Putting quantum machine learning algorithms to the test

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Introduction

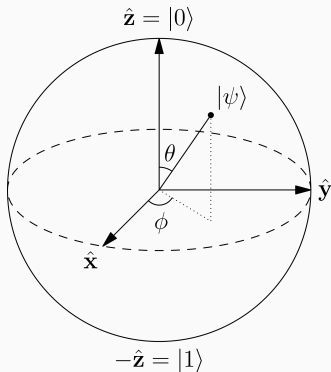## Quantum Computing & Qubits

Figure 1: Arbitrary two-dimensional qubit $|\psi\rangle$ visualized on the Bloch sphere.

Most general form of a 2-D qubit:

$$|q\rangle = \alpha |0\rangle + \beta |1\rangle \qquad (1)$$

where $\alpha, \beta \in \mathbb{C}$.

Can also be visualized in spherical polar coords on the unit or Bloch sphere as follows:

$$|q\rangle = \cos\frac{\theta}{2} |0\rangle + e^{i\phi} \sin\frac{\theta}{2} |1\rangle \quad (2)$$

where $0 \leq \theta \leq \pi$ and $0 \leq \phi \leq 2\pi$

Classical Machine Learning

- Approximately 2.5 quintillion (10^{18}) bytes of digital data are created every day[1]

- Need for advanced algorithms that can make sense of data content, retrieve patterns and reveal correlations $\rightarrow$ Machine learning (ML)

- ML algorithms often involve

  - solving large systems of linear equations

  - inverting large matrices

  - distance computations

- Performing these computations on large data sets gets increasingly difficult[2]

[1]IBM. (2016). What is big data? https://www-01.ibm.com/software/data/bigdata/what-is-big -data.html. (Accessed: 2016-09-08)
[2] Bekkerman, R., Bilenko, M., & Langford, J. (2011). Scaling up machine learning: Parallel and distributed approaches. Cambridge University Press.

Classical Machine Learning

Machine learning can be subdivided into three major fields.

Supervised ML
- Based on *input* and *output* data
  "I know how to classify this data but I need the algorithm to do the computations for me."

Unsupervised ML
- Based on *input* data only
  "I have no clue how to classify this data, can the algorithm create a classifier for me?"

Reinforcement learning
- Based on *input* data only
"I have no clue how to classify this data, can the algorithm classify this data and I'll give it a reward if it's correct or I'll punish it if it's not."

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Some general info about QML. How can quantum computing aid classical machine learning?

Experimental realizations so far

Until now there have been only few experimental verifications of QML algorithms that establish proof- of-concept. Li, Liu, Xu, and Du (2015) successfully distinguished a handwritten six from a nine using a quantum support vector machine on a four-qubit nuclear magnetic resonance test bench. In addition, Cai et al. (2015) were first to experimentally demonstrate quantum machine learning on a photonic QC and showed that the distance between two vectors and their inner product can indeed be computed quantum mechanically. Lastly, Rist et al. (2015) solved a learning parity problem with five superconducting qubits and found that a quantum advantage can already be observed in non error-corrected systems.

Classical k-nearest neighbour
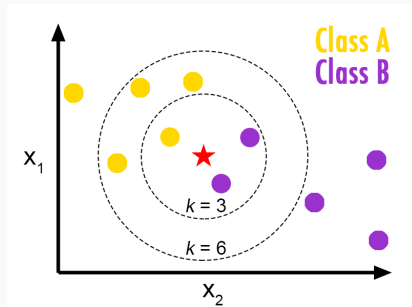
Some description goes here.

Figure 2: Visualization of a kNN classifier[1]

Two different algorithms with respect to initial state preparation:

Data encoded into qubits

k-dimensional probability vector requires $4k$ classical bits which are encoded one-to-one into $4k$ qubits, e.g.

$$\begin{pmatrix} 0.6 \\ 0.4 \end{pmatrix} * 10 \rightarrow \begin{pmatrix} 6 \\ 4 \end{pmatrix} \rightarrow \begin{pmatrix} 0110 \\ 0100 \end{pmatrix} \rightarrow n = 01100100 \rightarrow |n\rangle = |01100100\rangle$$

Data encoded into amplitudes

k-dimensional probability vector is encoded into $log_2(k)$ qubits, e.g.

$$\begin{pmatrix} 0.6 \\ 0.4 \end{pmatrix} \quad \rightarrow \quad |n\rangle = \sqrt{0.6}\,|0\rangle + \sqrt{0.4}\,|1\rangle$$

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Amplitude-based kNN algorithm

The algorithm

metropolis supports 4 different titleformats:

- Regular

- SMALLCAPS

- ALLSMALLCAPS

- ALLCAPS

They can either be set at once for every title type or individually.

Algorithmic complexity

$\mathcal{O}(\frac{1}{p_{acc}})$

This frame uses the `smallcaps` titleformat.

Potential Problems

Be aware, that not every font supports small caps. If for example you typeset your presentation with pdfTeX and the Computer Modern Sans Serif font, every text in `smallcaps` will be typeset with the Computer Modern Serif font instead.

