

PiecewiseInference.jl: a machine learning framework for inverse ecosystem modelling

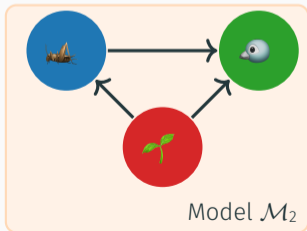
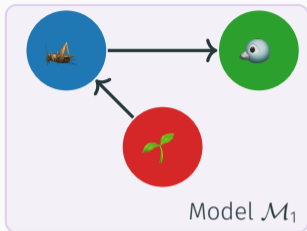
Victor Boussange^{1,2}, Pau Vilimelis Aceituno², and Loïc Pellissier^{1,2}

April 26, 2023

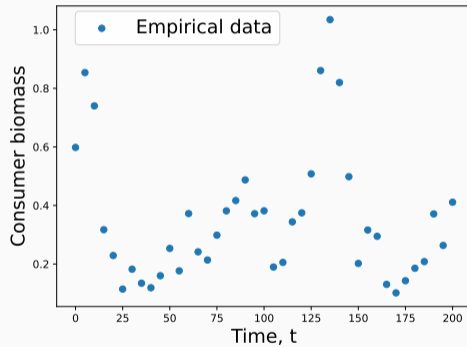
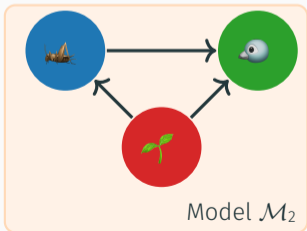
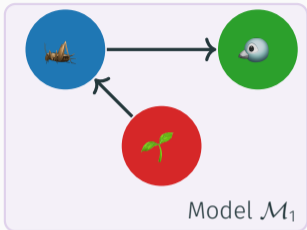
¹WSL Birmensdorf, ²ETH Zürich



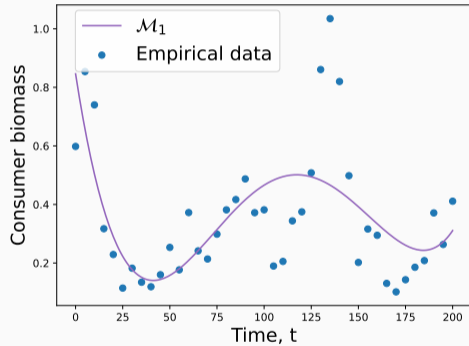
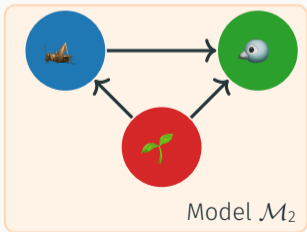
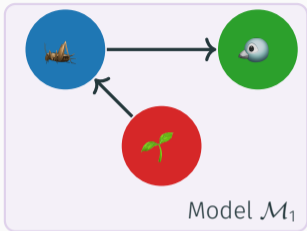
Motivation



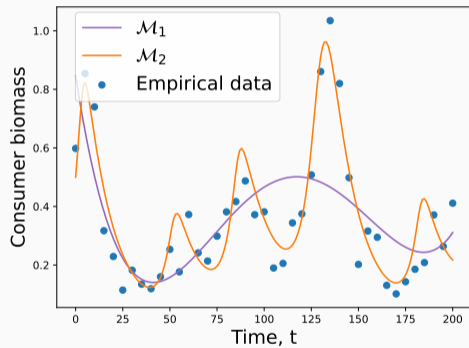
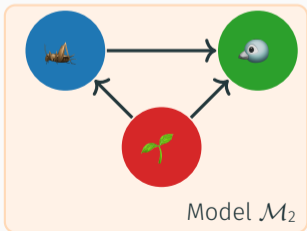
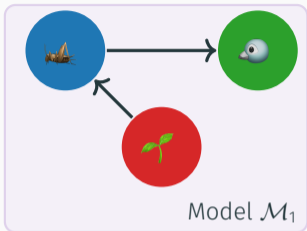
Motivation



