Reservoir Computing : passage à la pratique avec **ReservoirPy**

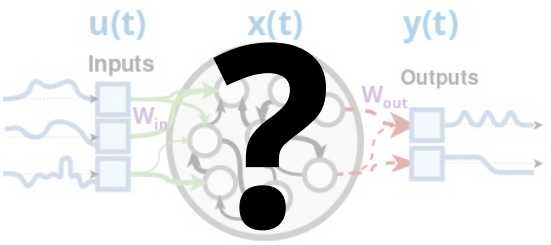
Xavier HINAUT – Institut d'Optique - 2025

Quel outil Python pour le reservoir computing ?

scikit learn

SciPy

TensorFlow



PyTorch

Introduction

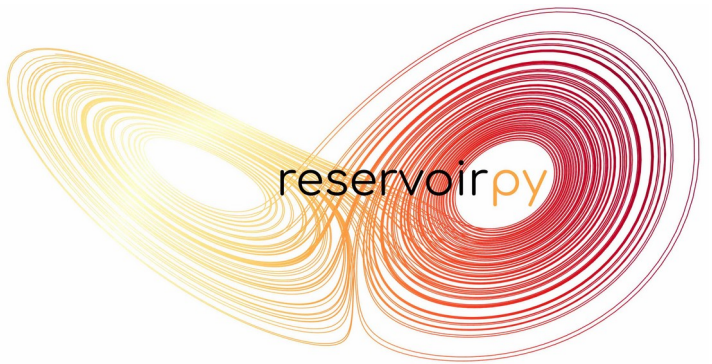
Library	Language	Main dependency	Last activity	Package	Doc.	Tests	Off.	On.	Fb.	Model type	Deep
PyRCN	Python 3	Scikit-learn	Nov 2022	pip	✓	✓	✓	x	x	ESN	✓
EchoTorch	Python 3	PyTorch	Sep. 2021	pip	✓	✓	✓	x	x	ESN, Conceptors	✓
★Res.Comp.jl [3]	Julia	Julia	Sept 2023	Pkg	✓	✓	✓	x	x	ESN	x
Pytorch-esn	Python 3	Pytorch	Feb 2022	x	x	x	✓	x	x	ESN	✓
DeepESN	Matlab	Matlab	Feb. 2019	Matlab	✓	?	✓	x	x	ESN	✓
RCNet	C#	C#	Aug. 2021 (closed)	x	partial	x	✓	x	x	ESN, LSM	x
LSM	Python 3	Nest	Nov. 2020	x	x	x	✓	x	x	LSM	x
Oger	Python 2	mdp	2012 (obsolete)	x	x	✓	✓	✓	✓	LSM, ESN	✓
★**reservoirpy (this package)**	Python 3	Numpy	Sept 2023	pip	✓	✓	✓	✓	✓	ESN	✓

Table 1: Comparative table of some open source software for Reservoir Computing. This table might not be exhaustive. **Doc.** Complete documentation. **Off.** Offline learning strategies included. **On.** Online learning strategies included. **Fb.** Feedback and delayed connections. **Deep** The software allows the design of complex models where basic RC elements such as reservoirs and readouts can be stacked to form so-called "deep" networks.

ReservoirPy: un module Python pour le reservoir computing

Basé sur l'écosystème NumPy + SciPy
➡ léger

- Facile à prendre en main
- Flexible



https://github.com/reservoirpy/reservoirpy

Format des données

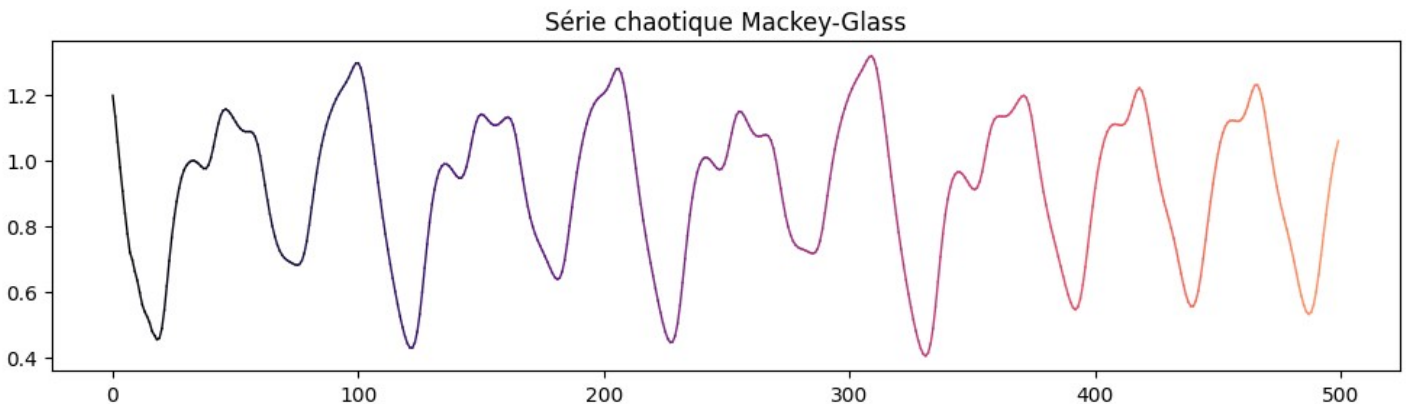
Toutes les données sont des tableaux NumPy.

