Applied QML

Lecture 3: Informatique Quantique, bases avec Pennylane

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Table des matières

Sujets intra + articles

PennyLane

Portes à 1 qubit

Porte à 2 qubits

Challenges

Simple classifieur

Méthode pour lire un article

Intra

- Sujets intra
  - Tensor Networks
  - Input problem
  - Hamiltonien en QML
  - Déquantisation
  - Comment le QML peut-être utilisé dans la simulation des matériaux?
  - Quantum Avantage
  - Quantum Image Generation

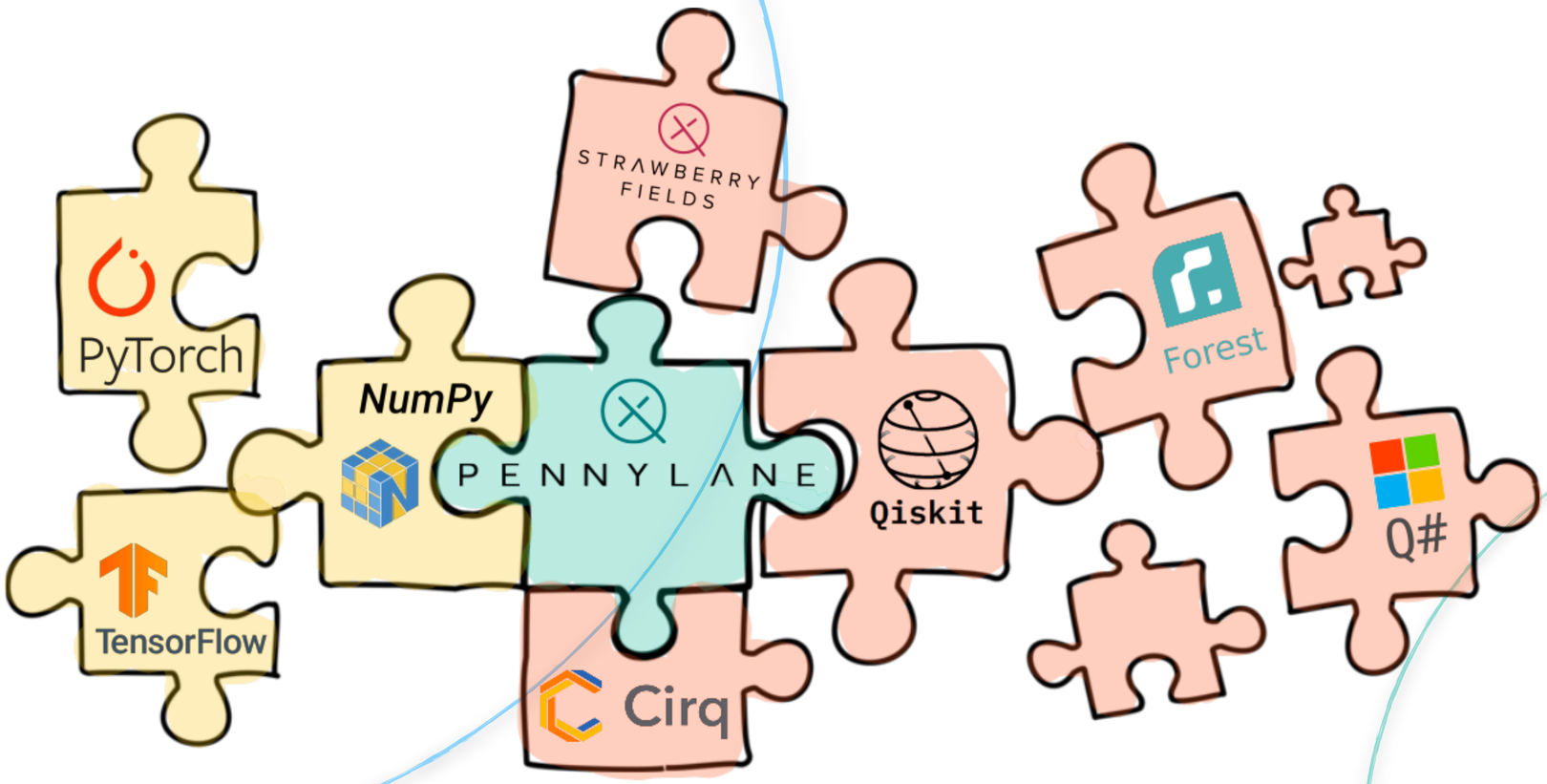
Articles

Senokosov et al. 2023, Quantum machine learning for image classification	https://arxiv.org/pdf/2304.09224.pdf
Verdon et al., 2019, Graph Neural Networks	https://arxiv.org/pdf/1909.12264.pdf
DiAdamo et al., 2022, Practical Quantum K-Means Clustering: Performance Analysis and Applications in Energy Grid Classification	https://arxiv.org/pdf/2112.08506.pdf
Huang et al., 2021, Experimental Quantum Generative Adversarial Networks for Image Generation	https://arxiv.org/pdf/2010.06201v3.pdf
Grossi et al., 2022, Mixed Quantum-Classical Method For Fraud Detection with Quantum Feature Selection	https://arxiv.org/pdf/2208.07963.pdf
Wozniak et al., 2023, Quantum anomaly detection in the latent space of proton collision events at the LHC	https://arxiv.org/pdf/2301.10780.pdf
Slabbert et al., 2023, Pulsar Classification: Comparing Quantum Convolutional Neural Networks and Quantum Support Vector Machines	https://arxiv.org/pdf/2309.15592.pdf

Introduction

PennyLane

Xanadu



Installation

```
$> python3 -m pip install pennylane
```

Import

```
import pennylane as qml
```

Introduction

Objectif

"Team Building"

Apprendre à utiliser PennyLane

2 par 2

Mini exercises

Chronométré

Fun

PennyLane

Comment faire un circuit

Éléments nécessaires

Qubit

device

QNode

Portes logiques

"State"

Paramètre

Wires

```
qml.device("lightning.qubit", wires=1)
```

