ECCCos from the Black Box

Faithful Model Explanations through Energy-Constrained Conformal Counterfactuals

Patrick Altmeyer Mojtaba Farmanbar Arie van Deursen
Cynthia C. S. Liem

Delft University of Technology

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Pick your Poison

All of these counterfactuals are valid explanations for the model's prediction.

Which one would you pick?

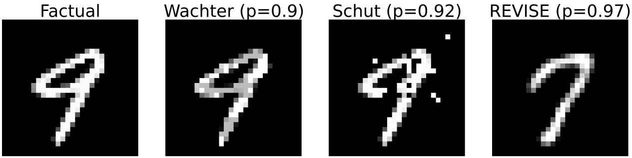

Figure 1: Turning a 9 into a 7: Counterfactual explanations for an image classifier produced using *Wachter* (Wachter, Mittelstadt, and Russell 2017), *Schut* (Schut et al. 2021) and *REVISE* (Joshi et al. 2019).

Faithfulness first, plausibility second.

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We propose *ECCCo*: a new way to generate faithful model explanations that are as plausible as the underlying model permits.

Summary

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- **Method**: constrain the model's energy and predictive uncertainty for the counterfactual.
- **Result**: faithful counterfactuals that are as plausible as the model permits.
- **Benefits**: enable us to distinguish trustworthy from unreliable models.

Counterfactual Explanations

$$\min_{\mathbf{Z}'\in\mathcal{Z}^L}\{\text{yloss}(M_\theta(f(\mathbf{Z}')),\mathbf{y}^+)+\lambda\text{cost}(f(\mathbf{Z}'))\}$$

Counterfactual Explanations (CE) explain how inputs into a model need to change for it to produce different outputs.

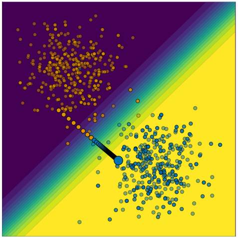

Figure 2: Gradient-based counterfactual search.

Reconciling Faithfulness and Plausibility

Plausibility

Definition (Plausible Counterfactuals)

Let $\mathcal{X}|\mathbf{y}^+ = p(\mathbf{x}|\mathbf{y}^+)$ denote the true conditional distribution of samples in the target class $\mathbf{y}^+$. Then for $\mathbf{x}'$ to be considered a plausible counterfactual, we need: $\mathbf{x}' \sim \mathcal{X}|\mathbf{y}^+$.

Why Plausibility?

Plausibility is positively associated with actionability, robustness (Artelt et al. 2021) and causal validity (Mahajan, Tan, and Sharma 2020).

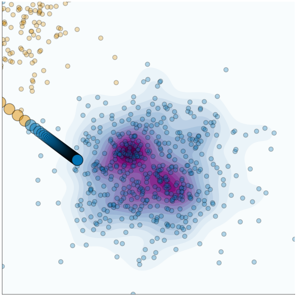

Figure 3: Kernel density estimate (KDE) for the conditional distribution, $p(\mathbf{x}|\mathbf{y}^+)$, based on observed data. Counterfactual path as in Figure 2.

Faithfulness

Definition (Faithful Counterfactuals)

Let $\mathcal{X}_\theta|\mathbf{y}^+ = p_\theta(\mathbf{x}|\mathbf{y}^+)$ denote the conditional distribution of $\mathbf{x}$ in the target class $\mathbf{y}^+$, where θ denotes the parameters of model M_θ. Then for $\mathbf{x}'$ to be considered a faithful counterfactual, we need: $\mathbf{x}' \sim \mathcal{X}_\theta|\mathbf{y}^+$.

Trustworthy Models

If the model posterior approximates the true posterior ($p_\theta(\mathbf{x}|\mathbf{y}^+) \to p(\mathbf{x}|\mathbf{y}^+)$), faithful counterfactuals are also plausible.

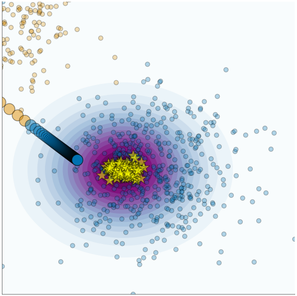

Figure 4: KDE for learned conditional distribution, $p_\theta(\mathbf{x}|\mathbf{y}^+)$. Yellow stars indicate conditional samples generated through SGLD for a joint energy model (JEM).

ECCCo

Key Idea

Use the hybrid objective of joint energy models (JEM) and a model-agnostic penalty for predictive uncertainty: Energy-Constrained ($\mathcal{E}_\theta$) Conformal (Ω) Counterfactuals (*ECCCo*).

ECCCo objective[a]:

$$\min_{\mathbf{Z}' \in \mathcal{Z}^L} \{L_{\text{clf}}(f(\mathbf{Z}'); M_\theta, \mathbf{y}^+) + \lambda_1 \text{cost}(f(\mathbf{Z}')) + \lambda_2 \mathcal{E}_\theta(f(\mathbf{Z}')|\mathbf{y}^+) + \lambda_3 \Omega(C_\theta(f(\mathbf{Z}'); \alpha))\}$$

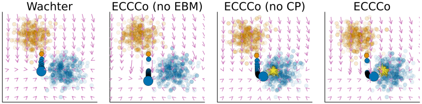

Figure 5: Gradient fields and counterfactual paths for different generators.

