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Quantum Computing for Finance

Summary

1. Introduction - Multiverse Computing
2. Multiverse benchmarks and use-cases for Finance
3. Singularity Portfolio optimization
4. Singularity Python Frontend demo

MULTIVERSE - Global Quantum Software Revolution Winner

Largest & Fastest-Growing Quantum Software Company Globally

- Top-3 Global Player
- ~$8B Medium-Term Market Opportunity
- ~$45B Long-Term Opportunity in Quantum Software
- Offices in Spain, Canada, France & Germany

More Blue-Chip Clients & Real-World Revenue Generating Use Cases than Anyone

BASF We create chemistry · BANK OF CANADA BANQUE DU CANADA · BOSCH · REPSOL

High-Growth Recurring Revenue Profile

- €6.7M Total Contract Value Sold in 2021
- Significant Projected Revenues in 2022 and Beyond

Highly-Scalable Hardware Agnostic Singularity SaaS Platform

- Revolutionary Hardware-Agnostic SaaS Platform
- 22 Patents Filed in 2021
- 24 More Patents Planned in 2022

Visionary Industry-Leading World-Class Team

9,000+	25%	30%	23
Citations	PhDs	Women	Nationalities

Global Industry Accolades

Gartner	Sifted	BCG
"Cool Vendor" 2022	100x Speed Improvements in Banking 2021	Quantum Startup for Financial Services 2020

Fundamental Technology Platform and Unrivalled Expertise to Accelerate ESG Strategies

Clean Energy	Green AI	Sustainable
Industrial	Health & Life Sciences	Materials
Operations		Climate Technology

Early Specialist Expert Investors

QUANTO NATION · JME VENTURES · inveready

We Deliver Value to Blue-Chip Customers Across an Unparalleled Set of Industry Verticals

Aerospace

Aerospace Predictive Maintenance

Trading

Forex Trading

Finance

Price Derivatives Accurately

Life / Healthcare

Predict Patient Health Crises

Government

Market Simulation

Engineering

Optimize Component Functionality

Manufacturing / Supply Chain

Quantum Digital Twin

Renewable Energy

Simulate Energy Demand

Logistics

Routing Optimization

Chemistry

Green Hydrogen

Customers and Qualified Prospects

Strictly Private and Confidential

Benchmarks and use-cases for Finance

Singularity Toolbox

D-Wave The Quantum Computing Company · IBM · IONQ · rigetti · XANADU

APPS

Integrate our cutting edge solutions straight out of the box

SINGULARITY FINANCE

- Asset management
- Derivatives pricing
- Risk management

python™

Develop your own quantum applications built on top of Singularity core - **No quantum experts required!**

CORE

SINGULARITY MACHINE LEARNING

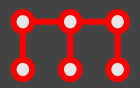
- Leverage a suite of **powerful and easy to use** quantum machine learning algorithms
- Classification, regression, deep learning

SINGULARITY OPTIMIZATION

- Quickly build and solve optimization problems
- Solve challenging discrete optimization

BACKENDS

Harness the power of quantum technologies backends



TENSOR NETWORK (Quantum Inspired)

- Multiverse tensor networks developed by our **leading world experts**
- No quantum hardware needed

QUANTUM

- Run on the latest quantum hardware from our partners
- Leverage true quantum power

Summary of Application Areas

Asset Management

- Static Portfolio Optimization — CaixaBank Bankia
- Dynamic Portfolio Optimization — CaixaBank Bankia
- Index Tracking — ally
- Algorithmic FX Trading — BASF We create chemistry
- New Application Areas
  - Collateral Optimization
  - Optimal Trade Execution

Derivatives Pricing

- High Dimensional Basket Options Pricing (Heston) — CA CIB
- Bermudan Swaptions Pricing — Large European Bank
- Autocallable Notes — Large South American Bank

Risk Management and Macroeconomics

- Credit Downgrade Prediction — CA CIB
- Fraud Detection — Data from Citi
- Cryptocurrency Adoption Networks — BANK OF CANADA BANQUE DU CANADA
- Financial Crash Prediction

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Derivatives Pricing

Experts in quantum inspired deep learning approaches

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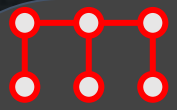
Derivatives Pricing at a Glance



Tensor Network

- Real advantages and value **TODAY**
  - **Efficient -** Less parameters -> Faster learning
  - **Reliable** - More precise pricing and tighter confidence
  - **Scalable** - Handle models past the breaking point of current standard pricers.
- Deep learning with Tensorized Neural Networks (TNN)

What can we price:

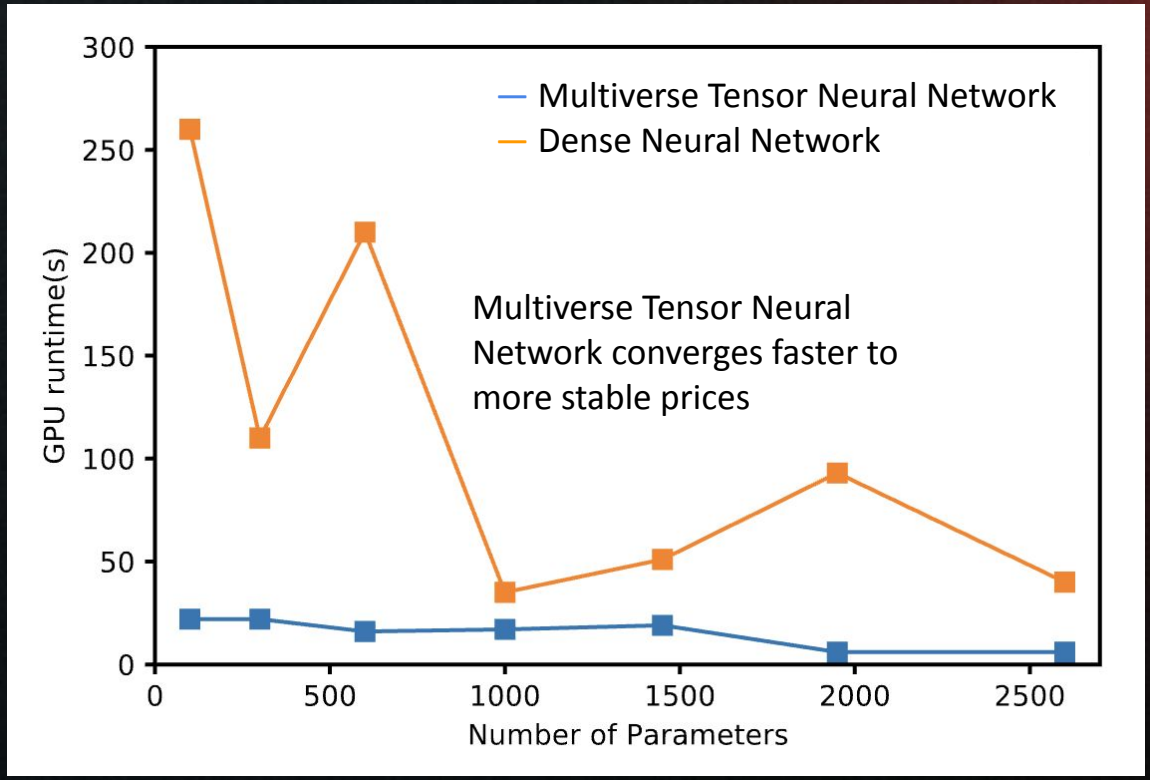
- High dimensional models
- **American style payoffs: New accurate approach**
- Path dependent payoffs

