BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF INFORMATION TECHNOLOGY
FAKULTA INFORMAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF INTELLIGENT SYSTEMS
ÚSTAV INTELIGENTNÍCH SYSTÉMŮ

REINFORCEMENT LEARNING FOR AUTOMATED STOCK PORTFOLIO ALLOCATION

VYUŽITÍ ZPĚTNOVAZEBNÉHO UČENÍ PRO AUTOMATICKOU ALOKACI AKCIOVÉHO PORTFOLIA

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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BRNO 2023

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF INFORMATION TECHNOLOGY

Bachelor's Thesis Assignment

148202

Institut:	Department of Intelligent Systems (UITS)
Student:	**Lapeš Zdeněk**
Programme:	Information Technology
Specialization:	Information Technology
Title:	**Reinforcement Learning for Automated Stock Portfolio Allocation**
Category:	Artificial Intelligence
Academic year:	2022/23

Assignment:

1. Study the state-of-the-art methods for automated stock portfolio allocation. Focus on the methods based on reinforcement learning and planning in Markov Decision Processes.
2. Experimentally evaluate selected open access tools for automated portfolio allocation including e.g. FinRL-Meta and identify their weak points.
3. Propose and implement improvements of a selected method/tool allowing to mitigate theseweak points.
4. Using suitable benchmarks and datasets, perform a detailed experimental evaluation of the implemented improvements with the focus on the portfolio allocation returns.

Literature:
Rao A., Jelvis T., Foundations of Reinforcement Learning with Applications in Finance. 1st Edition, Taylor & Francis 2022
* Li, Xinyi and Li, Yinchuan and Zhan, Yuancheng and Liu, Xiao-Yang, Optimistic Bull or Pessimistic Bear: Adaptive Deep Reinforcement Learning for Stock Portfolio Allocation, In ICML 2019.
* Liu X.-Y. Rui J. Gao J. aj.: FinRL-Meta: A Universe of Near-Real Market Environments for Data-Driven Deep Reinforcement Learning in Quantitative Finance. Workshop on Data Centric AI 35th Conference on Neural Information Processing Systems at NeurIPS 2021.
* Mao Guan and Xiao-Yang Liu. 2021. Explainable Deep Reinforcement Learning for Portfolio Management: An Empirical Approach. In ICAIF 2021.

Requirements for the semestral defence:
Items 1, 2, and partially 3.

Detailed formal requirements can be found at https://www.fit.vut.cz/study/theses/

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Beginning of work:	1.11.2022
Submission deadline:	10.5.2023
Approval date:	3.11.2022

Abstract

Portfolio allocation is about selecting a set of assets to invest in. The goal is to maximize the expected return for a given level of risk for an investing horizon selected by us. In former times, this the process is usually done manually by an expert investor. Nowadays, there are many portfolio allocation methods that are not successful in the real world or can be improved and the potential of current technologies is not fully explored in the financial market. To solve the problem of portfolio allocation, I propose a methods based on reinforcement learning. The agent will learn the exact strategies of selecting assets and their weight for the portfolio based on which the human expert would select it, like fundamental analysis and the health of the company. The thesis deals with the problem of portfolio allocation using reinforcement learning, which helps in selecting the best assets and their importance for the portfolio.

Abstrakt

Alokace portfolia je o výběru souboru aktiv, do kterých investujete. Cílem je maximalizovat očekávaný výnos pro danou míru rizika pro námi zvolený investiční horizont. V dřívějších dobách tohle proces je obvykle prováděn ručně zkušeným investorem. V dnešní době existuje mnoho metod alokace portfolia, které nejsou úspěšné v reálném světě nebo je lze zlepšit a potenciál současných technologií není na finančním trhu plně prozkoumán. Pro řešení problému alokace portfolia navrhuji metody založené na posilovacím učení. Agent se naučí přesné strategie výběru aktiv a jejich váhu pro portfolio, na základě kterého by je lidský expert vybíral, jako je fundamentální analýza a zdraví společnosti. Diplomová práce se zabývá problémem alokace portfolia pomocí posilovacího učení, které pomáhá při výběru nejlepších aktiv a jejich důležitosti pro portfolio.

Keywords

artificial intelligence, AI, reinforcement learning, stock portfolio allocation, modern portfolio theory, Q-learning, neural networks, stock market

Klíčová slova

umělá inteligence, AI, posilované učení, alokace akciového portfolia, moderni teorie portfolia, Q-learning, neuronové sítě, akciový trh

Reference

LAPEŠ, Zdeněk. *Reinforcement Learning for Automated Stock Portfolio Allocation*. Brno, 2023. Bachelor's thesis. Brno University of Technology, Faculty of Information Technology. Supervisor doc. RNDr. Milan Češka, Ph.D.