$shape = (timesteps, features)$

```
from reservoirpy.datasets import mackey_glass

timeseries = mackey_glass(n_timesteps=2_000)
timeseries.shape
```

✓ 0.0s Python

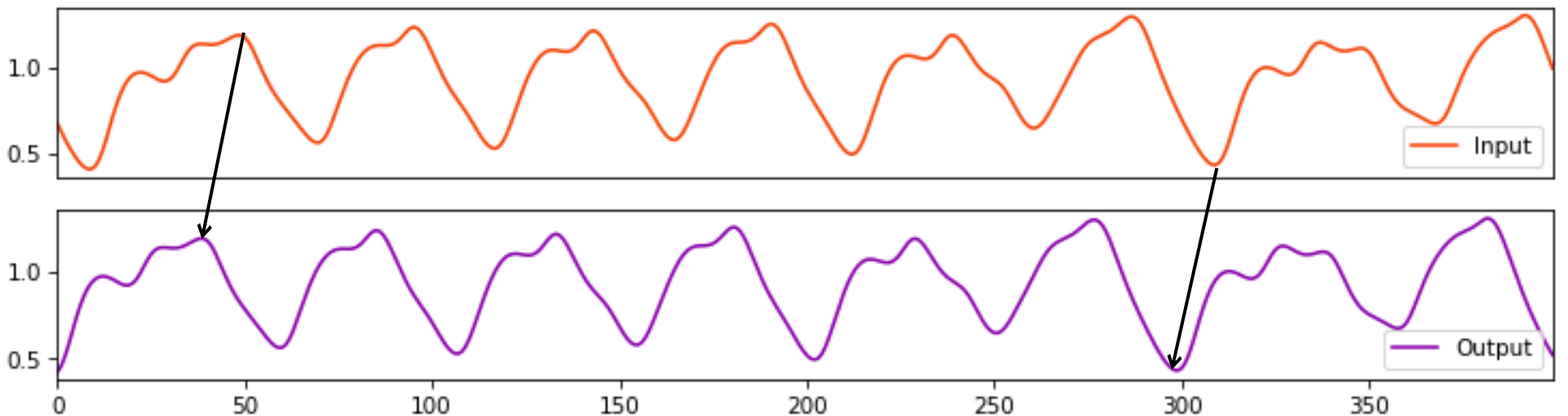
```
(2000, 1)
```



Préparer les données

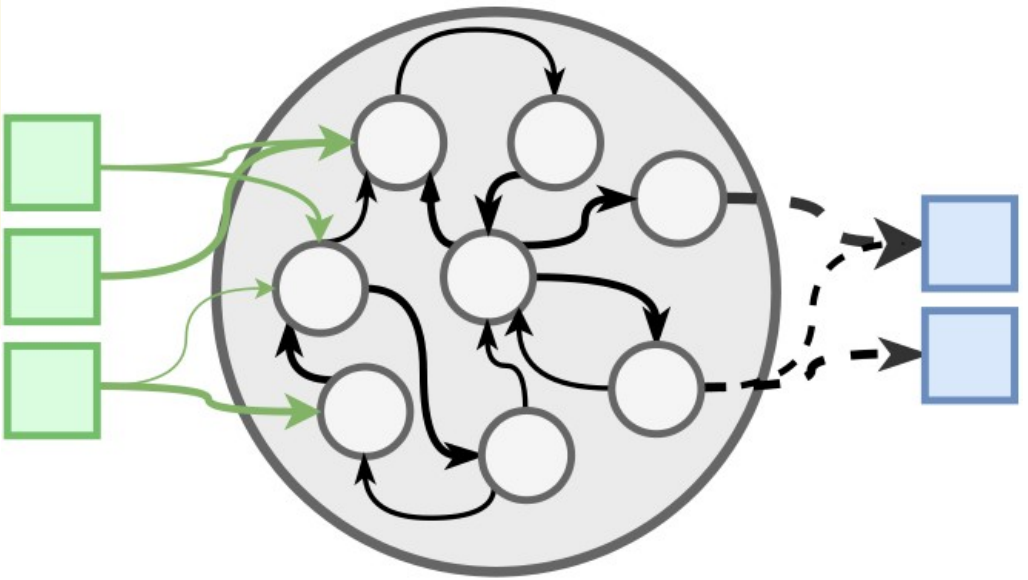
```
from reservoirpy.datasets import to_forecasting

dataset = to_forecasting(X, forecast=10, test_size=0.2)
x_train, x_test, y_train, y_test = dataset
```

✓ 0.0s



Créer un ESN

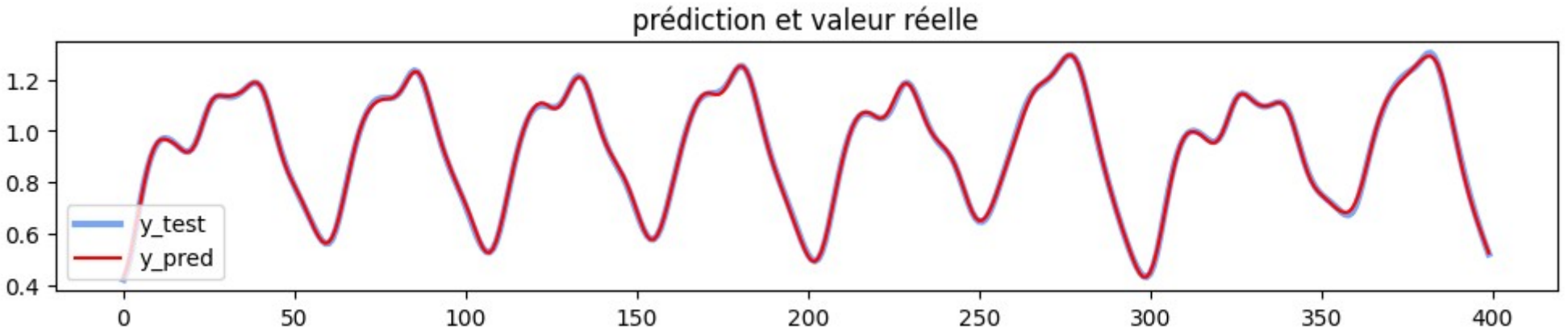
```python
from reservoirpy.nodes import ESN
model = ESN(
    units=100,
    lr=0.3,
    sr=1.25,
    ridge=1e-8
)
```



