Escherichia coli-based physical reservoir computing : potential and applications

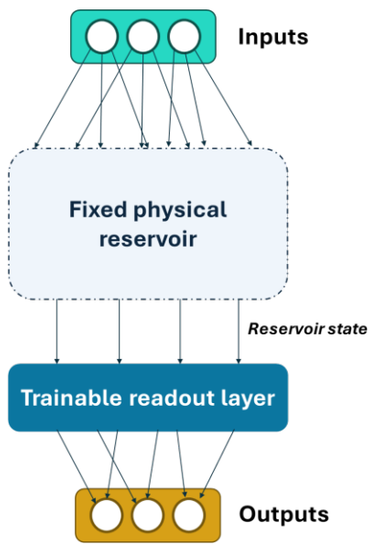
BioRetroSynth and Ekinocs teams

Ahavi Paul[1], Bastien Mollet[2], Antoine Cornuejols[2], Audrey Le Gouellec[3], Evelyne Lutton[2] and Jean-Loup Faulon[1], Alberto Tonda[2]

[1]Micalis Institute (UMR 1319), INRAE - Paris-Saclay University - 78352 Jouy-en-Josas, France
[2]UMR MIA, AgroParisTech, INRAE - Paris-Saclay University - 91120 Palaiseau, France
[3]TIMC-IMAG/TheRex laboratory - Joseph Fourier University (Grenoble I) - 38700 La Tronche CEDEX - France

Context

- Computation using bacteria has mostly relied on synthetic circuits since the early days of synthetic biology
- These circuits allowed to implement relatively complex functions in cells but displayed serious limitations [1] restricting the complexity of the tasks they can perform
- Reservoir computing might outperform these circuits
- Jones et al. [2] already used bacteria as reservoirs to solve a XOR problem. Bacteria-based reservoirs exploit the bacterial natural non-linear dynamics to project features from the growth medium to the observable space
- Here, we go further and demonstrate that bacterial metabolism can be used as a reservoir to solve regression and classification machine learning (ML) problems
- To showcase some potential applications of this new biocomputing method, an *Escherichia coli* multi-reservoir will be constructed to perform prognosis on COVID-19 infected patients



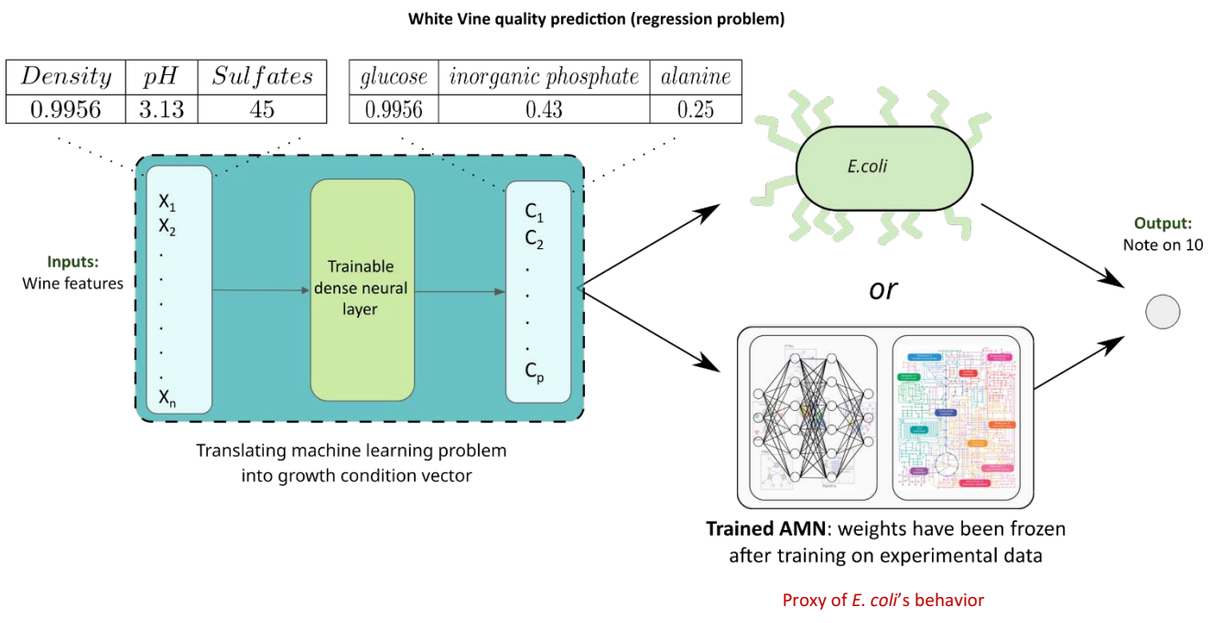
Resolution of machine learning problems

1 – Framework presentation

White Vine quality prediction (regression problem)

