Portfolio Theory of Information Retrieval

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ABSTRACT

This paper studies document ranking under uncertainty. It is tackled in a general situation where the relevance predictions of individual documents have uncertainty, and are dependent between each other. Inspired by the Modern Portfolio Theory, an economic theory dealing with investment in financial markets, we argue that ranking under uncertainty is not just about picking individual relevant documents, but about choosing the right combination of relevant documents. This motivation us to quantify a ranked list of documents on the basis of its expected overall relevance (mean) and its variance; the latter serves as a measure of risk, which was rarely studied for document ranking in the past. Through the analysis of the mean and variance, we show that an optimal rank order is the one that balancing the overall relevance (mean) of the ranked list against its risk level (variance). Based on this principle, we then derive an efficient document ranking algorithm. It generalizes the well-known probability ranking principle (PRP) by considering both the uncertainty of relevance predictions and correlations between retrieved documents. Moreover, the benefit of diversification is mathematically quantified; we show that diversifying documents is an effective way to reduce the risk of document ranking. Experimental results in text retrieval confirm the theoretical insights with improved retrieval performance.

Categories and Subject Descriptors

H.3.3 [Information Search and Retrieval]: Retrieval models, Search process, and Selection process

General Terms

Algorithms, Experimentation, Measurement, Performance

Keywords

Modern portfolio theory, Mean-variance analysis, Probability ranking principle, Ranking under uncertainty

1 Introduction

Information retrieval (IR) concerns how to retrieve documents for a user information need. The process of retrieving documents may be divided into two stages. In the first stage, the relevance between the given user information need and each of the documents in a collection is calculated. Probabilistic retrieval models that have been proposed and tested over decades are primarily focusing on this task, aiming at producing a "best guess" at a document's relevance. Examples include the RSJ model [15] (a further development of that model led to the BM25 term weighting function [16]), and the language modelling approaches [23]. The second stage focuses on how to present (normally rank) documents to the user. The probability ranking principle (PRP) [6] forms the basis in this stage, stating that the system should rank documents in order of decreasing probability of relevance; it has been shown that, following the principle, the overall effectiveness of an IR system, such as expected Precision, is maximised [13].

If we make an analogy with the field of finance, our ranking task resembles the investment problem in financial markets; for example, suppose that an investor needs to select a set (portfolio) of n stocks that will provide the best distribution of future return, given his or her investment budget — an analogy with IR is that we invest ranking positions in documents. The PRP of IR might suggest that, for optimal selection, one should first rank stocks in order of decreasing future returns and then choose the top-n most "profitable" stocks to construct the portfolio. Such a principle that essentially maximises the expected future return was, however, rejected by an economist Harry Markowitz in his Nobel Prize winning work, the Modern Portfolio Theory (MPT) of finance, in 1952 [11]. As one of the most influential economic theories dealing with finance and investment, the MPT was motivated on the basis of the following two observations [11]. 1) The future return of a stock is unknown and cannot be calculated with absolute certainty. Investors have different preferences of the risk associated with uncertainty. Therefore, it is highly desirable to have a method of quantifying this uncertainty or risk, and reflect them and incorporate users' risk preferences when selecting stocks. 2) Since in practice the future returns of stocks are correlated, assuming independence between the returns and selecting them independently to construct a portfolio is not preferable.

Realizing the two fundamental issues, the MPT emphasises that risk (uncertainty) is an inherent part of future return, and quantifies it by using the variance (or the standard deviation) of the return. The theory suggests that, for a risk-averse decision, an investor should both maximise the return as a desirable thing and minimise the variance of the return as an undesirable thing. Under such a formulation, the MPT mathematically shows that diversification, known as "not putting all of your eggs in one basket", is an effective way to reduce the risk of the portfolio.

Going back to our IR problem, we have two similar critical issues: 1) during retrieval, the relevance of documents is unknown and cannot be estimated with absolute certainty from IR models. There are many sources of uncertainty such as ambiguity in the query, specific user preferences,

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