Quantum

- Quantum Monte Carlo (QMC)
- Prepare for the quantum winter
- Build hardware ready infrastructure
- Evaluate performance of current hardware
- State-of-the-art circuits for path dependent options

High Dimensional Baskets - Heston Model

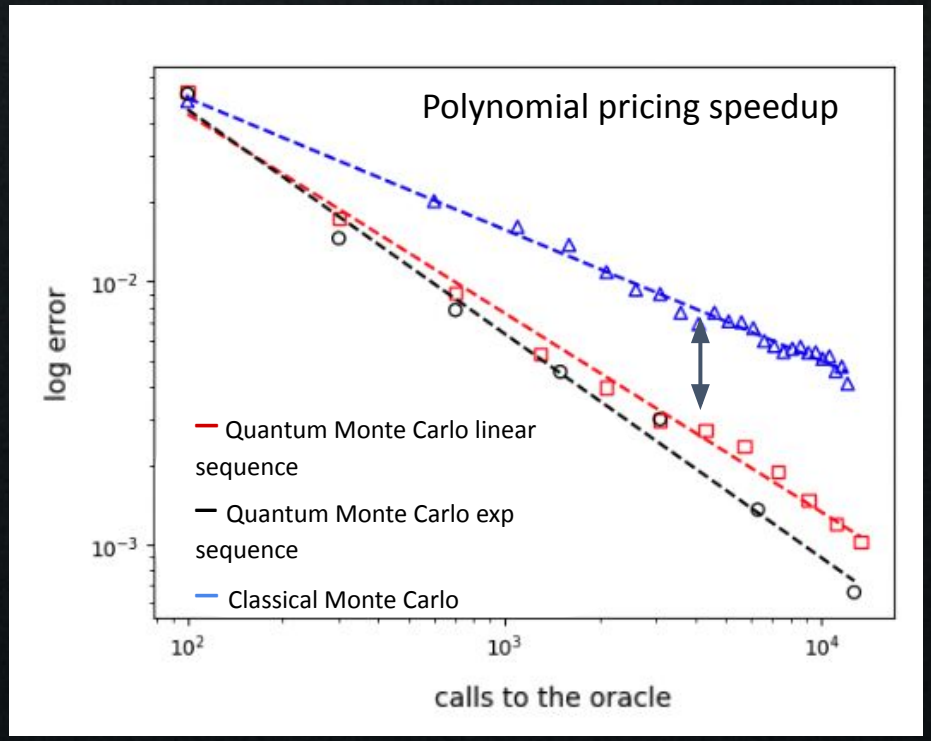
- Less parameters with better accuracy than current state-of-the-art methods
  - 1950 classical parameters, 600 tensor network parameters
- Faster and more stable prices compared to state-of-the-art methods

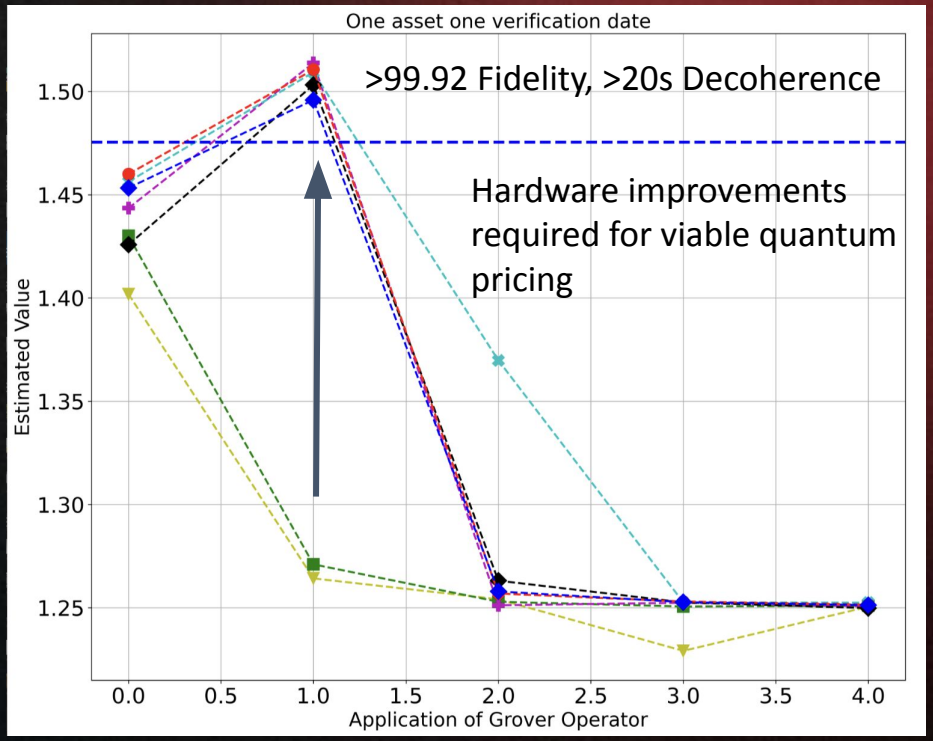


Large south American bank

Autocallables - Quantum Monte Carlo

- Study potential of applying quantum monte carlo for path dependant barriers
- Novel circuit to encode Autocallable note payoffs





