Jet-based TMD measurements with H1 data

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on behalf of the **H1** Collaboration

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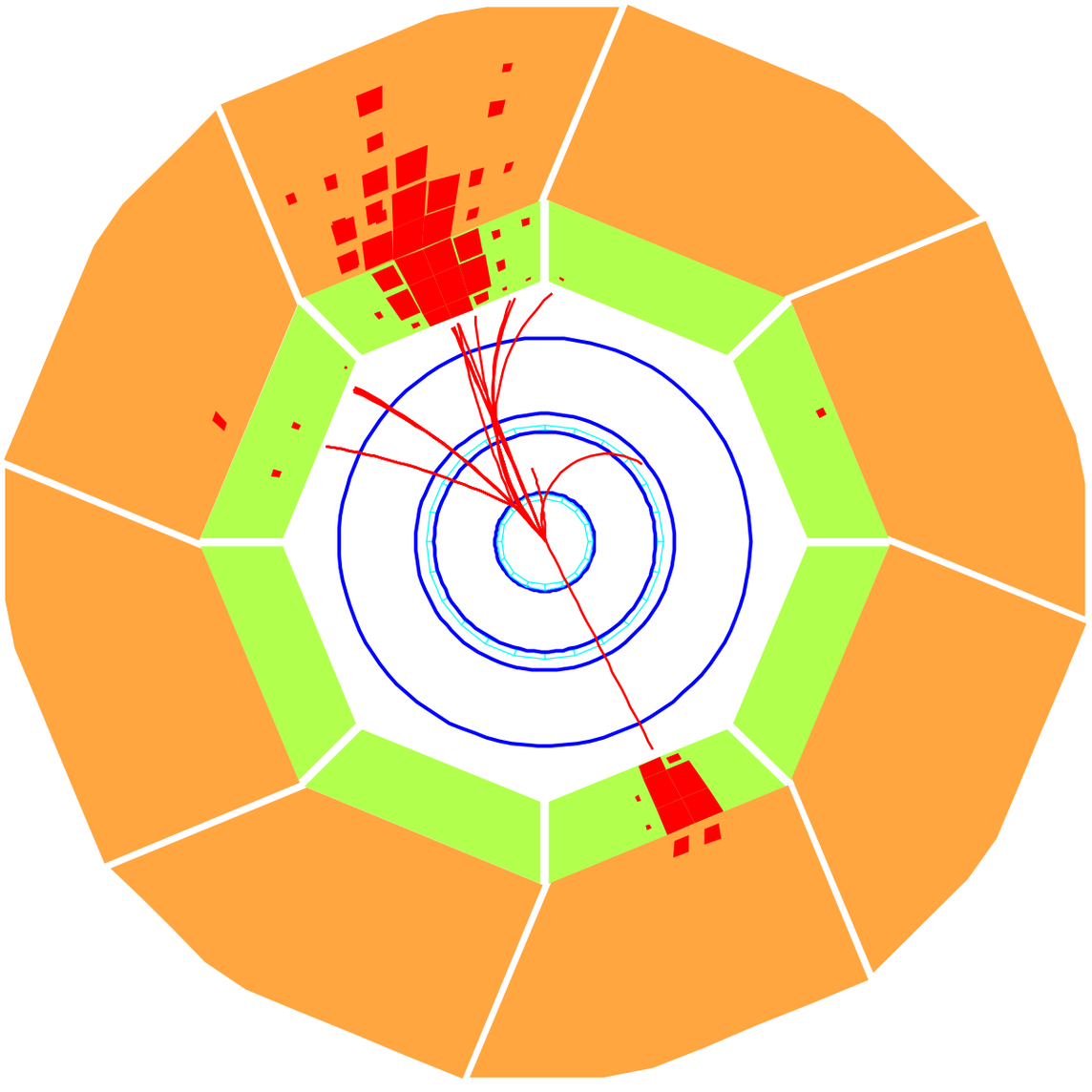
International Symposium on Multi-particle Dynamics

July 14, 2021

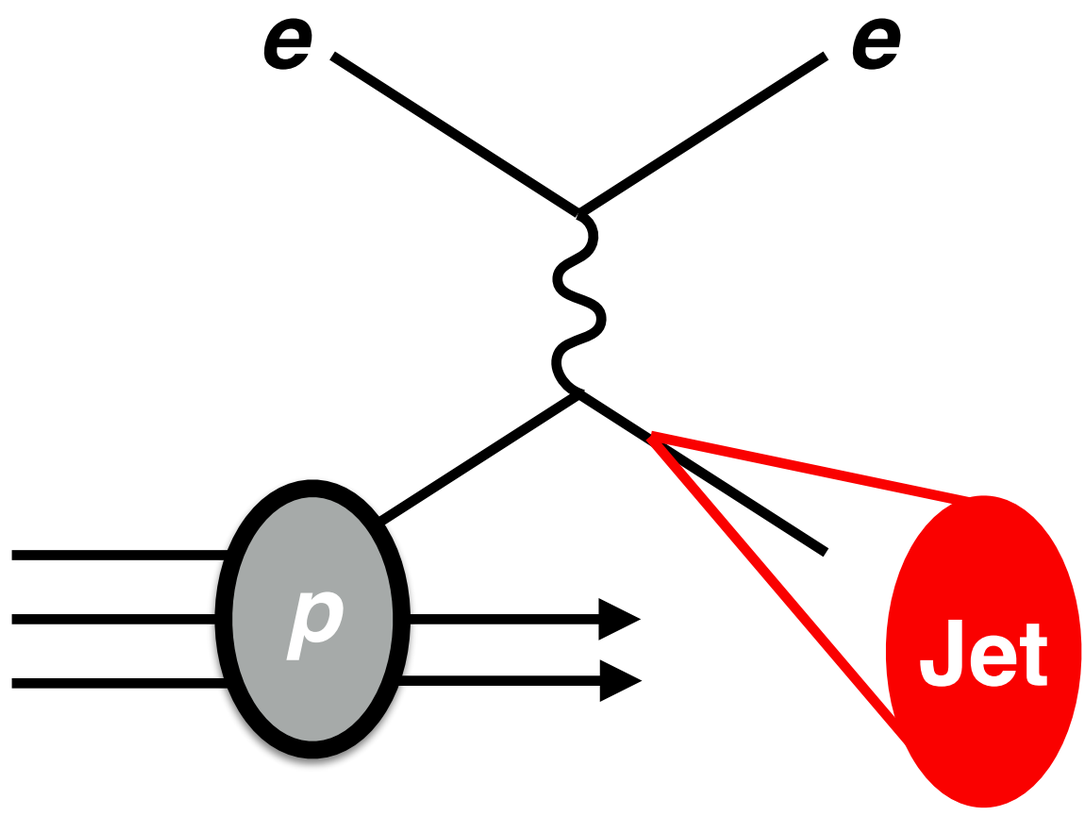
H1 @ HERA

T. Janssen gave a great introduction to H1 & HERA yesterday

For this talk: 2006-2007 data, 136 pb^{-1}, 320 GeV

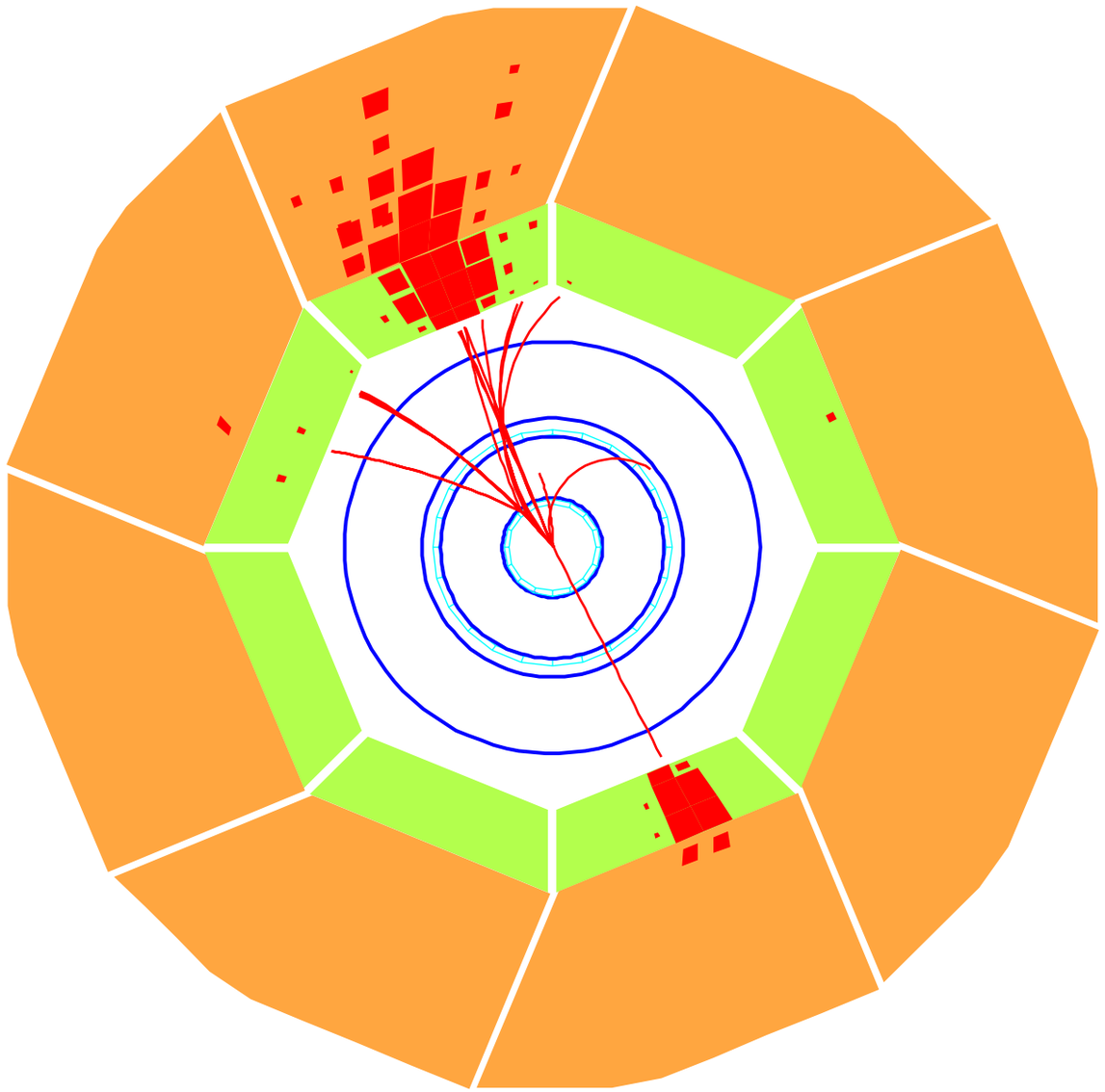


I'll present a measurement of the electron-jet inbalance



Why electron-jet imbalance?

Born-level configuration, electron and jet are back-to-back

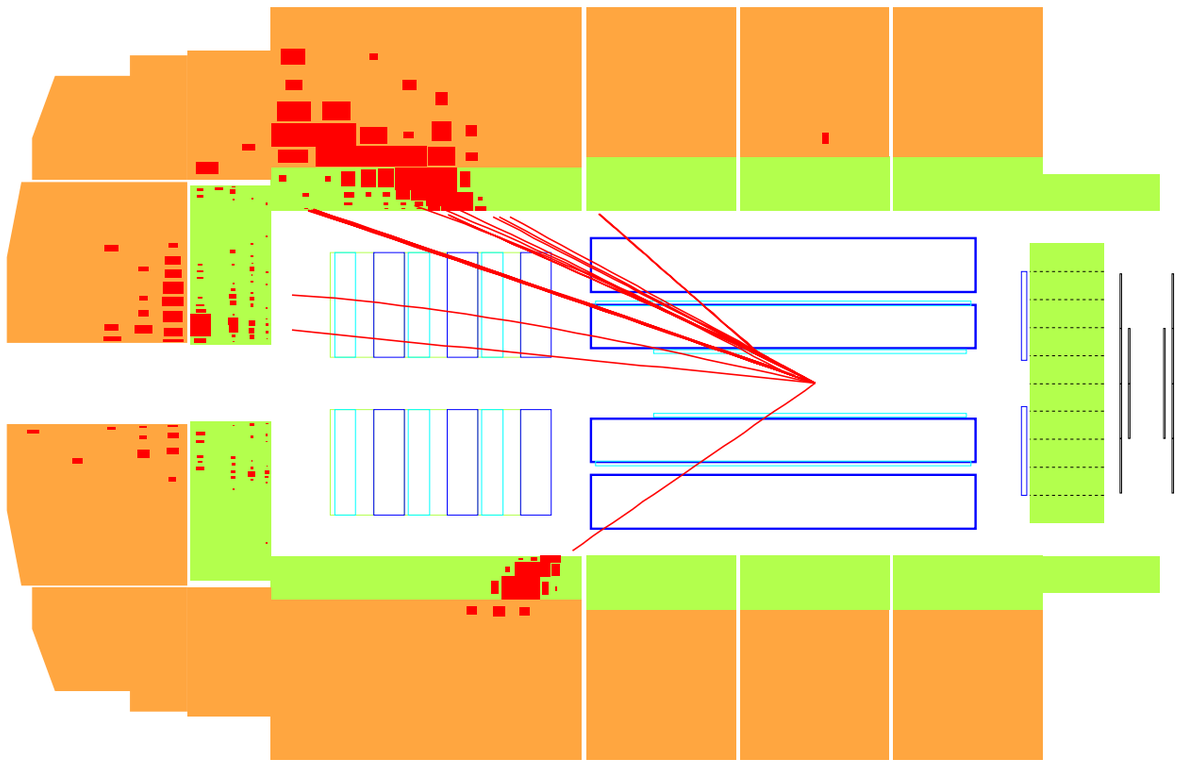


Typically, jets are studied in the Breit frame, where the Born-level configuration is discarded

However, jet production in the lab frame can be useful for probing Transverse Momentum Dependent (TMD) Parton Distribution Functions (PDFs)

See e.g. Lieu et al. PRL (2019) 192003;
Gutierrez et al. PRL (2018) 162001

Jets at H1

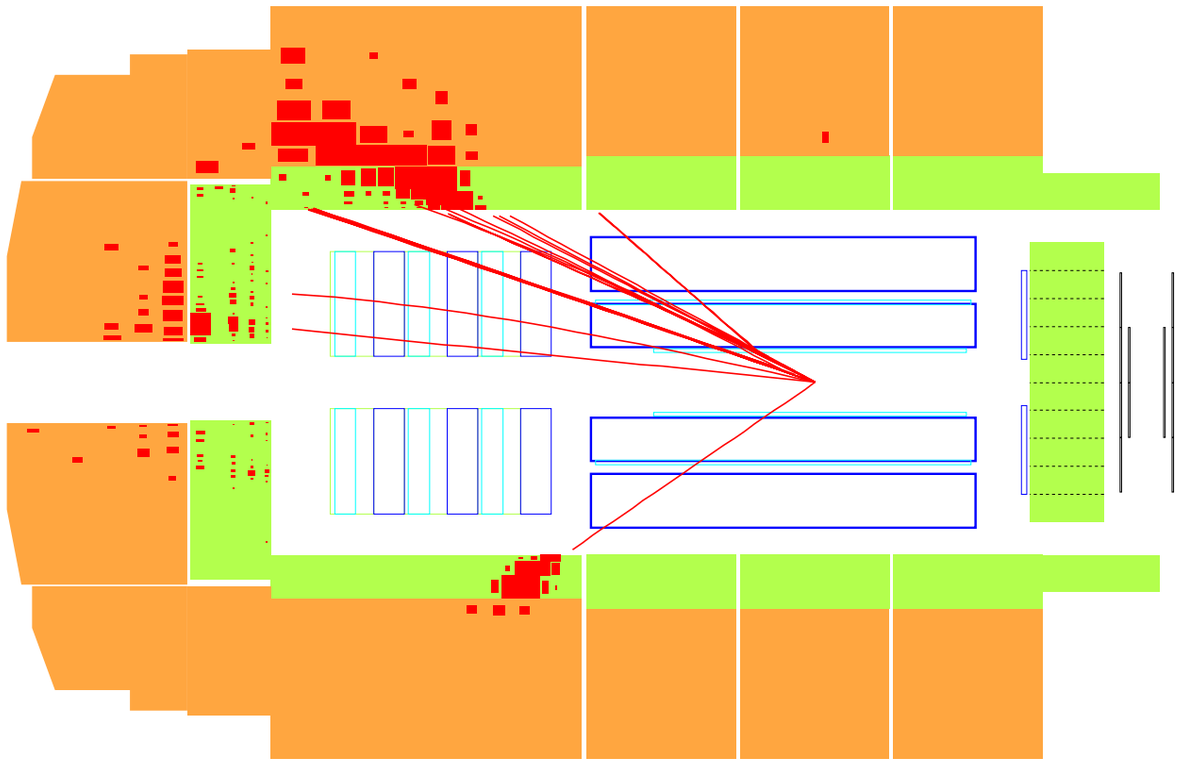


Energy flow algorithm (HFS) combines information from tracker and calorimeters

Neural network-based energy regression

1% jet energy scale uncertainty; 0.5-1% lepton energy scale uncertainty

Jets at H1



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Challenge: **unfold multidimensional phase space**

Jets at H1

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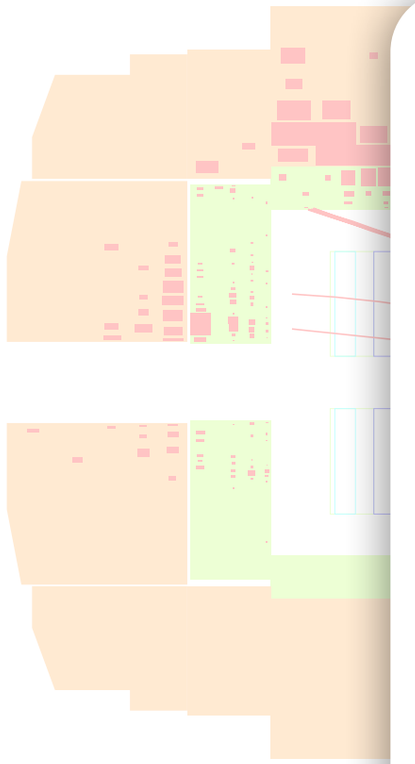
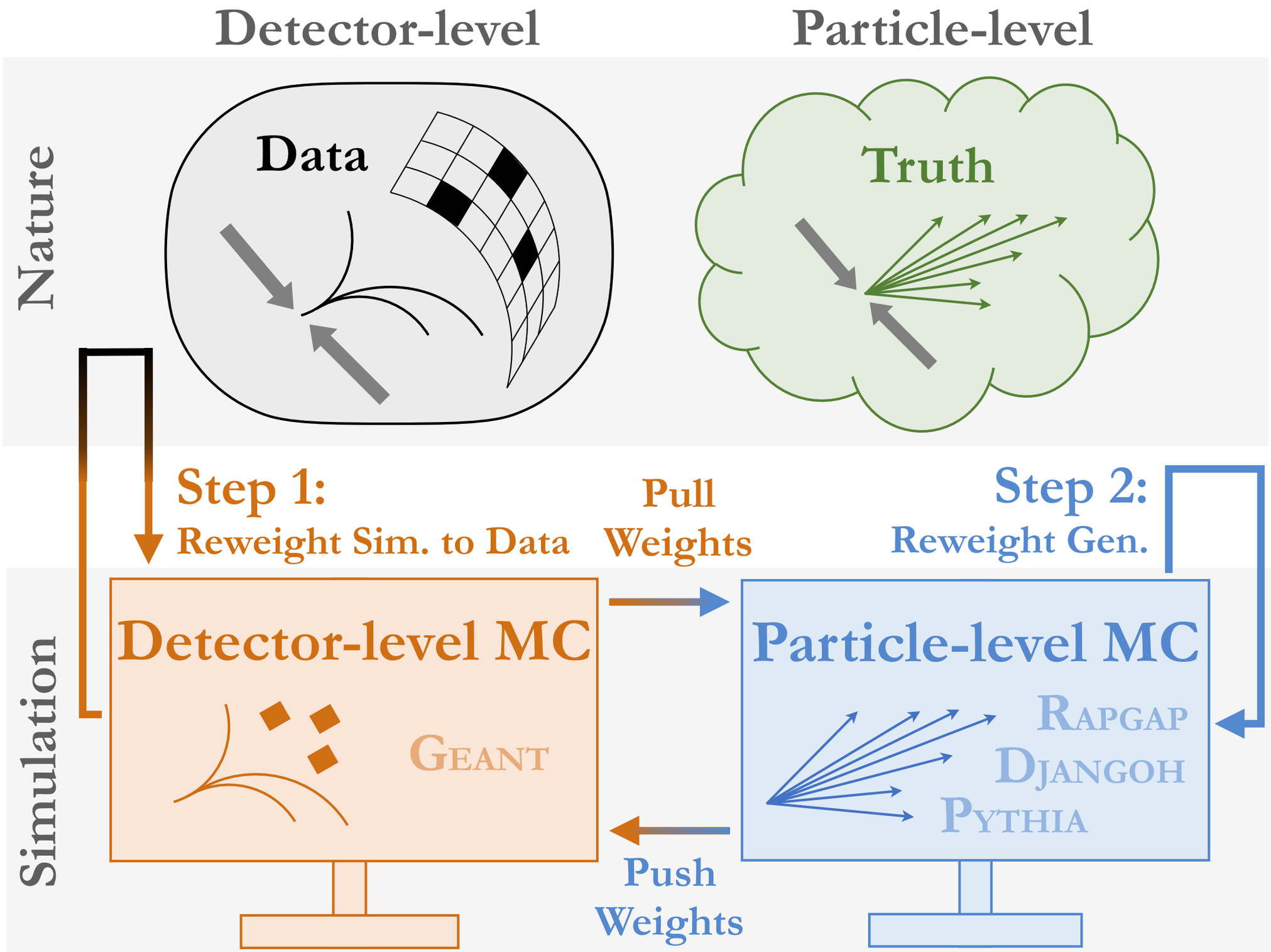


Solution: **use deep learning!**

…can do unbinned, high (and variable-)dimensional unfolding

Challenge: **unfold multidimensional phase space**

Unfold by iterating: OmniFold



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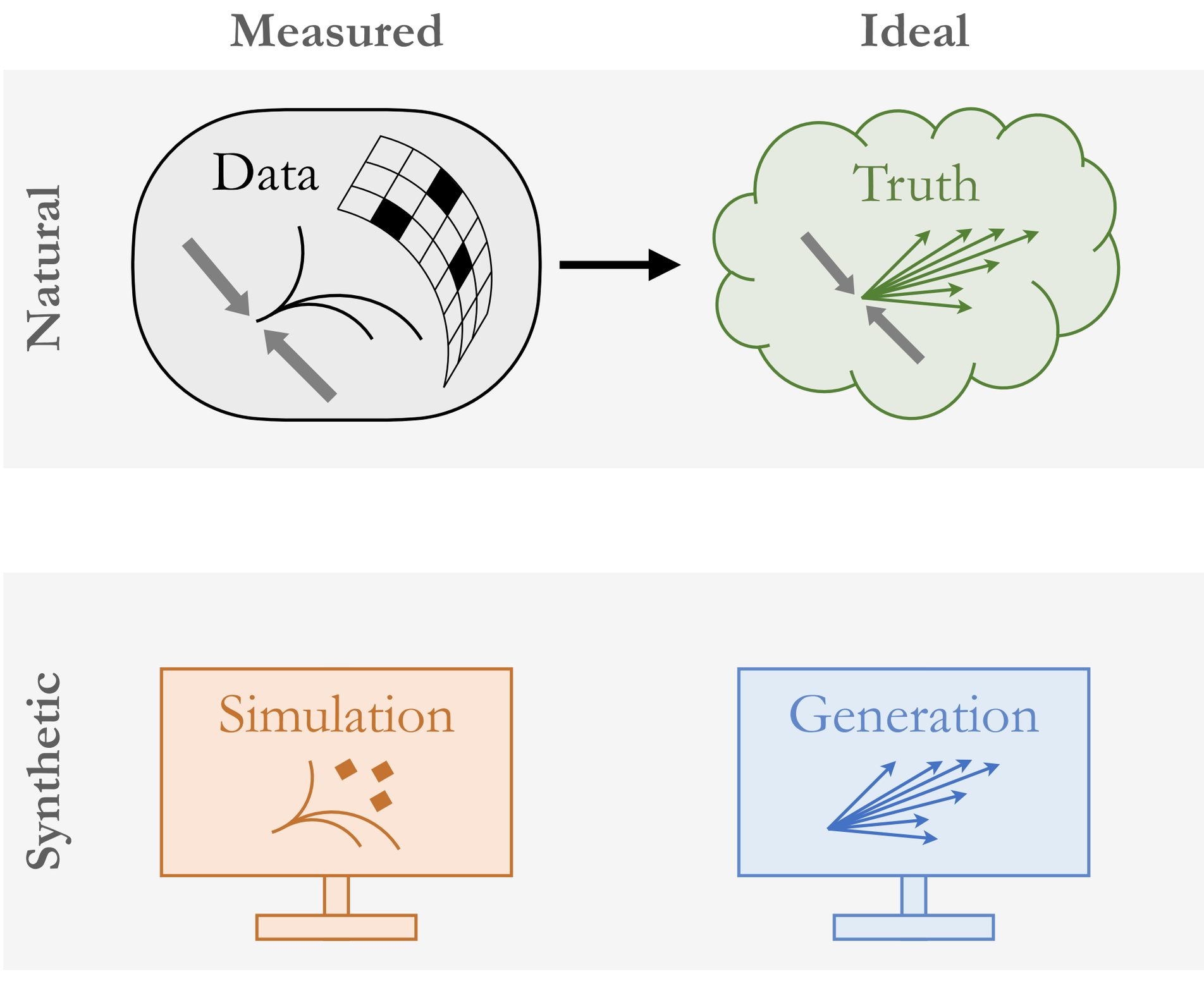