Entraîner et lancer le modèle

```
model.fit(x_train, y_train)
y_pred = model.run(x_test)
```

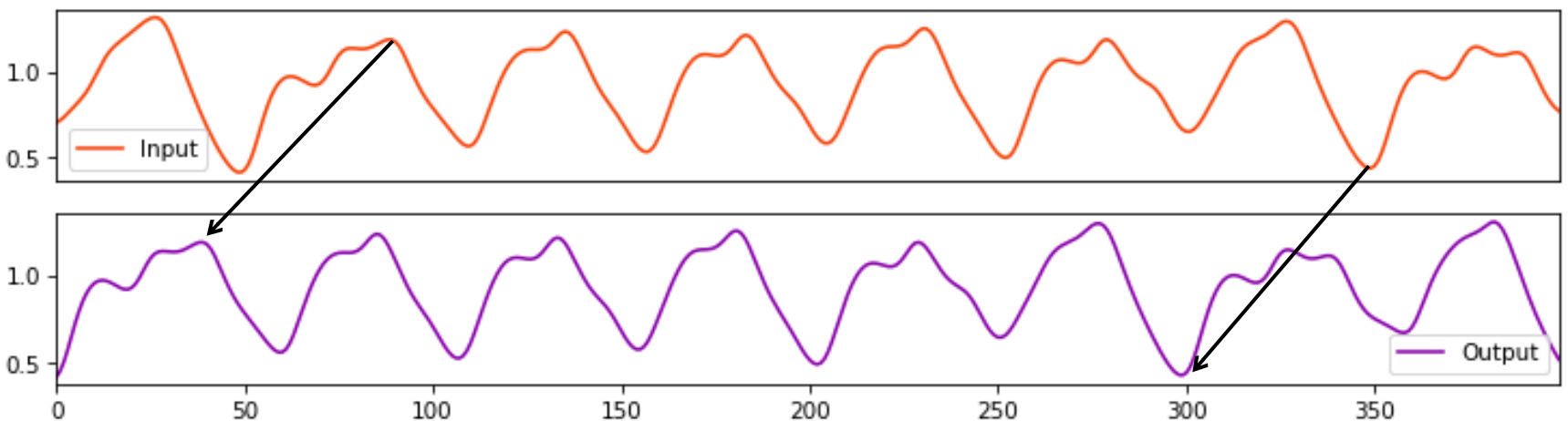
✓ 0.4s Python



… et avec une prédiction à t+50 ?

```
from reservoirpy.datasets import to_forecasting

dataset = to_forecasting(X, forecast=50, test_size=0.2)
x_train, x_test, y_train, y_test = dataset
```

✓ 0.0s Python

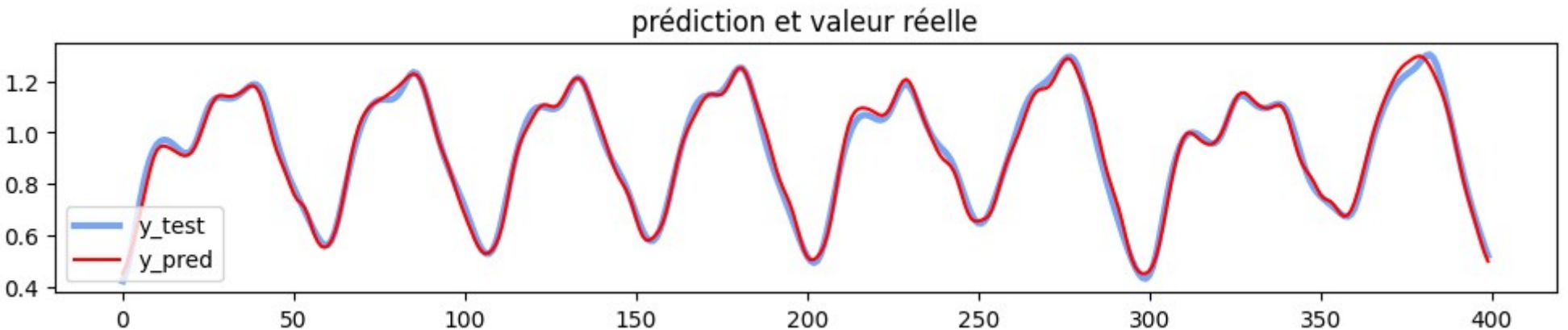


… et avec une prédiction à t+50 ?

le résultat

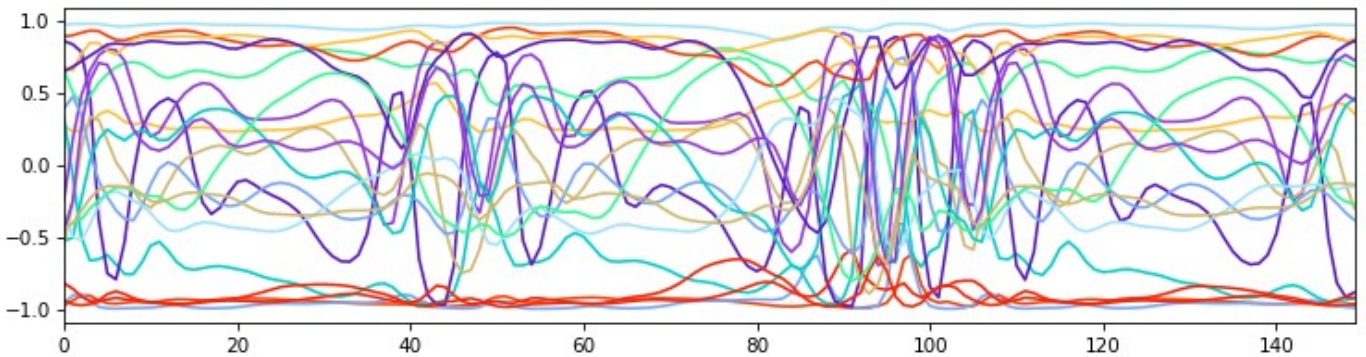
```
from reservoirpy.datasets import to_forecasting

dataset = to_forecasting(X, forecast=50, test_size=0.2)
x_train, x_test, y_train, y_test = dataset
```

