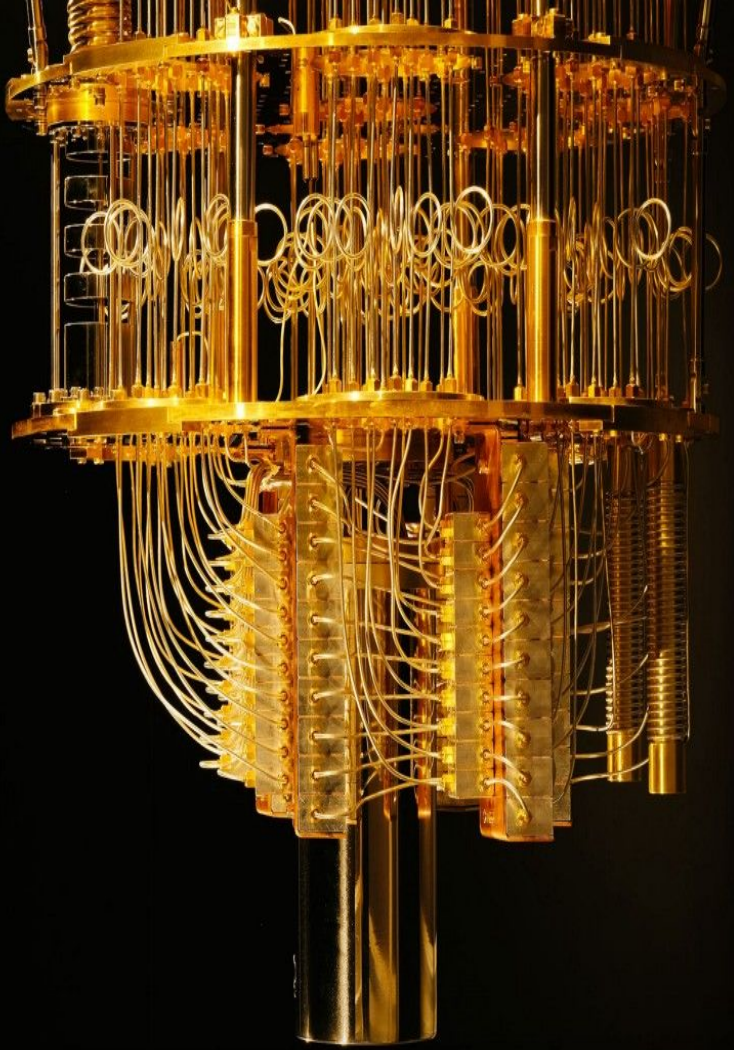
Quantum Finance

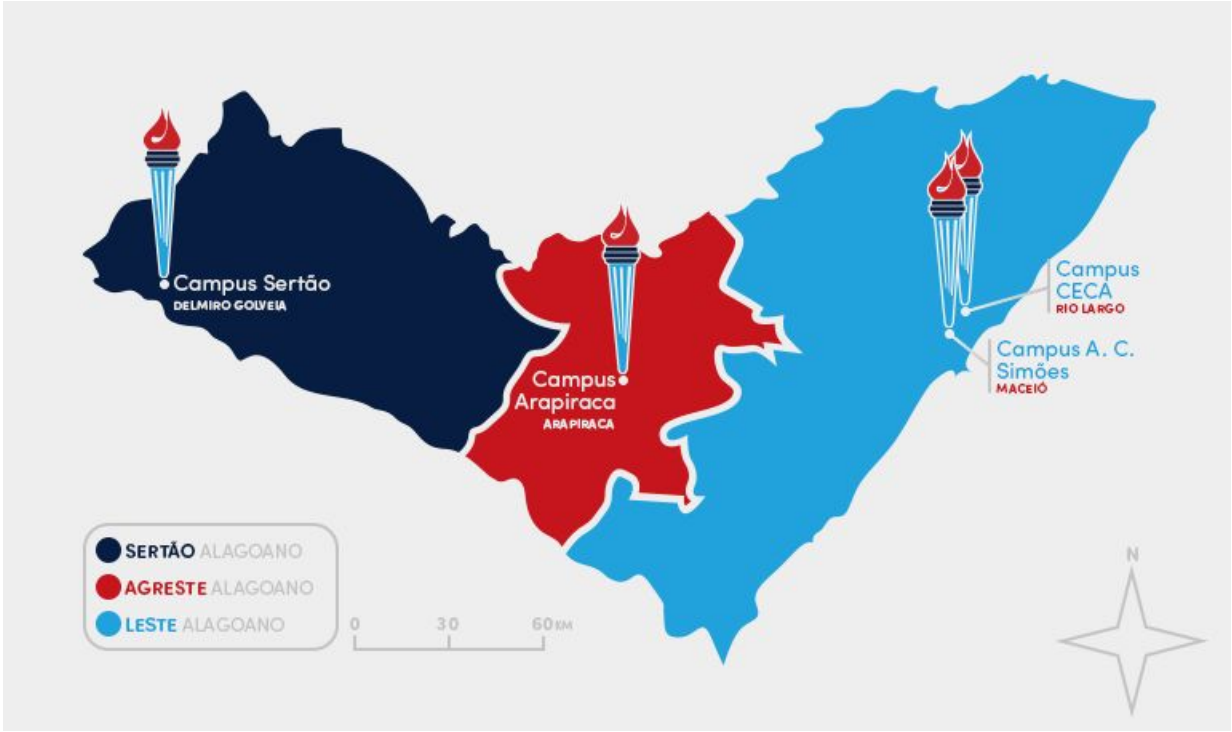
(Quantum Computing for Finance)