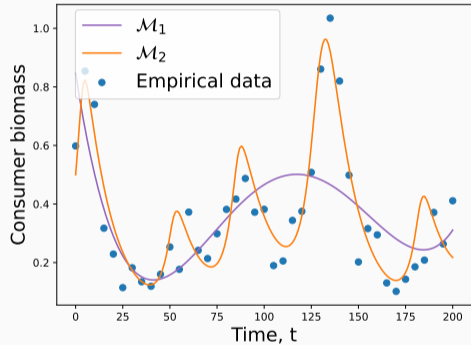
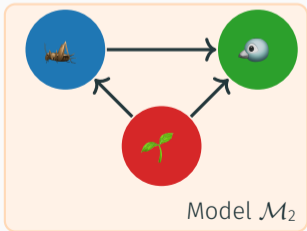
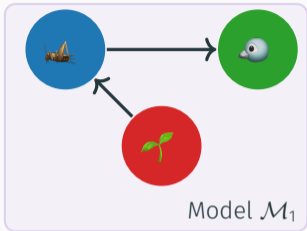
Motivation



Motivation



Motivation



$$P(\mathcal{M}_2|\text{Data}) > P(\mathcal{M}_1|\text{Data})$$

Global search
(e.g. Bayesian inference with MCMC)

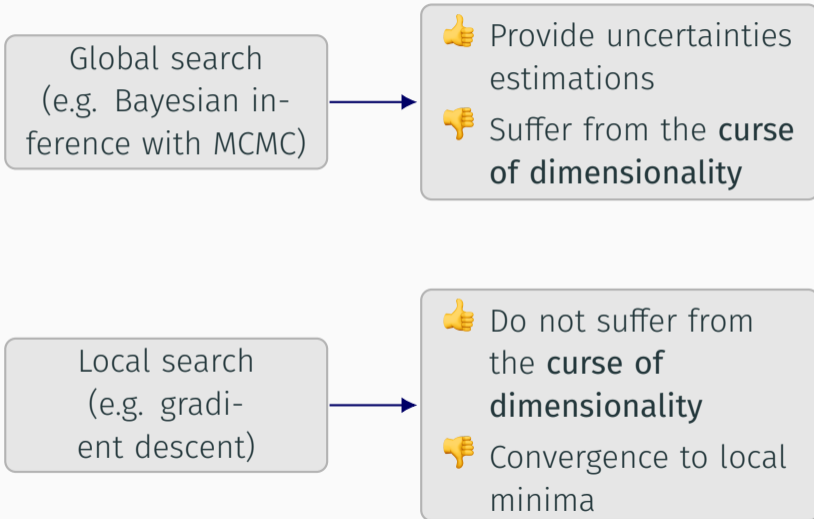


Provide uncertainties estimations

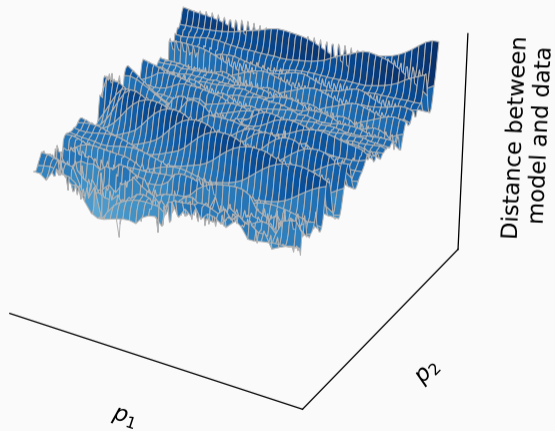


Suffer from the **curse of dimensionality**

Inverse modelling methods



Model non-linearities lead to highly complex likelihood landscapes



A framework for inverse ecosystem modelling

PiecewiseInference.jl

PiecewiseInference.jl

- is a framework for inverse modeling of complex dynamical systems.