```
qml.device("default.qubit", wires=1)
qml.device("default.mixed", wires=1)
qml.device("default.qutrit", wires=1)
qml.device("default.gaussian", wires=1)
```

Hardware

Nombre de qubits

Peut également être des noms: `wires=['ancilla', 'q11', 'q12', -1, 1]`

https://docs.pennylane.ai/en/stable/code/qml.html

PennyLane

Comment faire un circuit

Éléments nécessaires

Qubit

device

QNode

Portes logiques

"State"

Paramètre

Wires

```
qml.device("lightning.qubit", wires=1)
```

ou

```
@qml.qnode(dev)
qnode = qml.QNode(circuit, dev)
```

```
qml.state()
```

Angle ϕ

```
qml.RX(x, wires=0)      qml.PauliX(0)
qml.RZ(x, wires=0)      qml.PauliZ(0)
qml.RY(y, wires=1)      qml.PauliY(1)
qml.CNOT(wires=[0,1])
```

Qubit

https://docs.pennylane.ai/en/stable/code/qml.html

Portes à 1 qubit

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|0\rangle = \begin{pmatrix} \alpha \\ 0 \end{pmatrix}$$

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ \beta \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \qquad \texttt{qml.PauliY(0)}$$

$$Y|0\rangle = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ i \end{pmatrix} = i|1\rangle$$

```
@qml.qnode(dev)
def qcirc():
    qml.PauliY(0)
    return qml.state()
```

```
>> qcirc()
tensor([0.0j, 0.+1.j], requires_grad=True)
```

Portes à 1 qubit

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|0\rangle = \begin{pmatrix} \alpha \\ 0 \end{pmatrix}$$

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ \beta \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

```
@qml.qnode(dev)
def qcirc2():
    qml.PauliX(0)
    qml.PauliY(0)
    return qml.state()
```

$$X|0\rangle = |1\rangle$$

```
>> qcirc2()
tensor([0.-1.j, 0.0.j], requires_grad=True)
```

$$Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

`qml.PauliY(0)`

$$Y|1\rangle = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} -i \\ 0 \end{pmatrix} = -i|0\rangle$$