Askery Canabarro
Campus Arapiraca - UFAL

PostDoc Opportunity

Where: IF/UFAL (Maceió-AL)
Field: Quantum Optics
PhD Conclusion: 01.01.2016 to 30.11.2022
Deadline: 25/11/2022
Contacts [send (Lattes)CV to]:
eduardo@fis.ufal.br or willamys@fis.ufal.br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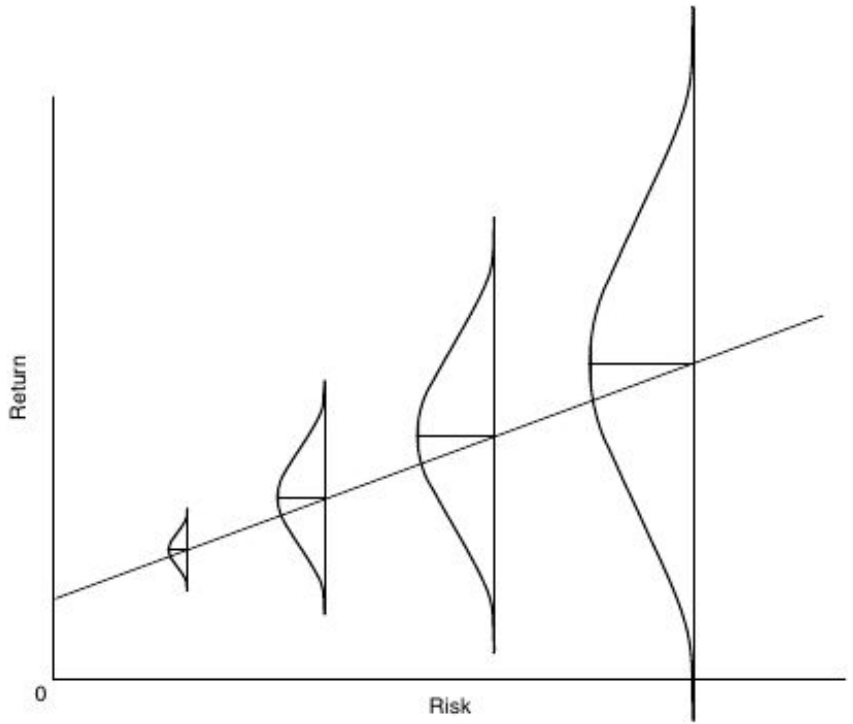
Marechal Deodoro-AL

Outline (Day 2)

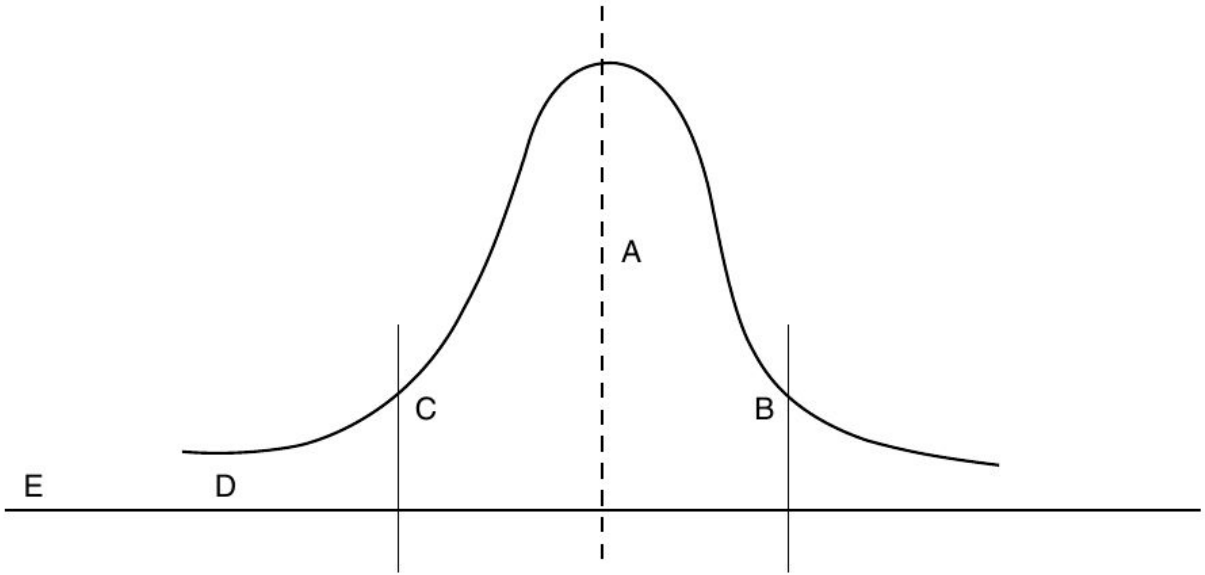
1. More thoughts about the financial market
2. Portfolio and Portfolio Optimization
   2.1 Soccer Squad comparison (Quantum Approach)
3. QAOA
   3.1 Implementation and Results
4. Final thoughts