Density	*pH*	*Sulfates*
0.9956	3.13	45

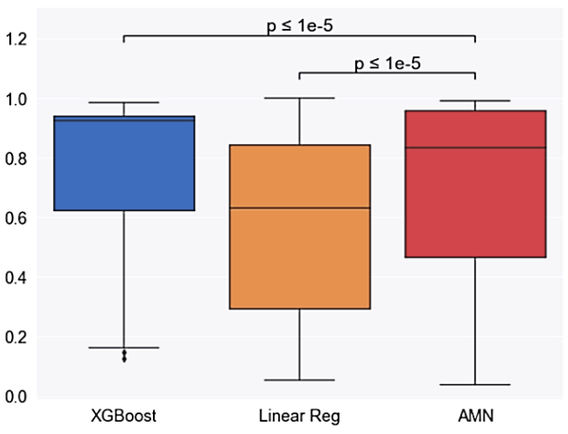
glucose	*inorganic phosphate*	*alanine*
0.9956	0.43	0.25



Trained AMN: weights have been frozen after training on experimental data

Proxy of *E. coli*'s behavior

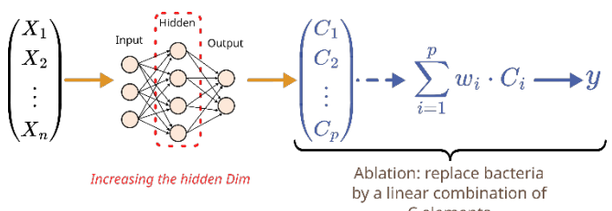
2 – Benchmark with other ML methods



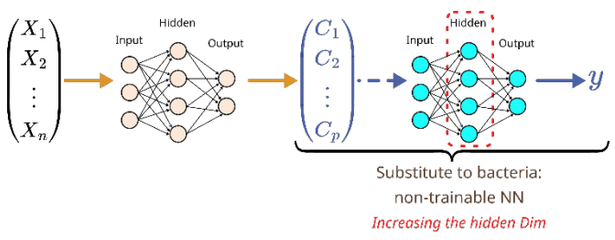
➢ The AMN-based reservoir outperforms linear methods, but is still less performant than XGBoost

3 – Assessing the contribution of the bacteria

Ablation :

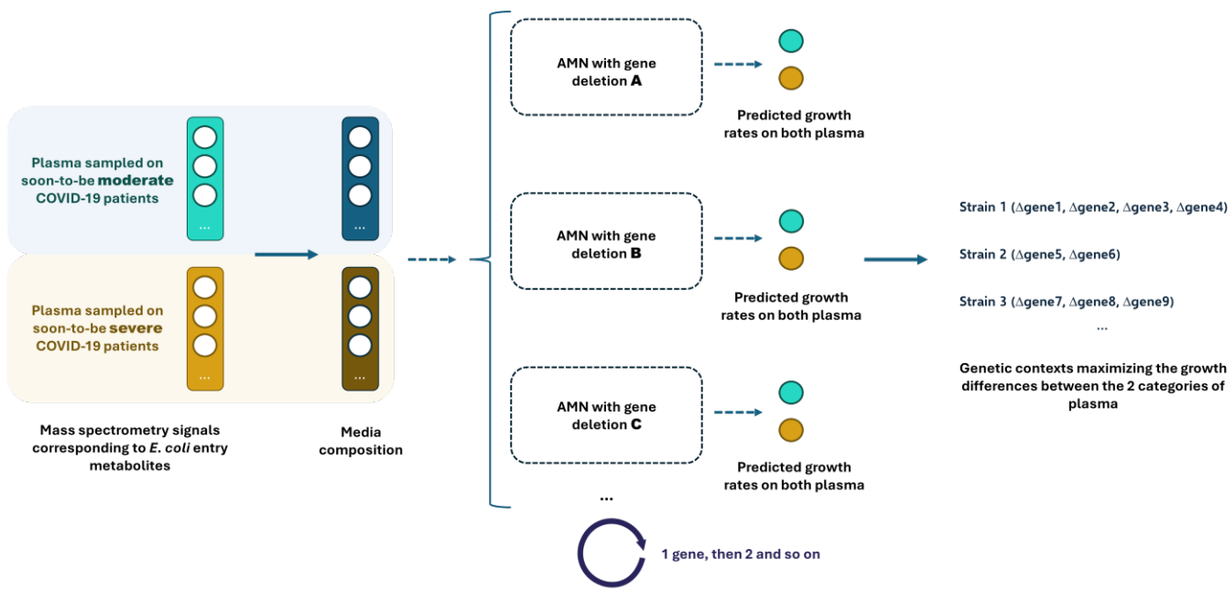


Substitution :