PiecewiseInference.jl

- is a **framework for inverse modeling** of complex dynamical systems.
- Built upon
 - **gradient descent** with Deep Learning **optimization algorithm** (Adam)

PiecewiseInference.jl

- is a **framework for inverse modeling** of complex dynamical systems.
- Built upon
 - **gradient descent** with Deep Learning **optimization algorithm** (Adam)
 - **automatic differentiation**

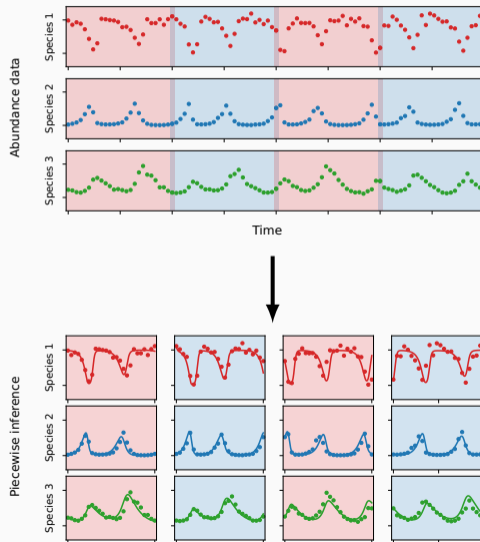
PiecewiseInference.jl

- is a **framework for inverse modeling** of complex dynamical systems.
- Built upon
 - **gradient descent** with Deep Learning **optimization algorithm** (Adam)
 - **automatic differentiation**
 - a **training strategy** that **improves the convergence** of local search methods by regularizing the inference problem

A framework for inverse ecosystem modelling

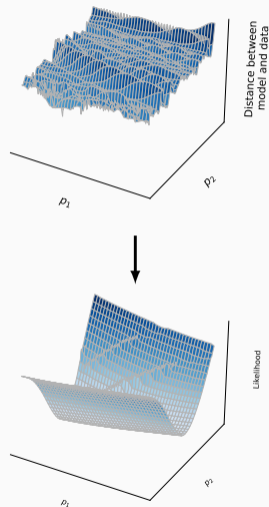
PiecewiseInference.jl

- is a framework for inverse modeling of complex dynamical systems.
- Built upon
 - **gradient descent** with Deep Learning **optimization algorithm** (Adam)
 - **automatic differentiation**
 - a **training strategy** that **improves the convergence** of local search methods by regularizing the inference problem

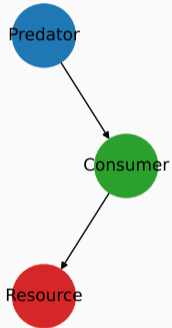


PiecewiseInference.jl

- is a **framework for inverse modeling** of complex dynamical systems.
- Built upon
 - **gradient descent** with Deep Learning **optimization algorithm** (Adam)
 - **automatic differentiation**
 - a **training strategy** that **improves the convergence** of local search methods by regularizing the inference problem



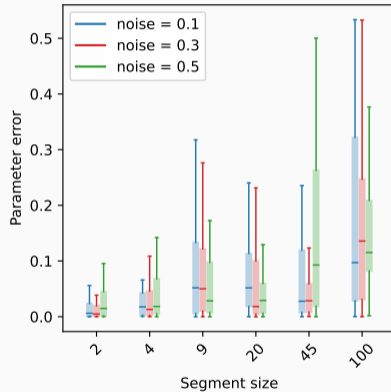
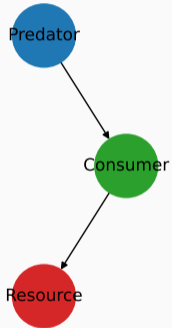
Optimal segment size



Chaotic food web
system

Hastings et al. 1991.