1. More thoughts about the financial market

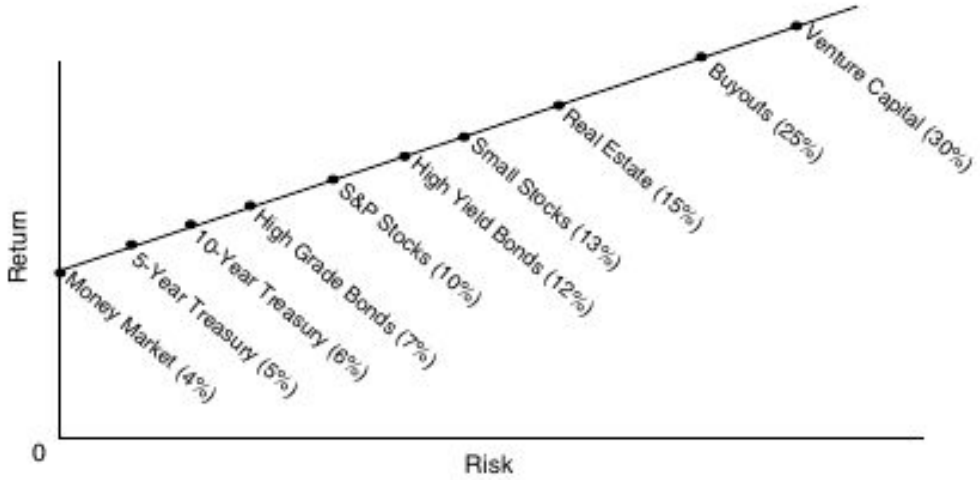


Source: H. Marks, The Most Important Thing

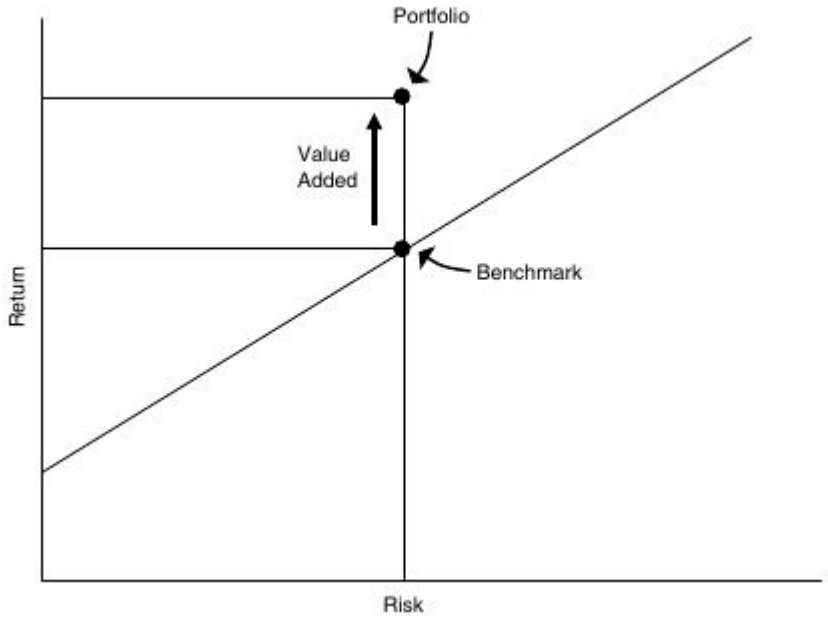
Future as a probability distribution



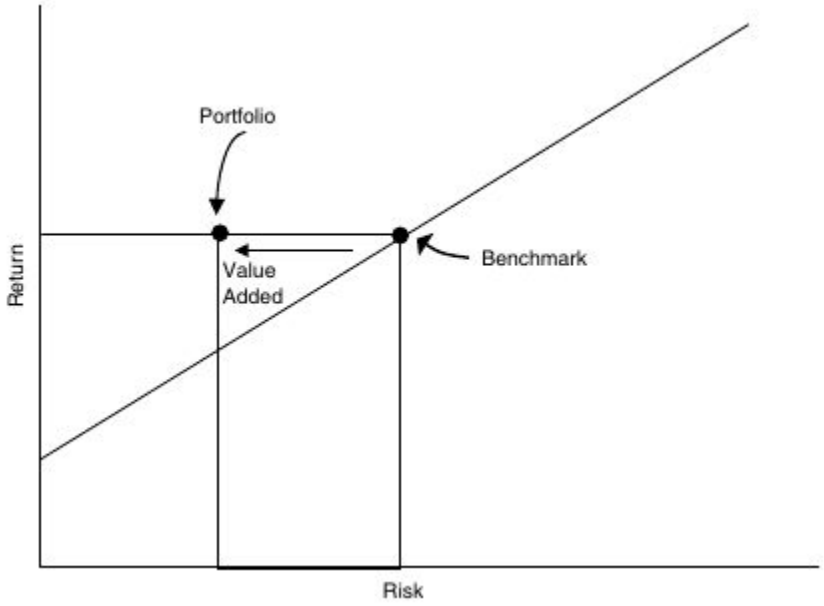
Risk means more things can happen than will happen (Elroy Dimson)
Source: H. Marks.