Portes à 1 qubit

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|0\rangle = \begin{pmatrix} \alpha \\ 0 \end{pmatrix}$$

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ \beta \end{pmatrix}$$

$$|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$|+\rangle = H|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

$$|+\rangle = H|0\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

```
@qml.qnode(dev)
def qcirc():
    qml.Hadamard(0)
    return qml.state()
```

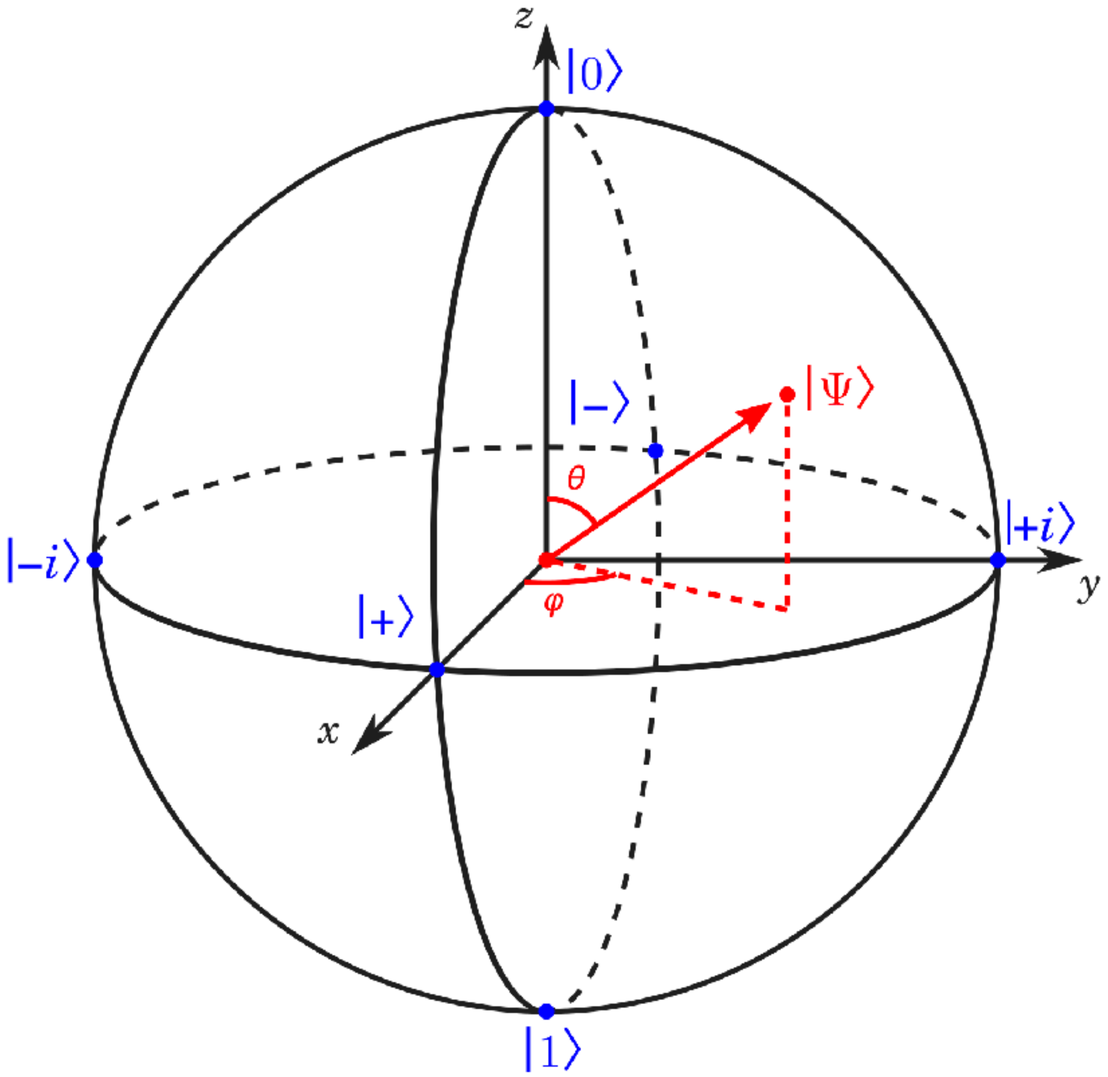
```
>> qcirc()
tensor([0.70710678+0.j, 0.70710678+0.j], ...)
```