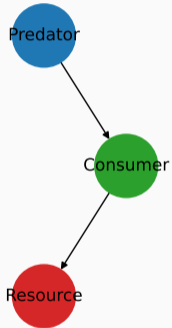
Optimal segment size



Chaotic food web
system

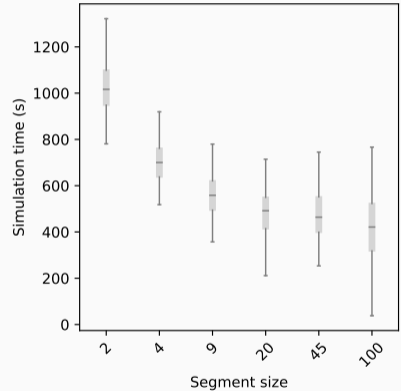
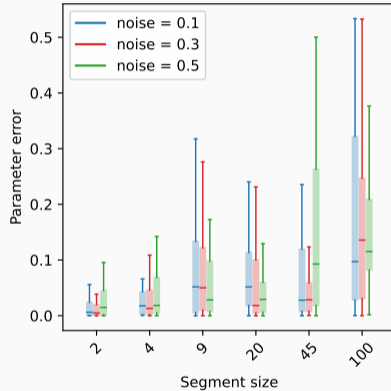
Hastings et al. 1991.

Optimal segment size





Chaotic food web
system

Hastings et al. 1991.



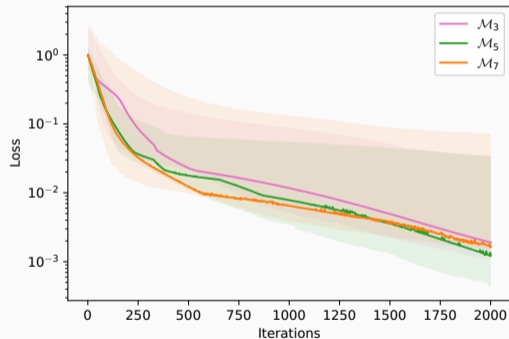
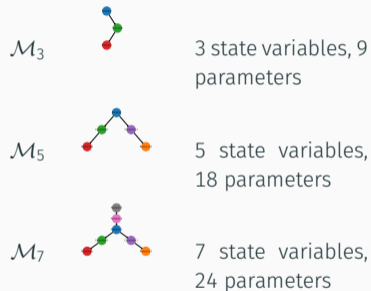
Scaling with model complexity

\mathcal{M}_3  3 state variables, 9 parameters

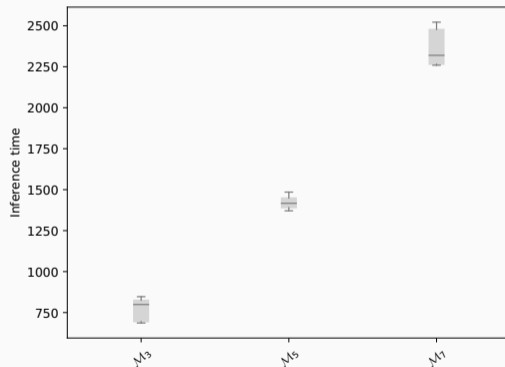
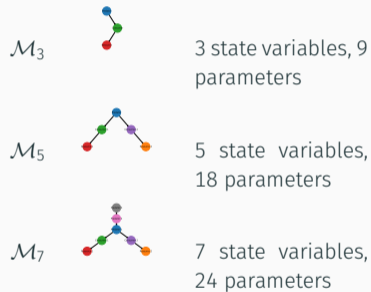
\mathcal{M}_5  5 state variables, 18 parameters

\mathcal{M}_7  7 state variables, 24 parameters

Scaling with model complexity



Scaling with model complexity

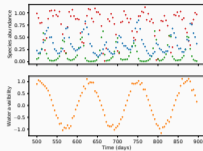
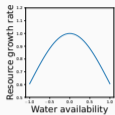


Hypothesis testing and processes discovery

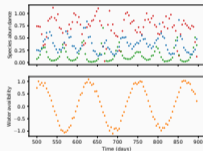
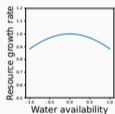