In progress

- Study determining hardware conditions for accurate pricing on real hardware

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Risk Management

Experts in quantum machine learning for unbalanced data

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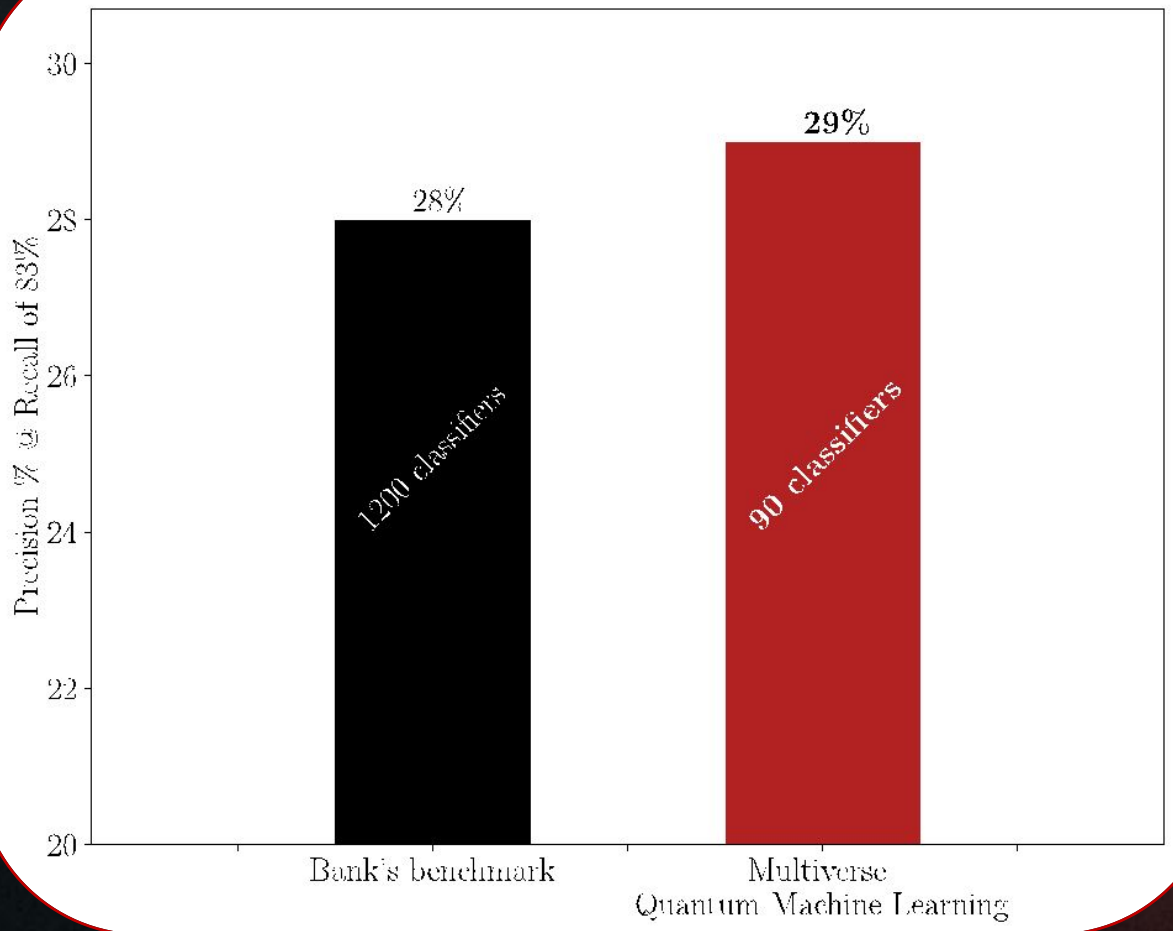
Risk Management at a Glance

Using state-of-the-art quantum machine learning we **improve the accuracy and efficiency**.

- **Fallen Angels - Credit downgrades**
  - Improved prediction accuracy with **x13 smaller model**
- **Credit Card Fraud**
  - **100x faster**, improved accuracy saves up to **$80M/year**
- **Predicting Financial Crashes**
  - Perturbation analysis of financial network stability
  - Analyse large networks **classically intractable**
- **Cryptocurrency Network Adoption**
  - Analyse complex network formation dynamics
  - Analyse large networks **classically intractable**

Fallen Angels: Multiverse predicts credit scoring better

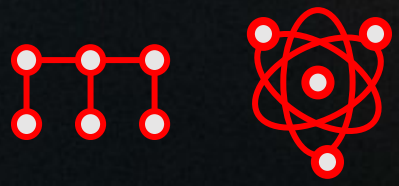


- Multiverse Quantum Machine Learning catches the same number of credit downgrades* with more precision and less false positives
- Multiverse solution is way more interpretable with much less classifiers used to predict the credit downgrade

*these are called Fallen Angels, for example clients/bonds/loans whose solvency is at risk.

Asset Management

Leveraging current quantum technologies to deliver real value for complex optimizations



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Asset Management at a Glance

Using quantum and quantum inspired technologies we can solve the most challenging optimization problems and machine learning tasks.

Algorithmic Trading

- **+38% increase in returns and reduced risk**

Index tracking

- **x2 better risk return and 25% less assets**
- Apply to ETF construction

Portfolio Optimization

- Multiverses' hybrid quantum solver provides superior results
  - **Optimal solutions, reduced computational overhead**
  - **Exactly solve** for discrete asset allocations
- Dynamic optimization solves computational intractable problems

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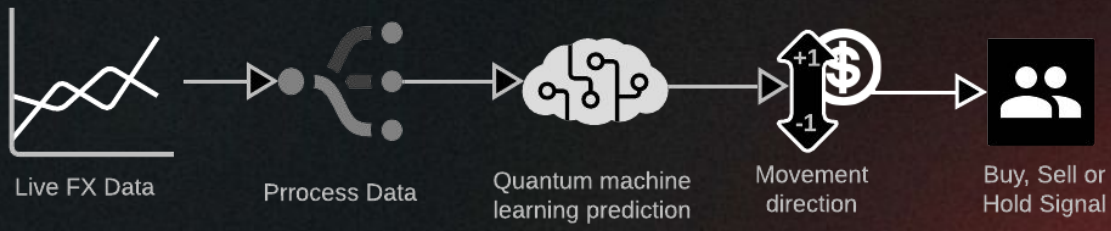
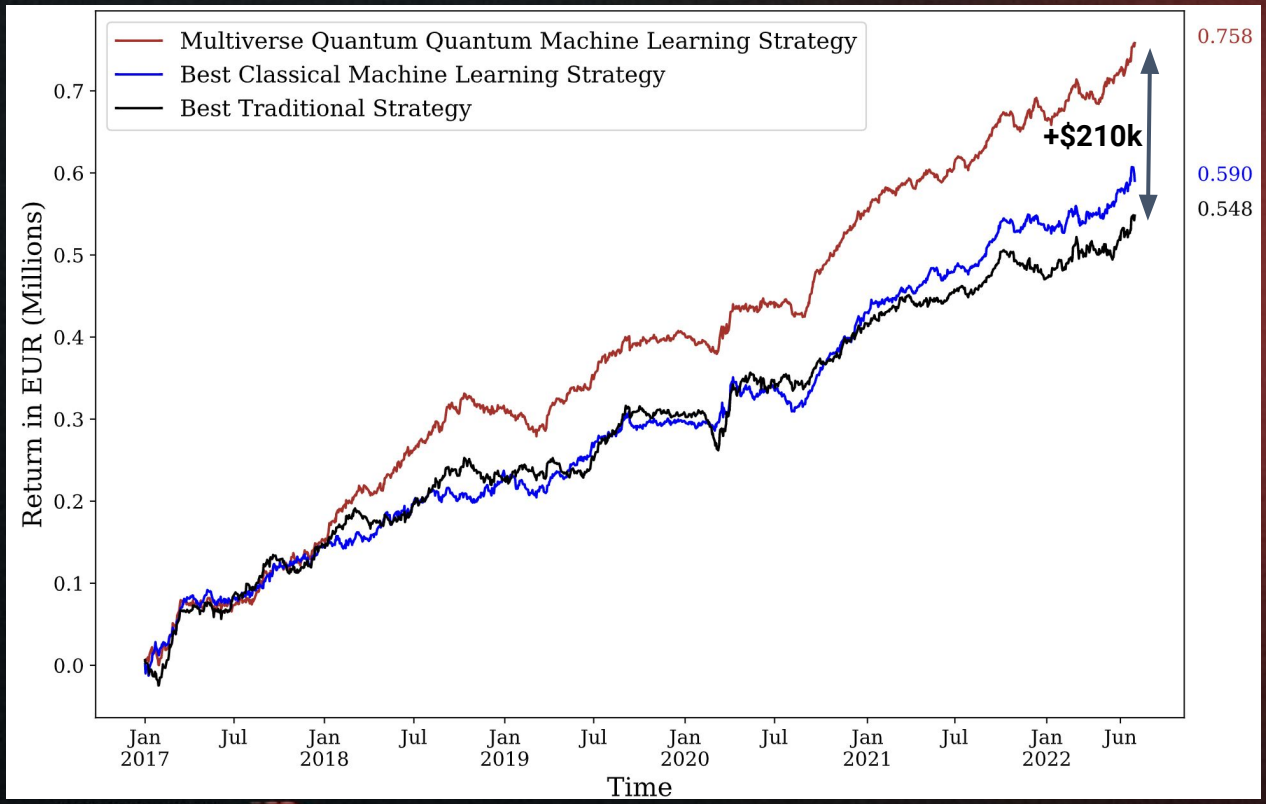
Algorithmic Trading - More profitable trades