This frame uses the `smallcaps` titleformat.

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Algorithmic complexity

$$\mathcal{O}(\frac{1}{p_{acc}}) + \mathcal{O}(somestuff)$$

Problems with universal gate sets

This frame uses the `allsmallcaps` titleformat.

Potential problems

As this titleformat also uses smallcaps you face the same problems as with the `smallcaps` titleformat. Additionally this format can cause some other problems. Please refer to the documentation if you consider using it.

As a rule of thumb: Just use it for plaintext-only titles.

Algorithmic complexity

$\mathcal{O}(\frac{1}{p_{acc}}) + \mathcal{O}(somestuff) + \mathcal{O}(somemorestuff)$

This frame uses the `allcaps` titleformat.

Potential Problems
This titleformat is not as problematic as the `allsmallcaps` format, but basically suffers from the same deficiencies. So please have a look at the documentation if you want to use it.

Qubit-based kNN quantum algorithm

Typography

```
The theme provides sensible defaults to
\emph{emphasize} text, \alert{accent} parts
or show \textbf{bold} results.
```

becomes

The theme provides sensible defaults to *emphasize* text, accent parts or show **bold** results.

Font feature test

- Regular

- *Italic*

- SMALLCAPS

- **Bold**

- **Bold Italic**

- **Bold SmallCaps**

- `Monospace`

- *`Monospace Italic`*

- `Monospace Bold`

- *`Monospace Bold Italic`*

Lists

Items
- Milk
- Eggs
- Potatos

Enumerations
1. First,
2. Second and
3. Last.

Descriptions
PowerPoint Meeh.
Beamer Yeeeha.

- This is important

- This is important

- Now this

- This is important

- Now this

- And now this

- This is really important
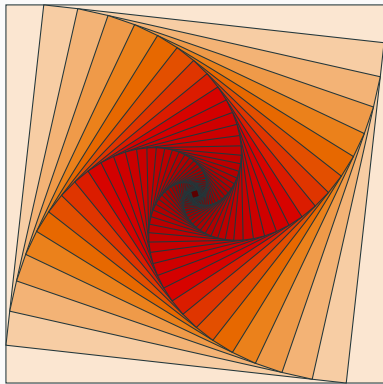
- Now this

- And now this

Figure 3: Rotated square from texample.net.

Tables

Table 1: Largest cities in the world (source: Wikipedia)

City	Population
Mexico City	20,116,842
Shanghai	19,210,000
Peking	15,796,450
Istanbul	14,160,467

Blocks

Three different block environments are pre-defined and may be styled with an optional background color.

Default
Block content.

Alert
Block content.

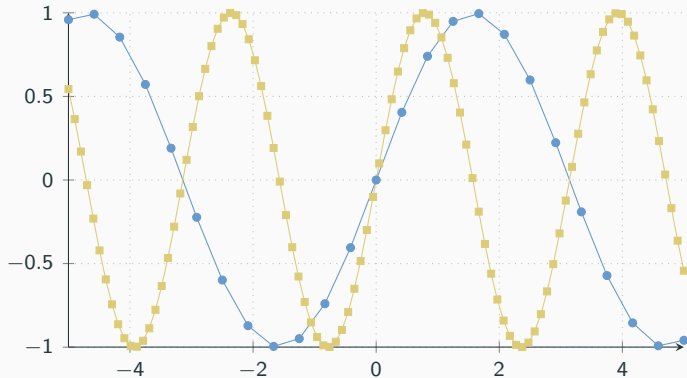**Example**
Block content.

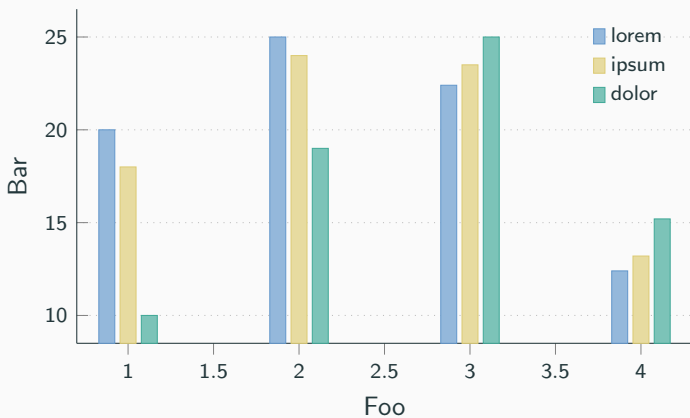**Default**
Block content.

Alert
Block content.

Example
Block content.

Math

$$e = \lim_{n \to \infty} \left(1 + \frac{1}{n}\right)^n$$

Veni, Vidi, Vici

Conclusion

Summary

sefsefesfsefsef

References

Some references to showcase [allowframebreaks] [**?**, **?**, **?**, **?**, **?**]

Questions?

Backup slide I

fefesfesfesfefesf

📄 IBM.

What is big data?

https://www-01.ibm.com/software/data/bigdata/
what-is-big-data.html, 2016.

Accessed: 2016-09-08.