Hypothesis testing and processes discovery

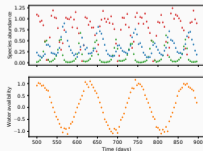
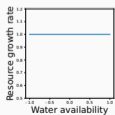
$s=1$



$s=0.5$

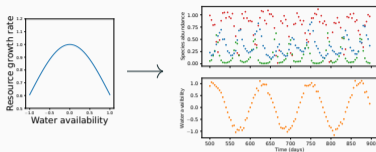


$s=0$

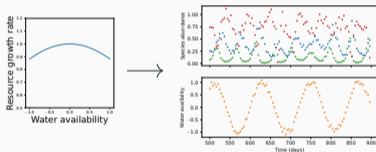


Hypothesis testing and processes discovery

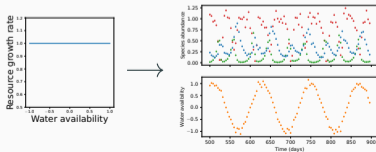
$s=1$



$s=0.5$



$s=0$



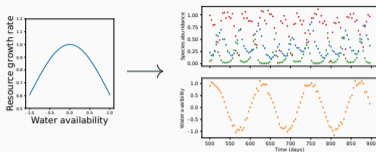
$$r_R = cst.$$

Model \mathcal{M}

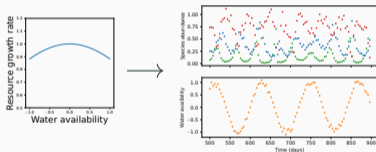
Hypothesis testing and processes discovery



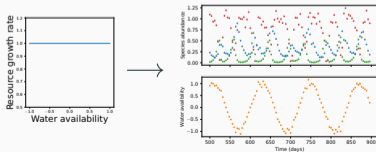
$s=1$



$s=0.5$



$s=0$



$$r_R = cst.$$

Model \mathcal{M}

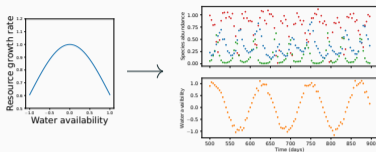
$$r_R = f(\text{water avail.})$$

Model \mathcal{M}^*

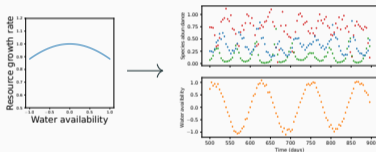
Hypothesis testing and processes discovery