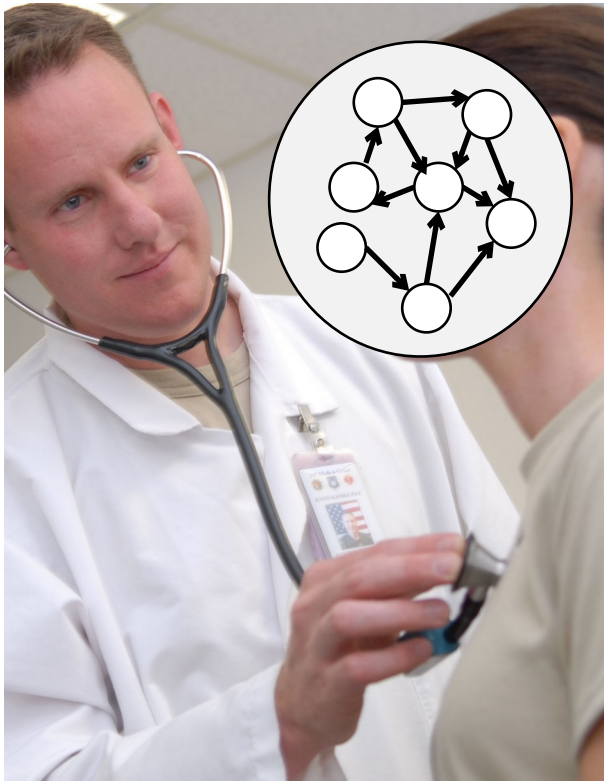
✓ 0.0s Python



Qu’est-ce qui se passe dans le réservoir ?

```
reservoir = Reservoir(units=20)
activity = reservoir.run(X_test)
```





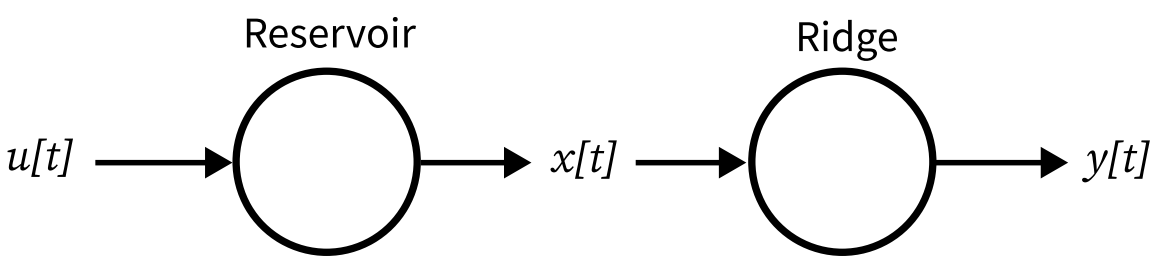
Crédits de l’image : Wikimedia

Récapitulatif

```python
from reservoirpy.datasets import (
    mackey_glass,
    to_forecasting,
)
from reservoirpy.nodes import ESN

timeseries = mackey_glass(n_timesteps=2_000)
dataset = to_forecasting(timeseries, forecast=100, test_size=0.2)
x_train, x_test, y_train, y_test = dataset

model = ESN(
    units=100,
    lr=0.3,
    sr=1.25,
    ridge=1e-8,
)

model.fit(x_train, y_train)
y_pred = model.run(x_test)
```

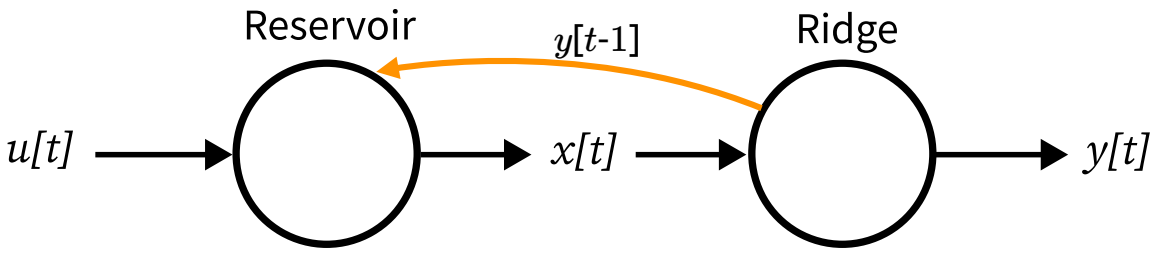
Les nœuds

```python
from reservoirpy.nodes import (
    Reservoir, Ridge
)
reservoir = Reservoir(units=10)
readout = Ridge(ridge=1e-4)

model = reservoir >> readout
```