A. Andreassen, P. Komiske, E. Metodiev, BPN, J. Thaler, PRL 124 (2020) 182001

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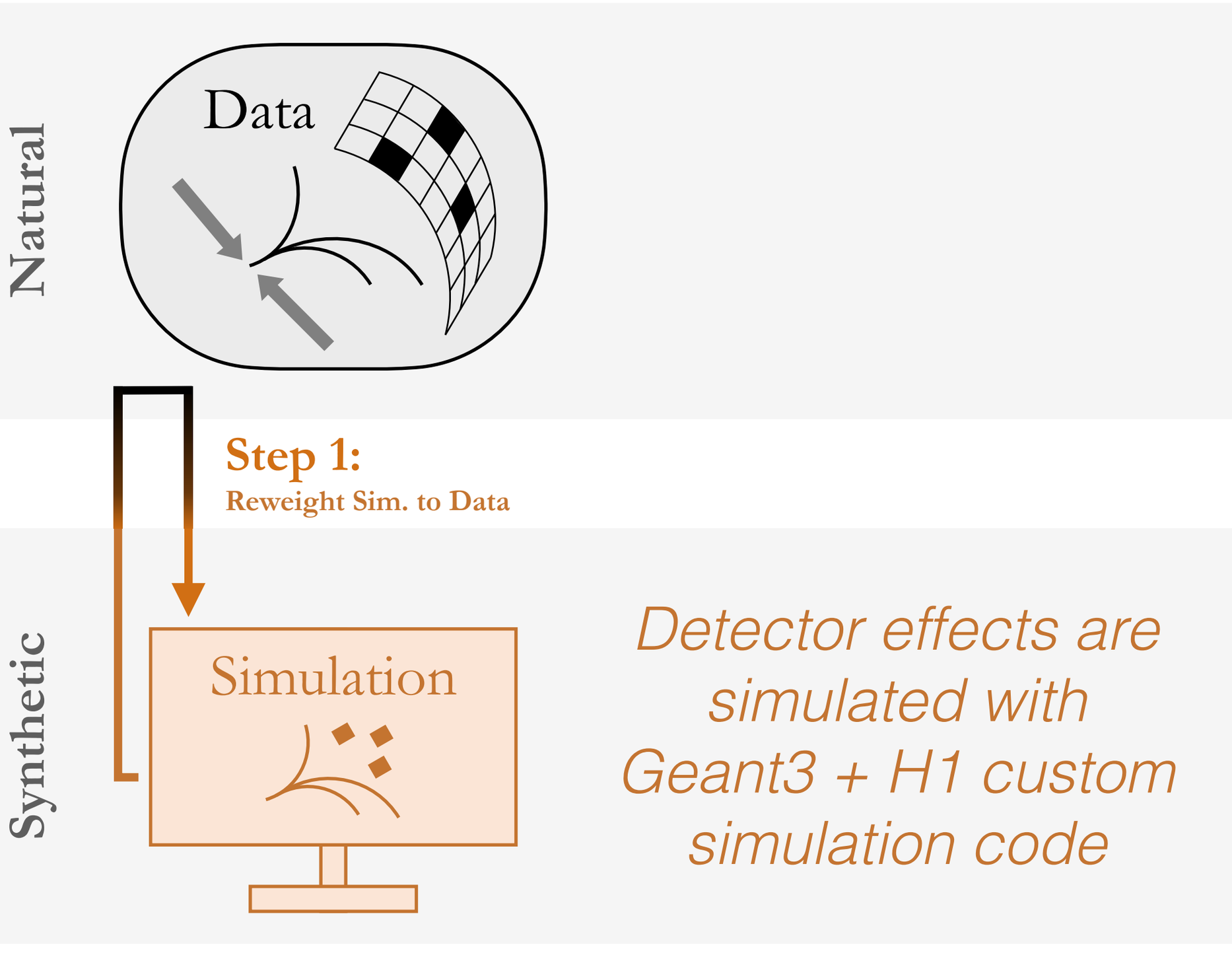

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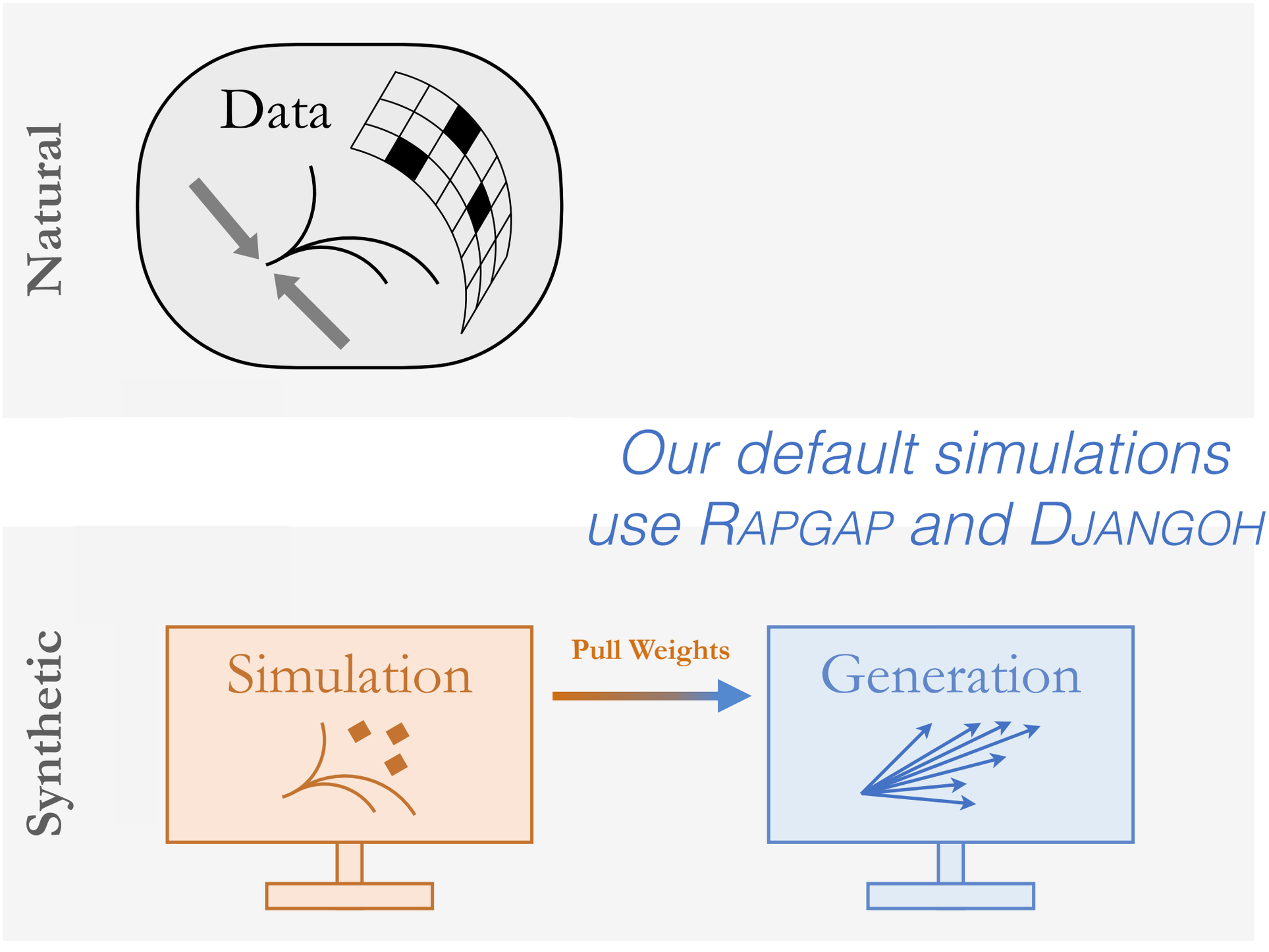

Our default simulations use RAPGAP and DJANGOH

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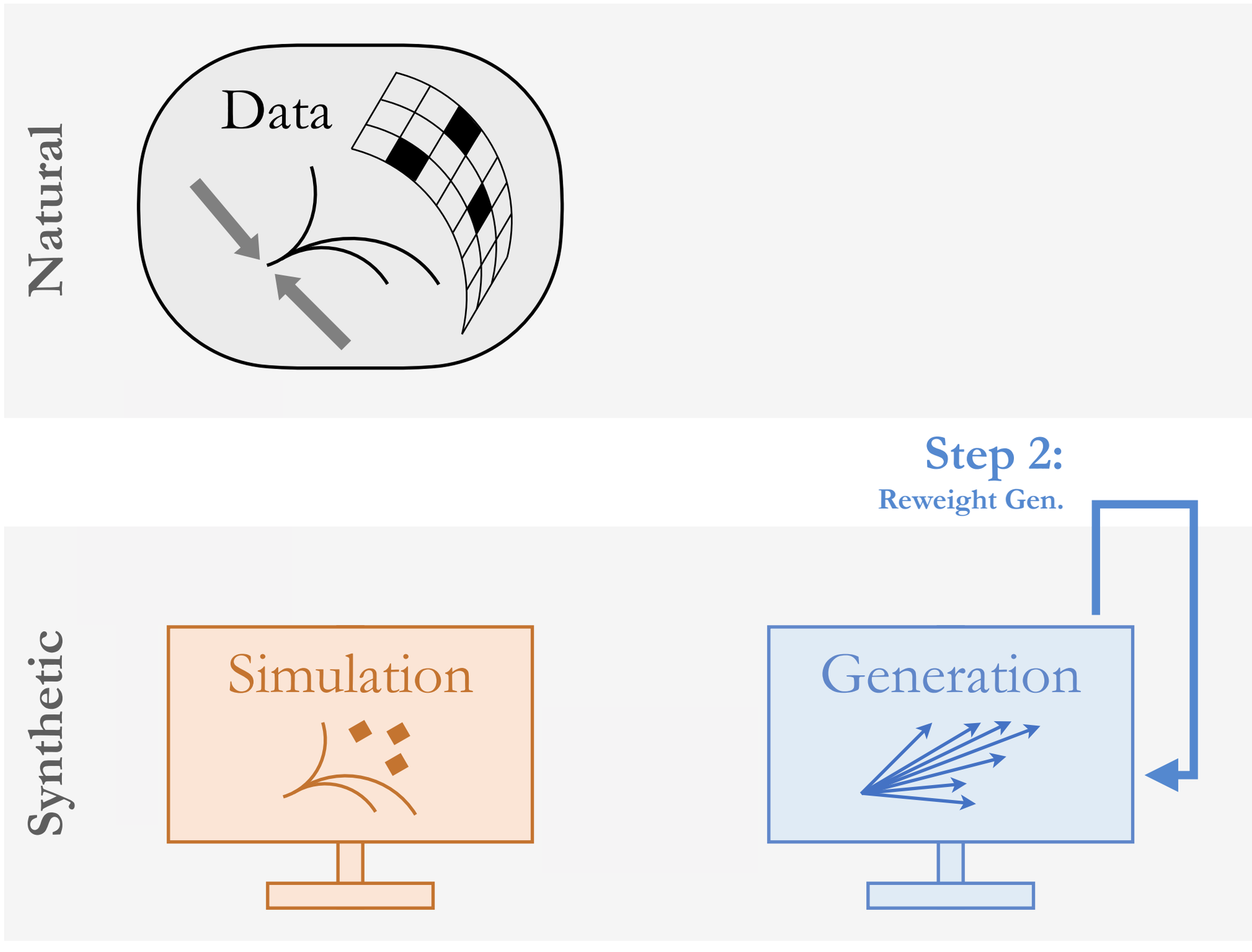

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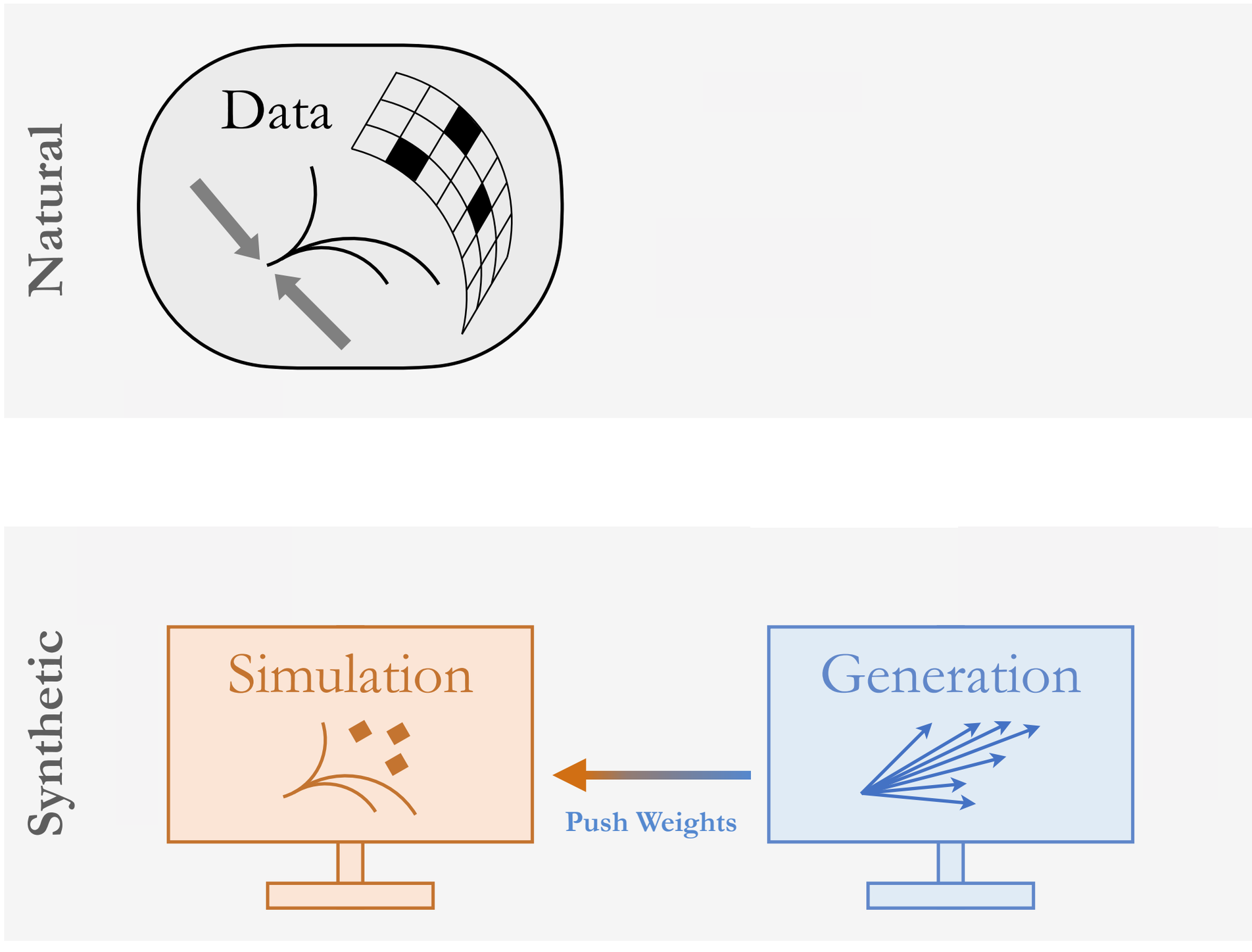

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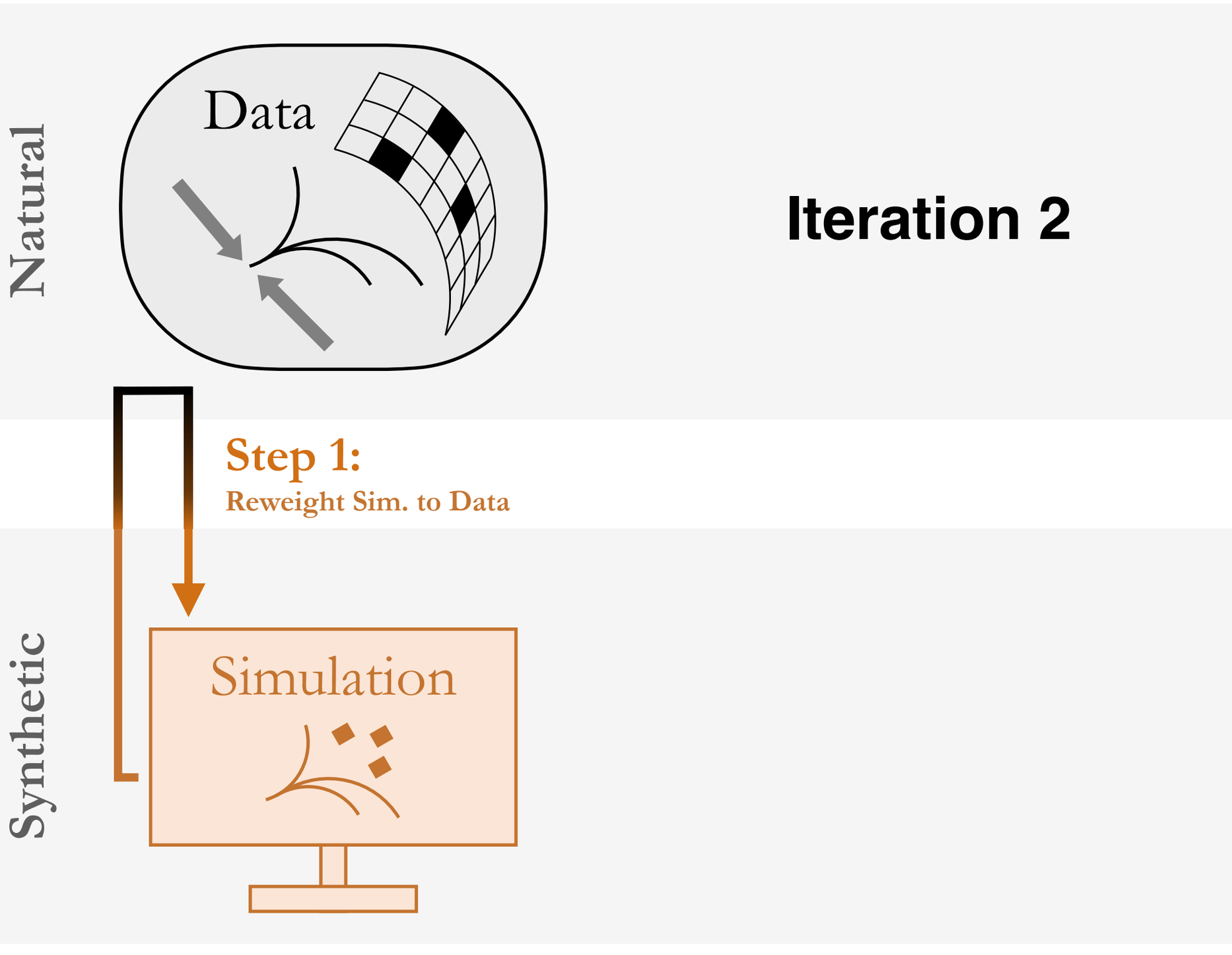

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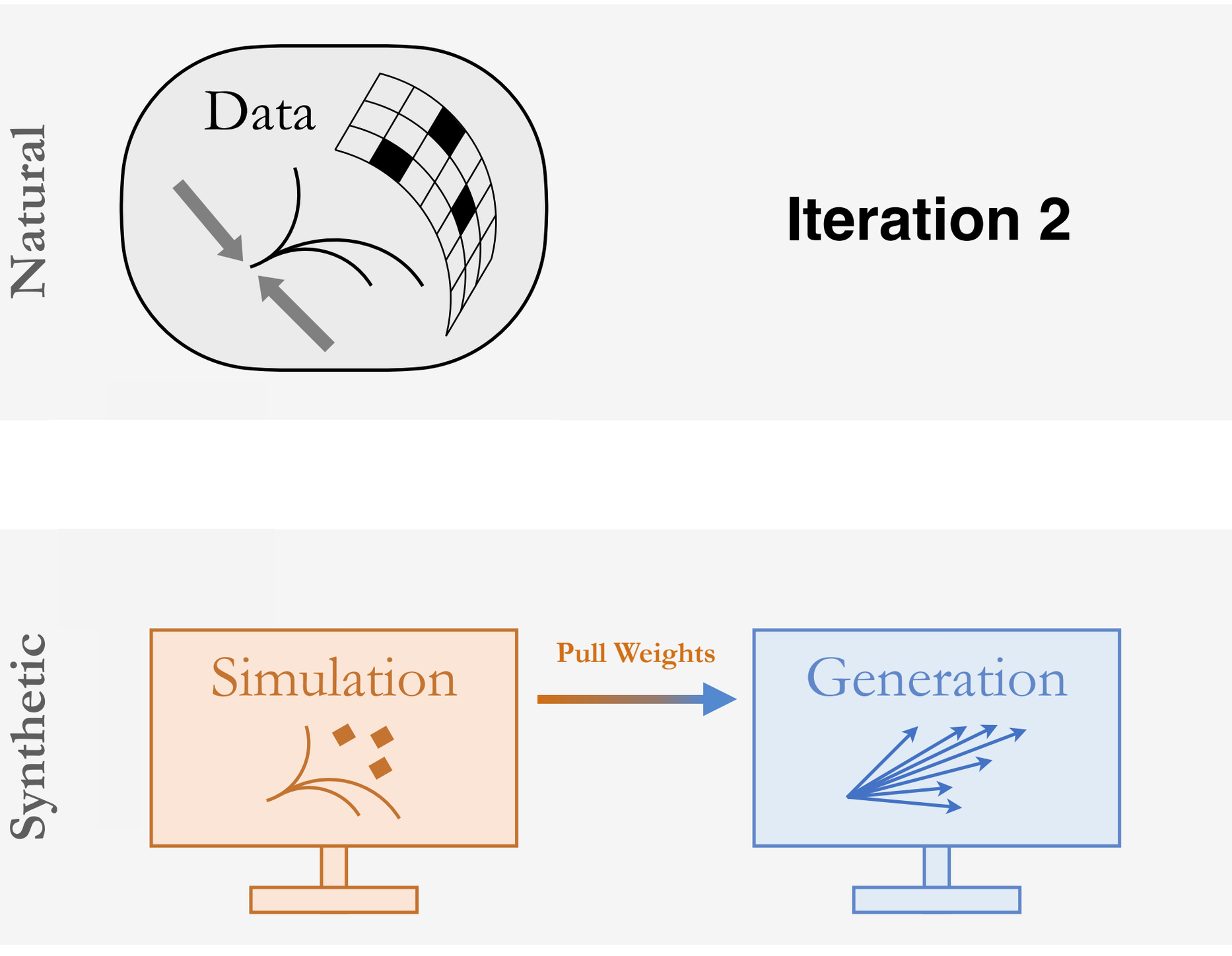

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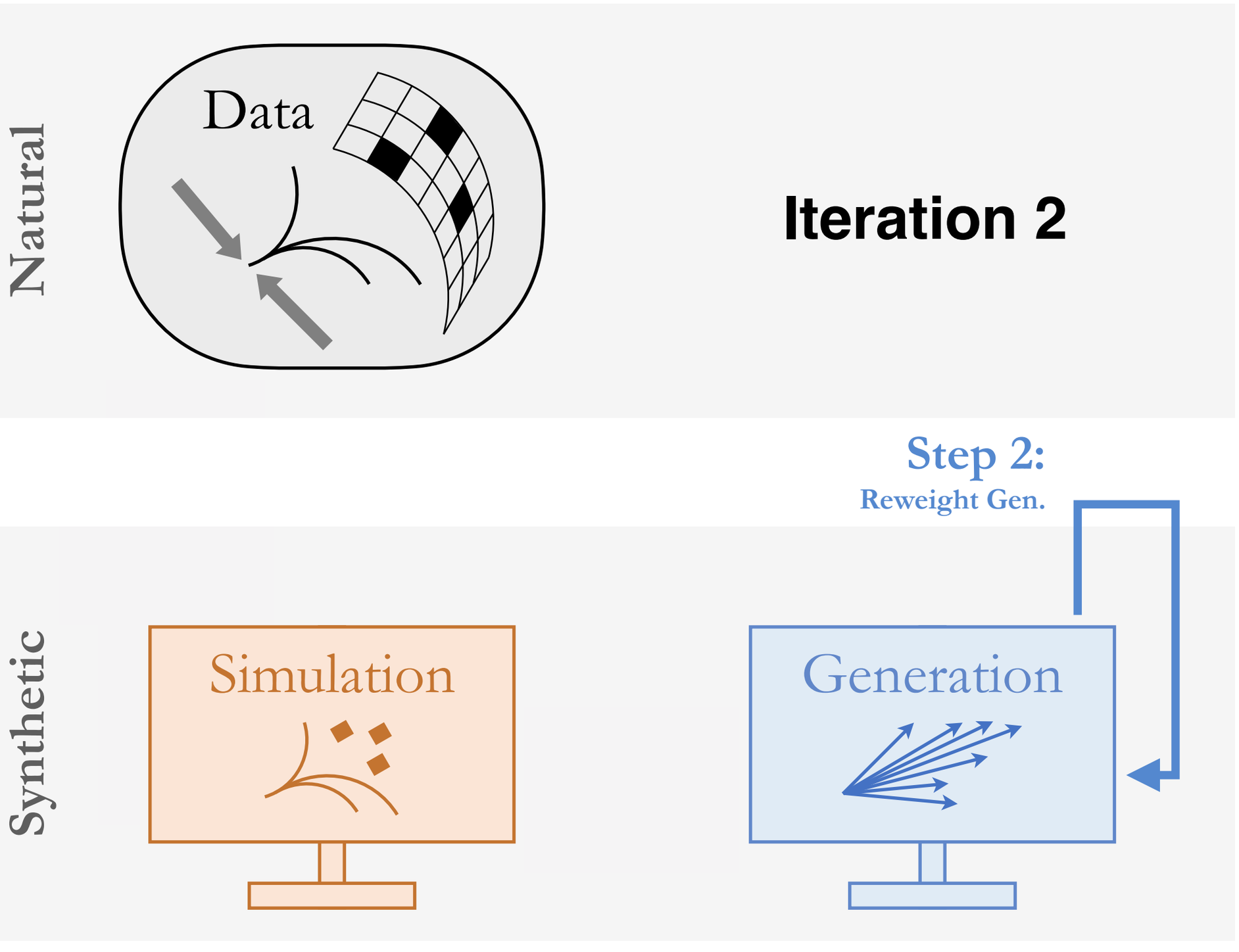