[a] We leverage ideas from Grathwohl et al. (2020) and Stutz et al. (2022). See the paper and appendix for a derivation of the objective from first principles.

Results

Visual Evidence

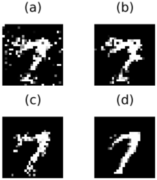

Figure 6: Turning a 9 into a 7. *ECCCo* applied to MLP (a), Ensemble (b), JEM (c), JEM Ensemble (d).

ECCCo generates counterfactuals that

- faithfully represent model quality (Figure 6).
- achieve state-of-the-art plausibility (Figure 7).

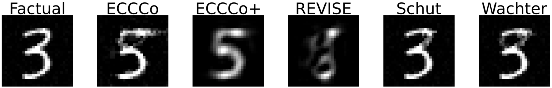

Figure 7: Results for different generators (from 3 to 5).

The Numbers

- Large benchmarks on a variety of models and datasets from various domains.
- *ECCCo* achieves state-of-the-art faithfulness across models and datasets and approaches state-of-the-art plausibility for more trustworthy models.

		California Housing			GMSC		
Model	Generator	Unfaithfulness ↓	Implausibility ↓	Uncertainty ↓	Unfaithfulness ↓	Implausibility ↓	Uncertainty ↓
MLP Ensemble	ECCCo	**3.69 ± 0.08****	1.94 ± 0.13	**0.09 ± 0.01****	3.84 ± 0.07**	2.13 ± 0.08	**0.23 ± 0.01****
	ECCCo+	3.88 ± 0.07**	1.20 ± 0.09	0.15 ± 0.02	**3.79 ± 0.05****	1.81 ± 0.05	0.30 ± 0.01*
	ECCCo (no CP)	3.70 ± 0.08**	1.94 ± 0.13	0.10 ± 0.01**	3.85 ± 0.07**	2.13 ± 0.08	0.23 ± 0.01**
	ECCCo (no EBM)	4.03 ± 0.07	1.12 ± 0.12	0.14 ± 0.01**	4.08 ± 0.06	0.97 ± 0.08	0.31 ± 0.01*
	REVISE	3.96 ± 0.07*	**0.58 ± 0.03****	0.17 ± 0.03	4.09 ± 0.07	**0.63 ± 0.02****	0.33 ± 0.06
	Schut	4.00 ± 0.06	1.15 ± 0.12	0.10 ± 0.01**	4.04 ± 0.08	1.21 ± 0.08	0.30 ± 0.01*
	Wachter	4.04 ± 0.07	1.13 ± 0.12	0.16 ± 0.01	4.10 ± 0.07	0.95 ± 0.08	0.32 ± 0.01
JEM Ensemble	ECCCo	1.40 ± 0.08**	0.69 ± 0.05**	0.11 ± 0.00**	1.20 ± 0.06*	0.78 ± 0.07**	0.38 ± 0.01
	ECCCo+	**1.28 ± 0.08****	0.60 ± 0.04**	0.11 ± 0.00**	**1.01 ± 0.07****	0.70 ± 0.07**	0.37 ± 0.01
	ECCCo (no CP)	1.39 ± 0.08**	0.69 ± 0.05**	0.11 ± 0.00**	1.21 ± 0.07*	0.77 ± 0.07**	0.39 ± 0.01
	ECCCo (no EBM)	1.70 ± 0.09	0.99 ± 0.08	0.14 ± 0.00*	1.31 ± 0.07	0.97 ± 0.10	0.32 ± 0.01**
	REVISE	1.39 ± 0.15**	**0.59 ± 0.04****	0.25 ± 0.07	1.01 ± 0.07**	**0.63 ± 0.04****	0.33 ± 0.07
	Schut	1.59 ± 0.10*	1.10 ± 0.06	**0.09 ± 0.00****	1.34 ± 0.07	1.21 ± 0.10	**0.26 ± 0.01****
	Wachter	1.71 ± 0.09	0.99 ± 0.08	0.14 ± 0.00	1.31 ± 0.08	0.95 ± 0.10	0.33 ± 0.01

Table 1: Results for tabular datasets: sample averages +/- one standard deviation across valid counterfactuals. The best outcomes are highlighted in bold. Asterisks indicate that the given value is more than one (*) or two (**) standard deviations away from the baseline (*Wachter*).

Questions?

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With thanks to my co-authors Mojtaba Farmanbar, Arie van Deursen and Cynthia C. S. Liem.

Code

The code used to run the analysis for this work is built on top of `CounterfactualExplanations.jl`.

There is also a corresponding paper, *Explaining Black-Box Models through Counterfactuals*, which has been published in JuliaCon Proceedings.

Figure 8: Trustworthy AI in Julia: github.com/JuliaTrustworthyAI

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