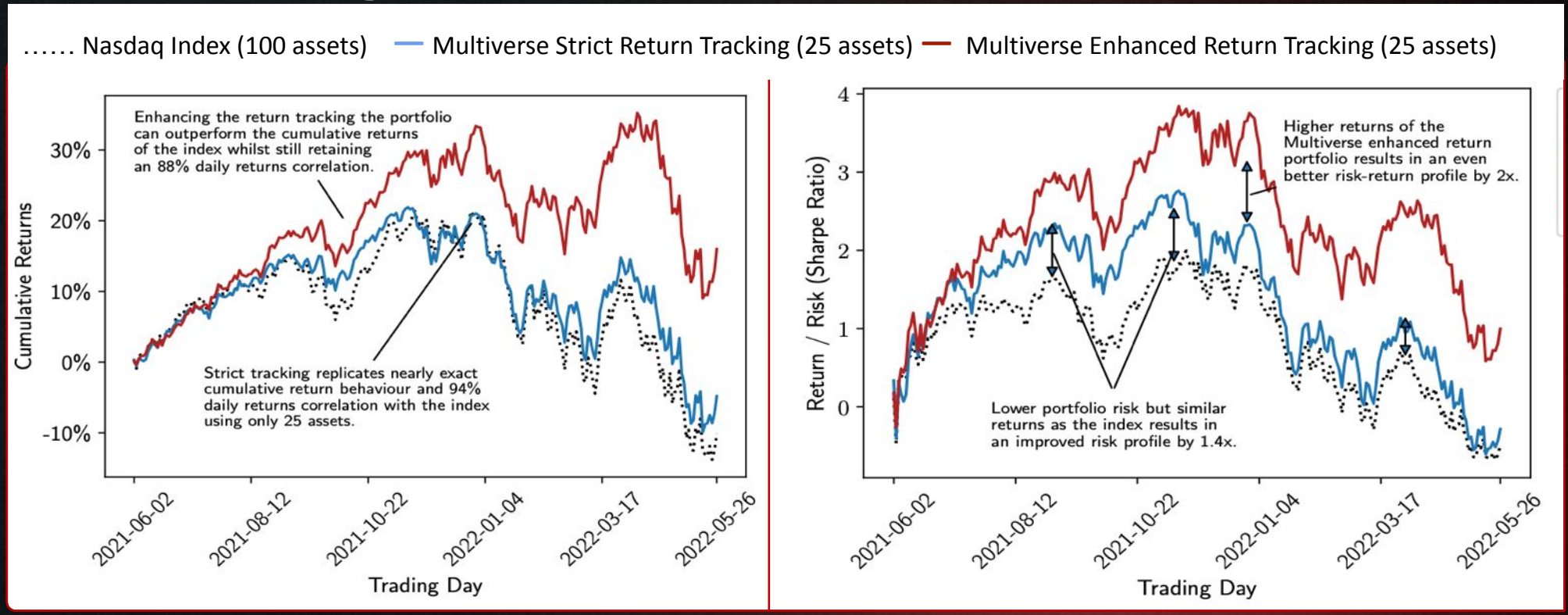


Why Quantum?

- **+38%** increase in returns compared to client trading strategy
- **+28%** increase compared to classical machine learning
- **+$1m** for client trading ($5million notional)
- Return increases are consistent and sustained year-on-year
- More reliable signals -> lower risk

*Multiverse enhanced classical machine learning toolkit.