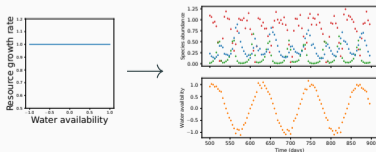
$s=1$



$s=0.5$



$s=0$



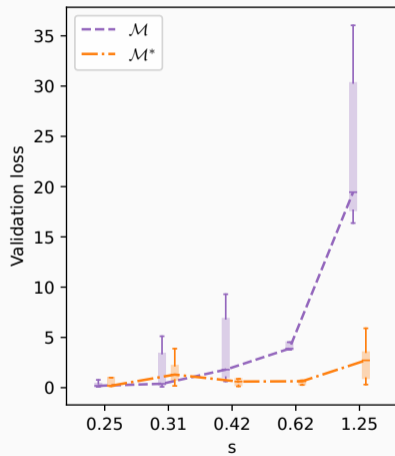
$$r_R = \text{cst.}$$

Model \mathcal{M}

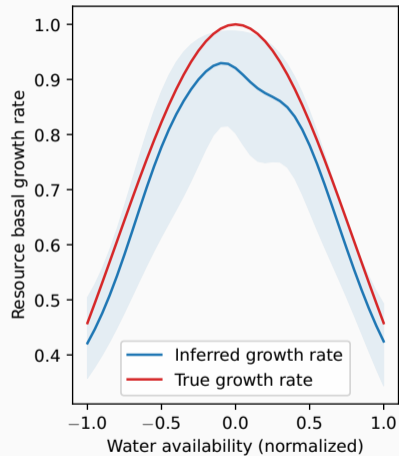
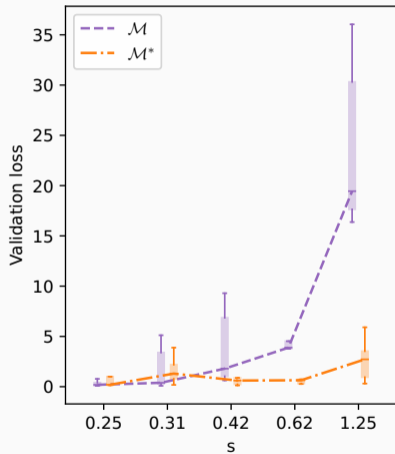
$$r_R = f(\text{water avail.})$$
$$f \equiv \text{NN}$$

Model \mathcal{M}^*

Hypothesis testing and processes discovery



Hypothesis testing and processes discovery



The ecosystem we are developing, and the next projects

[PiecewiseInference.jl](#) Public

Suite for inverse modelling of dynamical systems characterised by complex dynamics.

★ Starred ▾

[inference](#) [inverse-problems](#)



Julia ☆ 3 Updated yesterday

The ecosystem we are developing, and the next projects

PiecewiseInference.jl Public

Suite for inverse modelling of dynamical systems characterised by complex dynamics.

★ Starred ▾



inference inverse-problems

Julia ☆ 3 Updated yesterday

ParametricModels.jl Public

An AD friendly wrapper for consistently handling dynamical models

☆ Star ▾



Julia MIT License Updated on Feb 21

The ecosystem we are developing, and the next projects

PiecewiseInference.jl Public

Suite for inverse modelling of dynamical systems characterised by complex dynamics.

★ Starred ▾



inference inverse-problems

Julia ☆ 3 Updated yesterday

ParametricModels.jl Public

An AD friendly wrapper for consistently handling dynamical models

☆ Star ▾



Julia 📄 MIT License Updated on Feb 21

EcoEvoModelZoo.jl Public

A zoo of happy eco-evolutionary models.

☆ Star ▾



Julia ☆ 1 📄 MIT License Updated last week

The ecosystem we are developing, and the next projects

The screenshot displays three GitHub repository cards for Julia packages. Each card includes the repository name, a 'Public' badge, a description, a 'Starred' or 'Star' button, a green activity line graph, the programming language (Julia), star count, license, and update date.

- PiecewiseInference.jl** (Public): Suite for inverse modelling of dynamical systems characterised by complex dynamics. 3 stars, updated yesterday. License: MIT License.
- ParametricModels.jl** (Public): An AD friendly wrapper for consistently handling dynamical models. 1 star, updated on Feb 21. License: MIT License.
- EcoEvoModelZoo.jl** (Public): A zoo of happy eco-evolutionary models. 1 star, updated last week. License: MIT License.

A few tutorials available @vboussange.github.io

The ecosystem we are developing, and the next projects

The screenshot displays three GitHub repository cards for Julia packages. Each card includes the repository name, a 'Public' badge, a description, a 'Starred' or 'Star' button, a green activity line graph, the programming language (Julia), the number of stars, the license, and the update date.

- PiecewiseInference.jl** (Public): Suite for inverse modelling of dynamical systems characterised by complex dynamics. 3 stars, updated yesterday. License: MIT License.
- ParametricModels.jl** (Public): An AD friendly wrapper for consistently handling dynamical models. 1 star, updated on Feb 21. License: MIT License.
- EcoEvoModelZoo.jl** (Public): A zoo of happy eco-evolutionary models. 1 star, updated last week. License: MIT License.

