrich the pool of job listings. As shown in Figure 1, the emphasis is on extracting specific information from these job postings, including the job title, required skills, necessary experience, and educational requirements. All other data were excluded from the experiment for reasons thoroughly explained in the ethical considerations section of the thesis.

A screenshot of a computer

Description automatically generatedFollowing the final extraction, a dataset consisting of 1166 unique job advertisements, corresponding to the job titles of interest to the participants, was extracted from Indeed.com on two separate occasions, January 10th and 20th. It consists of six columns, each providing details such as the job title, job ID, page URL, posting date, assigned position label, and a detailed job description (refer to Figure 0). These columns encompass all the relevant information that was available on the website link. It's important to note again that certain details like salary, contact information, organisation locations, office location, etc. have been excluded from the job descriptions as mentioned earlier.

*Figure: Selection of random rows from the final DataFrame containing the extracted job ads.*

## Experimental Setup

The experiments were conducted using a Jupyter notebook on a computer equipped with the following hardware and software:

* Operating System: Windows 10, version 10.0.22631-SP0
* Python Environment: Python 3.11.4, release date July 5, 2023
* Processor: Quad-core CPU with a speed of 2496 MHz
* Graphics Card: NVIDIA GeForce GTX 1650
* Memory: 31.87 GB RAM
* Storage: 237.45 GB on the hard drive

Detailed documentation of the experiment's execution and the chronological coding activities are available on the GitHub repository at the following URL: <https://github.com/temulenbd/capstone_project>

## Experiment 1: Classification

### 3.3.1 Objective of the Experiment:

As mentioned earlier, the proposed JRS consists of three distinct components. The first part of the system, known as the Classification unit, labels the collected data of job seekers and job postings into distinct categories. The initial test will be implemented in this component, with the objective of assessing the quality of different text representation techniques in text classification within the JRSs. The outcomes of this experiment are crucial in addressing the research's first objective, by identifying the most effective embedding technique for a current assignment.

### 3.3.2 Model Selection

The simplicity of use is essential, given the study encompasses several experiments. Opting for a straightforward classification model allows for a clear demonstration of how embedding techniques affect the model's performance. Consequently, Logistic Regression was selected as the final layer for downstream tasks in this unit, which receives input from three distinct embedding methods.

*A diagram of a software structure

Description automatically generated*BERT: Built on a Transformer architecture, BERT incorporates several layers of multihead attention mechanisms. Unlike other language models, BERT processes the context from both sides at the same time, from left to right, across all of its layers when it trains bidirectional representations from text that hasn't been labelled. Essentially, BERT's self-attention mechanism operates bidirectionally, enabling a more comprehensive grasp of the context and flow of language than models that work in a single direction. Consequently, BERT can achieve top-tier results in NLP applications by adding just one more output layer for fine-tuning (Rückert and Sjögren, 2022). In this unit, the pre-trained Bert-Base-uncased model was selected for fine-tuning on a downstream classification task. The process involves extracting the values of the last hidden state, as shown in a figure 2, from its encoder layers for the purpose of model evaluation. The Bert-Base model is comprised of approximately 110 million parameters, with its architecture containing 12 transformer block layers and each layer housing 768 hidden units. Additionally, this model is equipped with 12 self-attention heads, enhancing its ability to focus on various segments of the input for improved context understanding and capture (Wolf, 2019).

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