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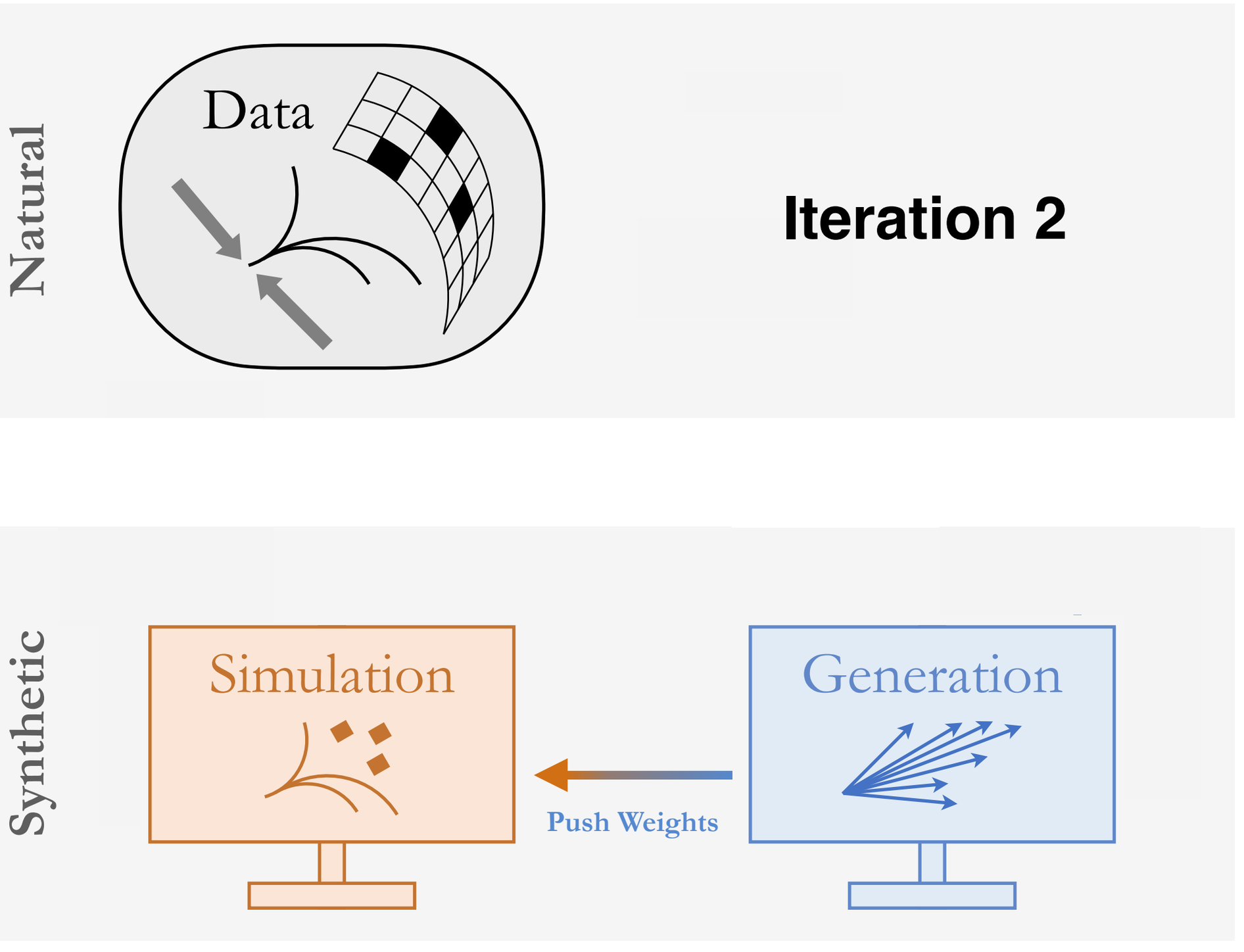

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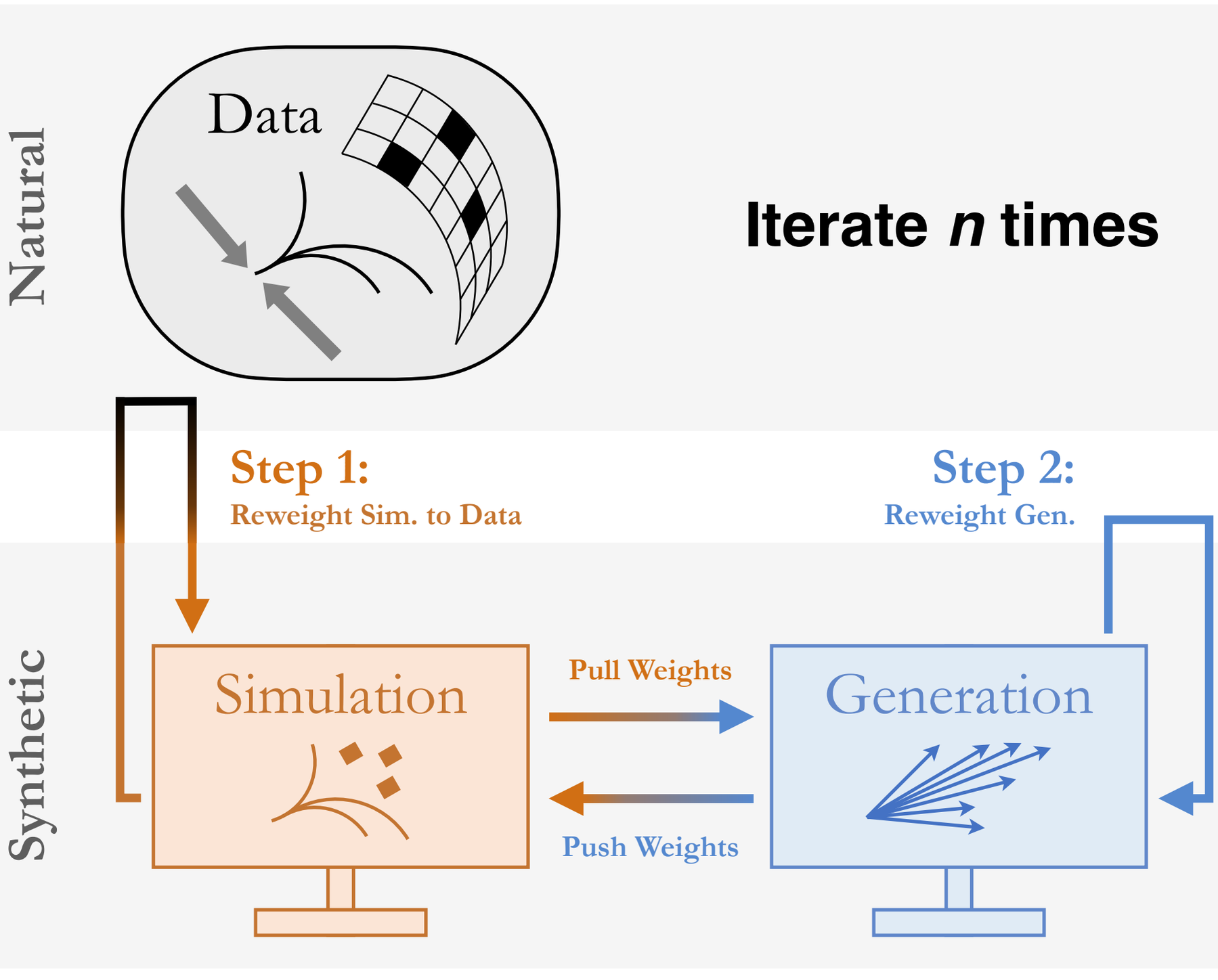

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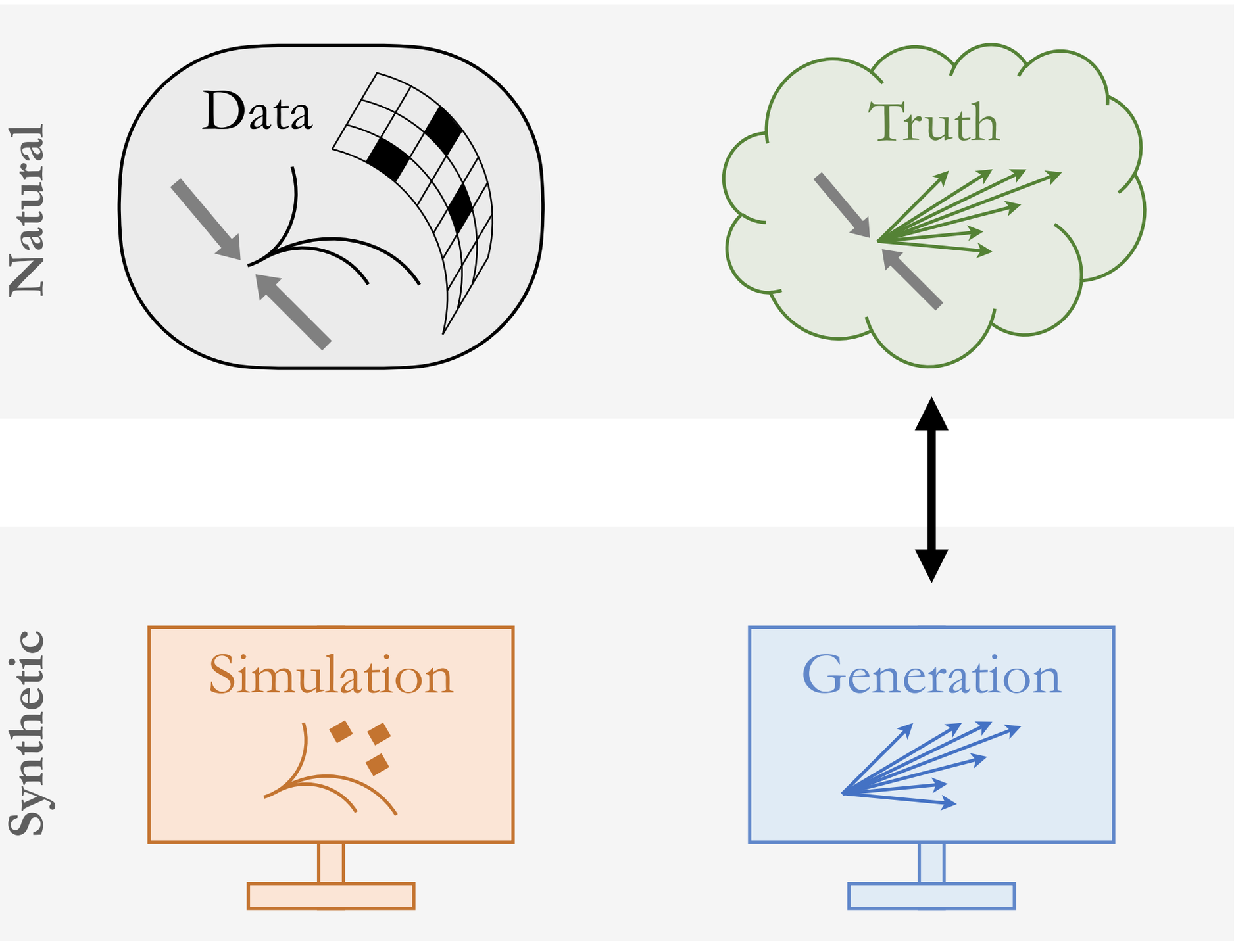

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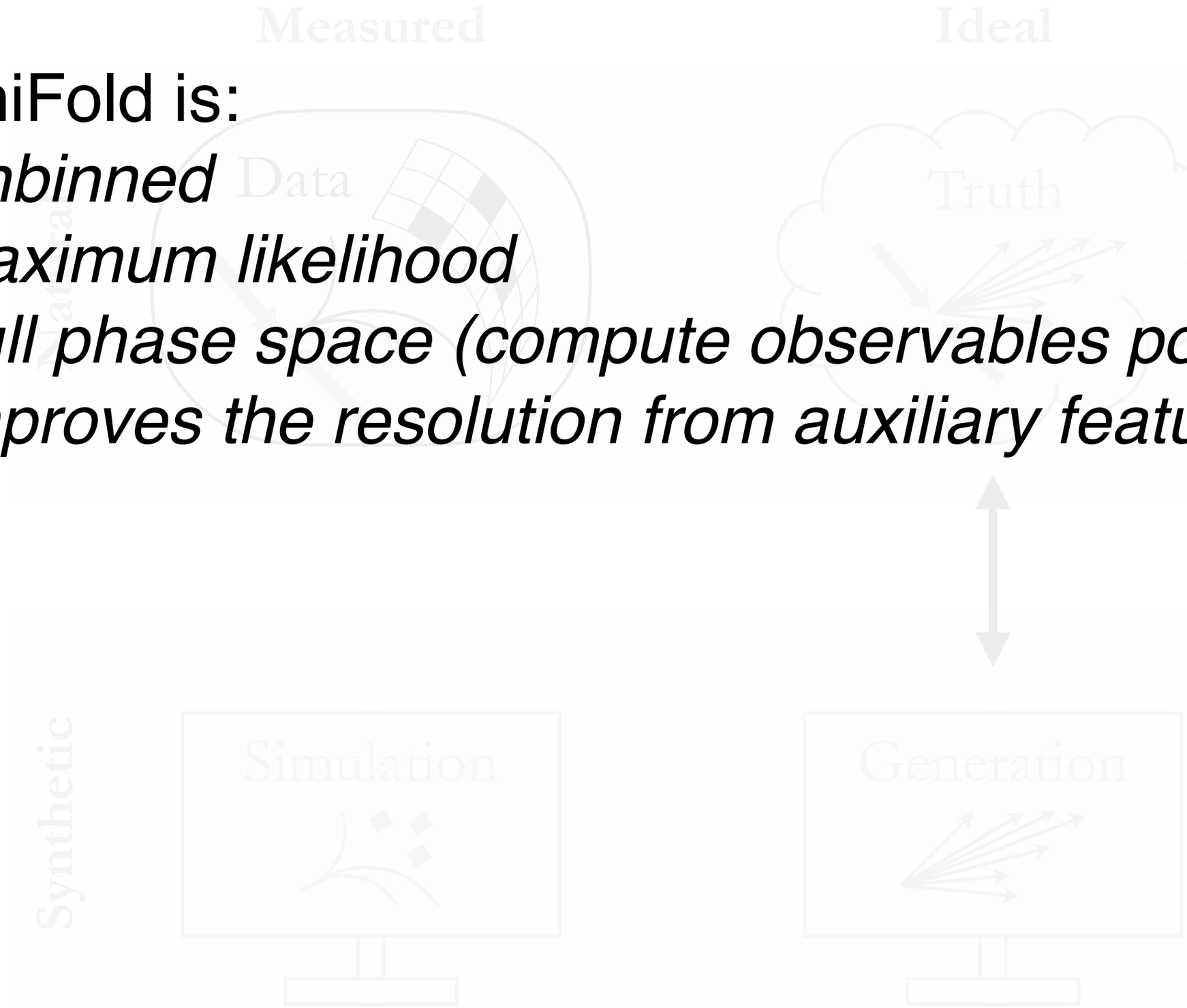
Unfold by iterating: OmniFold

OmniFold is:

- *Unbinned*
- *Maximum likelihood*
- *Full phase space (compute observables post-facto)*
- *Improves the resolution from auxiliary features*



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Unfold by iterating: OmniFold

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- *Unbinned*
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In this measurement: simultaneously unfold lepton and jet kinematics and report binned spectra for jet p_T, $\Delta\phi$, q_T/Q, and jet η

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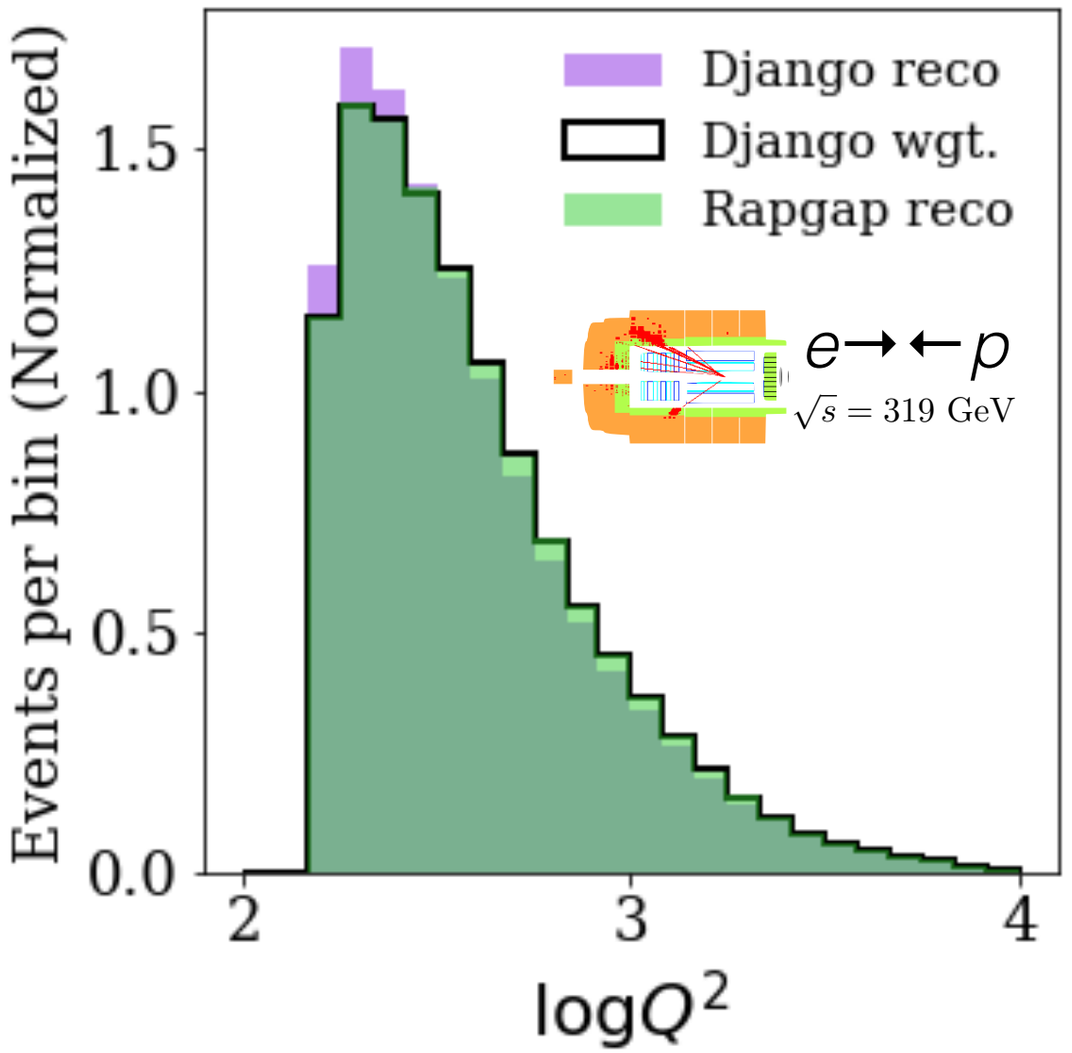
Classification for reweighting

Neural networks are naturally unbinned and readily process high-dimensional data.

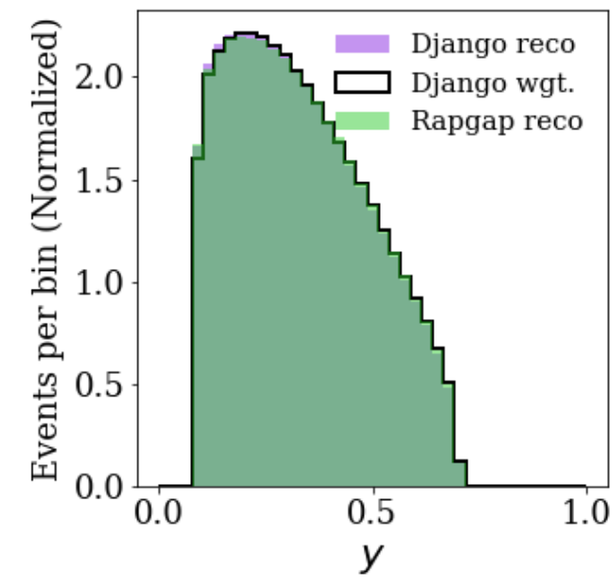
We use a trick whereby classifiers can be repurposed as reweighters

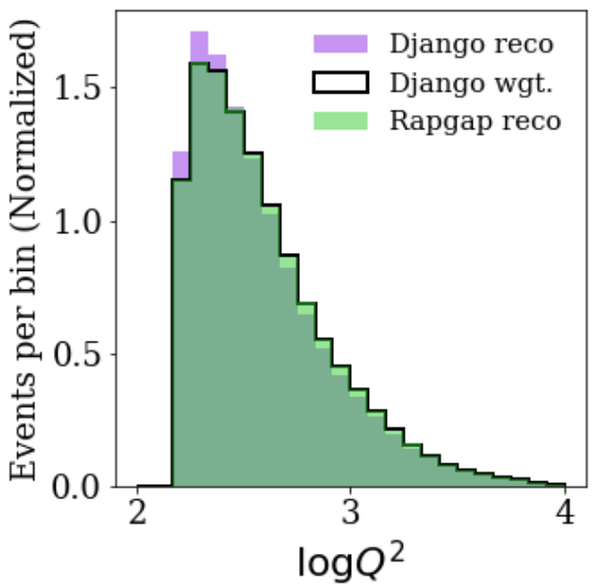
N.B. the distribution is binned for illustration, but the reweighting is unbinned.

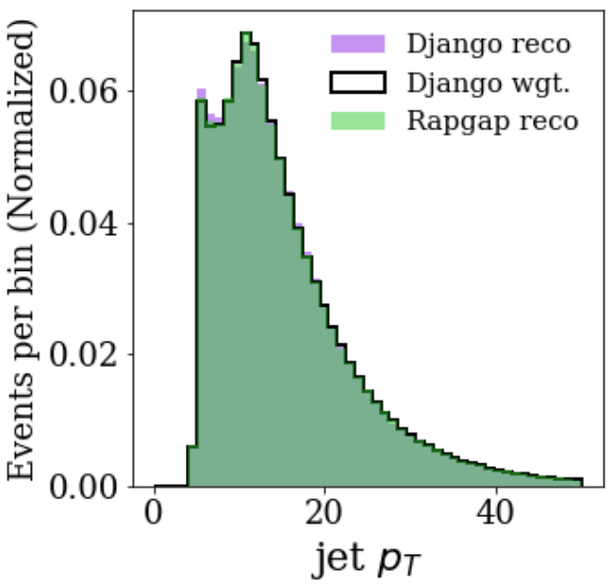


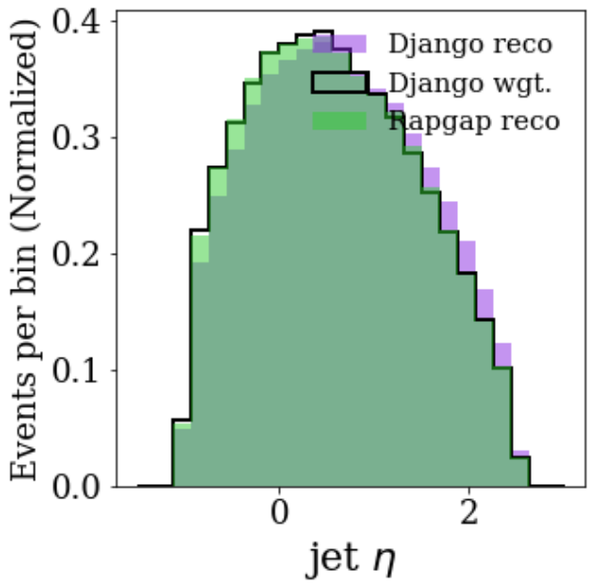
Classification for reweighting

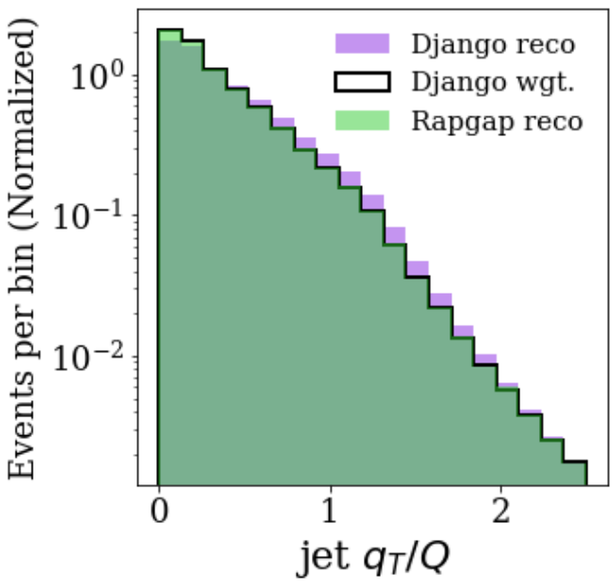
All of these distributions are simultaneously reweighted!