Connexion *feedback*

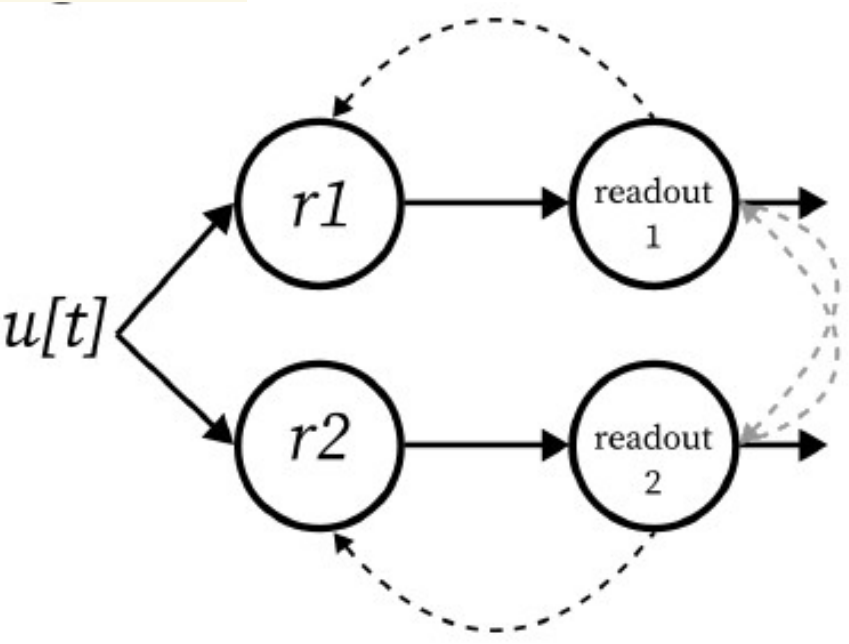
```python
from reservoirpy.nodes import (
    Reservoir, Ridge
)
reservoir = Reservoir(units=10)
readout = Ridge(ridge=1e-4)

reservoir <<= readout
model = reservoir >> readout
```



Architectures complexes

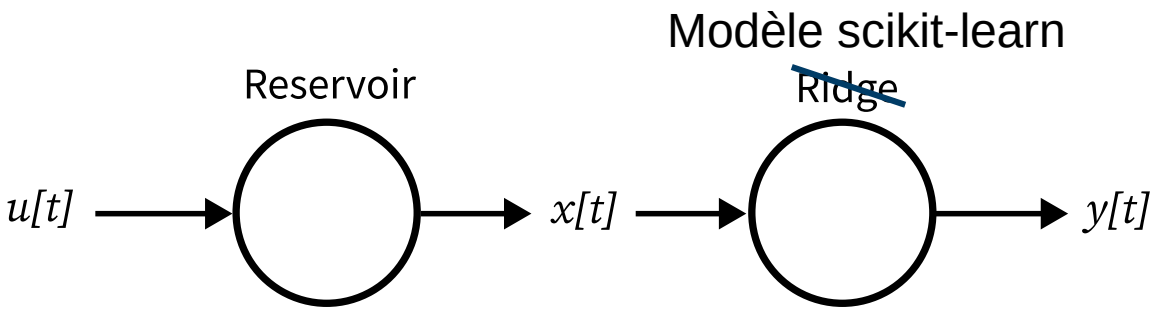
Créer des **modèles complexes** à partir de **briques simples**.

```python
from reservoirpy.nodes import Input
in_node = Input(name="u")
r1 = Reservoir(units=100, name="r1")
r2 = Reservoir(units=220, name="r2")
readout1 = Ridge(ridge=1e-4)
readout2 = Ridge(ridge=1e-2)

r1 <<= readout1
r2 <<= readout2
readout1 <<= readout2
readout2 <<= readout1

model = in_node >> [r1 >> readout1, r2 >> readout2]
```



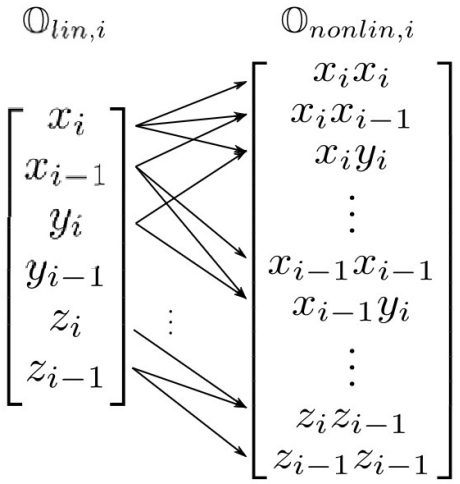
Les nœuds scikit-learn

```python
from sklearn.linear_model import RidgeClassifier, LogisticRegression, Perceptron

classifier         = ScikitLearnNode(RidgeClassifier)
logistic_regressor = ScikitLearnNode(LogisticRegression)
perceptron         = ScikitLearnNode(Perceptron)

model1 = reservoir >> classifier
model2 = reservoir >> logistic_regressor
model3 = reservoir >> perceptron
```

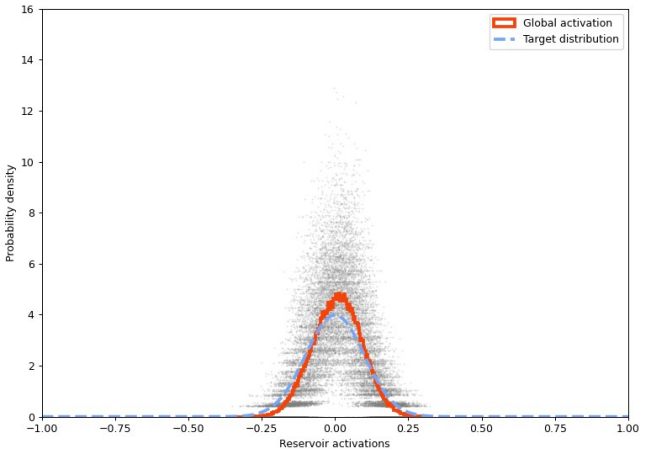


D’autres « réservoirs » plus exotiques...

