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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 UNIVERSITY OF TECHNOLOGY
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Bachelor's Thesis Assignment

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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/

Supervisor:	**Češka Milan, doc. RNDr., Ph.D.**
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Abstract

This thesis focuses on the design and implementation of a model capable of making decisions in a very fast-changing financial environment. It is based on the modern portfolio therory and reinforcement learning. In the first step, a simulation environment is created that allows testing various strategies. In the second step the agent is trained to try to achieve the maximum return. In the third step, the agent is tested on real data.

Abstrakt

Tato prace se zameruje na navrh a implementaci modelu schopnych delat rozhodnuti ve velmi rychle se menicim financnim prostredi. Vychazi z teorie moderniho portfolia a posilovaneho uceni. V prvnim kroku je vytvoreno simulacni prostredi, ktere umoznuje testovat ruzne strategie. V druhem kroku je trenovan agent, ktery se snazi dosahnout maximalniho navratu. V tretim kroku je agent testovan na realnych datech.

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

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Contents

List of Figures

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, such as stocks.[2]

This problem involves making crucial decisions about the allocating capital into different securities (stocks, ...). Goal is to allocates securities instead of cash which will be able to maximize the expected return of the portfolio, while minimizing the risk.

The 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 suitable for the portfolio management, because the market is highly stochastic and the models are not able to predict the future market conditions in an accurate way.

The stock market environment is stochastic and very uncertain environment, which is really hard to predict with the current strategies and models, which rely on the historical data.

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

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

Benefits of RL have been using in many different fields, such as robotics and games.

RL methods was studied how much a change in input would influence the output and what contributes to the decision making process of the DRL agents.[1]

Deep Reinforcement Learning (DRL) is a subfield of RL, which uses deep neural networks to approximate the large and complex state-action spaces and help to understand the mostly stochastic environments.

1.2 Problem Statement

There are a lot of different portfolio management strategies, such as Markowitz mean-variance portfolio optimization or modern portfolio theory (MPT)[3] is limited by the fact that they are all based on the 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.

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

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

- **State space design**
  The actions computed by the model should change only the portfolio operated by the agent, but not the financial market itself.
- **Action space design**
  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? 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 agent has to choose the 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 the long-term rewards.
- **Reward design**
  The reward should be able to reflect the agent's performance in the environment. Is the current portfolio value increasing or decreasing after the actions are taken by the agent?
- **Model Overfitting**
  The model should be able to generalize the environment and not overfit to 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 rely not follow all of the above-mentioned factors and rely on the technical analysis and covariances between the assets, which are not able to predict to fully understand the market and quality of each asset in the portfolio.

1.3 Aim of the Thesis

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

The specific objectives of this thesis are:

- Create a suitable dataset for the portfolio allocation problem with finite set of stocks.
- Implement and Train RL agents on the dataset with a finite cash budget.
- Evaluate the performance of the RL agents comparing them with the baseline portfolio management strategies, such as mean-variance optimization and indexes such as S&P 500.

This thesis aims to study if RL can learn optimal portfolio management strategies that yield better results than the current state-of-the-art portfolio management methods.

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