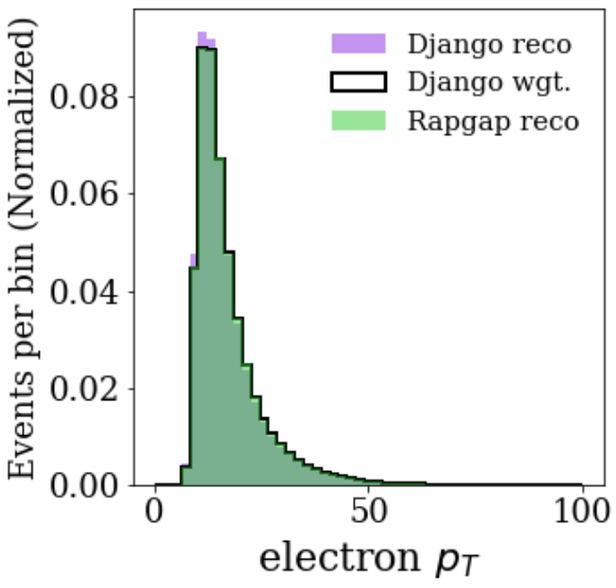


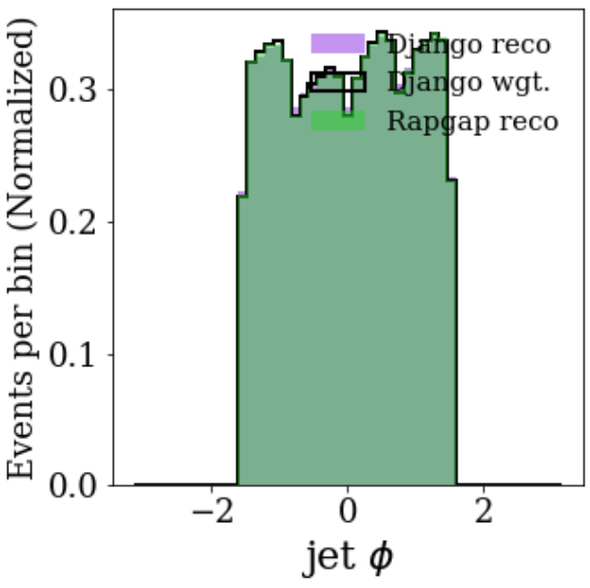


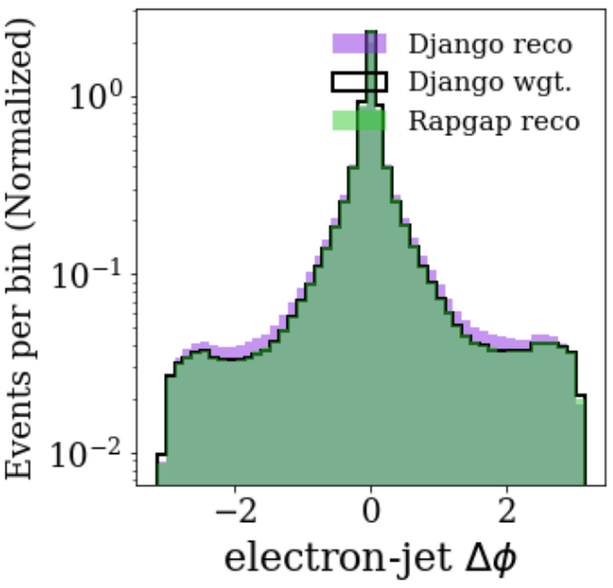












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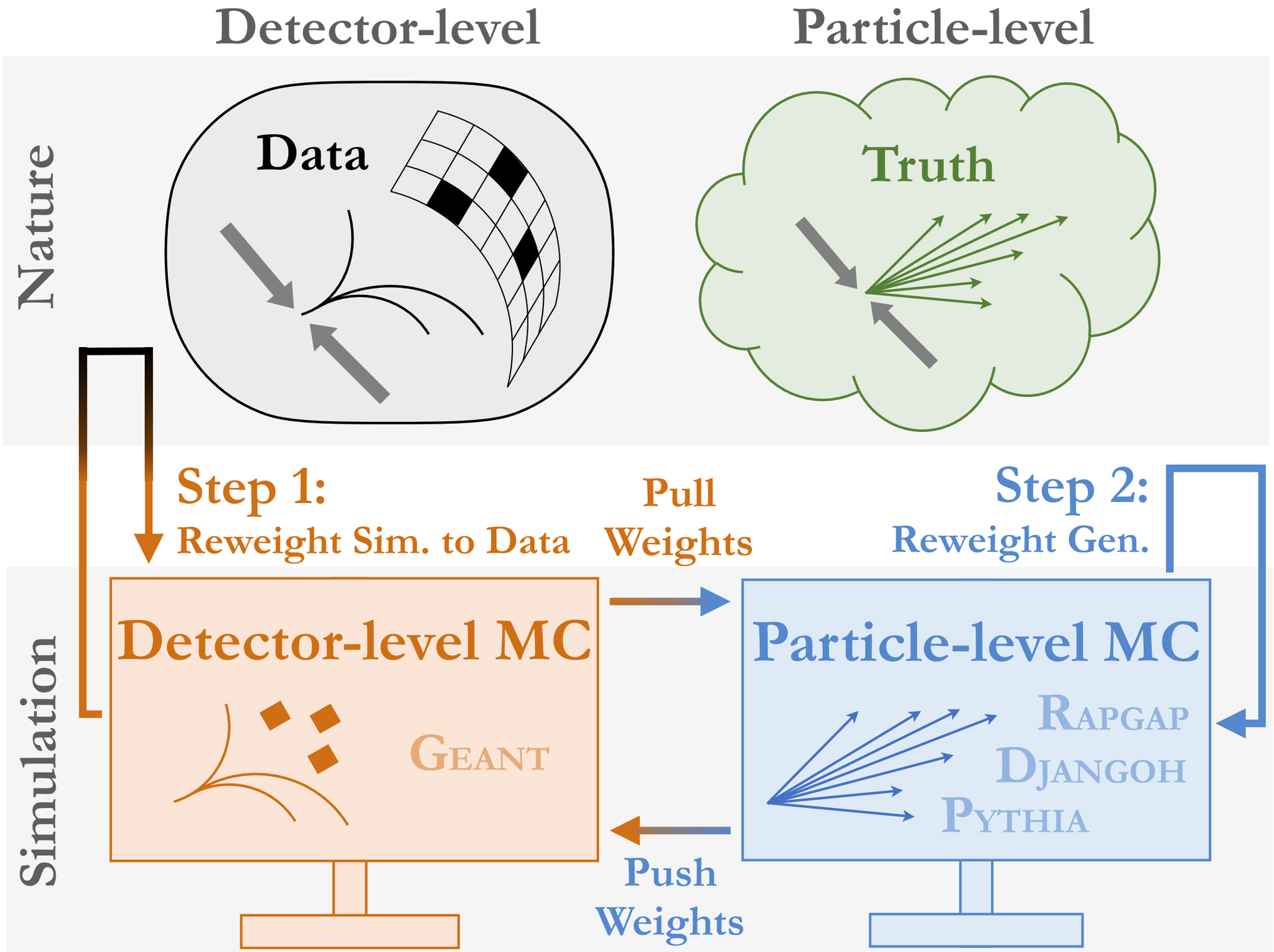
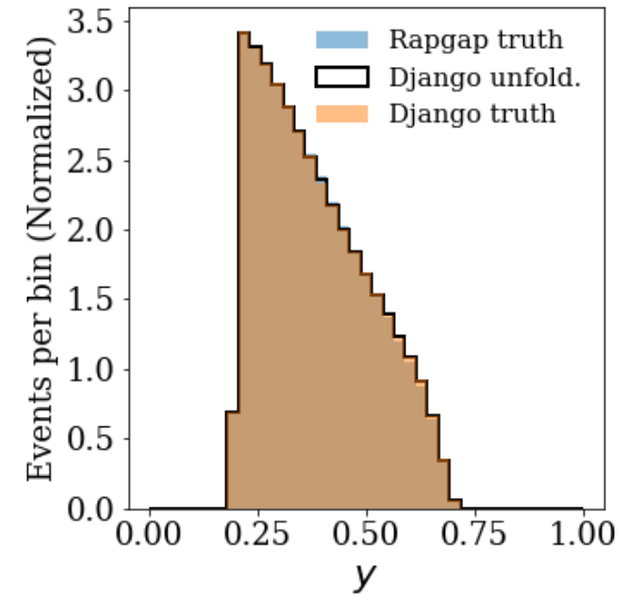
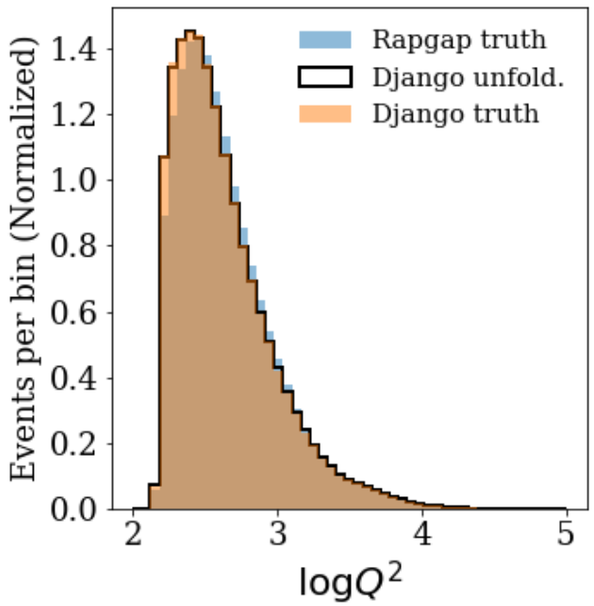
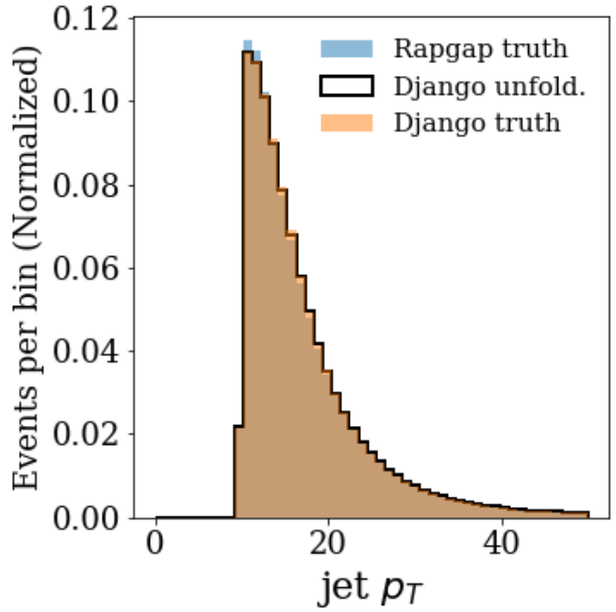


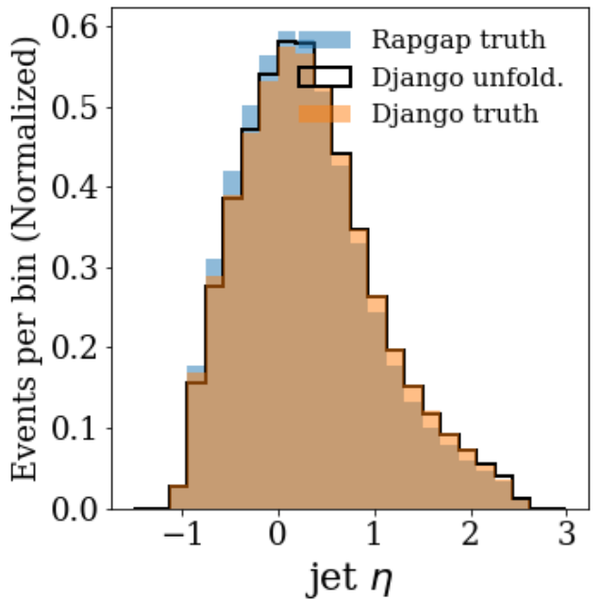
OmniFolding *ep* simulations

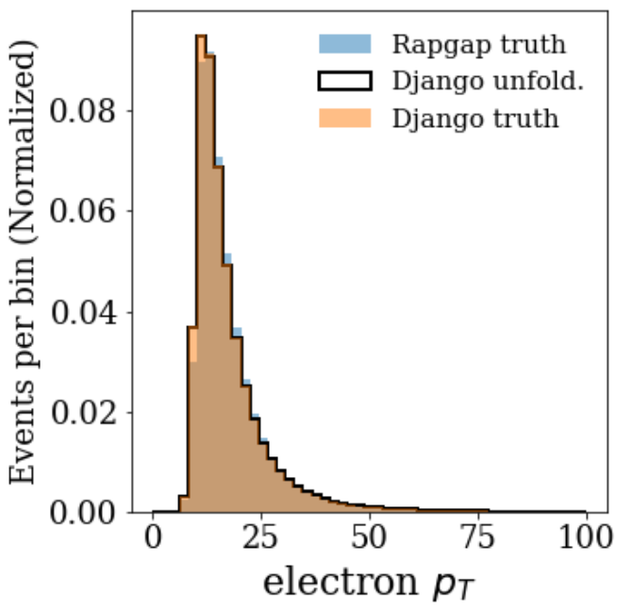
We see excellent closure for the full phase space!

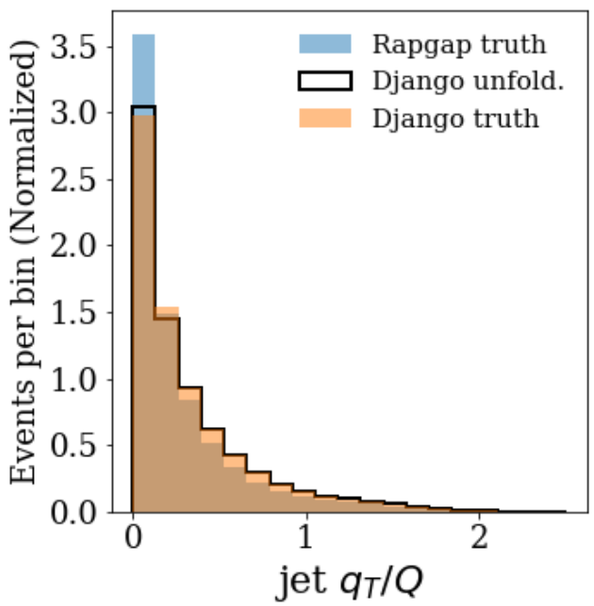


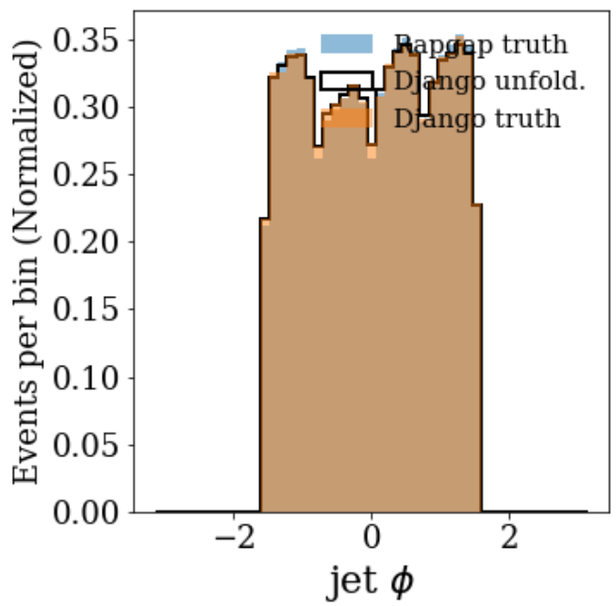


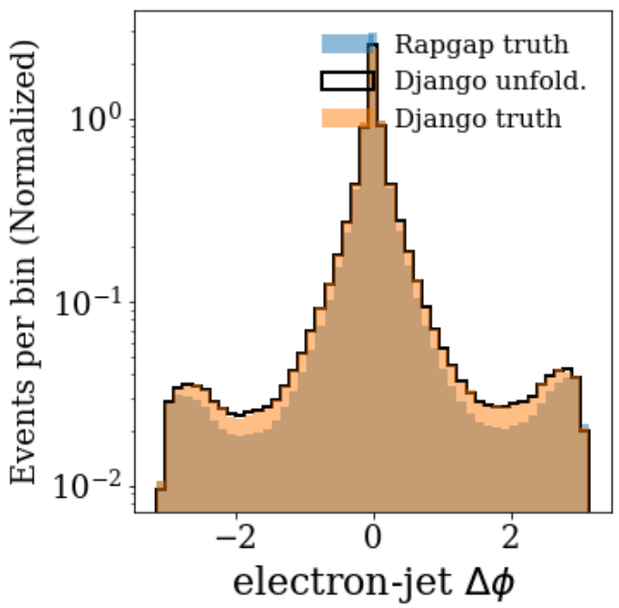












Preliminary Results

H1prelim-21-031
April 8, 2021

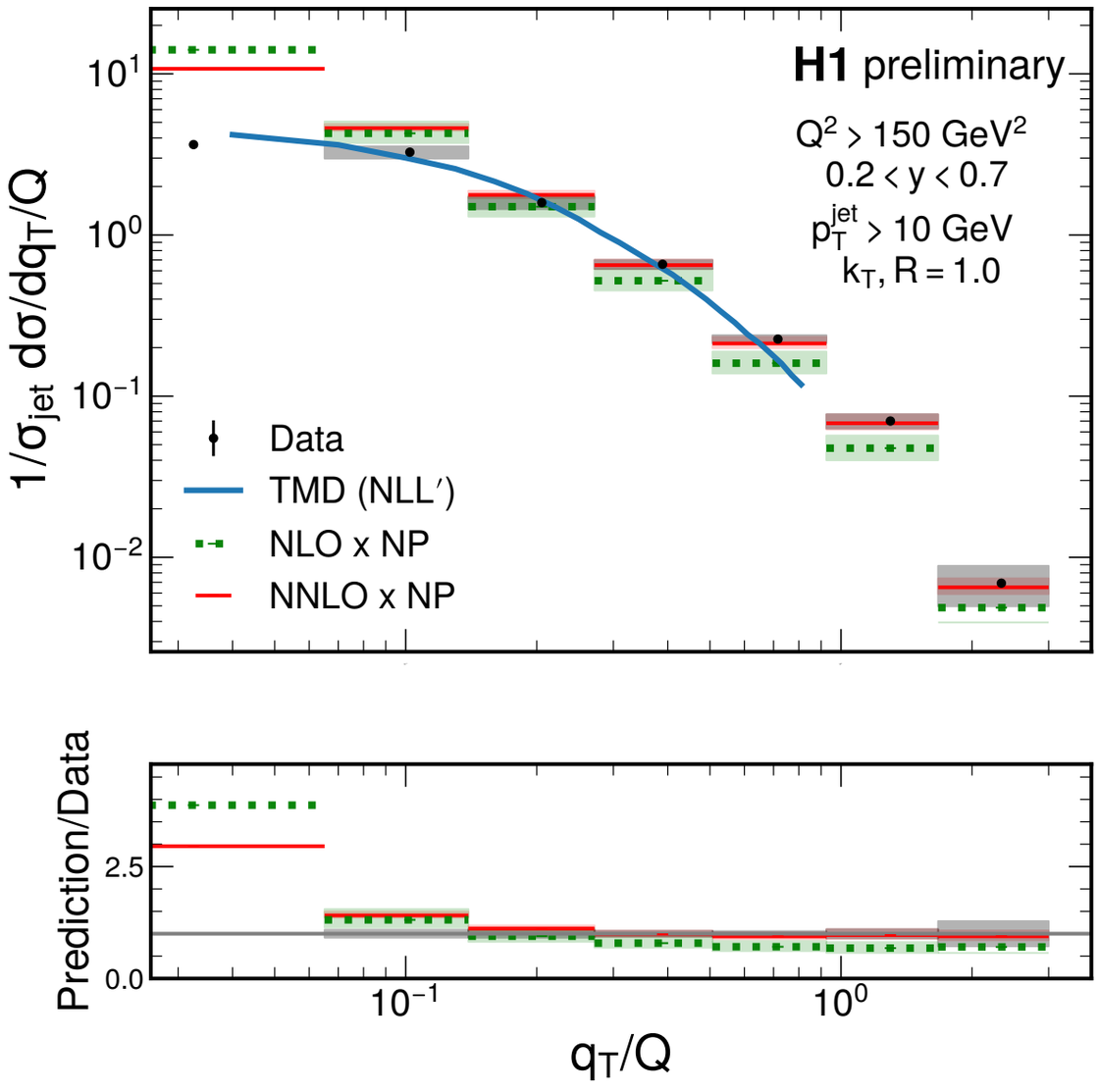
Measurement of lepton-jet correlations in high Q^2 neutral-current DIS with the H1 detector at HERA