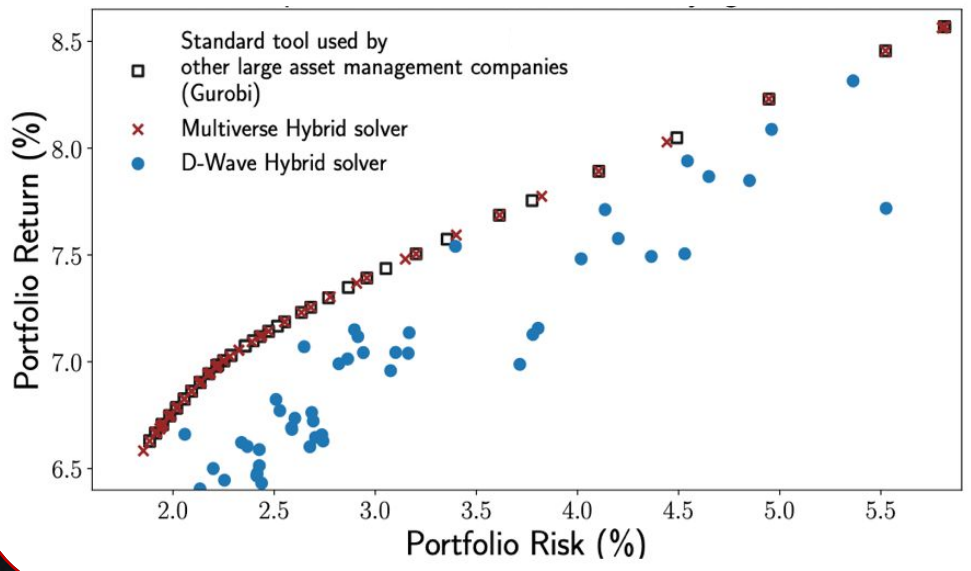
Index Tracking with smaller portfolios

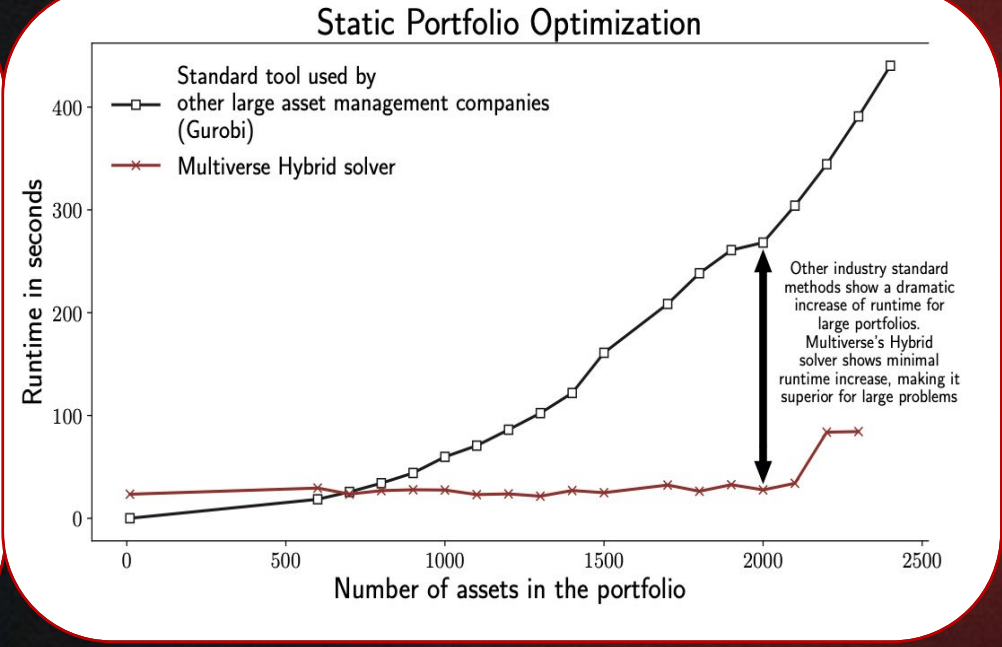


Why Multiverse Quantum?

- Achieve high degree of tracking (94%) with x4 less assets
- Cardinality constrained optimization challenging for classical solvers - **easy for quantum**
- Up to 2x reduction in risk relative to full index

Multiverse Hybrid Optimization





Why Multiverse Quantum?

- Same high quality solutions compared to industry standard solvers (Gurobi)
- Outperforms other best-in-class quantum solvers (DWave Leap Hybrid)
- Scalable to large numbers of asset 500+
- Faster for large portfolios - Minimal computational overhead

*these benchmarks are only applied to static portfolio optimization, given that the classical **state-of-the-art solutions used in the market cannot find any solution in more complex dynamic portfolio optimization problems, where Multiverse Hybrid solver does find optimal solutions.**

New Directions and Exploration

Pioneer and develop new quantum applications and innovations

New Directions and Exploration - A Taster

Portfolio Optimisation

Optimal Trade Execution

- Dynamic optimization explodes over many timesteps for classical
- Market impact of trades
- Reduce slippage

Collateral Optimization

- Optimize asset collateral
- Taking into account problem explodes for classical solver
- Quantum give faster and optimal solutions

ESG Optimization

- Include new ESG factor constraints and other complex investor preferences
- Solve for classically challenging constraints and large portfolios

Derivatives Pricing

Parametric Pricers

- Holy grail of derivatives pricing.
- Model learns the full pricing equation
- Incredibly fast pricing

Gaussian Processes and Quantum Kernels for Pricing

- Hot topic in finance
- Gaussian process have interpretable uncertainty
- More accurate prices and confidence

Quantum Reinforcement Learning for Pricing/Hedging

- Another hot topic in finance
- Price and hedge using optimal behaviour

Algorithmic Trading

Quantum Reinforcement Learning

- Learn dynamic trading behaviours
- Quantum could compactly represent decisions and actions
- More profitable trades

Statistical Arbitrage

- Quantum methods natural capture correlation
- Leverage to find arbitrage strategies

Our Finance Publications

1. Quantum-Inspired Tensor Neural Networks for Option Pricing
https://arxiv.org/abs/2212.14076

2. Financial Index Tracking via Quantum Computing with Cardinality Constraints
https://arxiv.org/abs/2208.11380

3. Quantum Portfolio Optimization with Investment Bands and Target Volatility
https://arxiv.org/abs/2106.06735

4. Use Cases of Quantum Optimization for Finance
https://arxiv.org/abs/2010.01312

5. Dynamic Portfolio Optimization with Real Datasets Using Quantum Processors and Quantum-Inspired Tensor Networks
https://arxiv.org/abs/2007.00017

6. Forecasting financial crashes with quantum computing
https://arxiv.org/abs/1810.07690

7. Hybrid Quantum Investment Optimization with Minimal Holding Period
https://arxiv.org/pdf/2012.01091.pdf

8. Financial Risk Management on a Neutral Atom Quantum Processor
https://arxiv.org/abs/2212.03223

9. Towards Pricing Financial Derivatives with an IBM Quantum Computer
https://arxiv.org/abs/1904.05803

10. Towards Prediction of Financial Crashes with a D-Wave Quantum Computer
https://arxiv.org/abs/1904.05808

11. Quantum computing for finance: overview and prospects
https://arxiv.org/abs/1807.03890

12.Quantum portfolio value forecasting
https://arxiv.org/abs/2111.14970

13. Quantum-Inspired Tensor Neural Networks for Partial Differential Equations
https://arxiv.org/abs/2208.02235

14. Variational Quantum Continuous Optimization: a Cornerstone of Quantum Mathematical Analysis https://arxiv.org/abs/2210.03136

15. The Future of Quantum Finance
https://www.proquest.com/openview/3f8a699a0ed484833e9d7e6d3b34c98c/1?pq-origsite=gscholar&cbl=48426

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JOIN US FOR THE QUANTUM LEAP!

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Singularity Portfolio Optimization
Excel Plugin v1.2

- Installs directly into Excel for Windows, super easy and straightforward!
- Target user: Portfolio Manager

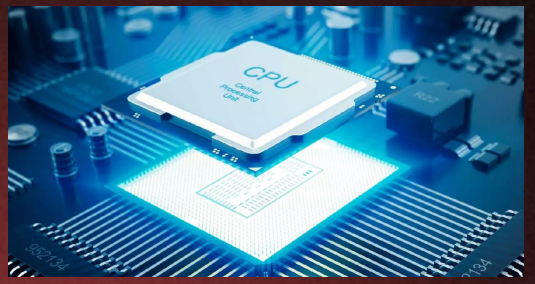
Inputs

- Forecasted returns
- Covariances
- Resolution: Precision of output holdings
- Risk aversion
  - 0 value: Aim for best return, no matter the risk
  - +infty value: Diversify portfolio across unrelated assets, at the expense of big reward
- Investment bands

Outputs

- Optimal Holdings
- Key Performance Indicators (KPI):
  - Return: return of the portfolio
  - Volatility: Risk of the portfolio
  - Sharpe ratio: Return per unit of risk