`reservoirpy.nodes.NVAR`



`reservoirpy.nodes.IPReservoir`



Créer ses propres nœuds ReservoirPy

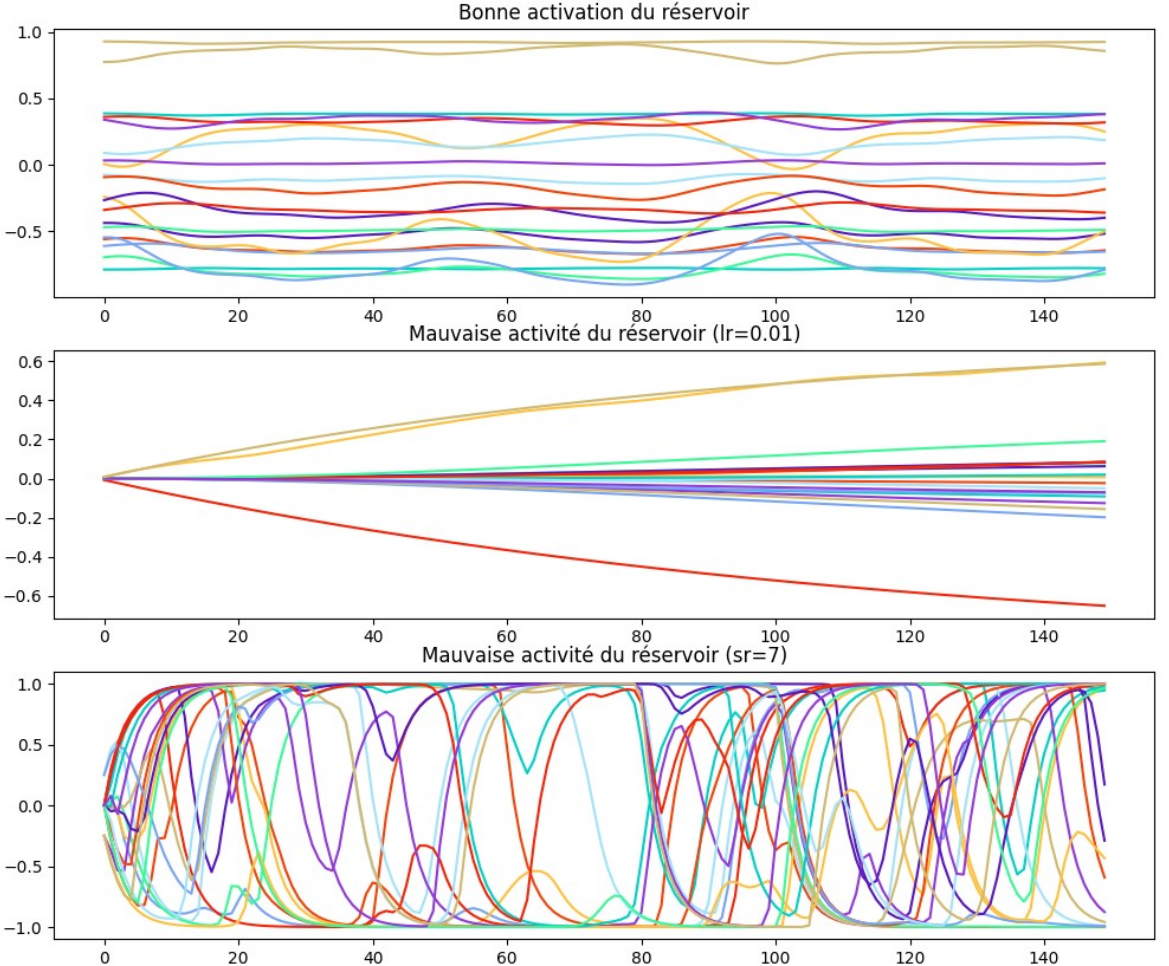
```python
from reservoirpy import Node

def initialize(node: Node, x: np.ndarray, y: np.ndarray) -> None:
    ... # setting input and output dimension, initialize parameters

def forward(node: Node, x: np.ndarray) -> np.ndarray:
    ... # called at each timestep, return the new node state

class MyNode(Node):
    def __init__(self, hyper1=1., name=None):
        super().__init__(
            forward = forward,
            initializer = initialize,
            hypers = {"hyper1": hyper1},
            params = {"param1": None},
            name = name,
        )
```