Ongoing projects

A few tutorials available @vboussange.github.io

The ecosystem we are developing, and the next projects


The screenshot displays three GitHub repository cards for Julia packages. Each card includes the package name, a 'Public' badge, a description, a 'Star' button, and a small green line graph. The first card, 'PiecewiseInference.jl', has a 'Starred' button and tags for 'inference' and 'inverse-problems'. The second card, 'ParametricModels.jl', has a 'Star' button and mentions 'MIT License'. The third card, 'EcoEvoModelZoo.jl', also has a 'Star' button and mentions 'MIT License'.

PiecewiseInference.jl Public
Suite for inverse modelling of dynamical systems characterised by complex dynamics.
inference inverse-problems
Julia ☆ 3 Updated yesterday

ParametricModels.jl Public
An AD friendly wrapper for consistently handling dynamical models
Julia MIT License Updated on Feb 21

EcoEvoModelZoo.jl Public
A zoo of happy eco-evolutionary models.
Julia ☆ 1 MIT License Updated last week

Ongoing projects

- Food webs dynamic in the Bay of Biscay with **Trawl Survey Data** 



A few tutorials available @vboussange.github.io

The ecosystem we are developing, and the next projects

The screenshot displays three GitHub repository cards for Julia packages. Each card includes the repository name, a 'Public' badge, a brief description, tags, the programming language (Julia), star count, license, and update date. A 'Starred' button and a green line graph are also visible on the right side of each card.

- PiecewiseInference.jl** (Public)
Suite for inverse modelling of dynamical systems characterised by complex dynamics.
Tags: inference, inverse-problems
Julia, 3 stars, Updated yesterday
- ParametricModels.jl** (Public)
An AD friendly wrapper for consistently handling dynamical models
Julia, MIT License, Updated on Feb 21
- EcoEvoModelZoo.jl** (Public)
A zoo of happy eco-evolutionary models.
Julia, 1 star, MIT License, Updated last week

Ongoing projects

- Food webs dynamic in the Bay of Biscay with **Trawl Survey Data** 
- Artic plant community build-up with **sedaDNA** 

A few tutorials available @vboussange.github.io

- PiecewiseInference.jl: an efficient inference framework combining a **segmentation method** together with **automatic differentiation** and **Deep Learning optimizers**

- PiecewiseInference.jl: an efficient inference framework combining a **segmentation method** together with **automatic differentiation** and **Deep Learning optimizers**
- Our framework can help better understand and predict the dynamics of biodiversity by allowing
 - the **testing ecological theory against data**
 - **learning the parametrization** of ecological processes

~~Boussange, V., Vilimelis-Aceituno, P., Pellissier, L., *Mini-batching ecological data to improve ecosystem models with machine learning.* [bioRxiv] (2022)~~

~~Boussange, V., Vilimelis-Aceituno, P., Pellissier, L., *Mini-batching ecological data to improve ecosystem models with machine learning.* [bioRxiv] (2022)~~

Boussange, V., Vilimelis-Aceituno, P., Schäffer, F., Pellissier, L., *Partitioning ecological time series to improve ecosystem models with machine learning*, In prep.

~~Boussange, V., Vilimelis-Aceituno, P., Pellissier, L., *Mini-batching ecological data to improve ecosystem models with machine learning.* [bioRxiv] (2022)~~

Boussange, V., Vilimelis-Aceituno, P., Schäffer, F., Pellissier, L., *Partitioning ecological time series to improve ecosystem models with machine learning*, In prep.

<https://vboussange.github.io>
for `PiecewiseInference.jl` tutorials.

~~Boussange, V., Vilimelis-Aceituno, P., Pellissier, L., *Mini-batching ecological data to improve ecosystem models with machine learning.* [bioRxiv] (2022)~~

Boussange, V., Vilimelis-Aceituno, P., Schäffer, F., Pellissier, L., *Partitioning ecological time series to improve ecosystem models with machine learning*, In prep.

<https://vboussange.github.io>
for `PiecewiseInference.jl` tutorials.

Thanks for your attention!