Capital Market Line
Source: H. Marks, The Most Important Thing



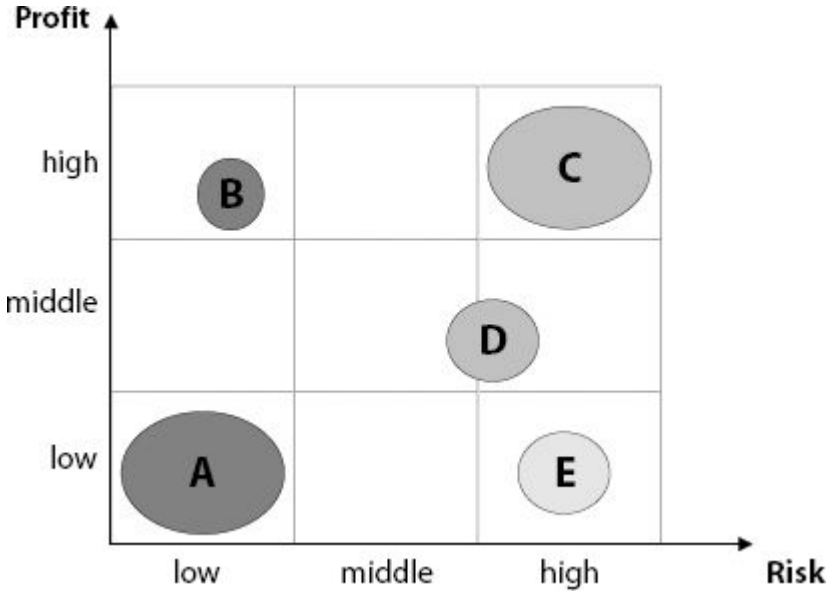
Source: H. Marks, The Most Important Thing



Source: H. Marks, The Most Important Thing

2. Portfolio and Portfolio Risk Management

2. Portfolio and Soccer Squad



Portfolio Management vs Soccer Squad

- Most of the players (assets) are on the field (portfolio) for the whole match
- The same squad (portfolio) plays the defensive and offensive game
- The squad (portfolio) has to deal with eventualities
- Collectively, they have score goals (profit) and avoid goals (losses)

2.1 Example

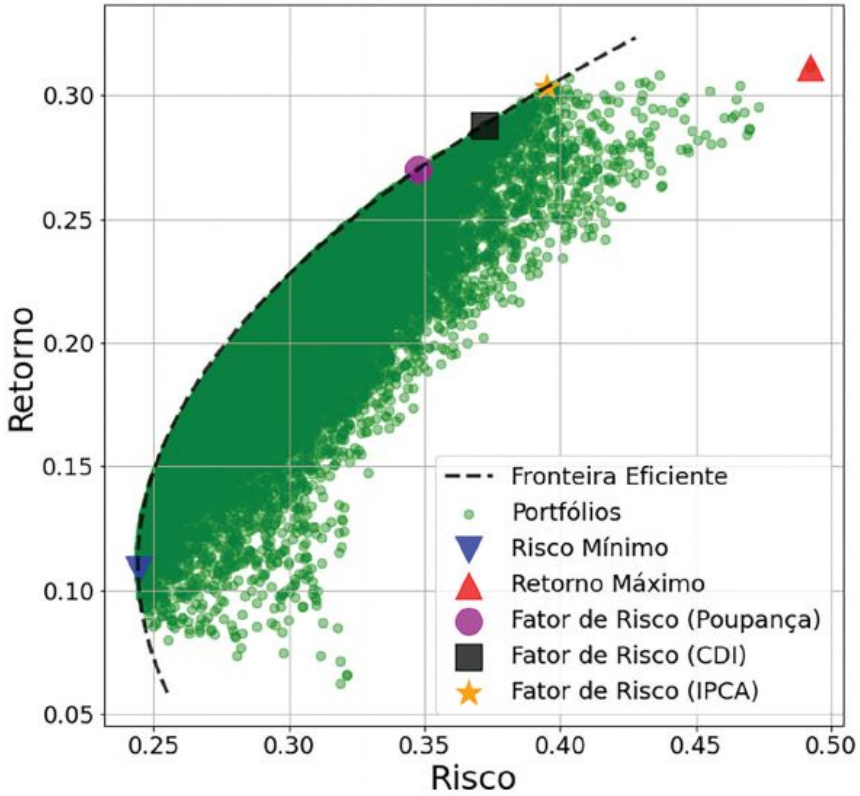
Return

Tabela 1: Retorno anual médio dos preços de fechamento das ações da Braskem (BRKM5), Itaú (ITUB4), Vale (VALE3) e Klabin (KLBN4) referentes ao período entre 01 de janeiro de 2016 até 20 de setembro de 2021.

Ativos	BRKM5	ITUB4	KLBN4	VALE3
Retorno (μ)	0.32	0.06	0.11	0.30

Covariance

Ativos	BRKM5	ITUB4	KLBN4	VALE3
BRKM5	1.00	0.37	0.28	0.33
ITUB4	0.37	1.00	0.18	0.36
KLBN4	0.28	0.18	1.00	0.24
VALE3	0.33	0.36	0.24	1.00

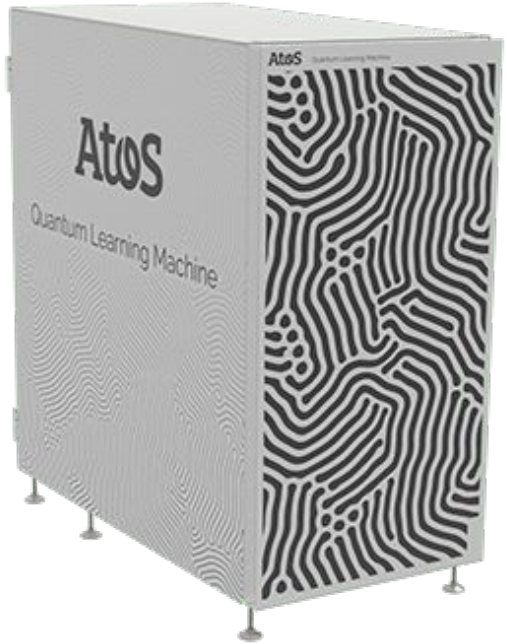


Efficient Frontier

Descrição do Portfólio	BRKM5	ITUB4	KLBN4	VALE3	Risco	Retorno
Risco Mínimo	0.009	**0.404**	**0.503**	0.083	0.244	0.108
Retorno Máximo	**0.919**	0.006	0.009	**0.066**	0.492	0.311
Melhor SR ($R_f = 0.015$)	**0.370**	0.000	0.193	**0.436**	0.347	0.270
Melhor SR ($R_f = 0.028$)	**0.403**	0.002	0.099	**0.496**	0.372	0.287
Melhor SR ($R_f = 0.100$)	**0.451**	0.000	0.022	**0.526**	0.395	0.303