https://reservoirpy.readthedocs.io/en/latest/user_guide/create_new_node.html

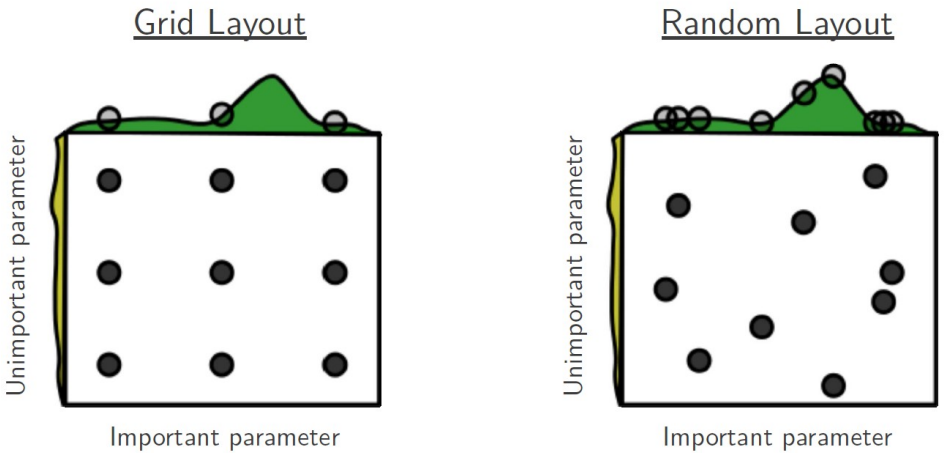
De l'importance des hyper-paramètres

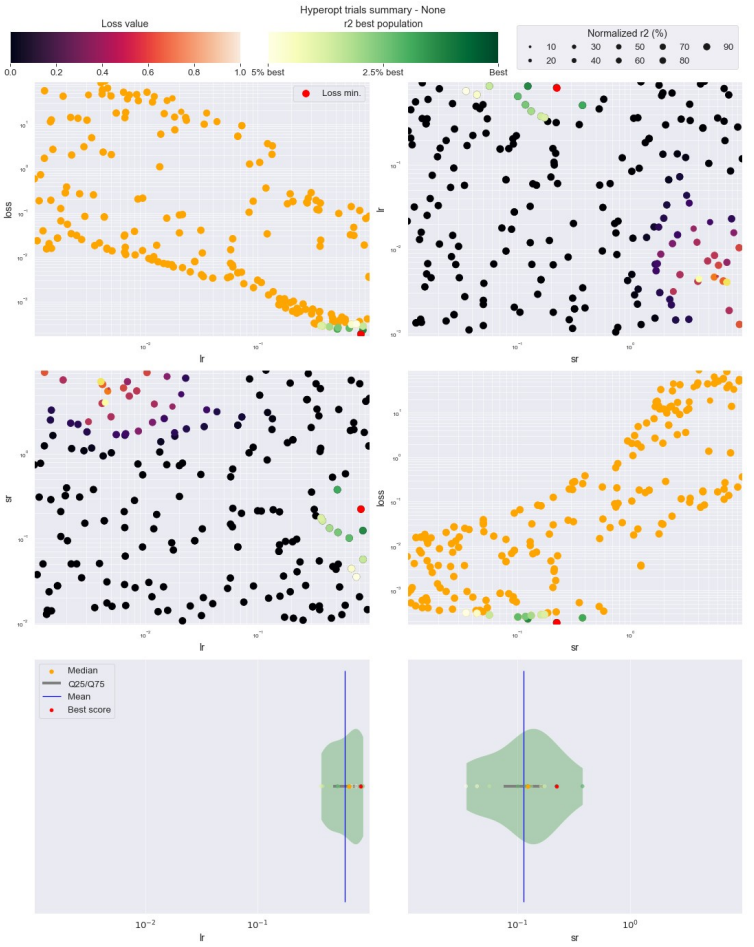
```
model = ESN(
    units=100,
    lr=0.3,
    sr=1.25,
    ridge=1e-8,
)
```

???

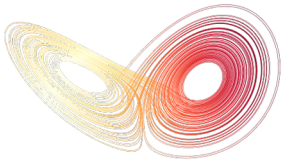


Recherche d'hyper-paramètres avec reservoirpy.hypers





Voir le tutoriel n°4:
https://github.com/reservoirpy/reservoirpy/tree/master/tutorials

reservoirpy  v0.3

Un *framework* Python dédié au Reservoir Computing:

- Apprentissage **en-ligne/hors-ligne**
- Boucles de **feedback**
- Modèles hiérarchiques, ***deep reservoir computing***
- **Parallèlisation** des calculs

Une boîte à outil pour construire des modèles de Reservoir Computing:

- Reservoir,
- Reservoir autoregressifs (NVAR),
- Ridge regression,
- FORCE learning,
- Intrinsic Plasticity...

Mais aussi:

- Des jeux de données, des métriques, des outils d'aide à l'optimisation des hyperparamètres avec *Hyperopt.*
- Des tutoriels, des exemples.

La philosophie de **ReservoirPy**

Libre et open-source (licence MIT)

Basé sur l'écosystème NumPy / SciPy

Entièrement documenté

De nombreux guides

https://github.com/reservoirpy/reservoirpy

Perspectives

- Intégration de nouvelles méthodes
- Calculs sur GPU (Jax)
- Réservoirs avec réseaux spiking

Ouverts aux suggestions et nouveaux cas d'applications !

Pour aller plus loin

https://github.com/reservoirpy/reservoirpy/

→ tutorials/

https://reservoirpy.readthedocs.io/

→ User Guide

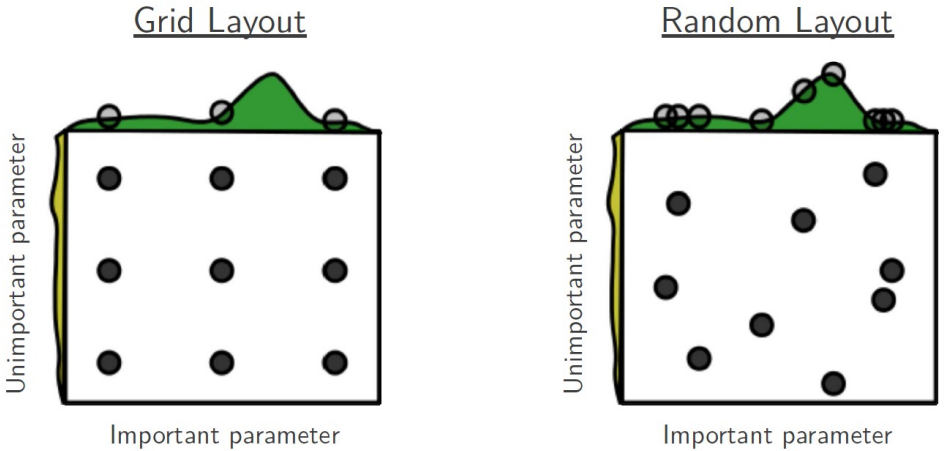
À vous !