Solvers

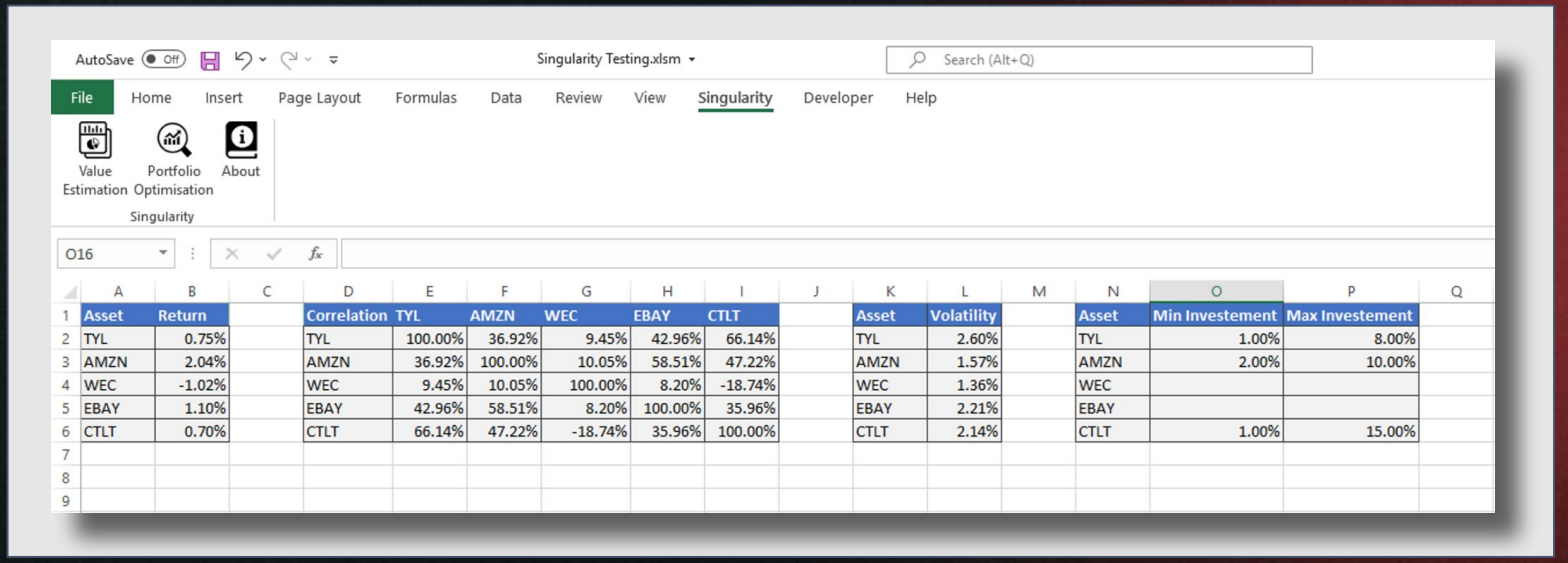


Multiverse Hybrid
- Quantum + Classical
  - Solve discretized convex problems
  - Fast

D-WAVE Leap Hybrid
- Hybrid solver
  - Solve any QUBO
  - Slow

Classical solver
- No quantum
  - Solve discretized convex problems
  - Fast

Features



Asset	Return
TYL	0.75%
AMZN	2.04%
WEC	-1.02%
EBAY	1.10%
CTLT	0.70%

Correlation	TYL	AMZN	WEC	EBAY	CTLT
TYL	100.00%	36.92%	9.45%	42.96%	66.14%
AMZN	36.92%	100.00%	10.05%	58.51%	47.22%
WEC	9.45%	10.05%	100.00%	8.20%	-18.74%
EBAY	42.96%	58.51%	8.20%	100.00%	35.96%
CTLT	66.14%	47.22%	-18.74%	35.96%	100.00%

Asset	Volatility
TYL	2.60%
AMZN	1.57%
WEC	1.36%
EBAY	2.21%
CTLT	2.14%

Asset	Min Investement	Max Investement
TYL	1.00%	8.00%
AMZN	2.00%	10.00%
WEC		
EBAY		
CTLT	1.00%	15.00%

- Finds optimal Portfolio for a target risk
- User interacts through Excel interface
- Inputs: Returns, Volatilities, Correlations, investment bands, total investment, default max investment per asset, target volatility
- Outputs: holdings, sharpe ratio, energy, total return, volatility

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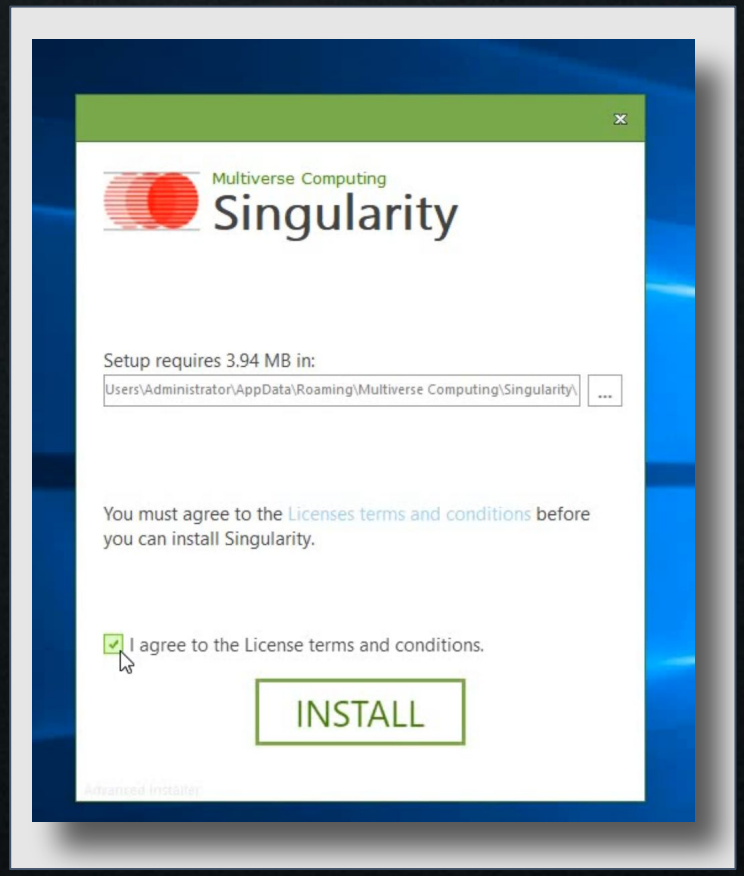
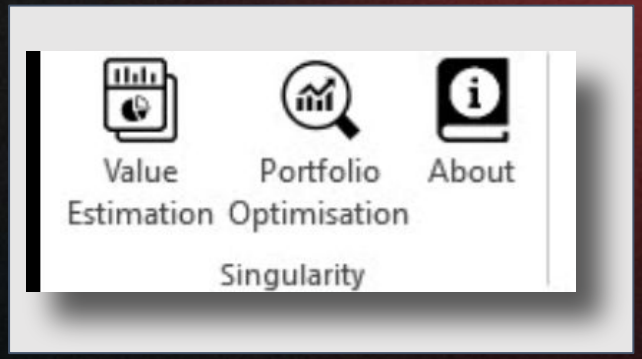
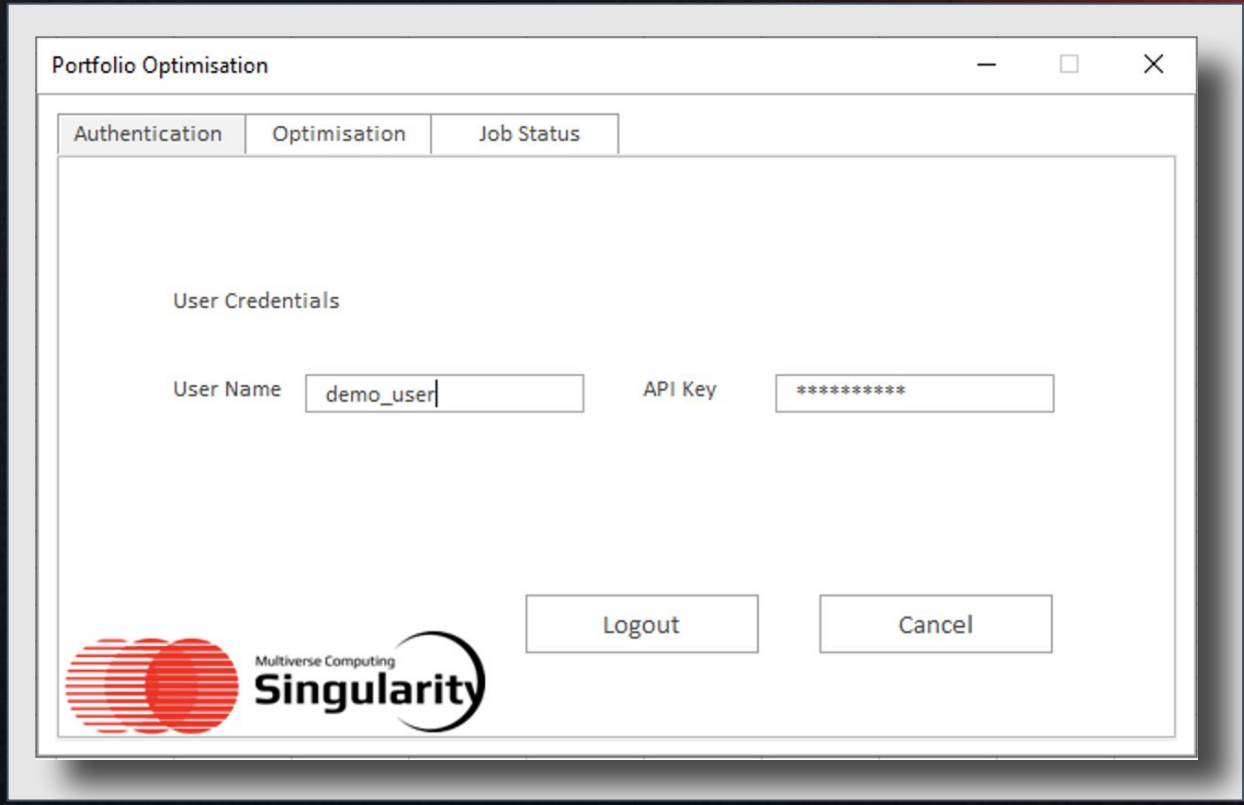
Installer