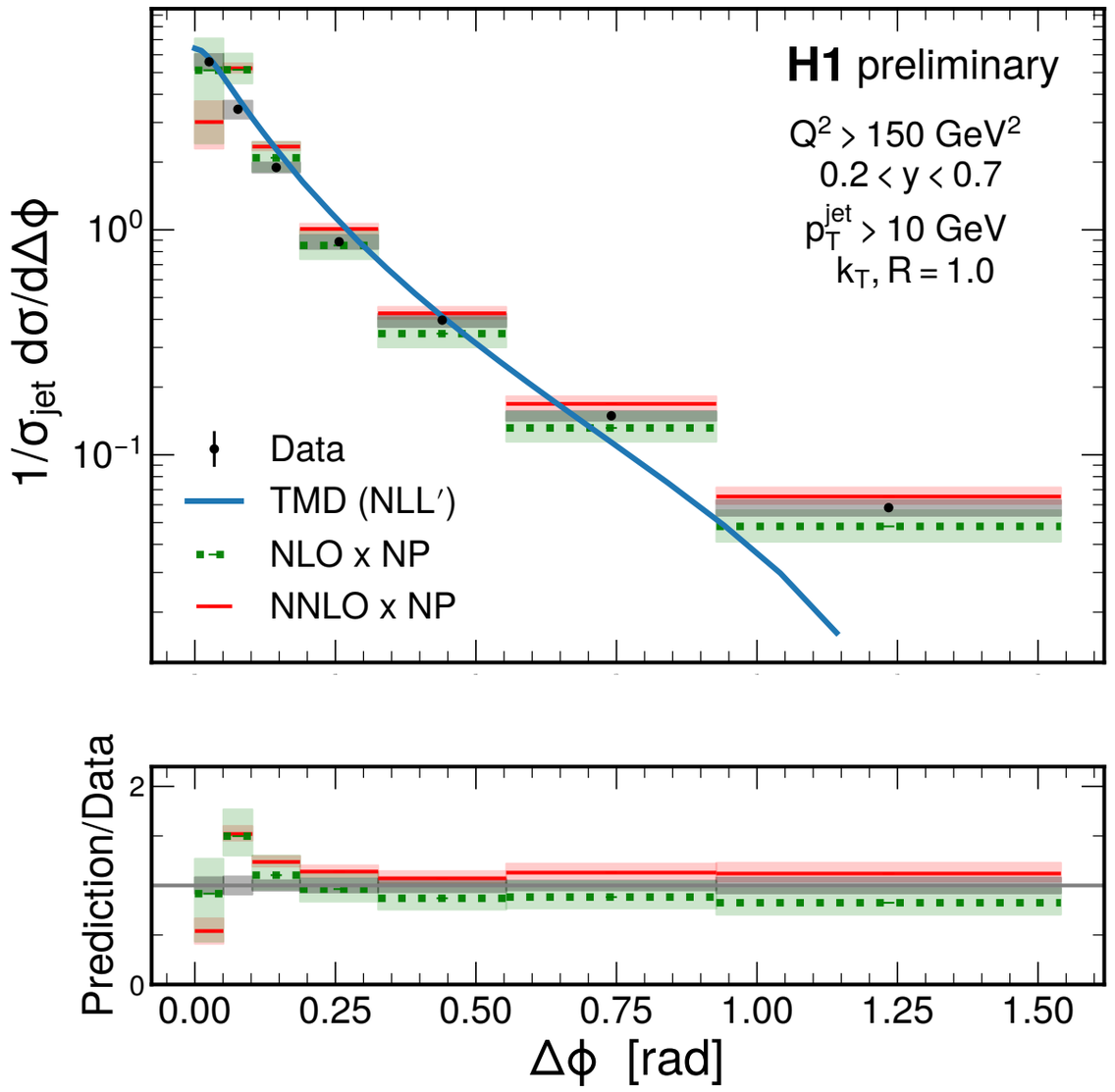
The H1 Collaboration

https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-21-031.long.html

Preliminary Results

see Sec. 9 in our note for theory citations

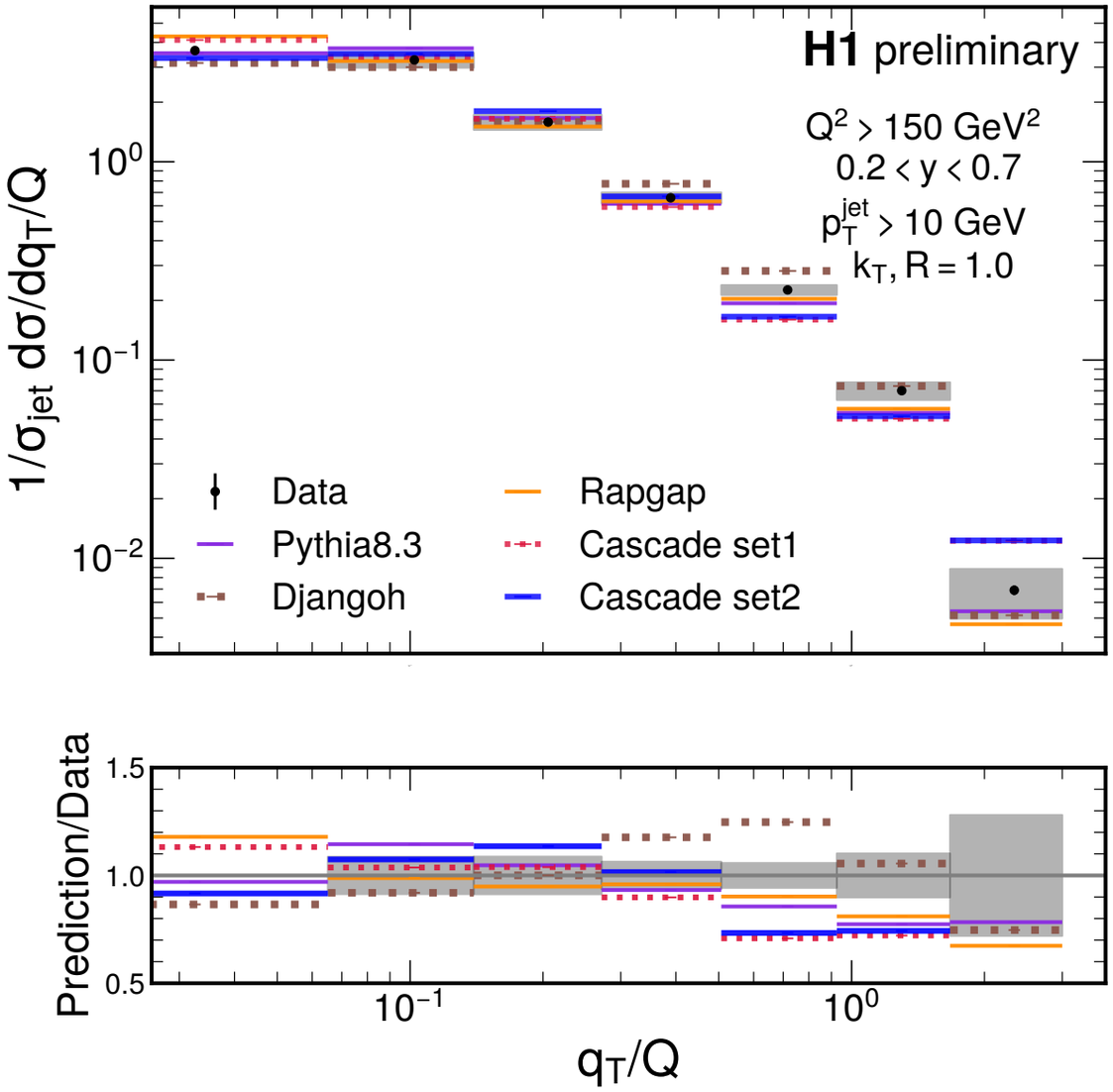


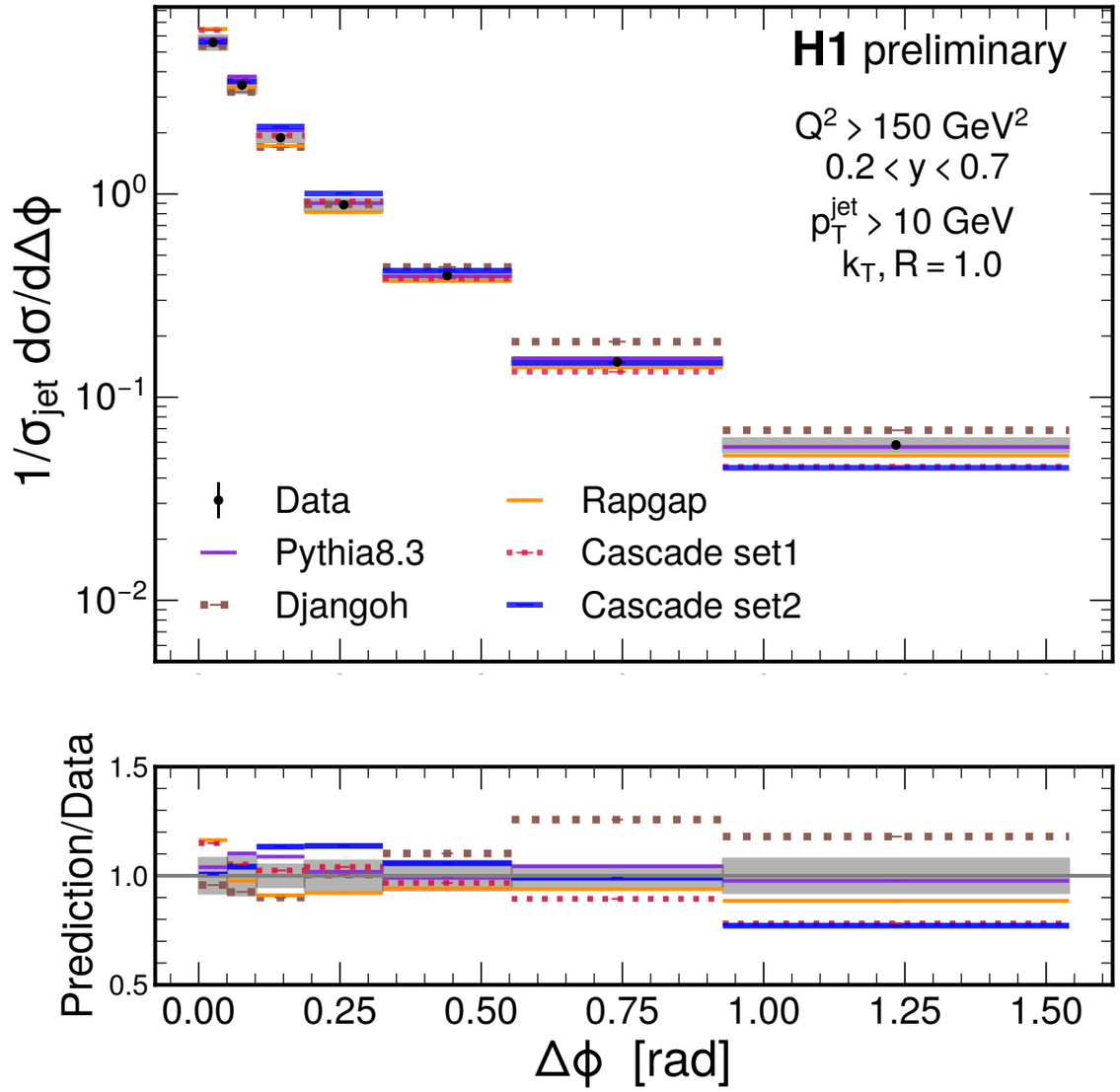


Excellent agreement with fixed order at high q_T, excellent agreement with TMD prediction at low q_T.

Preliminary Results

see Sec. 9 in our note for theory citations

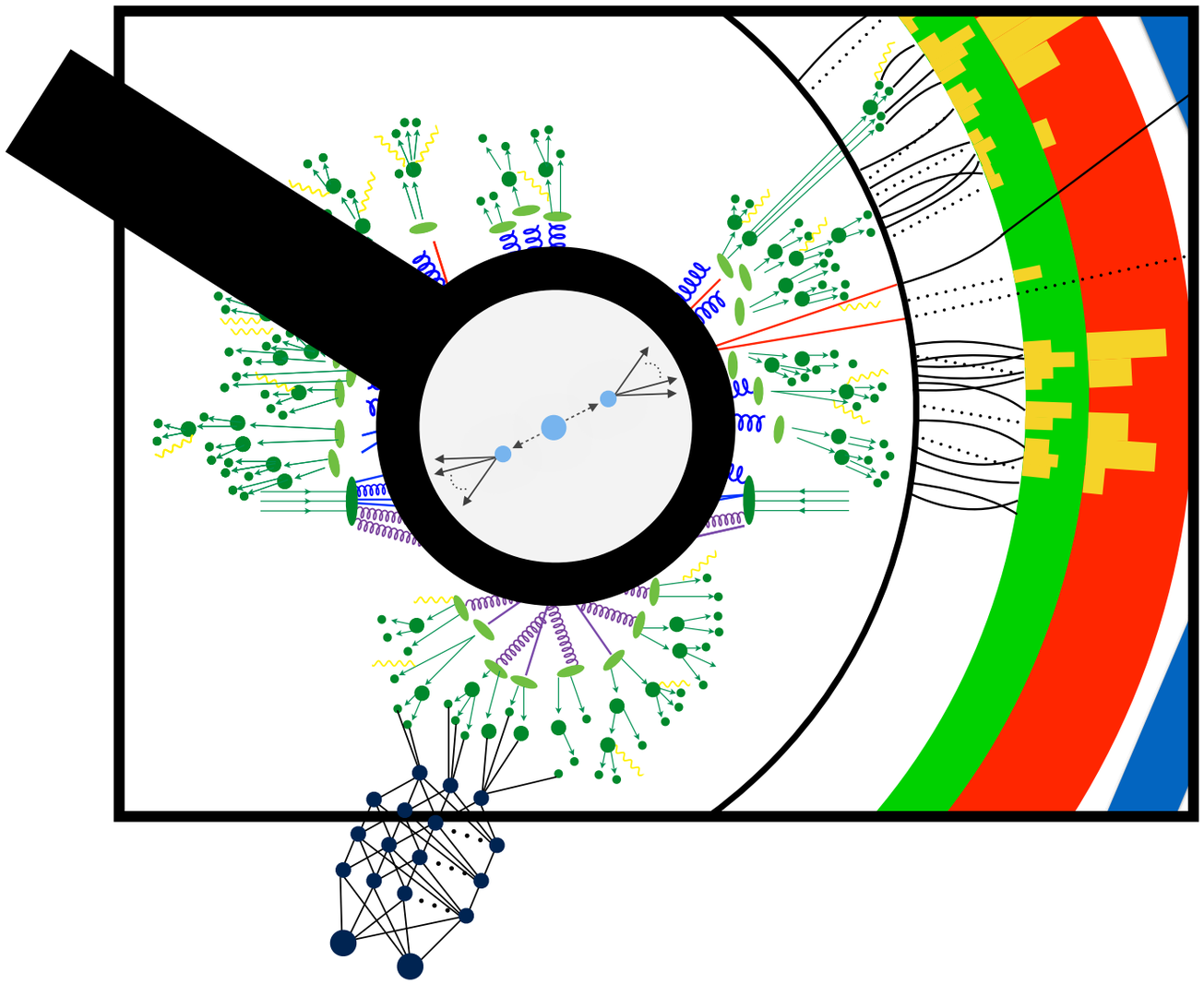




Parton shower Monte Carlo programs also provide excellent agreement with the data across the spectra.

Conclusions and outlook

Today, I have presented the first ML-based unfolding with collider data

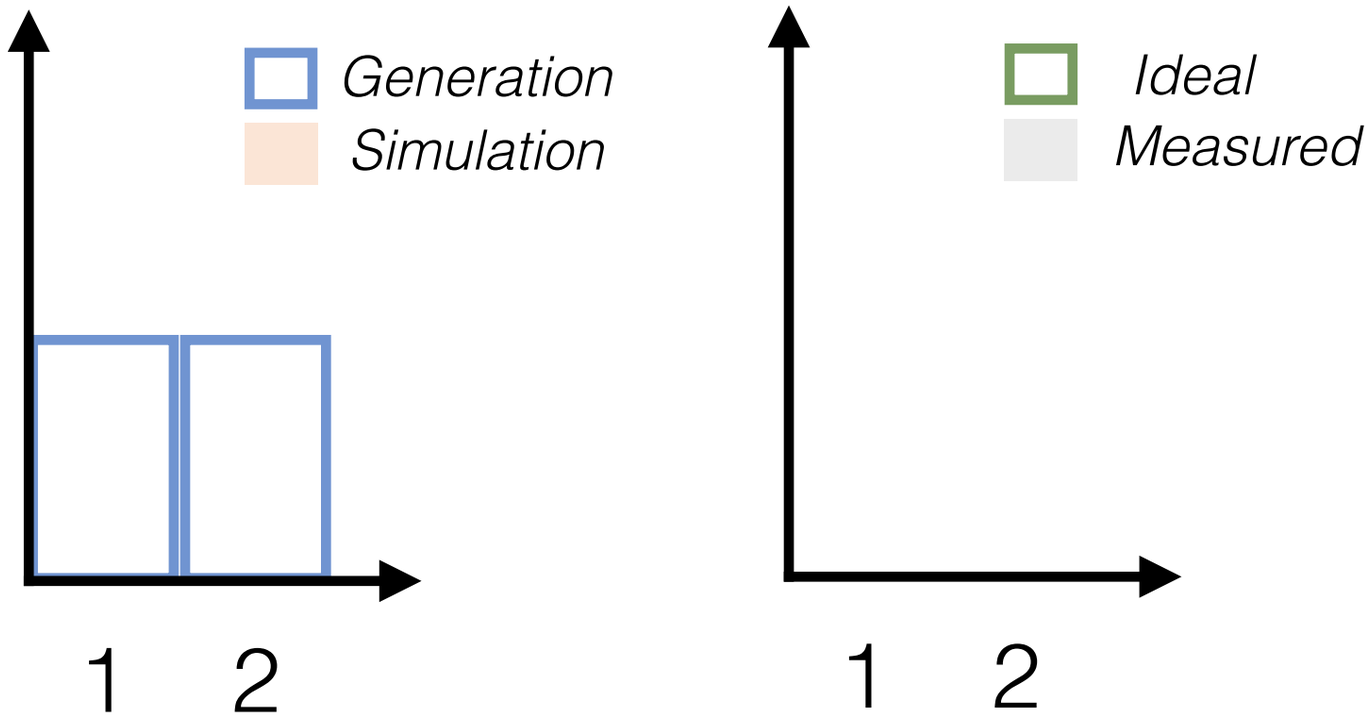


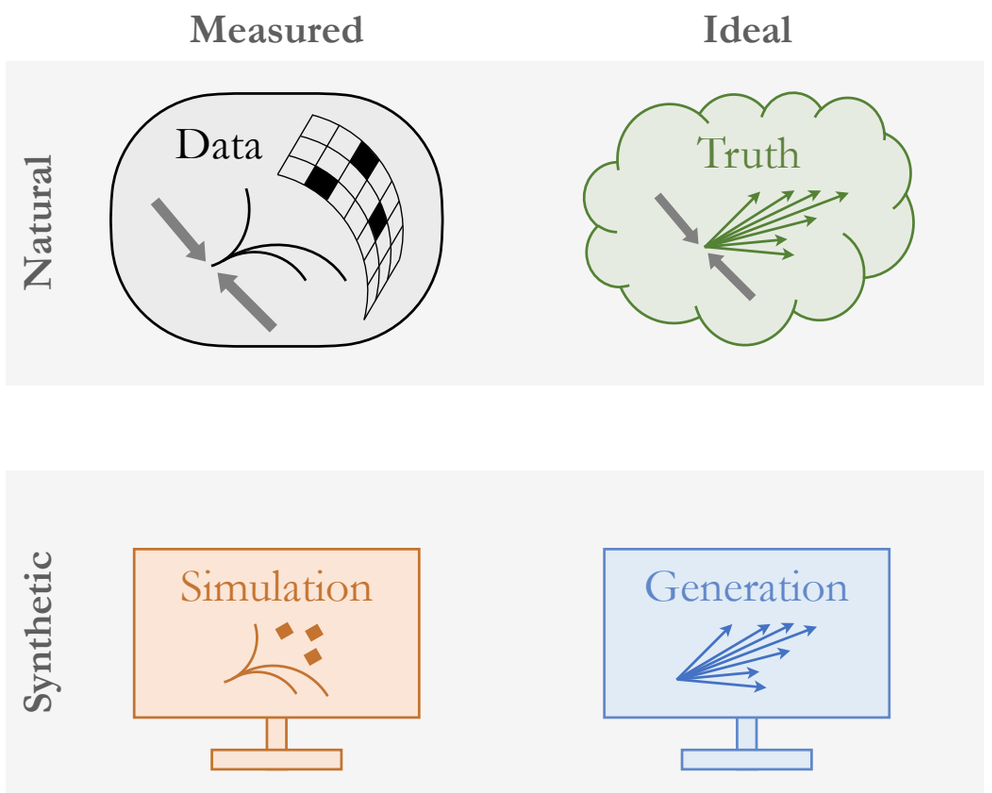
This is the start of an exciting program to advance our study of QCD into higher dimensions

This particular measurement has important constraining power for TMD PDFs and provides important input to planning and design for the future EIC

Backup

Unfold by iterating: OmniFold





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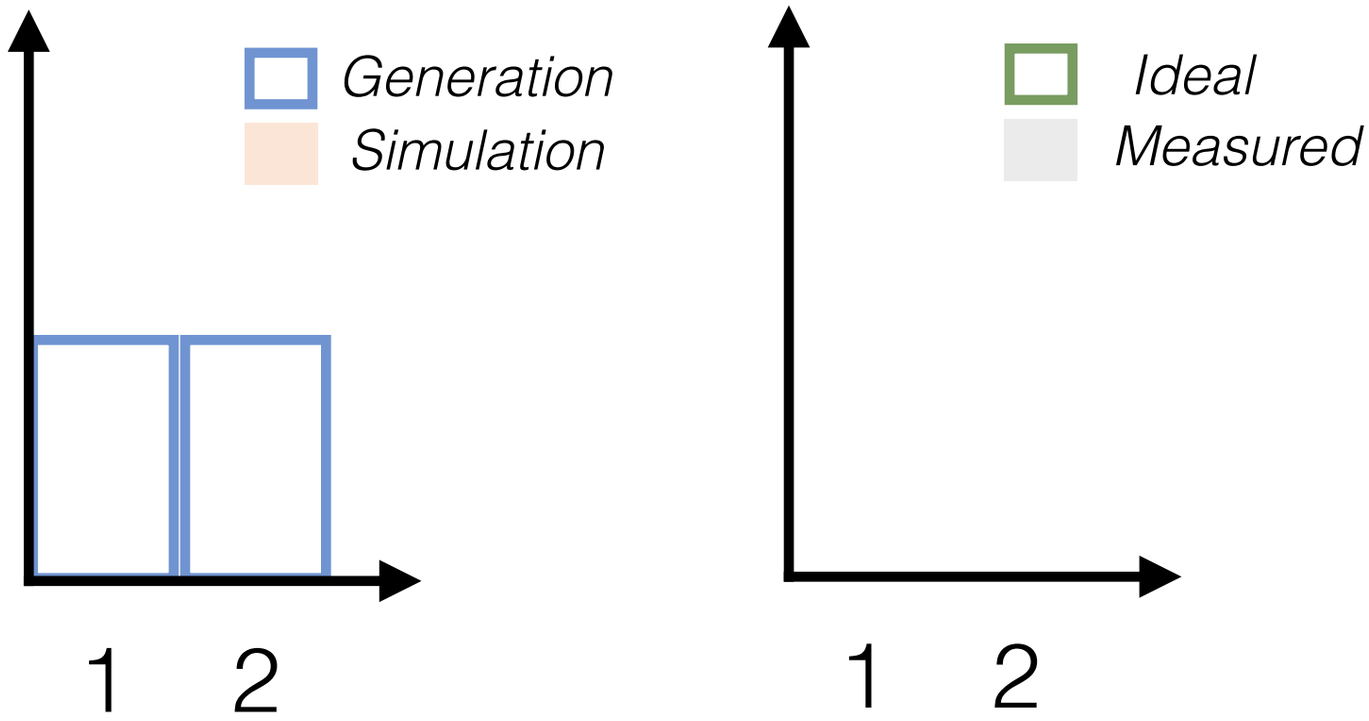