Portes à 2 qubits

```
@qml.qnode(dev)
def qcirc():
    qml.PauliX(0)
    qml.CNOT([0,1])
    return qml.state()
```

ab	CNOT
$\|00\rangle$	$\|00\rangle$
$\|01\rangle$	$\|01\rangle$
$\|10\rangle$	$\|11\rangle$
$\|11\rangle$	$\|10\rangle$

Bloch Sphere



Challenges

Comment construire les états:

$\|-\rangle$	2 min	1 pt
$\|i\rangle$	2 min	2 pt
$\|-i\rangle$	2 min	2 pt
$\frac{\sqrt{3}}{2}\|0\rangle - \frac{i}{2}\|1\rangle$	5 min	3 pt

QubitStateVector(state, wires)

Utilisez les portes RX, Hadamard, RZ, RY de PennyLane

Challenges

Comment construire les états de Bell?

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)$$ 2 min 2 pt

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle - |11\rangle\right)$$ 2 min 2 pt

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle + |10\rangle\right)$$ 2 min 2 pt

$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle - |10\rangle\right)$$ 2 min 2 pt

Comment construire l'état GHZ?

$$|GHZ\rangle = \frac{1}{\sqrt{2}}\left(|000\rangle + |111\rangle\right)$$ 3 min 3 pt

Avec 5 qubits?

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|00000\rangle + |11111\rangle\right)$$ 2 min 2 pt

Mesure

```
qml.state()
qml.expval(op)
qml.count()
qml.probs()
```

```
tensor([ 0.       +0.j,  0.70710678+0.j,
-0.70710678+0.j,  0.       +0.j], ...)
```

```
from qiskit.quantum_info import Statevector
Statevector(qml.state()).draw('latex')
```

$$\frac{1}{\sqrt{2}}|01\rangle - \frac{1}{\sqrt{2}}|10\rangle$$

Mesure

`qml.state()` → `tensor([[0.   +0.j, 0.70710678+0.j],
[-0.70710678+0.j, 0.   +0.j]], ...)`