Markowitz approach after trying 30000 random weights

3. Results from QAOA



Qlm has a full quantum ecosystem. Simulates up to 30 qubits.
There is one at SENAI/CIMATEC.

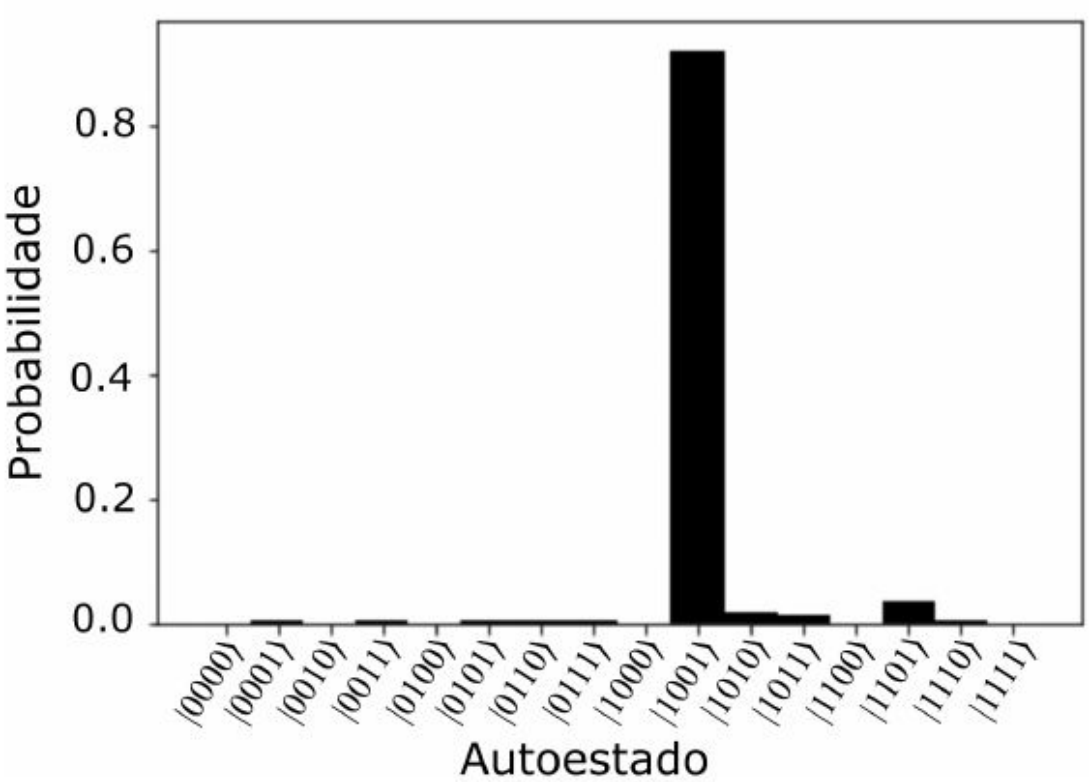


Figura 6: Histograma da distribuição de probabilidades de medição de cada estado da base computacional, considerando-se a solução ótima obtida pelo QAOA com 20 camadas.