Reinforcement Learning for Automated Stock Portfolio Allocation

Declaration

I hereby declare that this Bachelor's thesis was prepared as an original work by the author under the supervision of Mr. Milan Češka, Ph.D. I have listed all the literary sources, publications and other sources, which were used during the preparation of this thesis.

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Zdeněk Lapeš
December 28, 2022

Acknowledgements

I would like to thank my supervisor, Mr. Milan Češka, for his guidance and support during the preparation of this thesis. I would also like to thank my family and friends for their support.

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Chapter 1

Introduction

1.1 Background

The portfolio allocation task has been studied for a long time. The problem is to find the optimal allocation of the finite budget into a range of financial instruments/assets, e.g. stocks.[2]

This problem involves making crucial decisions about allocating capital into different securities (stocks, bonds, ...). The goal is to allocate assets instead of cash which will be able to constantly in a selected investing horizon valorize the initial capital and maximize the expected return of the portfolio, while minimizing the risk.

Portfolio management is the most important task for finance institutions, like banks, hedge funds, and asset management companies and there exist various existing portfolio management strategies, such as the Markowitz mean-variance portfolio optimization proposed by Hanry Markowitz[4, p. 4], the Black-Litterman model and the CAPM model.

The approaches based on predictive models are not appropriate for portfolio management, because the stock market is stochastic, volatile, quickly changing, and uncertain environment. Predictive models are not able to predict future market conditions in an accurate way.

Also, the current strategies and models, which rely on historical data are not suitable for that type of environment.

So, the most recent state-of-the-art portfolio management strategies are based on machine learning techniques, such as deep reinforcement learning (DRL), which shows promising results in the financial domain, such as stock trading and portfolio management tasks.

Reinforcement learning (RL) is becoming more popular in the last decade because it is able to learn from the large environment and make decisions based on the experience gained from the environment.a

Reinforcement Learning is a subfield of machine learning, concerned with how an agent can learn to make decisions in an environment to maximize the expected cumulative reward.[2]

The benefits of RL have been used in many different fields, such as robotics and games.

Reinforcement learning methods have been studied on how much a change in input would influence the output and what contributes to the decision-making process of the DRL agents.[1]

For large and complex environments with huge state space, the breakthrough was Deep Reinforcement Learning (DRL) which is a subfield of RL using deep neural networks to approximate the large and complex state-action spaces and help to understand the stochastic environments.

1.2 Problem Statement

There are a lot of different portfolio management strategies, such as Markowitz mean-variance portfolio optimization called as modern portfolio theory (MPT)[3] is limited by the fact that they are all based on historical data such as the historical prices of the stocks, which include a lot of noise and are not able to predict the future market conditions, because of the stochastic nature of the market. Markowitz's theory goal is on a well-diversified portfolio, which is for minimizing risk.

Reinforcement learning has advantages, such as flexibility, adaptability, and utilization of various information like e.q. experience gained from the environment under certain conditions.

However, the existing RL approaches do not consider all of these factors:

- **State space**
  The actions computed by the model should change only the portfolio managed by the agent, but not the conditions of the financial market itself.
- **Action space**
  Action space should be designed in a way that the agent weights the assets in the portfolio. How much of the budget should be allocated to each asset and should be this asset in the portfolio? These design decisions are crucial for the performance of the agent. It is really difficult to find the optimal policy for the portfolio allocation because the agent has to choose between multiple assets with various differences in information about the assets. Also, actions should be considered profitable and safe in the long term, which means that the agent has to make decisions based on long-term rewards.
- **Reward function**
  The reward should be able to reflect the agent's performance in the environment. Is the current portfolio value increasing or decreasing after the agent takes actions proposed by the policy?
- **Model Overfitting**
  The model should be able to generalize the environment and not overfit the training data. The dataset should be large enough to generalize the environment and split into the training and testing dataset.

The current model approaches of FinRL-Meta are based on the deep reinforcement learning (DRL) methods, which are able to learn from the environment, but they are not following all

of the above-mentioned factors and rely on the technical analysis and covariance between the assets. These objectives do not help so much in predicting and understanding the market and quality of each asset, on top of that, increasing the complexity of the model far more.

1.3 Aim of the Thesis

This thesis focus on learning deep reinforcement learning agents, which are able to learn optimal portfolio management strategies from the environment.

The objectives of this thesis are:

- Create a suitable dataset for the portfolio allocation problem with a finite set of stocks.
- Implement and Train RL agents on the dataset with a finite cash budget.
- Evaluate the performance of the RL agents by comparing them with the baseline portfolio management strategies, such as mean-variance optimization and baseline indexes such as DJI30 etc...

Using the programming language Python and open-source libraries such as NumPy, Pandas, Stable Baselines3, OpenAI gym, etc... I will implement the RL agents and evaluate their performance on the created dataset.

This thesis aims to discover if RL can learn optimal portfolio management strategies that yield better results than the current state-of-the-art portfolio management method focusing on the objectives mentioned above.

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