`qml.expval(op)` → Valeur moyenne de la mesure selon l'observable

`qml.count()` → Donne le nombre de fois que l'état a été observé

`qml.probs()`

```
{'00000': tensor(513, ...),
 '11111': tensor(487, ...)}
```

`qml.count(all_outcomes=True)`

Donne le nombre d'occurence de tous les états possibles

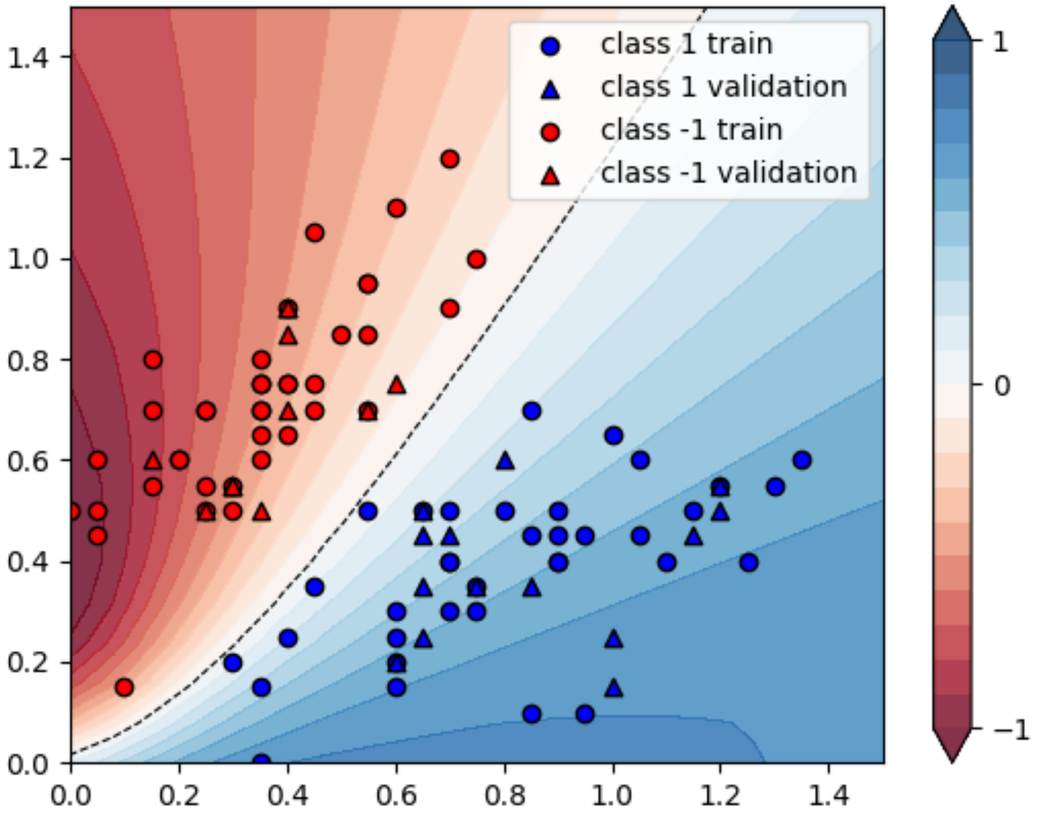
$2^5 =$ 32 possibilités

```
{'00000': tensor(513, ...),
 '00001': tensor(0, ...),
 '00010': tensor(0, ...),
 ...
 '11111': tensor(487, ...)}
```

