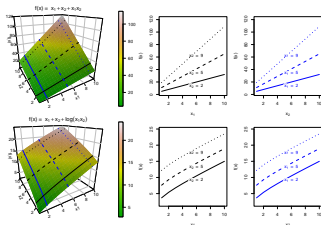


Interpretable Machine Learning

Feature Interactions



Learning goals

- Feature interactions
- Difference to feature dependencies

FEATURE INTERACTIONS

- Feature dependencies concern data distribution
- Feature interactions may occur in structure of **both** model or DGP (e.g., functional relationship between X and $\hat{f}(X)$ or X and $Y = f(X)$)
 \rightsquigarrow Feature dependencies may lead to feature interactions in a model



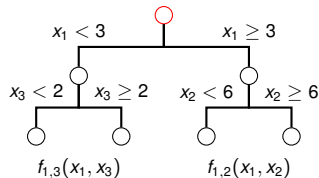
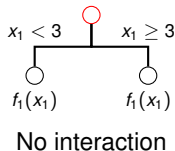
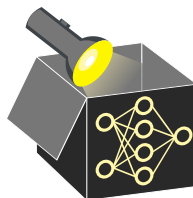
FEATURE INTERACTIONS

- Feature dependencies concern data distribution
- Feature interactions may occur in structure of **both** model or DGP (e.g., functional relationship between X and $\hat{f}(X)$ or X and $Y = f(X)$)
 - ↪ Feature dependencies may lead to feature interactions in a model
- No. of potential interactions increases exponentially with no. of features
 - ↪ Difficult to identify interactions, especially when features are dependent



FEATURE INTERACTIONS

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 - ↪ Feature dependencies may lead to feature interactions in a model
- No. of potential interactions increases exponentially with no. of features
 - ↪ Difficult to identify interactions, especially when features are dependent
- Interactions: A feature's effect on the prediction depends on other features
 - ↪ Example: $\hat{f}(\mathbf{x}) = x_1 x_2 \Rightarrow$ Effect of x_1 on \hat{f} depends on x_2 and vice versa



Interactions: x_1 and x_3 ,
 x_1 and x_2

No interactions: x_2 and x_3

FEATURE INTERACTIONS

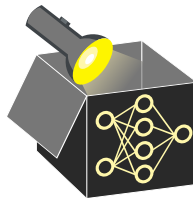
► Friedman and Popescu (2008)

Definition: A function $f(\mathbf{x})$ contains an interaction between x_j and x_k if a difference in $f(\mathbf{x})$ -values due to changes in x_j will also depend on x_k , i.e.:

$$\mathbb{E} \left[\frac{\partial^2 f(\mathbf{x})}{\partial x_j \partial x_k} \right]^2 > 0$$

⇒ If x_j and x_k do not interact, $f(\mathbf{x})$ is sum of 2 functions, each independent of x_j , x_k :

$$f(\mathbf{x}) = f_{-j}(x_1, \dots, x_{j-1}, x_{j+1}, \dots, x_p) + f_{-k}(x_1, \dots, x_{k-1}, x_{k+1}, \dots, x_p)$$

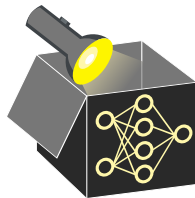


FEATURE INTERACTIONS

Example: $f(\mathbf{x}) = x_1 + x_2 + x_1 \cdot x_2$ (not separable)

$$\mathbb{E} \left[\frac{\partial^2 (x_1 + x_2 + x_1 \cdot x_2)}{\partial x_1 \partial x_2} \right]^2 = \mathbb{E} \left[\frac{\partial (1 + x_2)}{\partial x_2} \right]^2 = 1 > 0$$

\Rightarrow interaction between x_1 and x_2

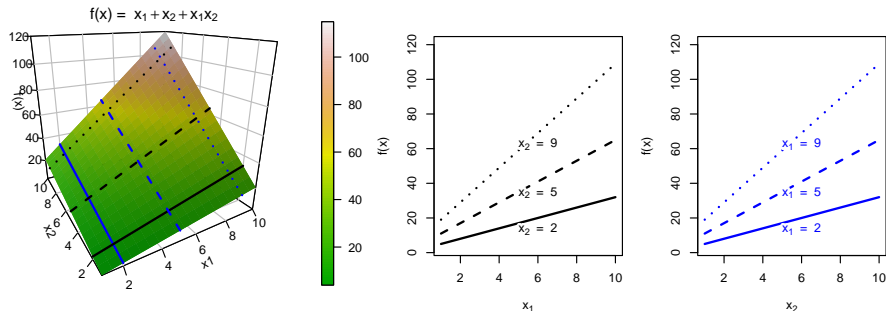


FEATURE INTERACTIONS

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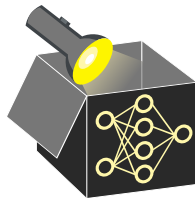
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⇒ interaction between x_1 and x_2



- Effect of x_1 on $f(\mathbf{x})$ varies with x_2 (and vice versa)

⇒ Different slopes



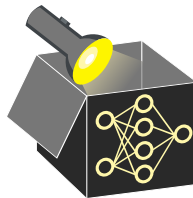
FEATURE INTERACTIONS

Example of separable function:

$$f(\mathbf{x}) = x_1 + x_2 + \log(x_1 \cdot x_2) = x_1 + x_2 + \log(x_1) + \log(x_2)$$

$$\Rightarrow f(\mathbf{x}) = f_1(x_1) + f_2(x_2) \text{ with } f_1(x_1) = x_1 + \log(x_1) \text{ and } f_2(x_2) = x_2 + \log(x_2)$$

$$\Rightarrow \text{no interactions due to separability, also } \mathbb{E} \left[\frac{\partial^2 f(\mathbf{x})}{\partial x_1 \partial x_2} \right]^2 = 0$$



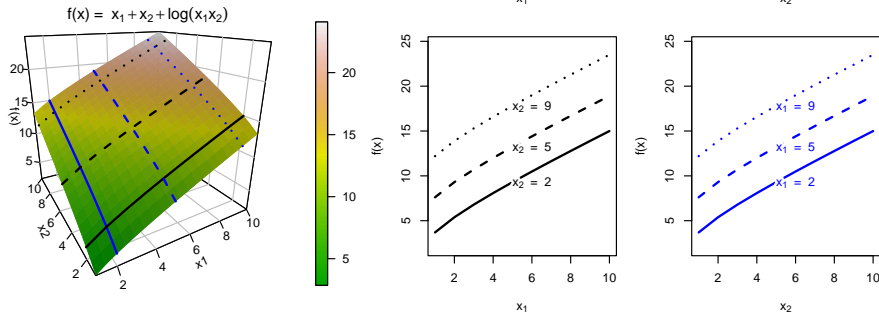
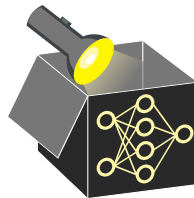
FEATURE INTERACTIONS

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- Effect of x_1 on $f(\mathbf{x})$ stays the same for different x_2 values (and vice versa)

\Rightarrow Parallel lines at different horizontal (blue) or vertical (black) slices