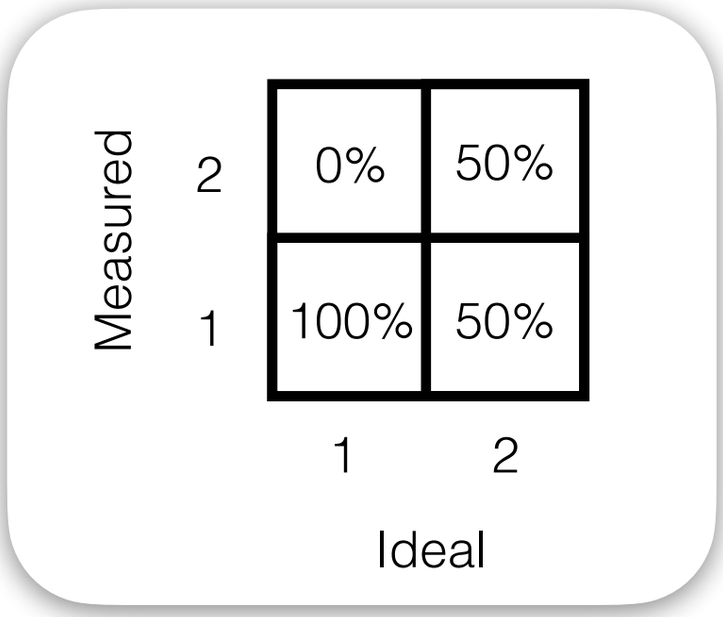

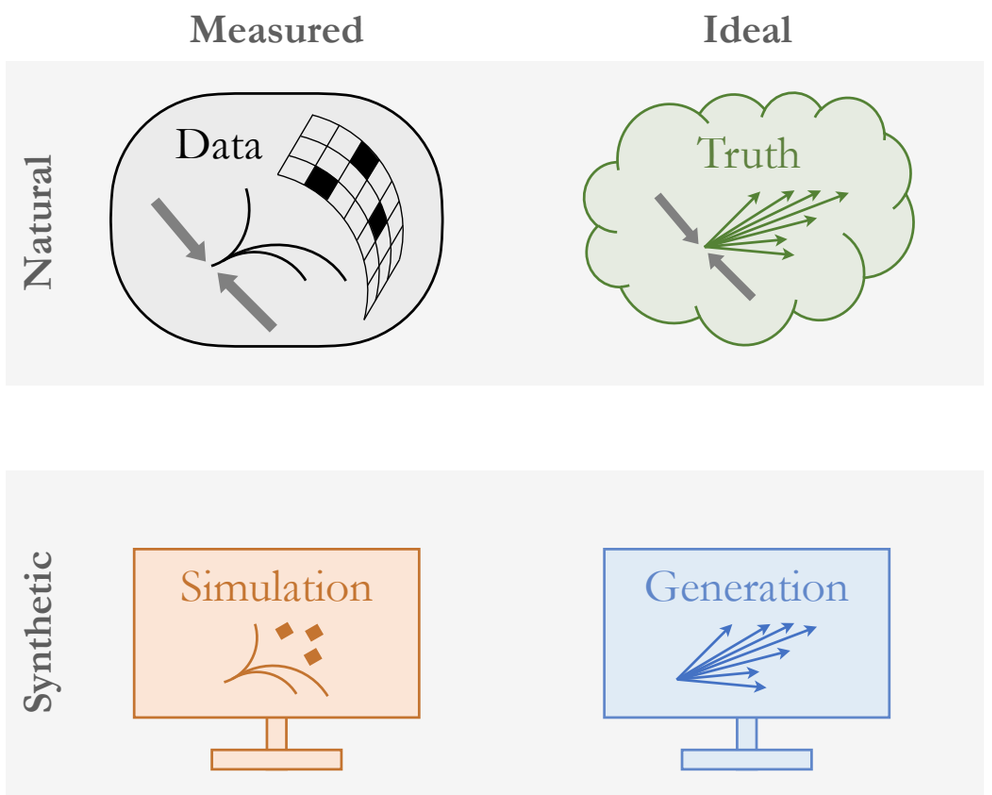

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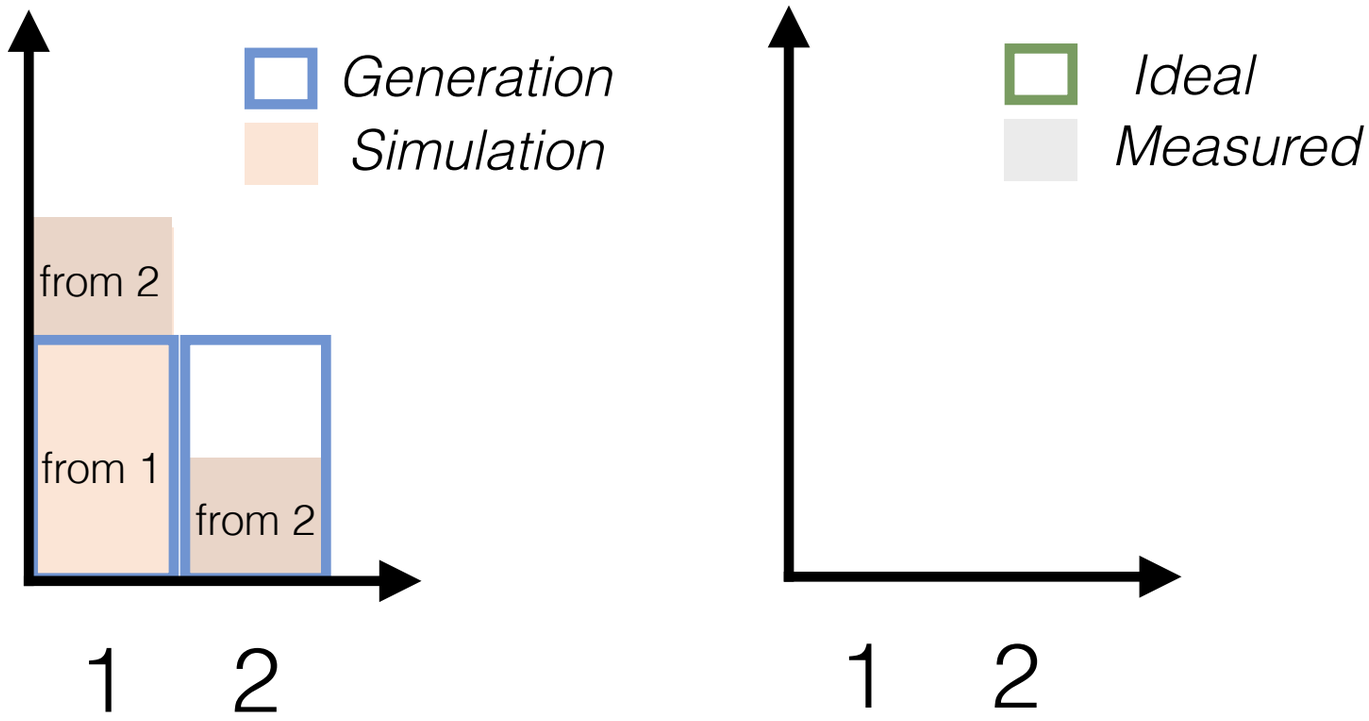
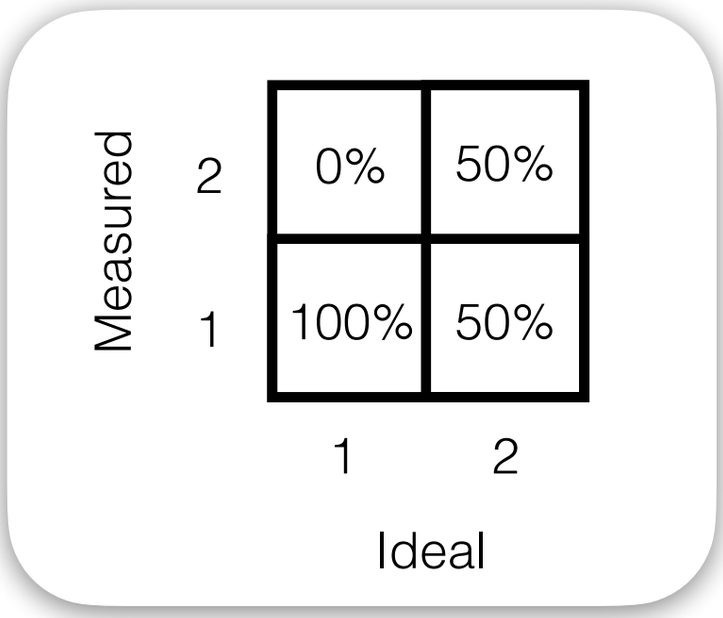
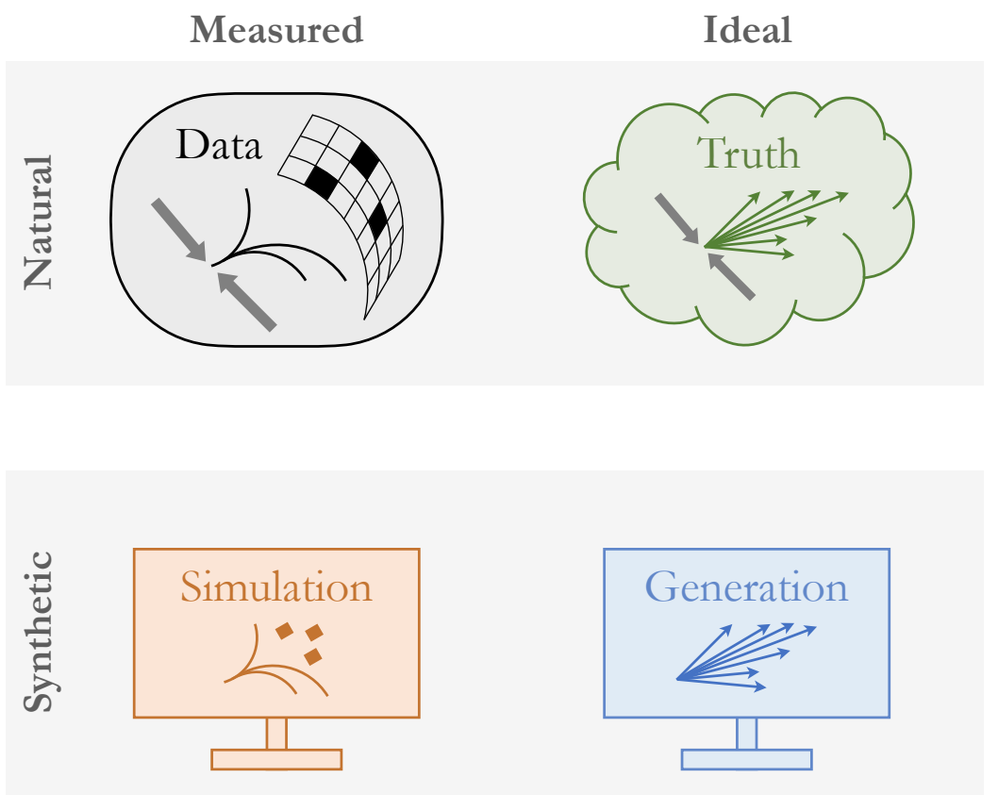
Unfold by iterating: OmniFold







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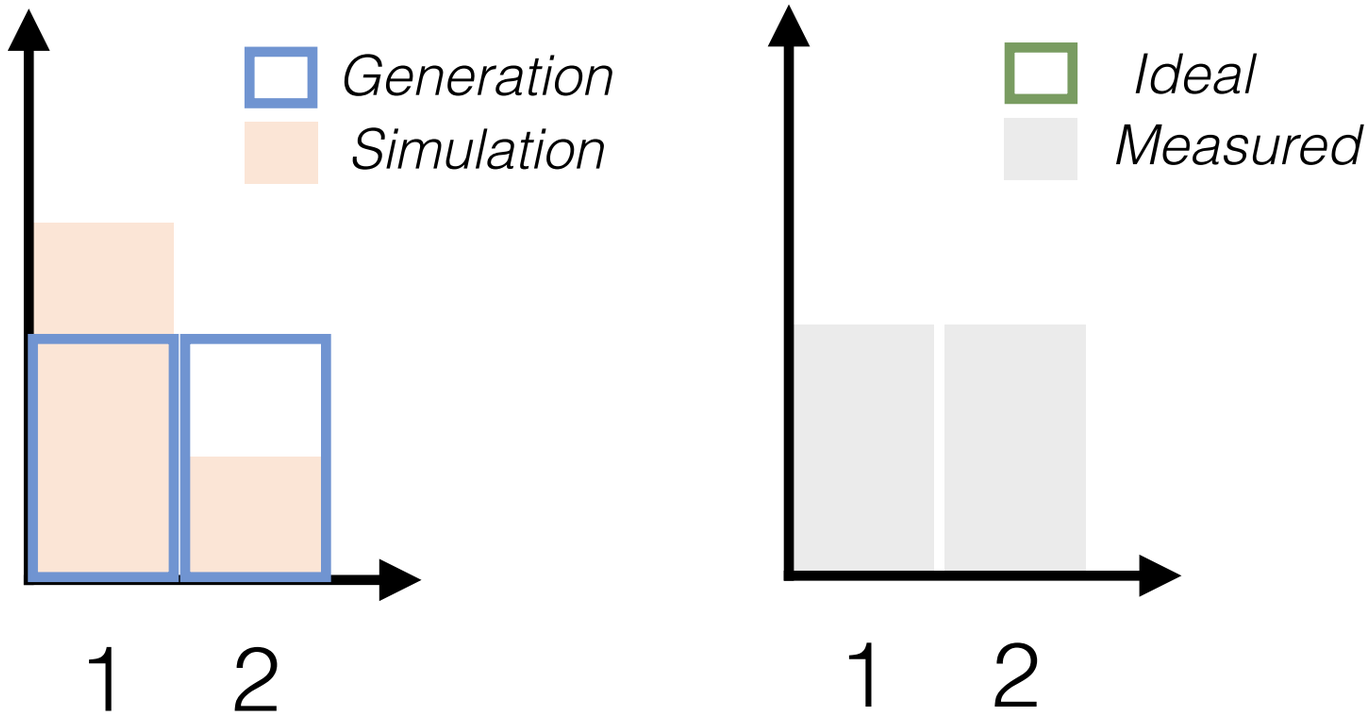

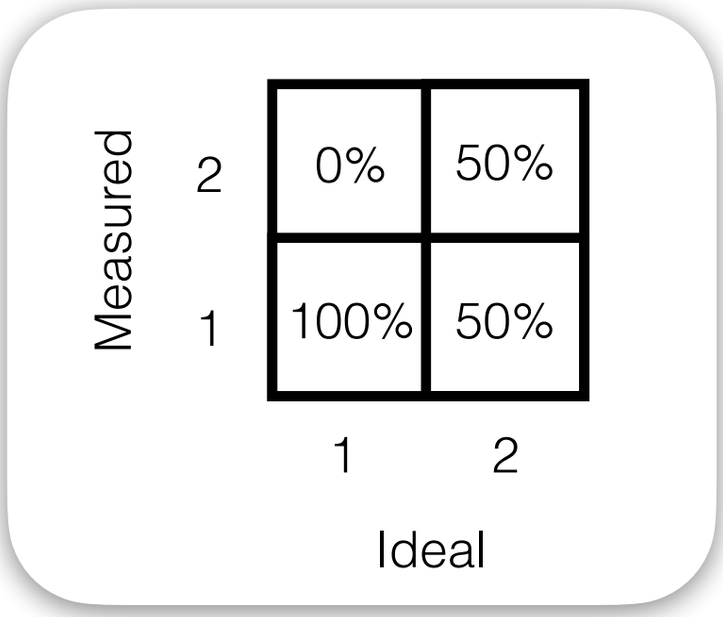

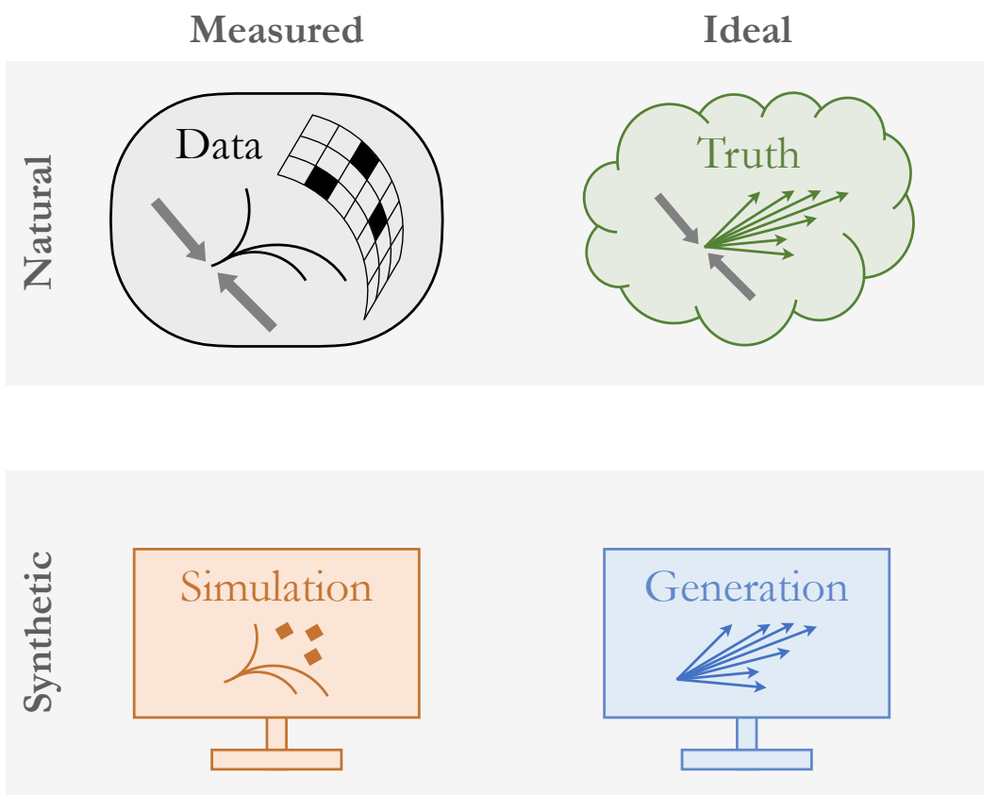

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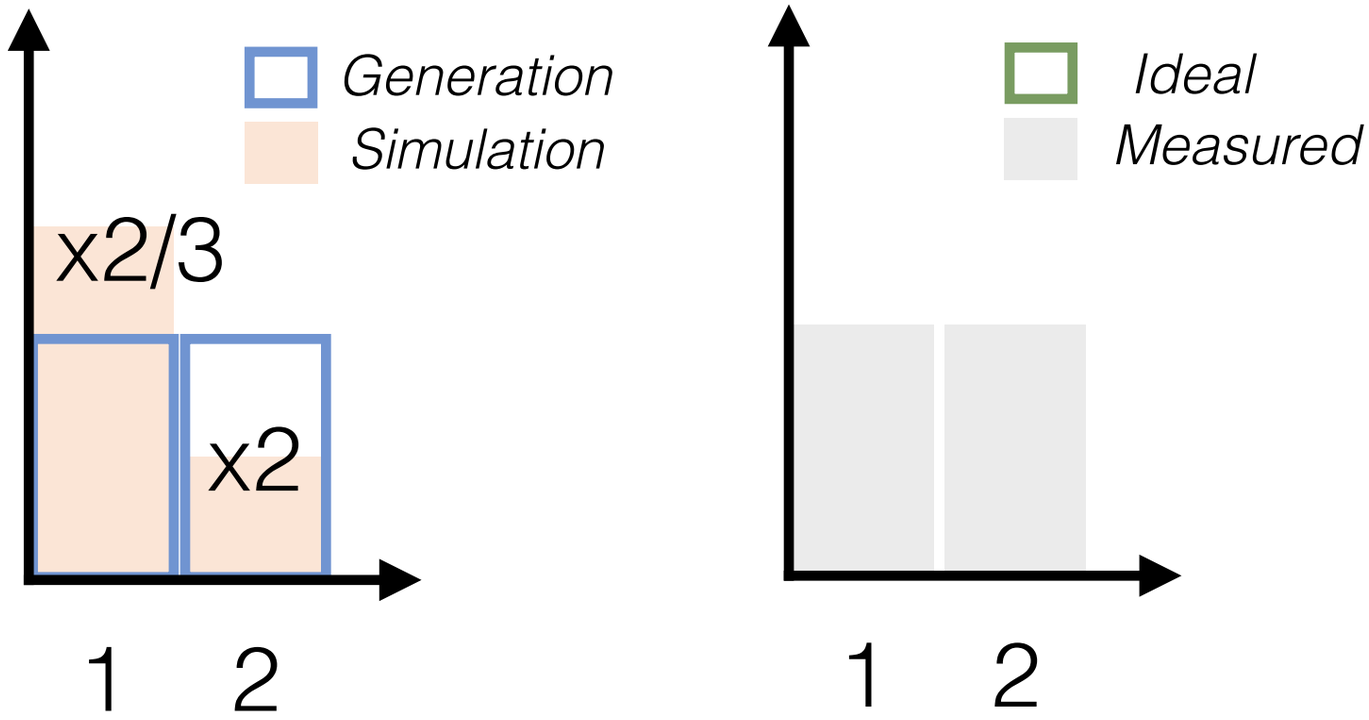

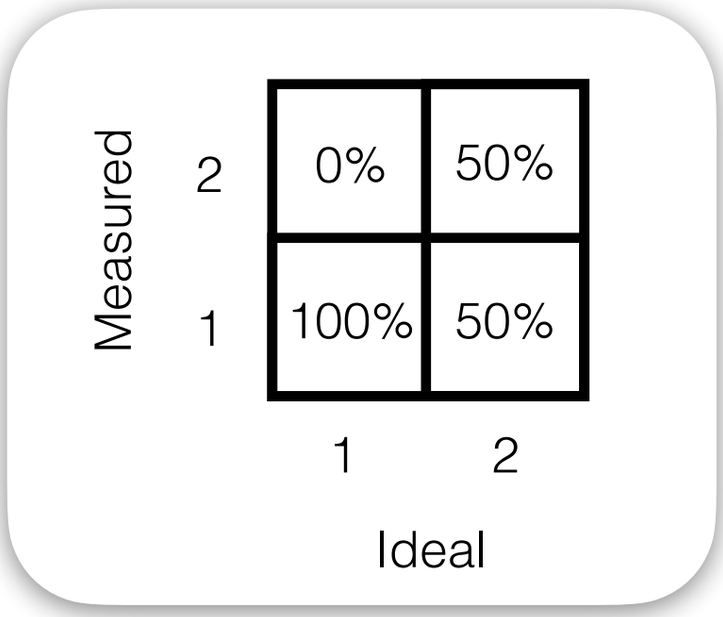

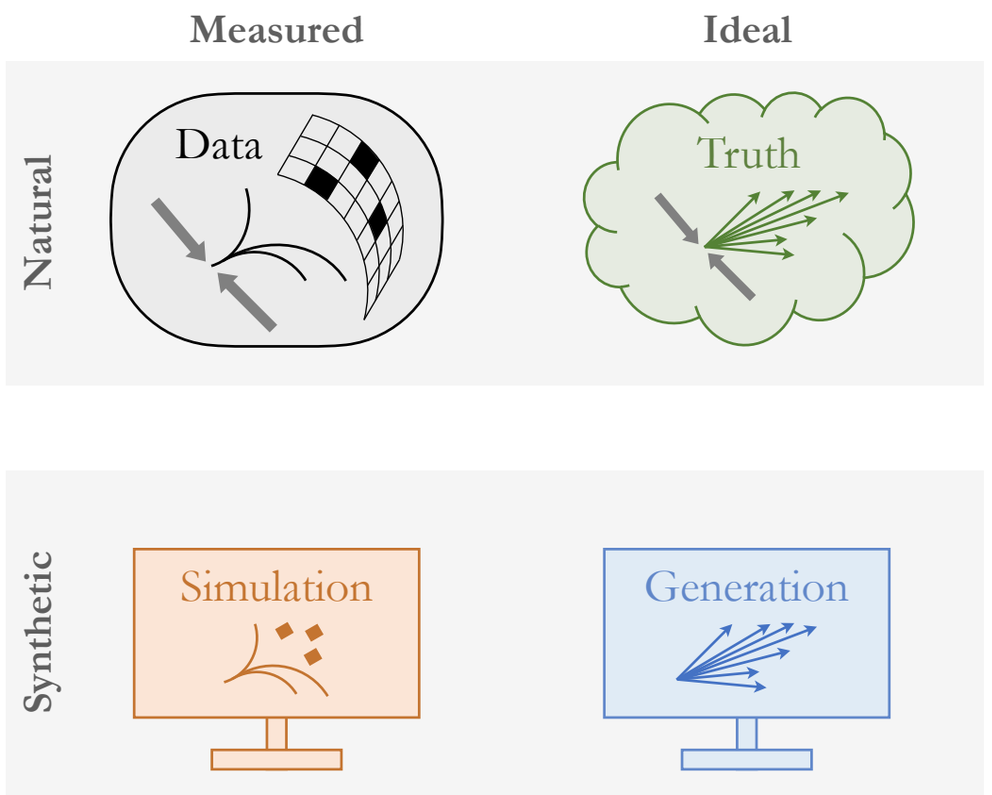

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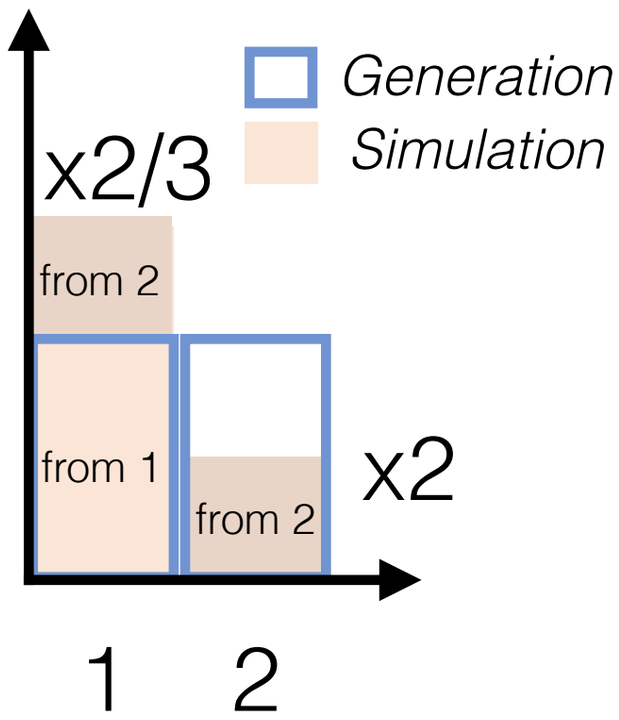