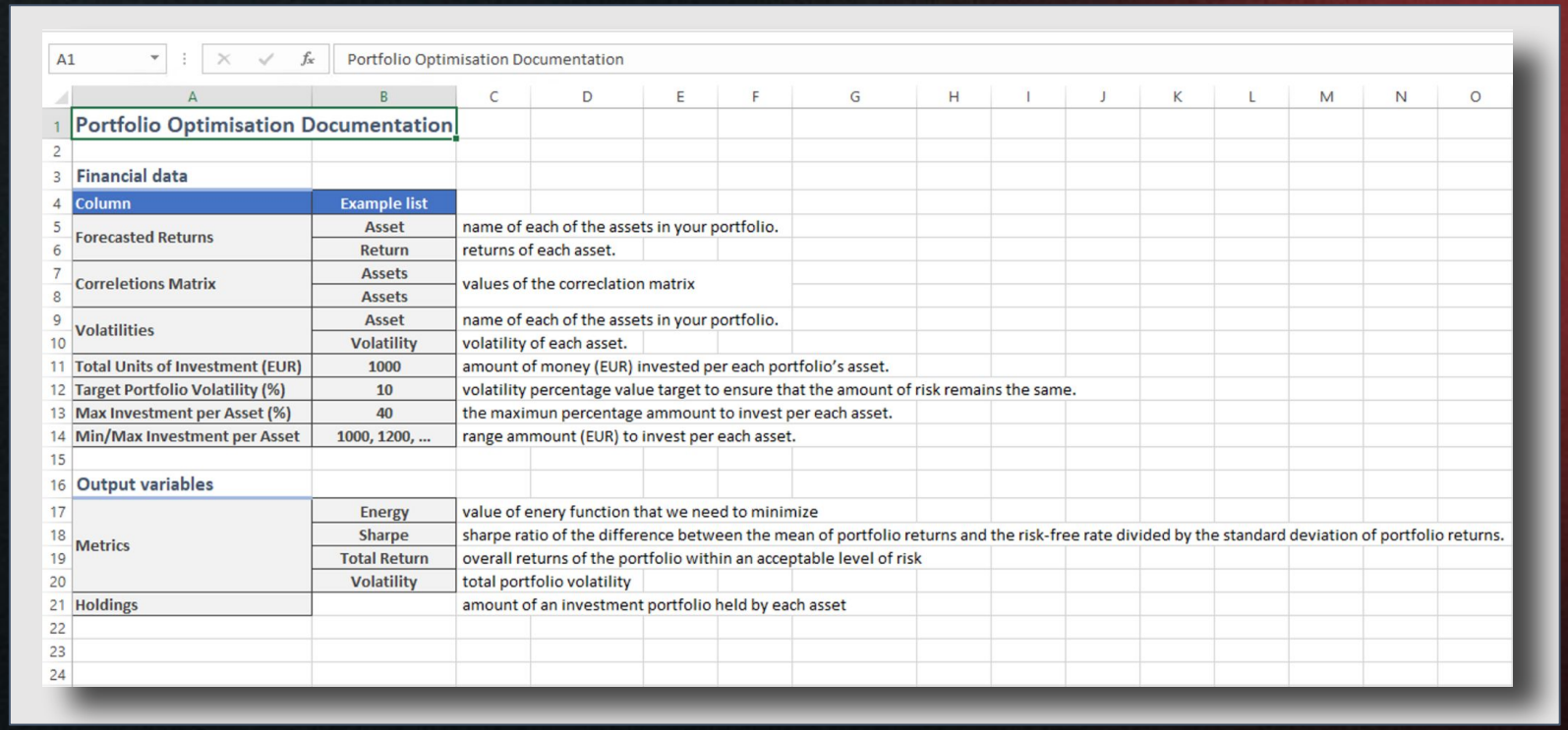




login



Documentation



A1 | Portfolio Optimisation Documentation

	A	B	C
1	**Portfolio Optimisation Documentation**		
2			
3	**Financial data**		
4	**Column**	**Example list**	
5	**Forecasted Returns**	**Asset**	name of each of the assets in your portfolio.
6		**Return**	returns of each asset.
7	**Correletions Matrix**	**Assets**	values of the correclation matrix
8		**Assets**	
9	**Volatilities**	**Asset**	name of each of the assets in your portfolio.
10		**Volatility**	volatility of each asset.
11	**Total Units of Investment (EUR)**	**1000**	amount of money (EUR) invested per each portfolio's asset.
12	**Target Portfolio Volatility (%)**	**10**	volatility percentage value target to ensure that the amount of risk remains the same.
13	**Max Investment per Asset (%)**	**40**	the maximun percentage ammount to invest per each asset.
14	**Min/Max Investment per Asset**	**1000, 1200, ...**	range ammount (EUR) to invest per each asset.
15			
16	**Output variables**		
17	**Metrics**	**Energy**	value of enery function that we need to minimize
18		**Sharpe**	sharpe ratio of the difference between the mean of portfolio returns and the risk-free rate divided by the standard deviation of portfolio returns.
19		**Total Return**	overall returns of the portfolio within an acceptable level of risk
20		**Volatility**	total portfolio volatility
21	**Holdings**		amount of an investment portfolio held by each asset
22			
23			
24			