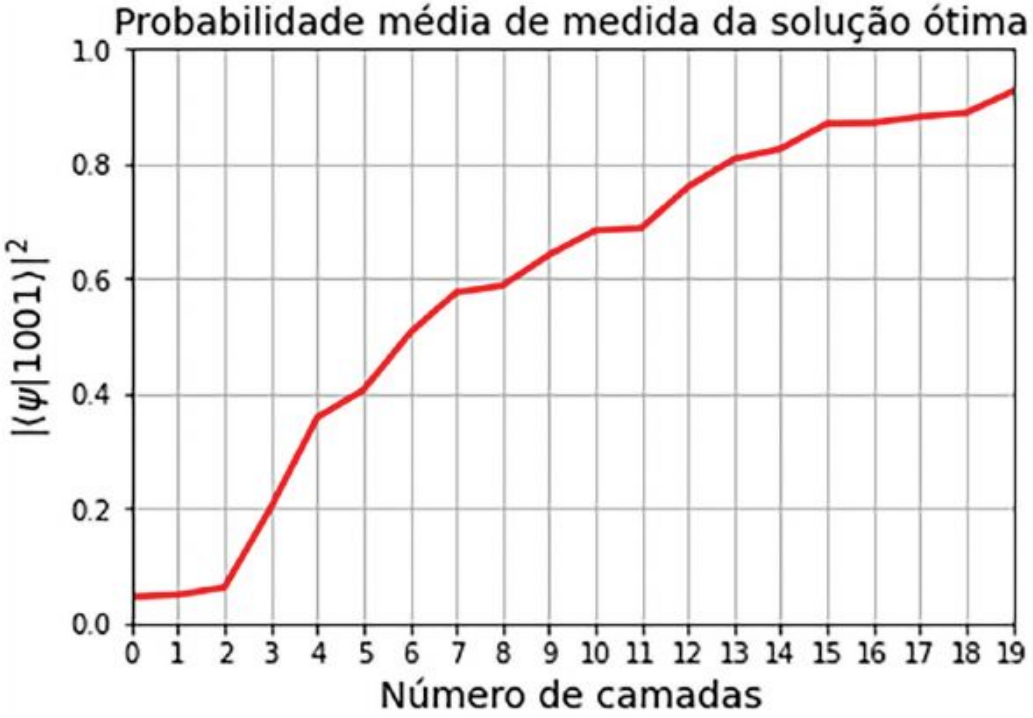


Figura 7: Probabilidade $|\langle\psi(\beta,\gamma)|1001\rangle|^2$ de que o estado encontrado pelo QAOA seja encontrado na solução ótima $|1001\rangle$, plotada em função do número de camadas no QAOA. Para cada número de camadas, consideramos uma média sobre as duas melhores dentre 10 otimizações.

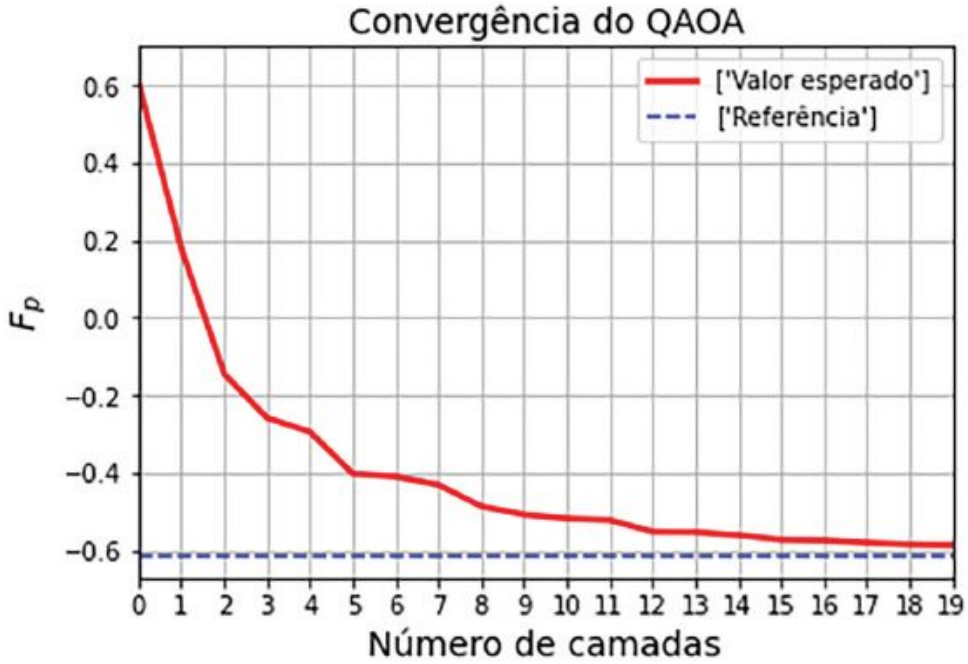


Figura 8: A energia da solução F_p (Eq. (34)) encontrada pelo QAOA como função do número de camadas. Como referência plotamos em azul a energia fundamental, associada ao auto-estado $|1001\rangle$ do Hamiltoniano dado por $\langle H\rangle_{min} = -0,6165$. Para cada número de camadas, consideramos uma média sobre as duas melhores dentre 10 otimizações.

3. Implementation of the QAOA

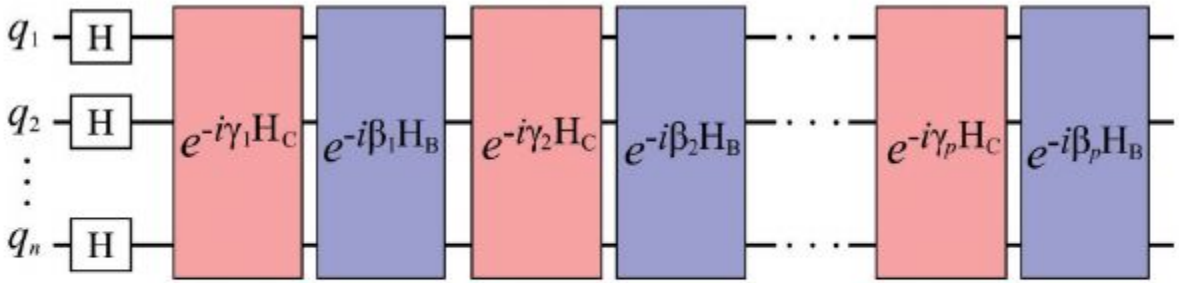


Figura 4: Circuito para implementação do QAOA.