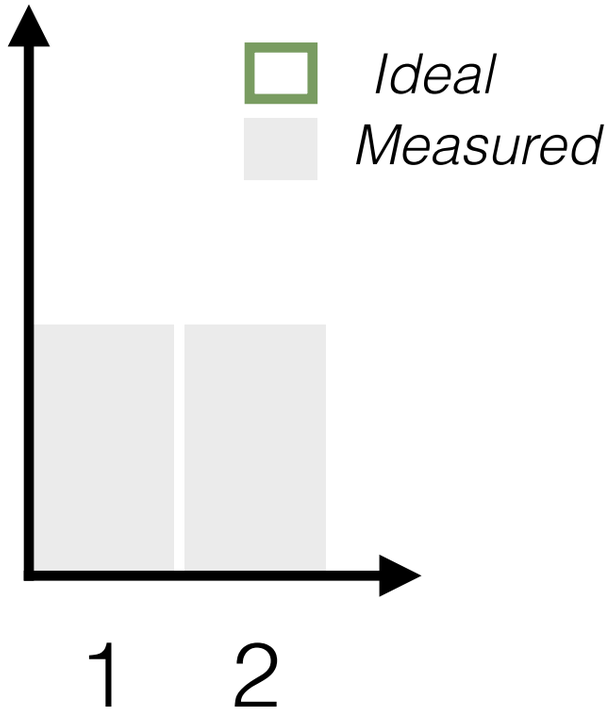

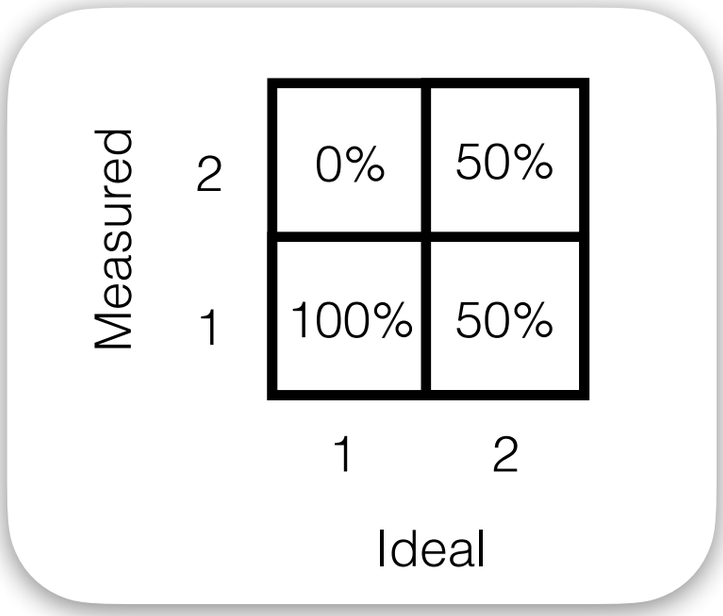

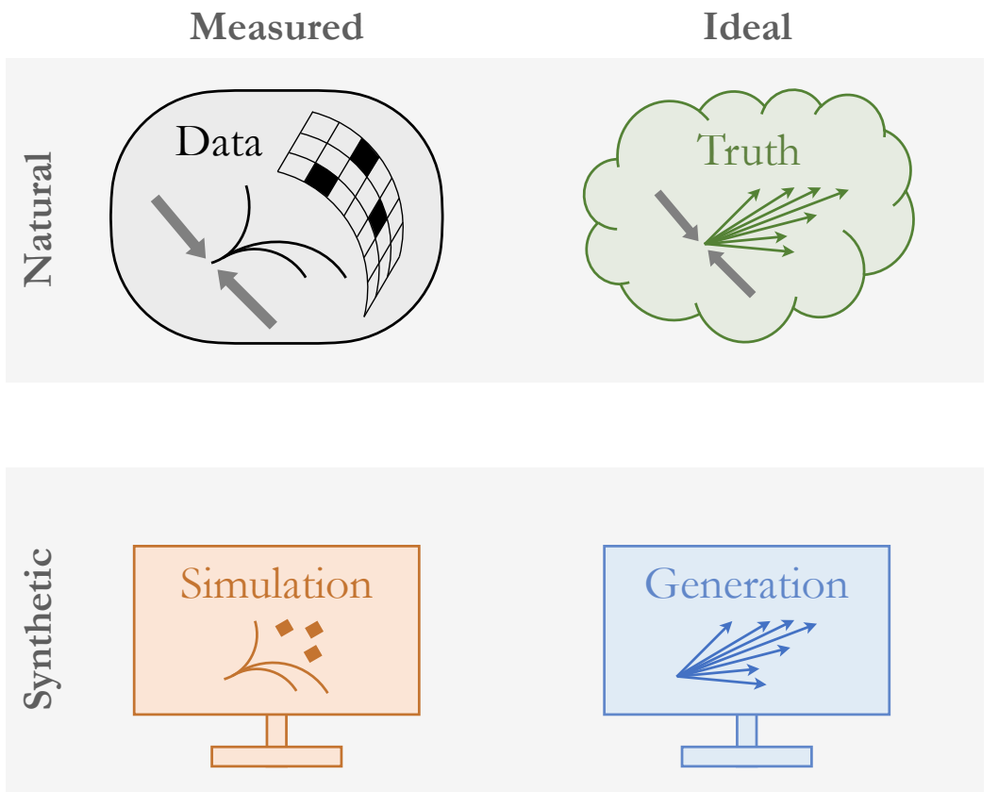

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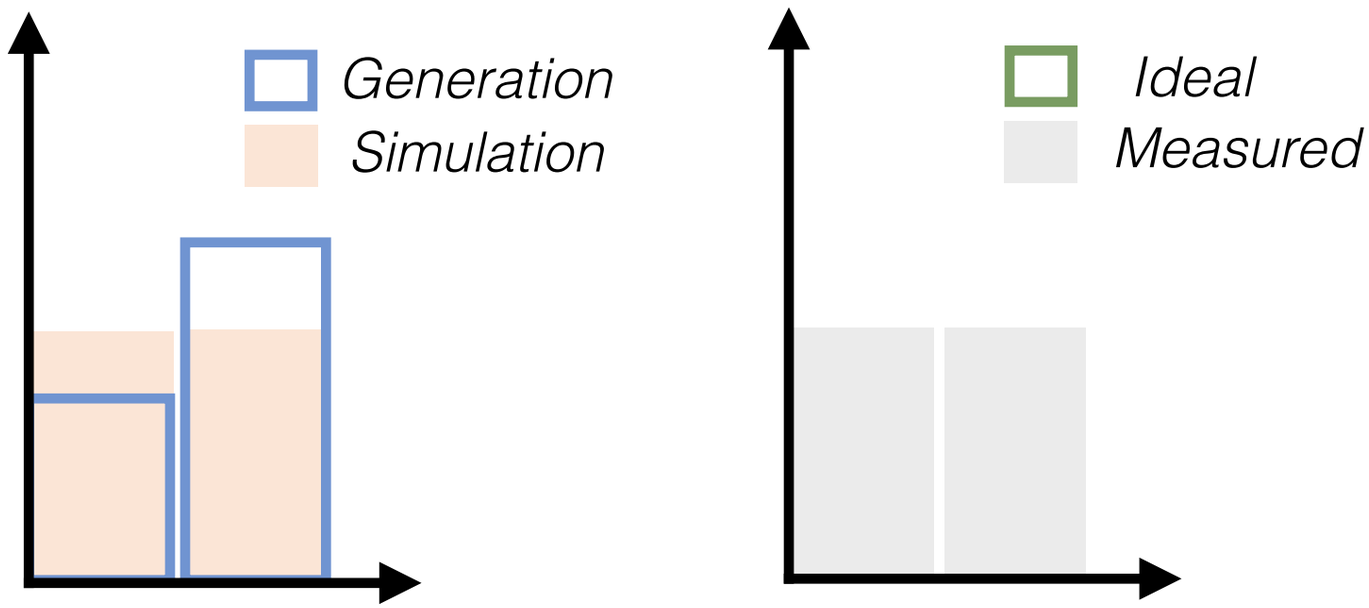
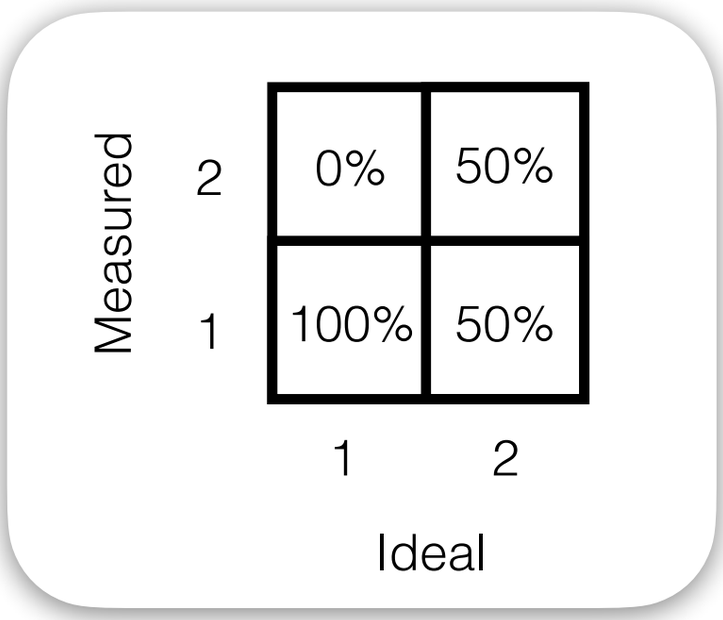
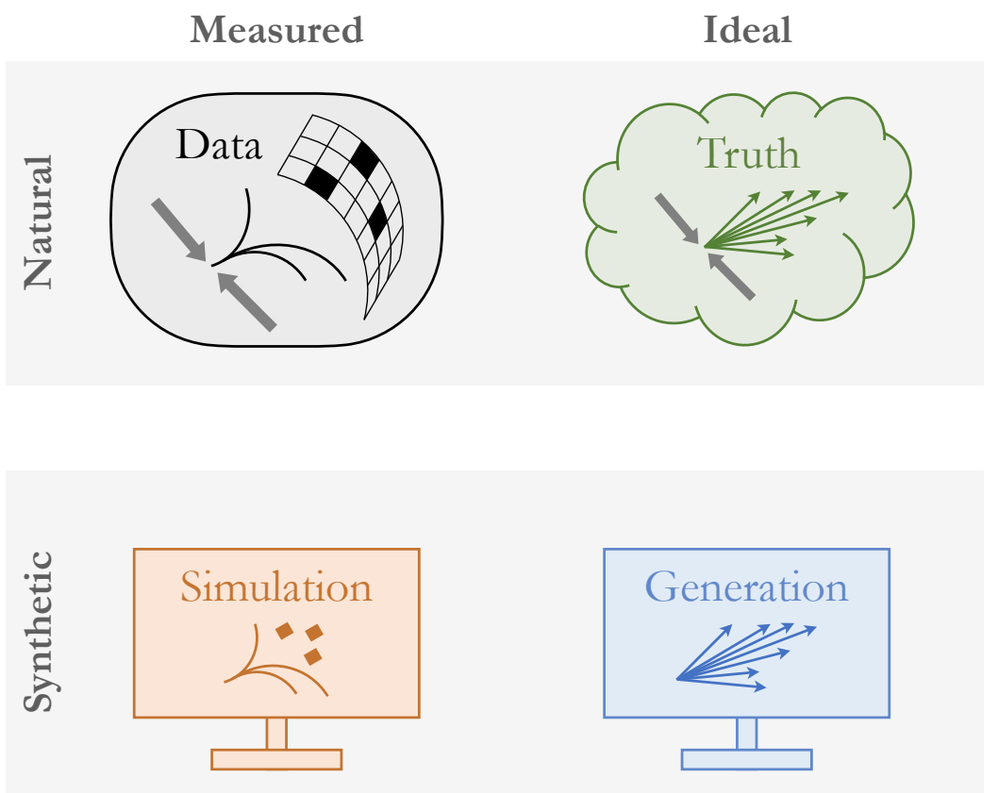
Unfold by iterating: OmniFold

After iteration 1







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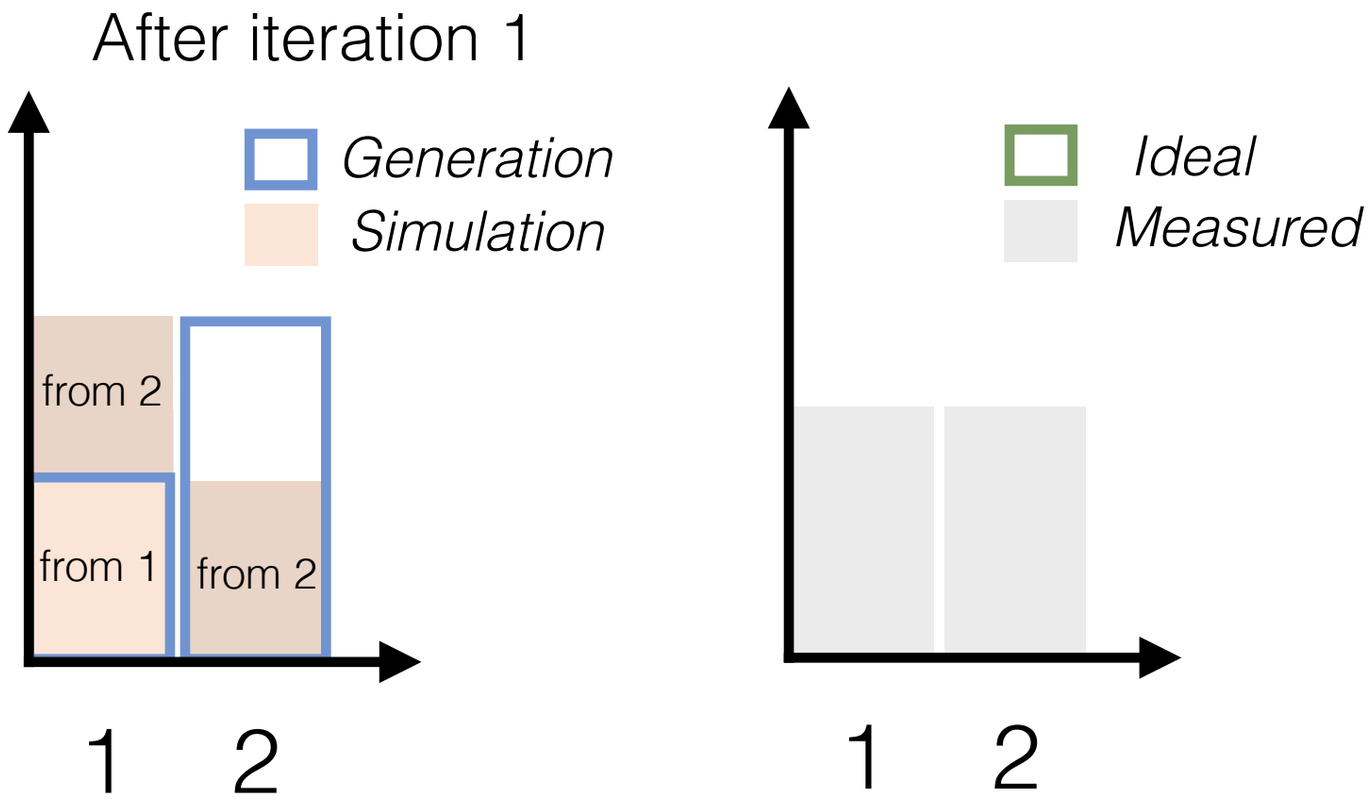
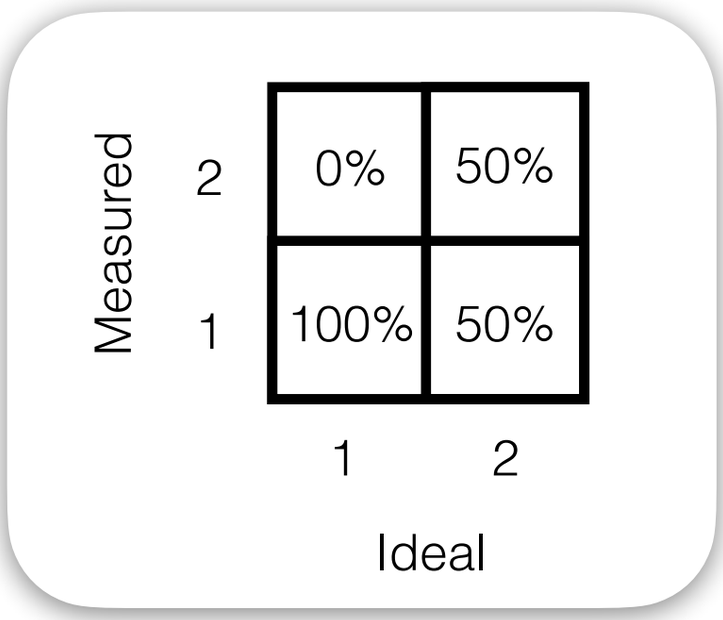
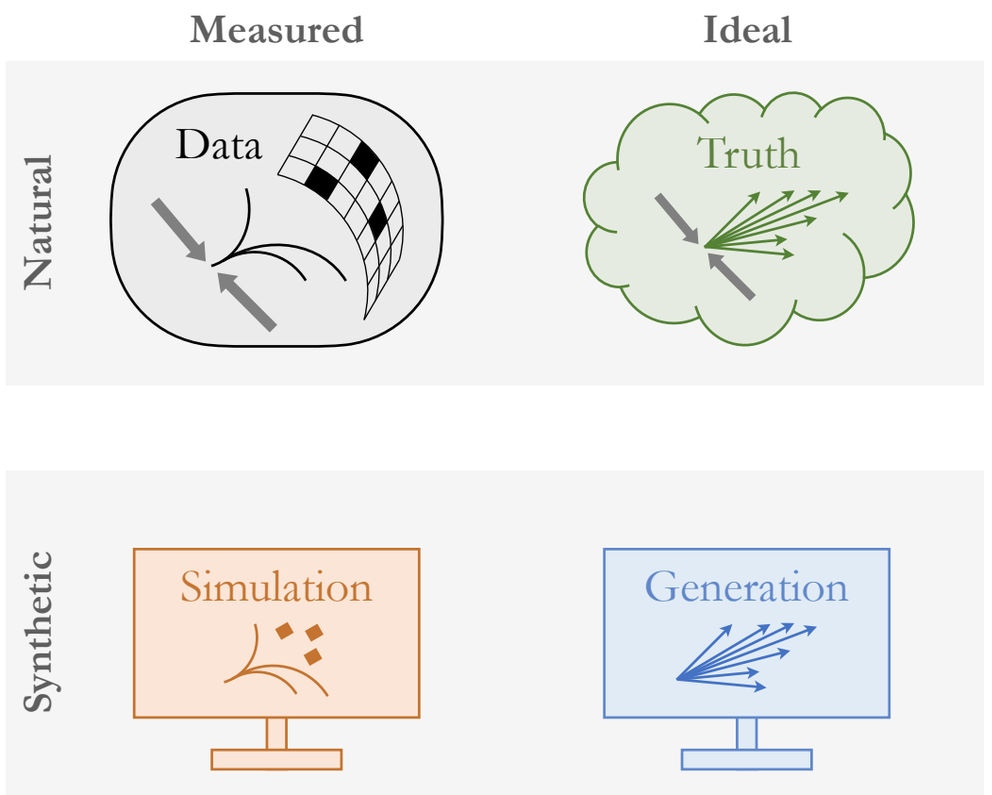
Unfold by iterating: OmniFold







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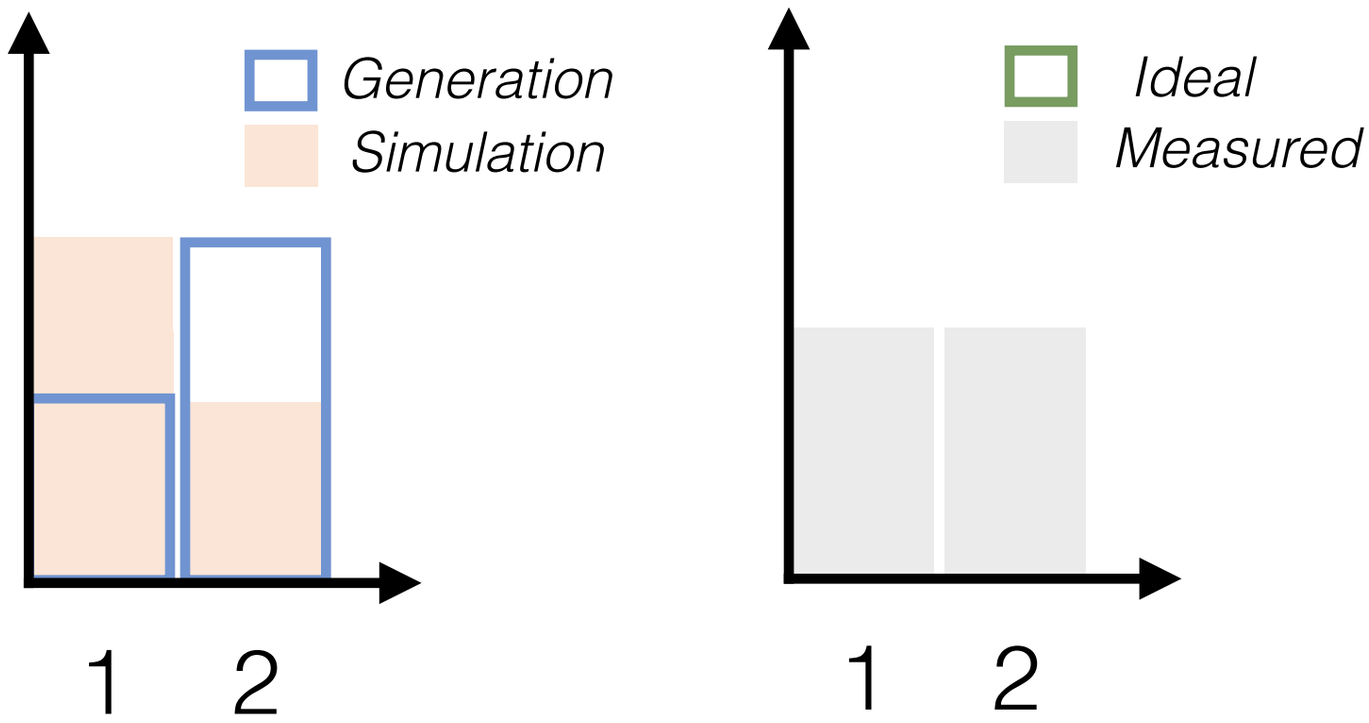
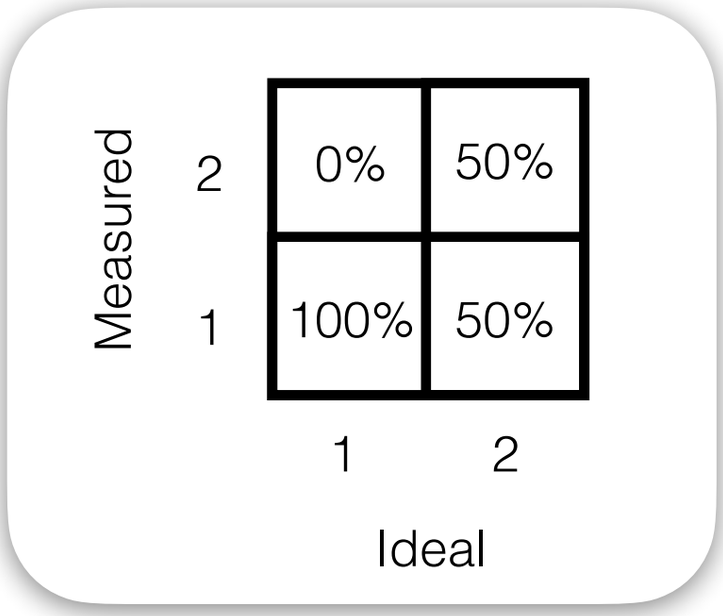
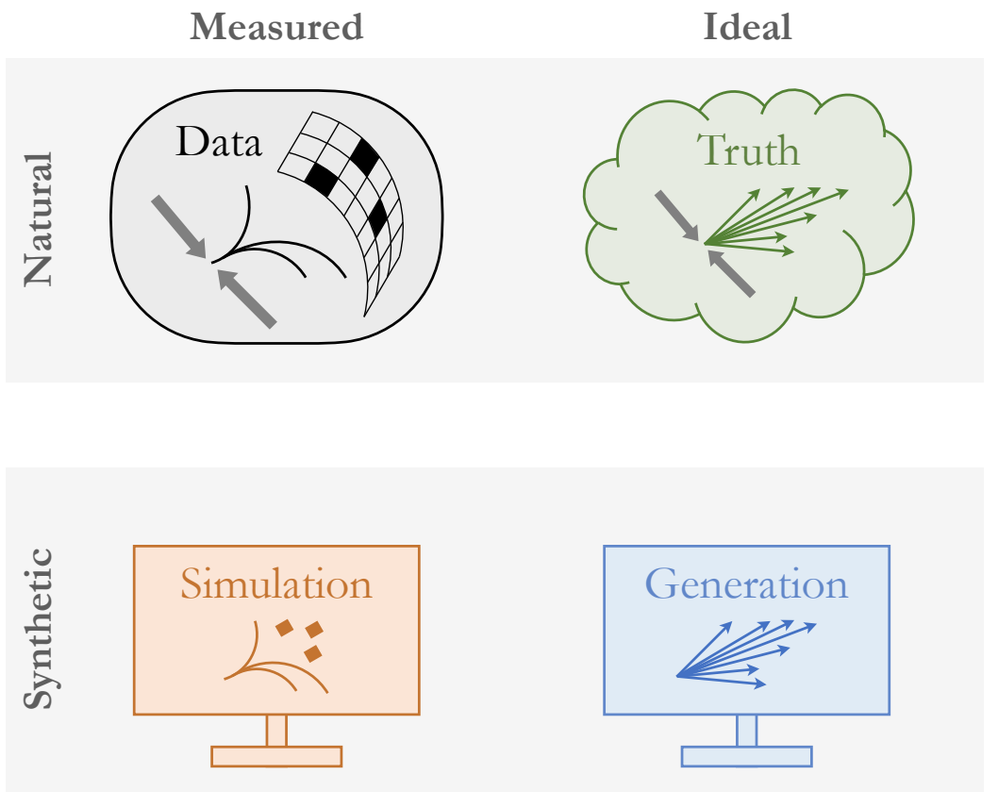
Unfold by iterating: OmniFold