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Submit optimisation job

Inputs

Asset	Return
TYL	0.75%
AMZN	2.04%
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EBAY	1.10%
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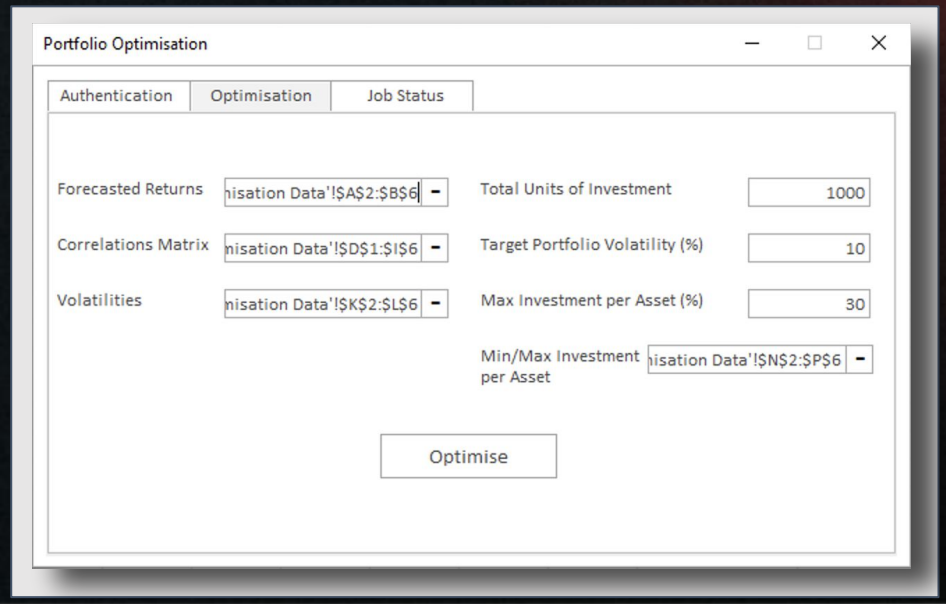
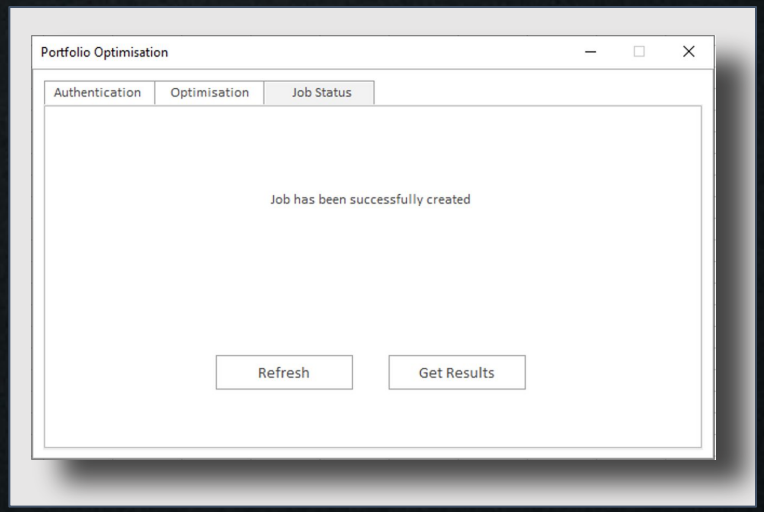
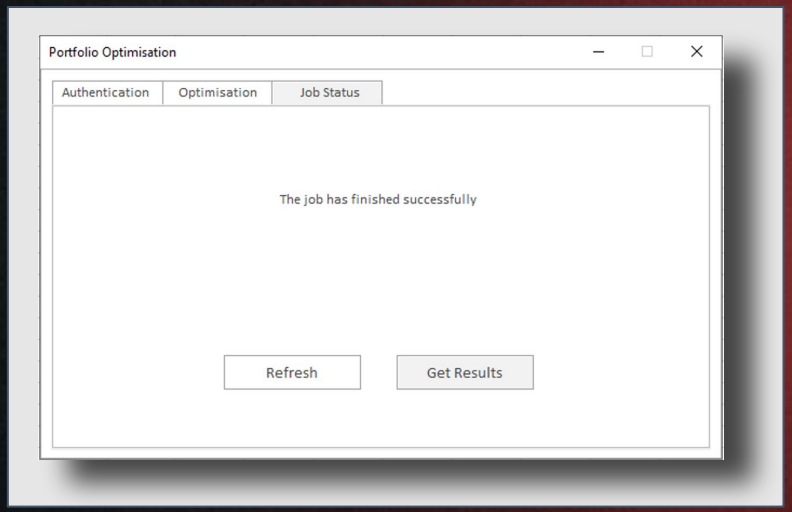


Job submission & Results sheet





Results

	A	B	C	D	E	F	G	H	I	J
1	Metrics			Holdings						
2	energy	0.002129214			TYL	AMZN	WEC	EBAY	CTLT	
3	Sharpe	0.500277235		58:08.4	0.08	0.1	0.159	0.511	0.15	
4	Total Return	1.007676994								
5	Volatility	0.015345479								
6										
7										

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Now let try to do a portfolio optimization on real quantum computer, but with the Python Frontend !

Singularity Portfolio Optimization Demo

In this notebook we demonstrate how to use the Singularity Portfolio Optimization to solve a common portfolio problem.

Data specification

The examples covered in this section make use of real market data for three of the largest market-cap stocks in the S&P 500 index as of January 2023, selected purely for demonstration. These are Exxon Mobil Corporation (XOM), Johnson & Johnson (JNJ), and Apple Inc. (AAPL). The publicly available input data included below reflects the annual return for these assets across 2022 and the covariance over that period based on daily price changes.

In [1]:
```
import logging
import singularity.portfolio_optimization as po
from dataclasses import asdict
from plot_bar_chart import plot_bar
```

Add the logger.

In [2]:
```
po.add_logger(logging.INFO)
```

First, specify the assets names and store them in the Assets object.

In [3]:
```
asset_names = ["XOM", "JNJ", "AAPL"]
assets = po.Assets(asset_names)
```

Then, specify the expected return of each asset.