$$U_C(\gamma) := e^{-i\gamma H_C},$$
$$U_B(\beta) := e^{-i\beta H_B}.$$

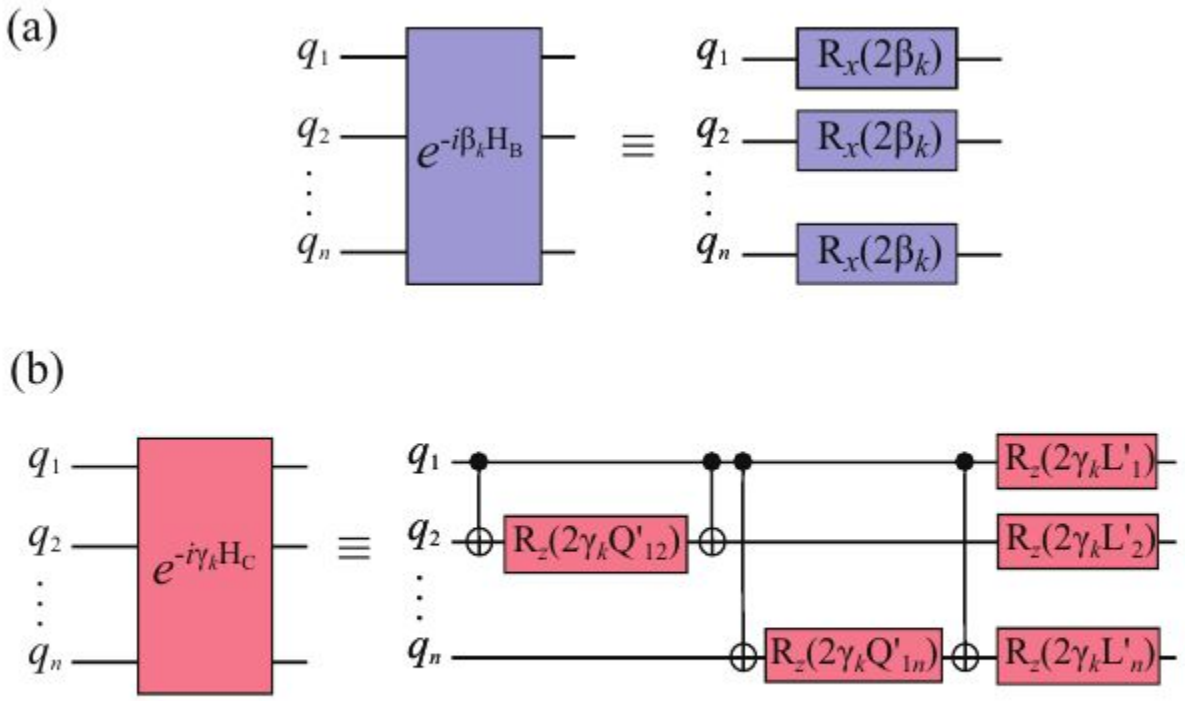
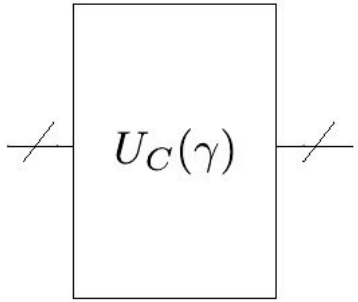


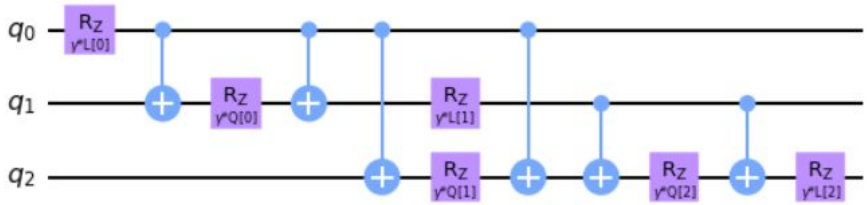
Figura 5: Circuitos implementando as unitárias (a) U_B e (b) U_C.

Exercise - Make a full QAOA implementation

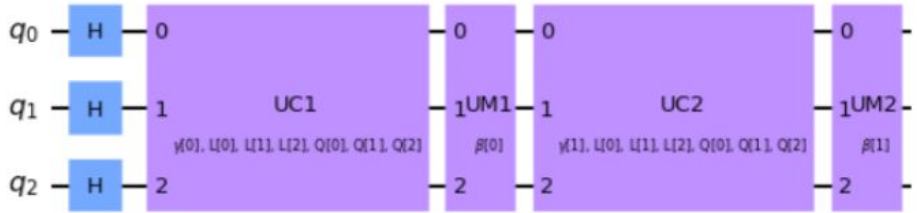
Qiskit

```
nqbits = 3

qc = QuantumCircuit(nqbits)

Q = ParameterVector('Q', int(nqbits*(nqbits-1)/2))
L = ParameterVector('L',nqbits)
gamma = Parameter(r'$\gamma$')

k=0
for i in range(nqbits):

    qc.rz(L[i]*gamma, i)

    for j in range(i+1, nqbits):
        qc.cx(i, j)
        qc.rz(Q[k]*gamma, j)
        qc.cx(i, j)
        k += 1

qc.draw('mpl');
```





```python
nqbits = 3
layers = 2

Q = ParameterVector('Q', int(nqbits*(nqbits-1)/2))
L = ParameterVector('L',nqbits)

gamma = ParameterVector(r'$\gamma$', layers)
beta  = ParameterVector(r'$\beta$', layers)

qc = QuantumCircuit(nqbits)

qc.h(range(nqbits))

for p in range(layers):

    uc = Uc(nqbits, gamma[p], Q, L).to_gate()
    uc.label = "UC" + str(p+1)

    qc.append(uc, qargs=[0,1,2])

    um = Um(nqbits, beta[p]).to_gate()
    um.label = "UM" + str(p+1)

    qc.append(um, qargs=[0,1,2])

qc.draw('mpl');
```



