Differentiable modeling to unify machine learning and physical models and advance Geosciences

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https://arxiv.org/abs/2301.04027

Example 3. Differentiable, learnable models to learn functions

Evolve model structure

Feng et al., 2022, WRR

Parameter regionalization

Differentiable process-based model - HBV*

Loss backpropagation & gradient descent to train weights of $g_A$

* Not all parameters and detailed processes of HBV are sketched here for the sake of simplicity

Attributes
soil, land cover, geology, others...

Forcing
$P, T, E_p$

$g_A(A, x)$
LSTM unit

Static $\theta$
or

Dynamic $\theta$

Precipitation/ Temperature

Rainfall
snowfall

$\beta, \gamma, E_a$

$\theta_{x_0}, \theta_{u_1}$

$S_o, S_{-1}$

$Q_0, Q_5, Q_0$

Implemented in PyTorch platform with Automatic Differentiation

Evolve model structure

Feng et al., 2022, WRR
Approaching LSTM!
But....

- Output untrained variables.
- Multivariate constraints.
- It extrapolates better.
- It can help us answer questions!

What the ANN learned functions look like?

\[ R/P_t = (S_m/F_c)^\beta \]

Blue line: original power law relation
Red dots: ANN simulations
Black lines: continuous plotting of ANN functions
Thank you!

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Hydroml.org
https://github.com/mhpi
http://water.engr.psu.edu/shen/hydroDL.html

CUAHSI cyberseminar series on BDML
WRR special issue on BDML

AGU Editor’s review
Differentiable parameter learning

\[ \theta = g_A(A) \]

\[ \text{data} \]
Point #1. Data scaling relationships (network effect?)

1. $dPL = SCEUA$ for lowest RMSE
2. $dPL$ scales better with more data
3. Orders of magnitude more efficient
4. (not shown) better results for untrained variables and better spatial generalization than traditional approach!

Relies on differentiable programming!

*Tsai et al. 2021, Nature Communications*
What is Differentiable Geoscientific Modeling (DG)?

Inserting “?” anywhere

2 perspectives
Example 2. River graph

Learn physics on the river graph

https://doi.org/10.1002/essoar.10512512.1
Example 3. Ecosystem modeling (photosynthesis)

Ecosystem modeling – DoE SC0021979

Example 4. Multiscale soil moisture – learning from two teachers

High-res sim  --  In-situ data

Coarsen

Low-res sim  --  Satellite data

Test period: 2015-04-01 to 2020-03-31

(a)  

(b)  

(c)  

ubRMSE

R

Geophysical Research Letters*

A multiscale deep learning model for soil moisture integrating satellite and in-situ data

Jiangtao Liu, Farshid Rahmani, Kathryn Lawson, Chaopeng Shen

First published: 14 March 2022 | https://doi.org/10.1029/2021GL096847