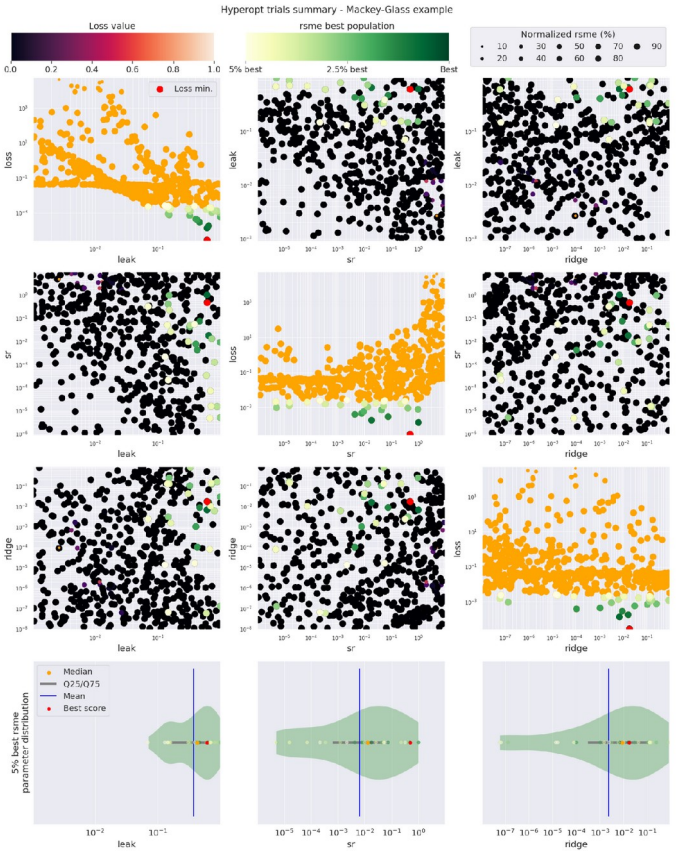
Téléchargez le dépôt et le notebook

https://github.com/reservoirpy/presentations

dans le dossier Institut-d-optique-2024-2025/

Optimisation des hyper-paramètres





https://github.com/reservoirpy/reservoirpy/blob/master/tutorials/4-Understand_and_optimize_hyperparameters.ipynb

Publications avec ReservoirPy

HAL publications related to this software

HAL id	HAL citation
hal-03699931	Nathan Trouvain, Xavier Hinaut. reservoirpy: A Simple and Flexible Reservoir Computing Tool in Python. 2022. ⟨hal-03699931⟩
hal-02595026	Nathan Trouvain, Luca Pedrelli, Thanh Trung Dinh, Xavier Hinaut. ReservoirPy: an Efficient and User-Friendly Library to Design Echo State Networks. *ICANN 2020 - 29th International Conference on Artificial Neural Networks*, Sep 2020, Bratislava, Slovakia. ⟨hal-02595026v2⟩
hal-03533731	Nathan Trouvain, Xavier Hinaut. Reservoir Computing : théorie, intuitions et applications avec ReservoirPy. *Plate-Forme Intelligence Artificielle (PFIA)*, Jun 2021, Bordeaux, France. ⟨hal-03533731⟩
hal-03203318	Xavier Hinaut, Nathan Trouvain. Which Hype for my New Task? Hints and Random Search for Reservoir Computing Hyperparameters. *ICANN 2021 - 30th International Conference on Artificial Neural Networks*, Sep 2021, Bratislava, Slovakia. ⟨hal-03203318v2⟩
hal-03482372	Silvia Pagliarini, Arthur Leblois, Xavier Hinaut. Canary Vocal Sensorimotor Model with RNN Decoder and Low-dimensional GAN Generator. *ICDL 2021- IEEE International Conference on Development and Learning*, Aug 2021, Beijing, China. ⟨hal-03482372⟩
hal-03203374	Nathan Trouvain, Xavier Hinaut. Canary Song Decoder: Transduction and Implicit Segmentation with ESNs and LTSMs. *ICANN 2021 - 30th International Conference on Artificial Neural Networks*, Sep 2021, Bratislava, Slovakia. pp.71--82, ⟨10.1007/978-3-030-86383-8_6⟩. ⟨hal-03203374v2⟩
hal-03761440	Nathan Trouvain, Nicolas P. Rougier, Xavier Hinaut. Create Efficient and Complex Reservoir Computing Architectures with ReservoirPy. *SAB 2022 - FROM ANIMALS TO ANIMATS 16: The 16th International Conference on the Simulation of Adaptive Behavior*, Sep 2022, Cergy-Pontoise / Hybrid, France. ⟨hal-03761440⟩
tel-03946773	Xavier Hinaut. Reservoir SMILES: Towards SensoriMotor Interaction of Language and Embodiment of Symbols with Reservoir Architectures. Artificial Intelligence [cs.AI]. Université de Bordeaux (UB), France, 2022. ⟨tel-03946773⟩
hal-03628290	Subba Reddy Oota, Frédéric Alexandre, Xavier Hinaut. Cross-Situational Learning Towards Robot Grounding. 2022. ⟨hal-03628290v2⟩
hal-03780006	Xavier Hinaut, Nathan Trouvain. ReservoirPy: Efficient Training of Recurrent Neural Networks for Timeseries Processing. *EuroSciPy 2022 - 14th European Conference on Python in Science*, Aug 2022, Basel, Switzerland. ⟨hal-03780006⟩
hal-03945994	Nathan Trouvain, Xavier Hinaut. Reservoir Computing : traitement efficace de séries temporelles avec ReservoirPy. *Dataquitaine 2022*, Feb 2022, Bordeaux, France. ⟨hal-03945994⟩