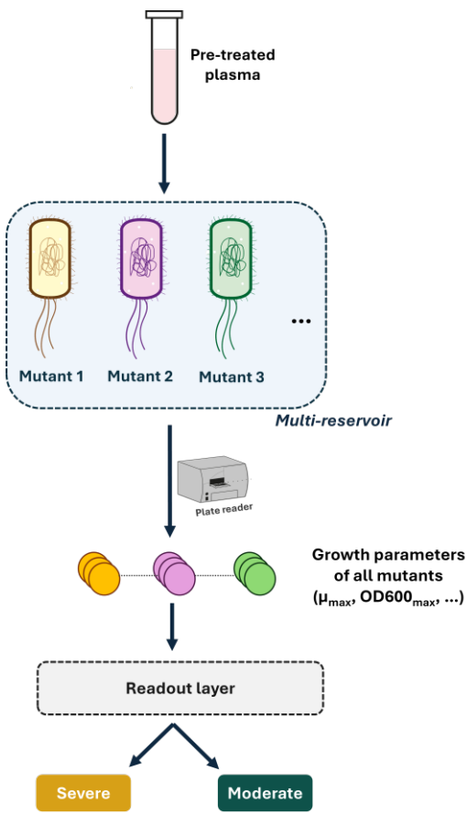


Application : prediction of COVID-19 severity

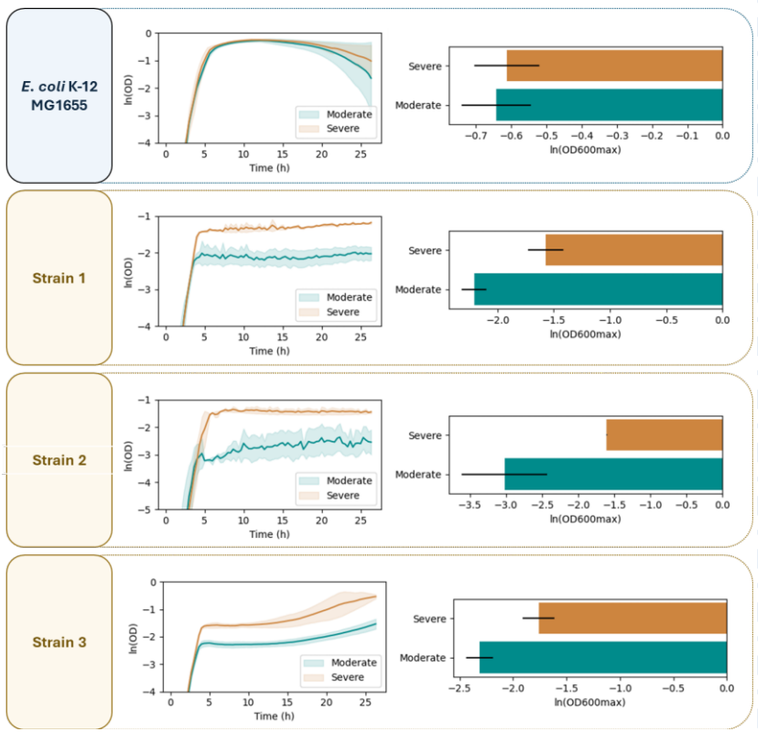
1 – Construction of the reservoir



2 – Experimental setup



3 – Preliminary results



➢ The strains tested display rather small growth profile differences when grown on the 2 categories of plasma

➢ But all together, they might create a more powerful classifier

Take-home messages

- A reservoir based on bacterial metabolism can perform complex computational tasks (solve ML problems) at low cost for the cell (no circuit constructed) in an easy-to-use framework
- Combining the unique features of living systems with physical reservoir computing could have potential applications in diagnostics and prognosis

References

[1] Meyer, A.J., Segall-Shapiro, T.H., Glassey, E. *et al. Escherichia* coli "Marionette" strains with 12 highly optimized small-molecule sensors. *Nat Chem Biol* **15**, 196–204 (2019). https://doi.org/10.1038/s41589-018-0168-3

[2] Jones, B., Stekel, D., Rowe, J., Fernando, C., 2007. Is there a Liquid State Machine in the Bacterium Escherichia Coli?, in: 2007 IEEE Symposium on Artificial Life. Presented at the 2007 IEEE Symposium on Artificial Life, pp. 187–191. https://doi.org/10.1109/ALIFE.2007.367795

Centre
Île-de-France - Jouy-en-Josas - Antony

Contact:
paul.ahavi@inrae.fr
bastien.mollet@inrae.fr