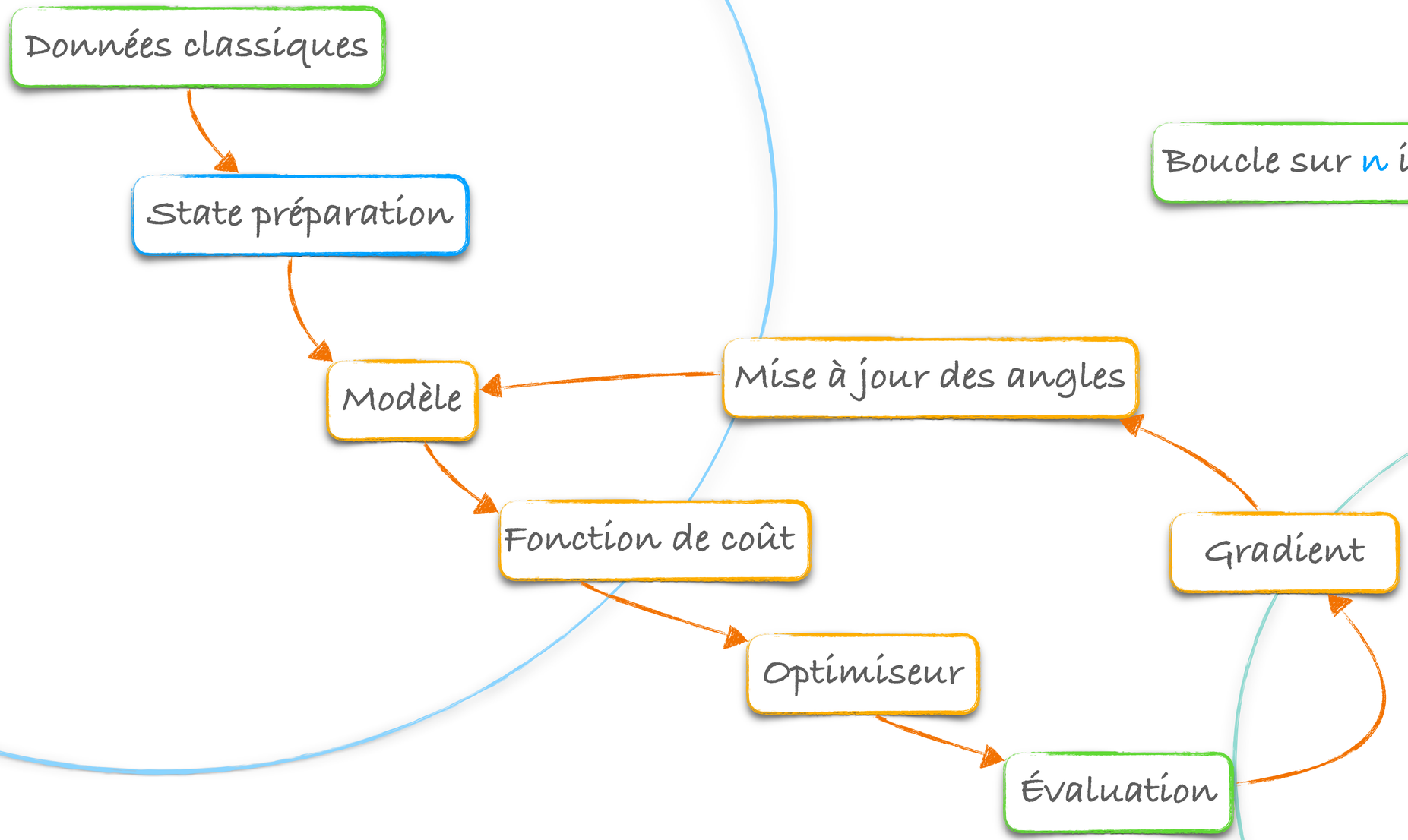
Simple classifieur

Exemple simple

Iris Data

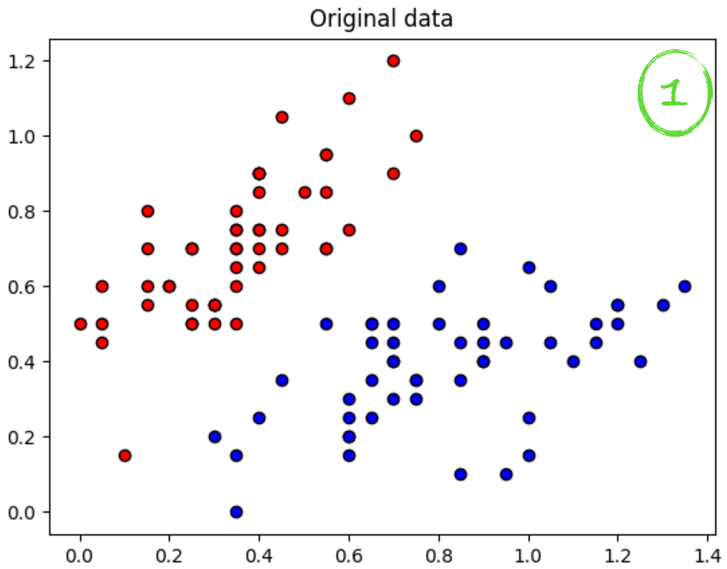


Simple classifieur

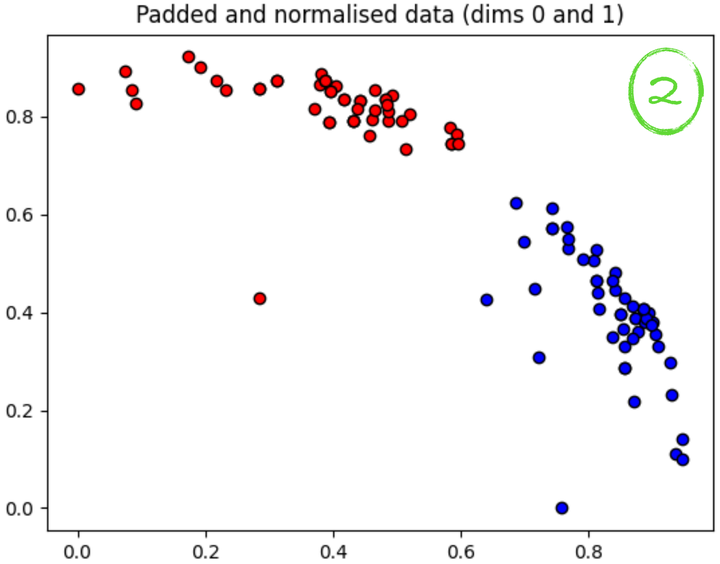


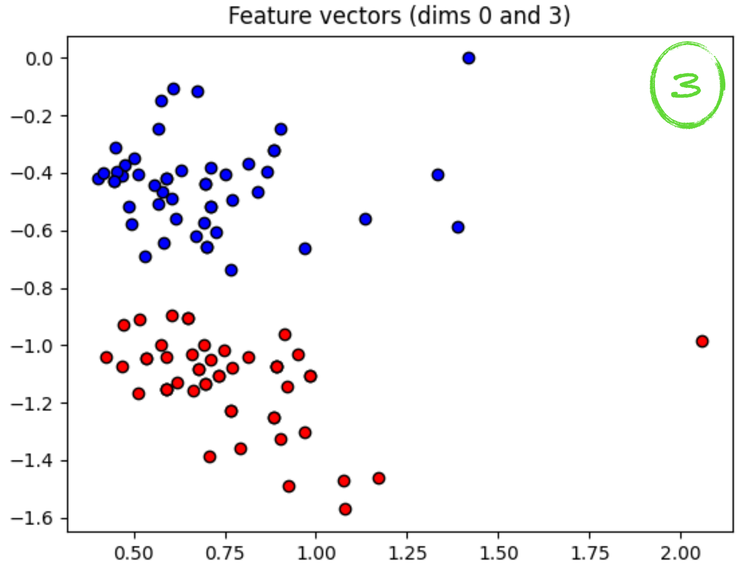
Simple classifieur

Données classiques



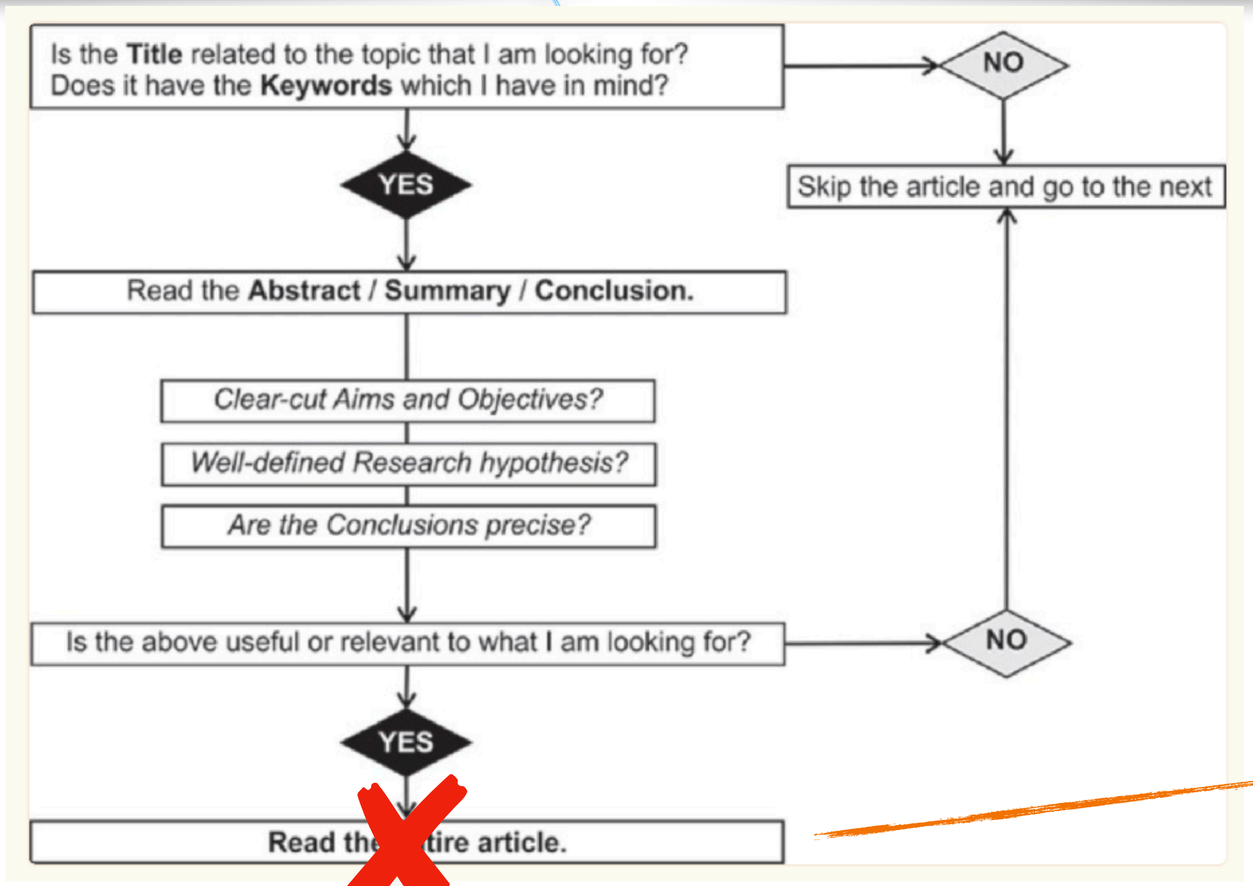
Classification binaire

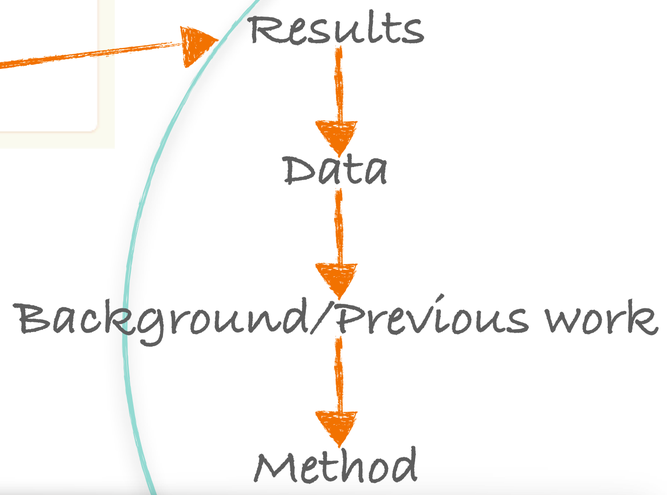




Comment lire un article?

Comment lire un article?





Subramanyam , 2013, Art of reading a journal article: Methodically and effectively

Comment lire un article?

Overall

1. What was the article type?
2. What was the title?
3. Who were the authors?

Introduction

4. What was the research problem?
5. Was there any mention of previous studies on this topic?
6. Why was this study performed (the rationale)?
7. What were the aims and objectives of the study?
8. What was the study (research) hypothesis?

Materials and methods