After iteration 1







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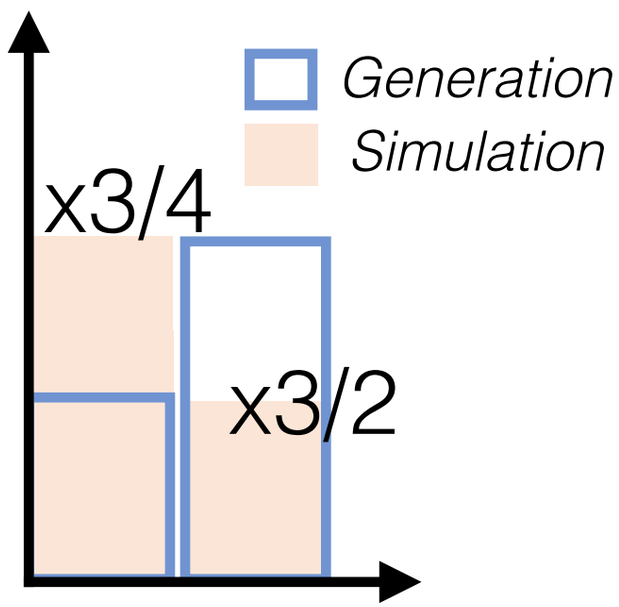
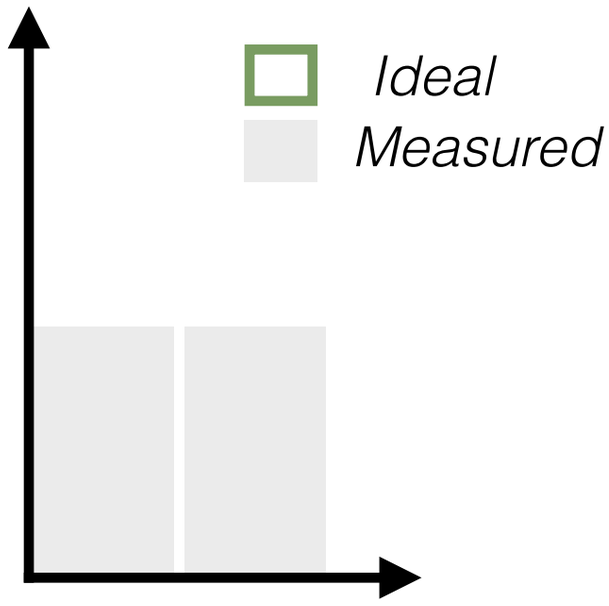
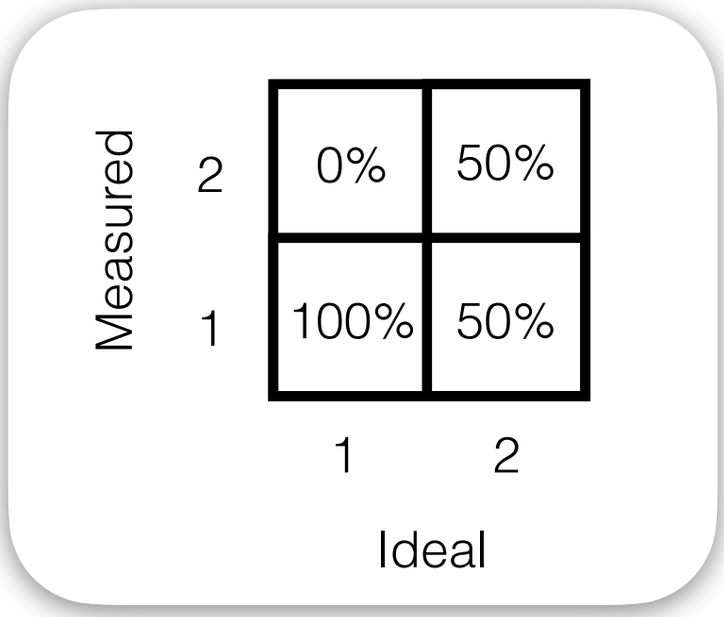
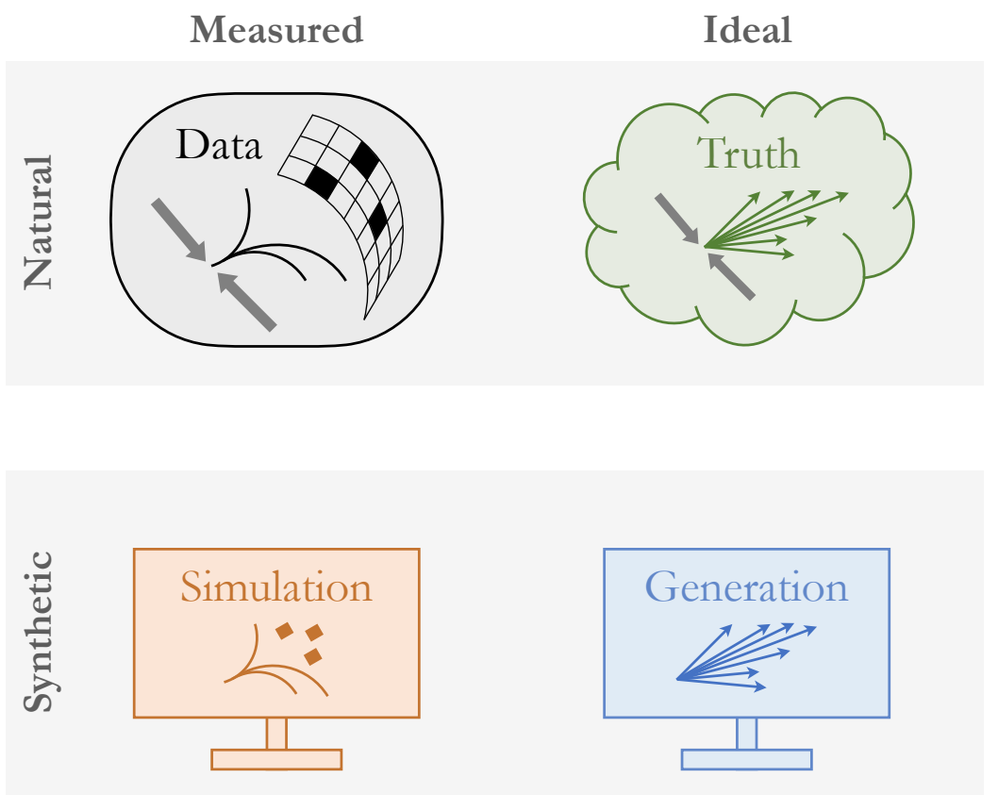
Unfold by iterating: OmniFold

After iteration 1









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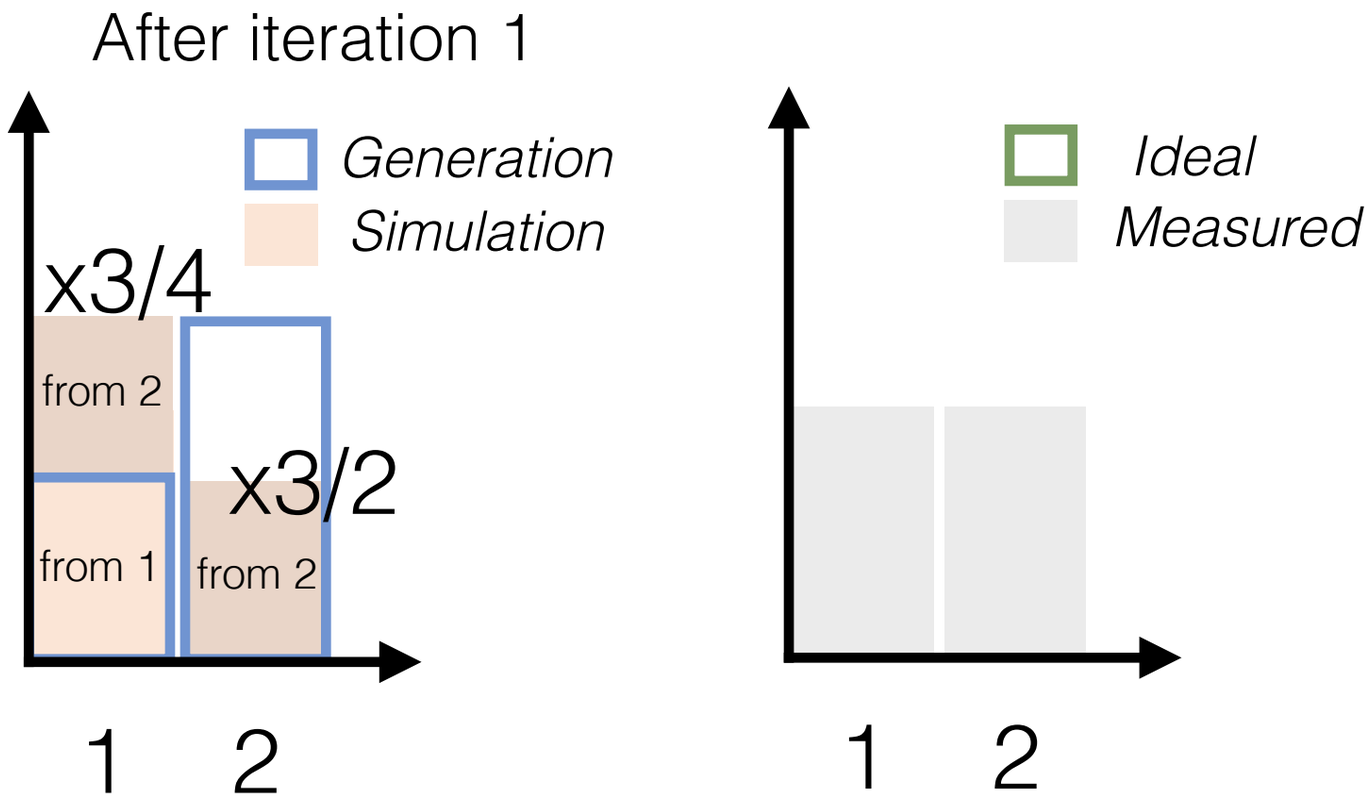

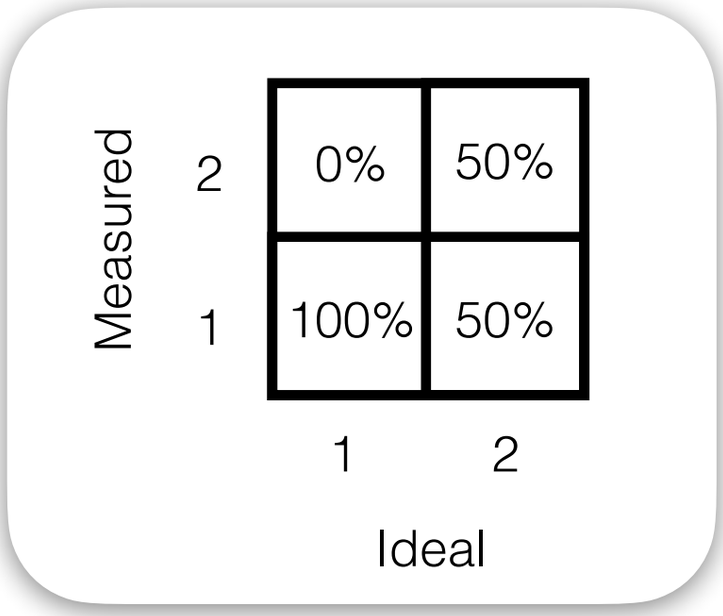

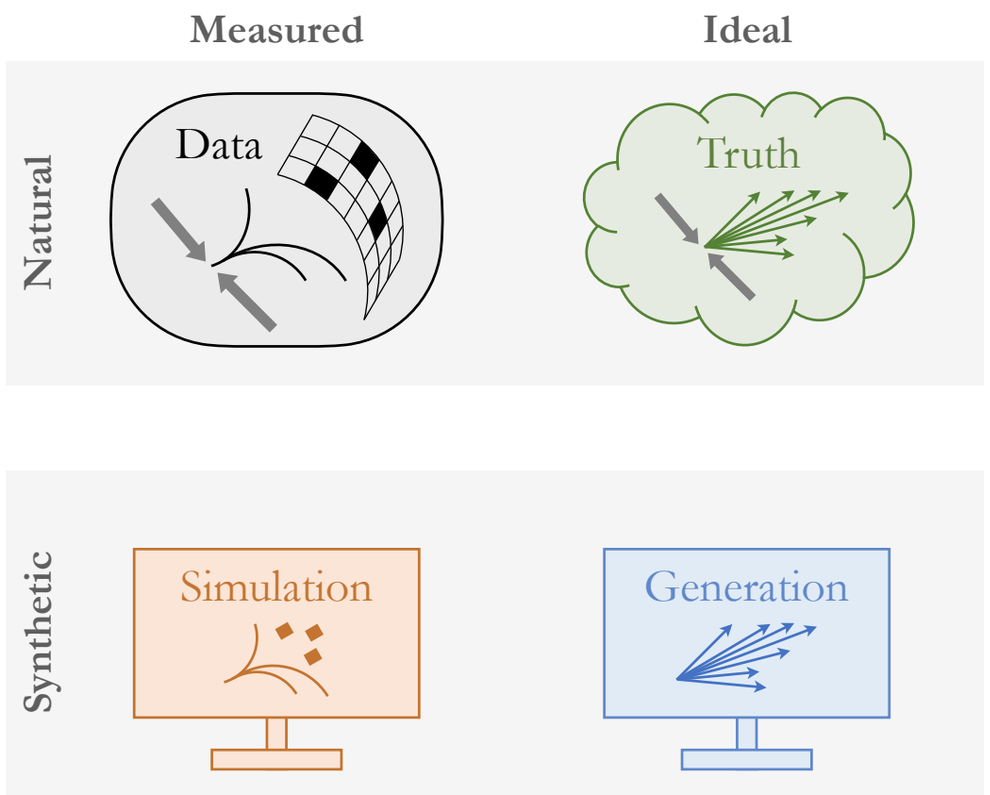

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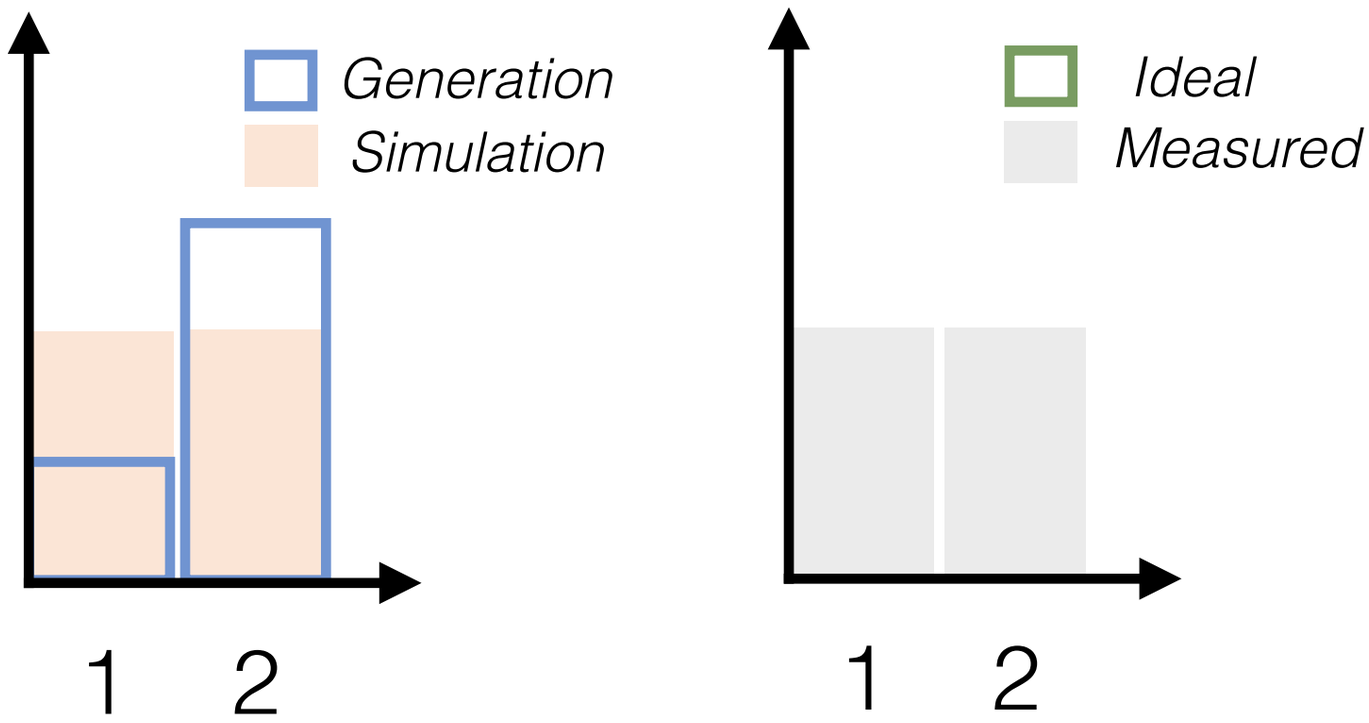
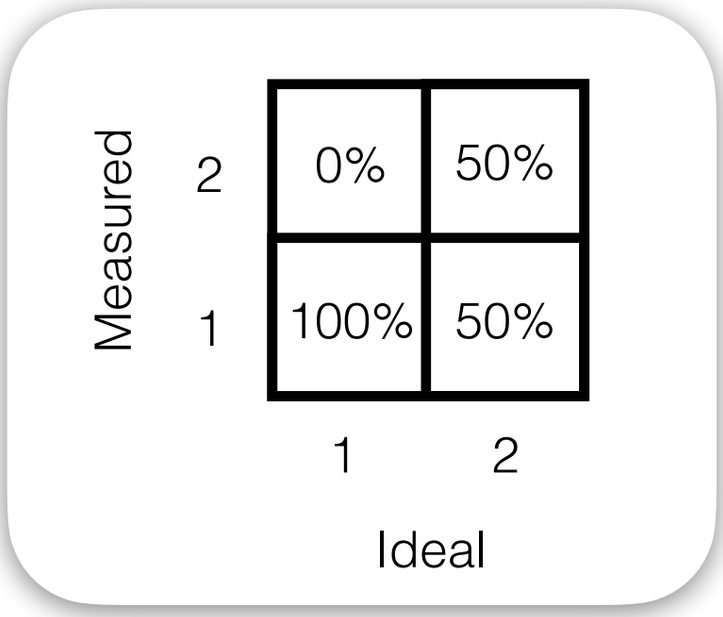
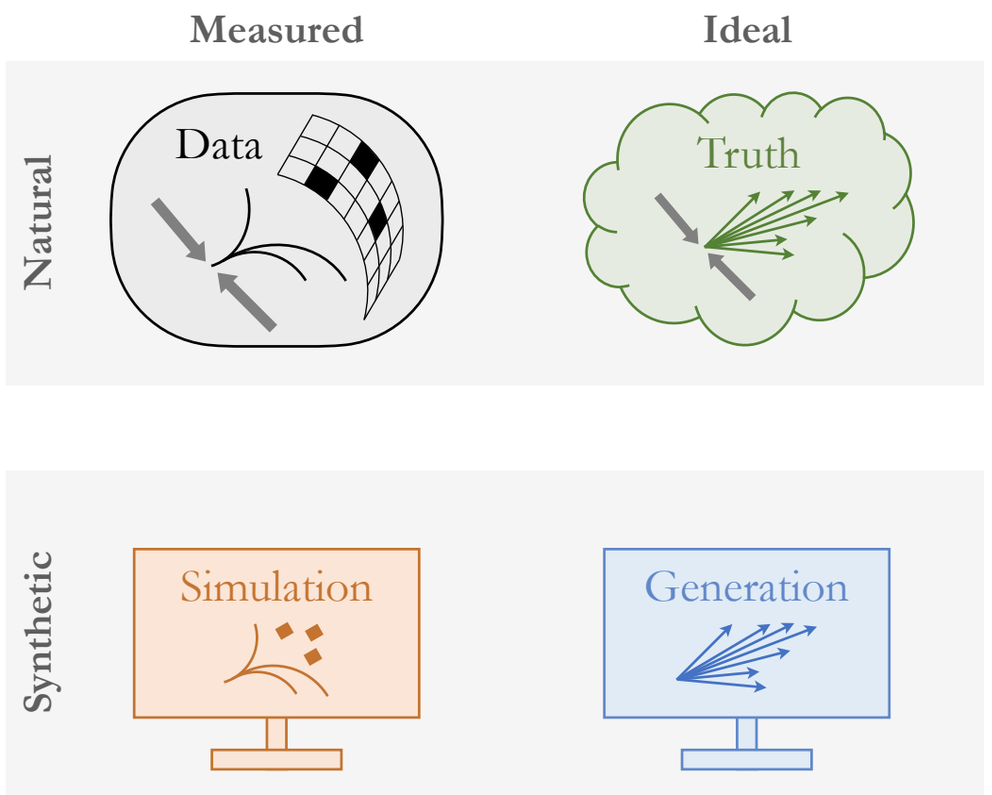
Unfold by iterating: OmniFold

After iteration 2







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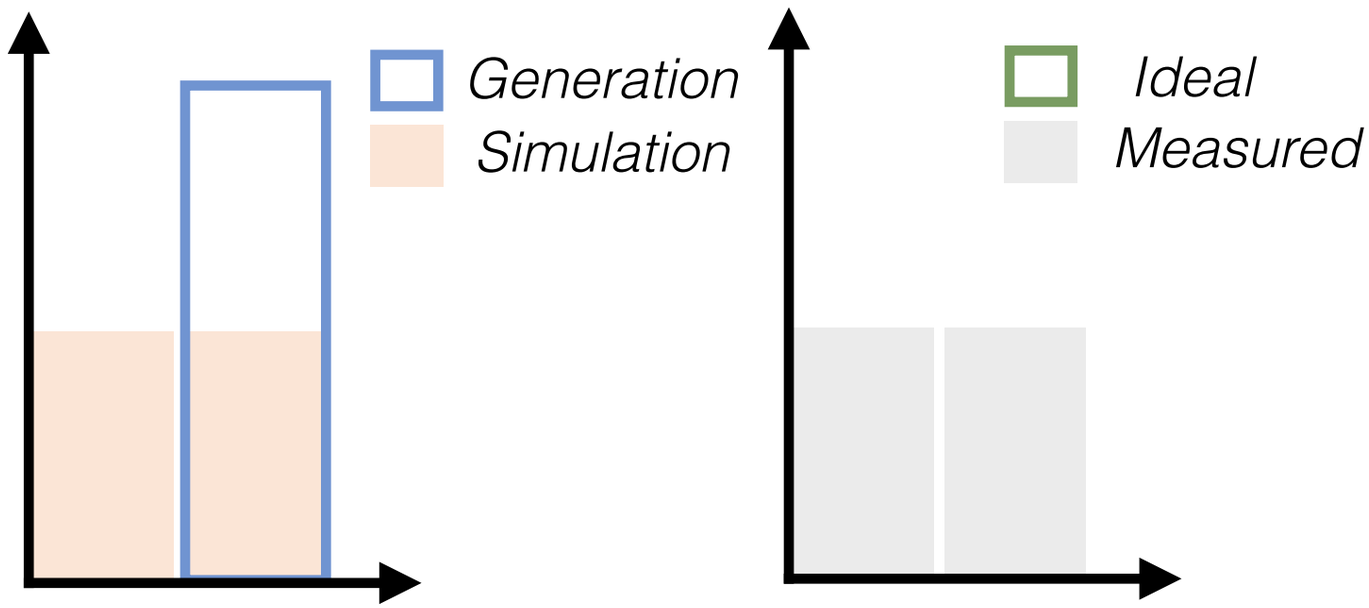
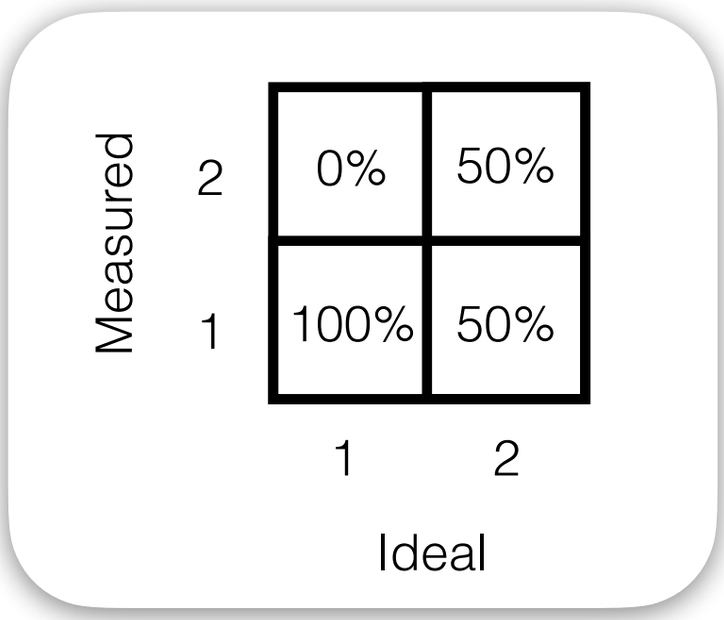
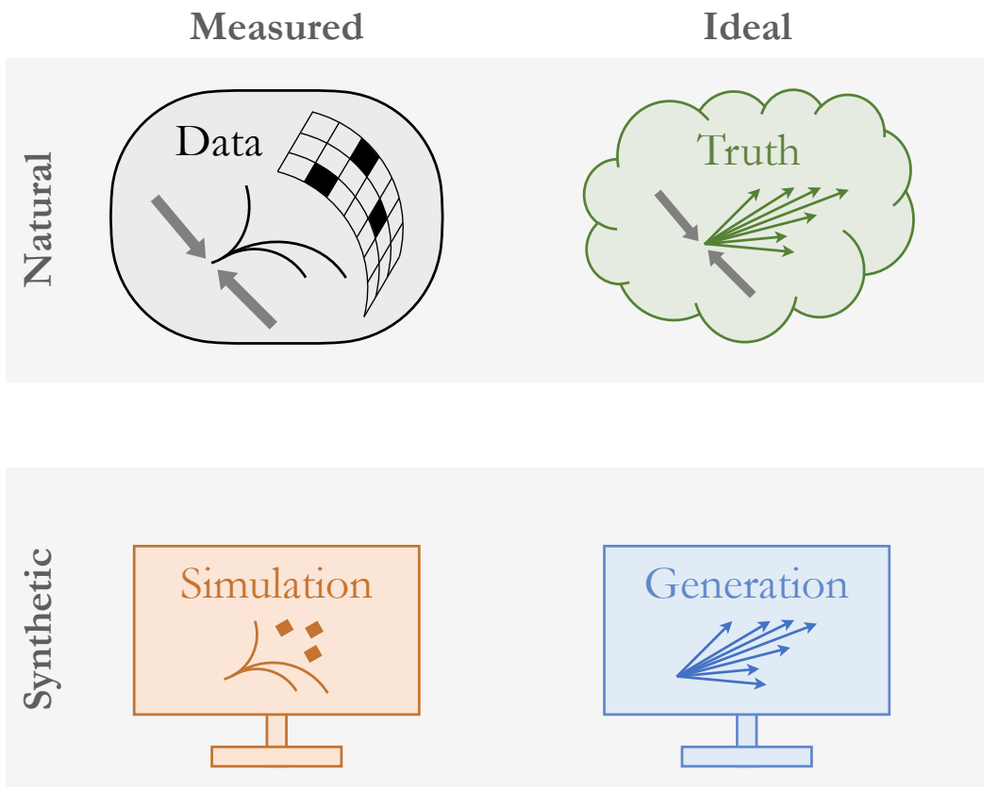
Unfold by iterating: OmniFold

After iteration ∞





N.B. if you just apply p(ideal | measured)*, you would have gotten the wrong answer!*



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