May try also

Qiskit

IBM Q

Cirq

TensorFlow Quantum

PENNYLANE

XANADU

Ocean

D-Wave

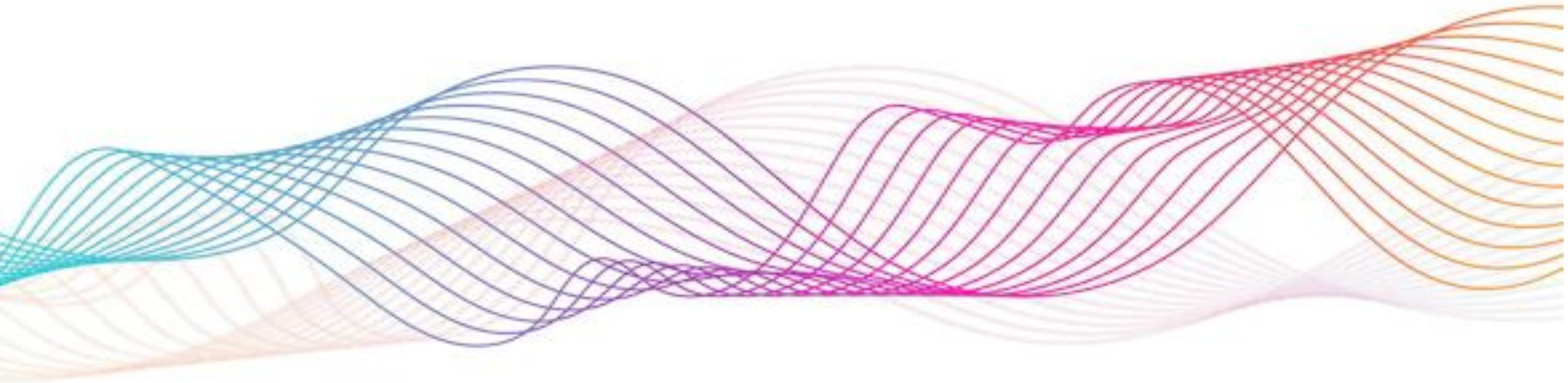
The Quantum Computing Company™

Conclusion

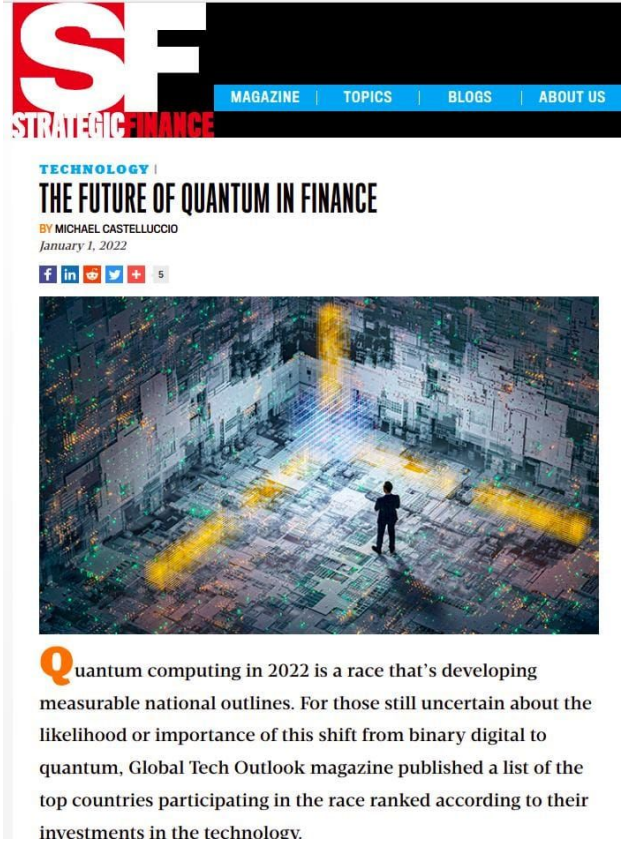
- QAOA is an interesting method for near-term noisy devices that could already provide some advantage with few resources
- Part of the family of Variational Quantum Algorithms with the benefit of being connected to Adiabatic Quantum Computing.
- Active area of research with potential for much experimentation (e.g. warm start, other ansatzes, optimization methods, etc.)
- Although simple, design considerations must be taken into account to avoid convergence problems (e.g. barren plateaus, NP-Hard classical optimization, ...)

Useful References

- ArXiv:1411.4028 – Original paper
- Algorithms 2019, 12(2), 34 – Other alternating ansatze
- ArXiv:1602.07674 – Supremacy via QAOA
- ArXiv:1911.05296 – Portifolio rebalancing
- Quantum 5, 479 (2021) – Warm start
- Phys. Rev. Lett. 127, 120502 – Classical optimization is NP-Hard
- ArXiv:2101.02138 – Controlability leads to barren plateaus
- ArXiv:2208.04382 – Our Quantum Finance tutorial (In Portuguese)



The Future of Quantum in Finance



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THE FUTURE OF QUANTUM IN FINANCE

BY MICHAEL CASTELLUCCIO

January 1, 2022

5

Quantum computing in 2022 is a race that's developing measurable national outlines. For those still uncertain about the likelihood or importance of this shift from binary digital to quantum, Global Tech Outlook magazine published a list of the top countries participating in the race ranked according to their investments in the technology.

https://sfmagazine.com/post-entry/january-2022-the-future-of-quantum-in-finance/

Exercise: take a time series for the price of a given stock and compute the error (r2 and MSE) of the naive strategy of predicting tomorrow future with the value of today

Thank you!!