9. How did the researcher attempt to answer the research question?
10. How was the sampling done?
11. How were they grouped (categorized)?
12. What were the inclusion criteria?
13. What were the exclusion criteria?
14. What procedures were followed?
15. Which variables were measured?
16. What equipment/instruments were used for data collection? Were they appropriate?
17. What statistical methods/tests were employed? Were they apt for evaluation?

Results

18. What were the key findings?
19. Were all the subjects present in the beginning of the study accounted for at the end of the study?
20. Were the results reliable?
21. Were the results valid?
22. Which results were statistically significant?
23. Which results were statistically non-significant?
24. Were the tables/graphs easy to comprehend?

Discussion

25. Did the results answer the research question?
26. What were the authors' interpretations of the data?
27. Was the analysis of the data relevant to the research question?
28. How were these results different/similar when compared to other studies?
29. What were the strengths of the study?
30. What were the limitations of the study?
31. Were there any extrapolations of the findings beyond the range of data?

Conclusions

32. What were the conclusions?
33. Were the authors' conclusions based upon reported data and analysis?
34. Were the conclusions reasonable and logical?
35. Will the results be useful in clinical practice or for further research?
36. Was the study worth doing?
37. Does the reader have any questions unanswered by the article?

References

38. Were the references cited according to journal's requirement?
39. Were all the citations correct?
40. Were all the references cited in the text?

Subramanyam , 2013, Art of reading a journal article: Methodically and effectively