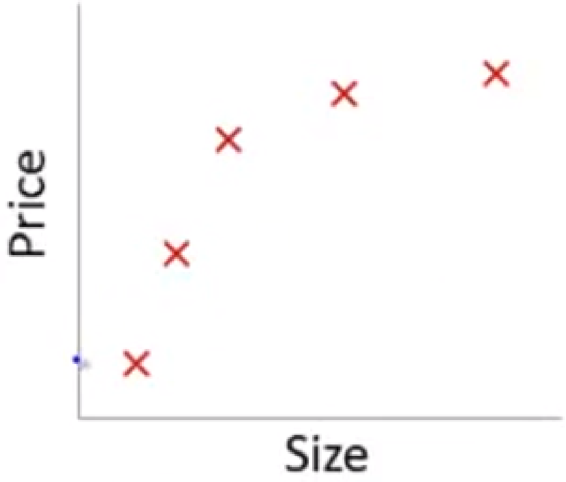
The Problem of Overfitting

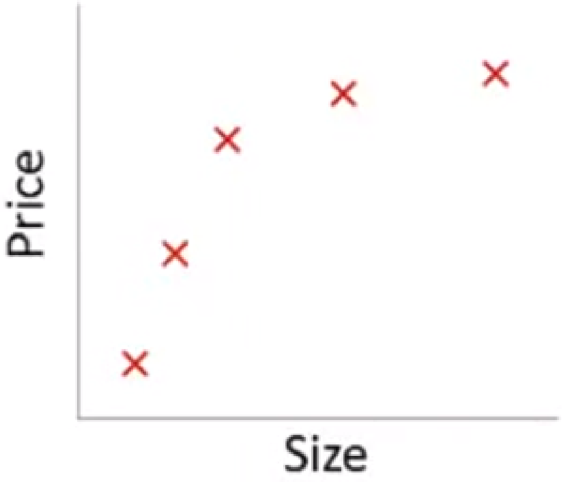
Solving the Problem of Overfitting

Regularization

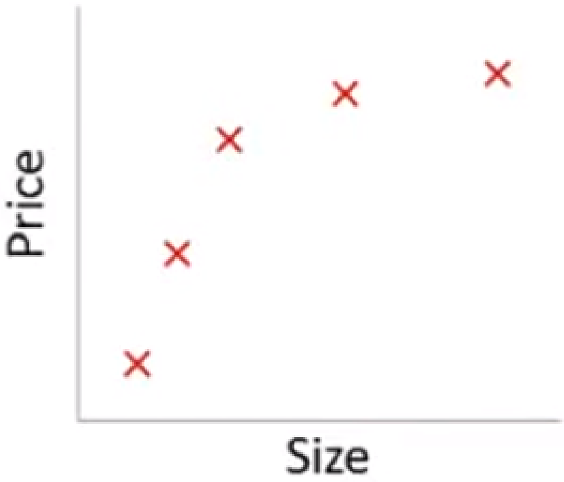
Example: Linear regression (housing prices)



$\theta_0 + \theta_1 x$



$\theta_0 + \theta_1 x + \theta_2 x^2$



$\theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$

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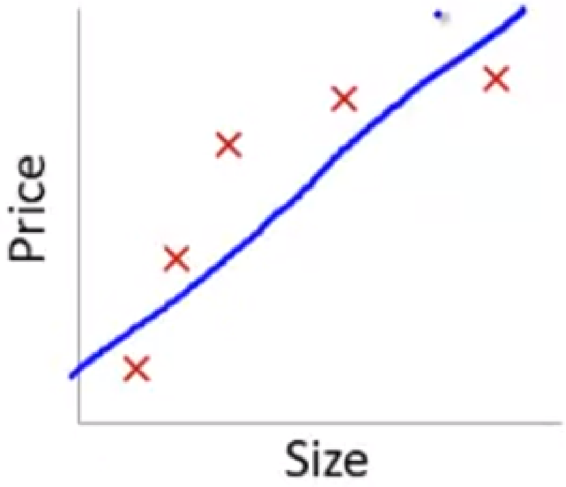

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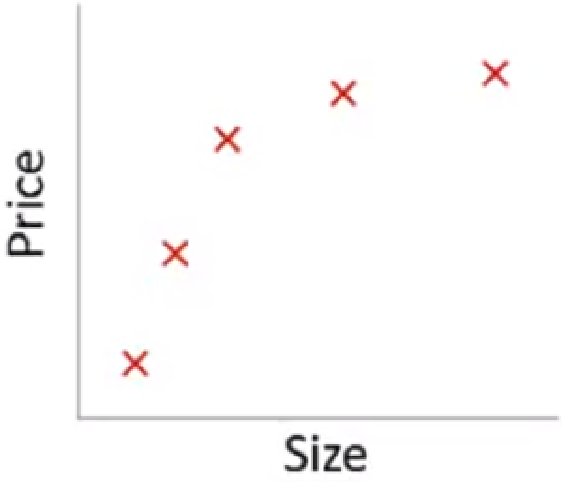
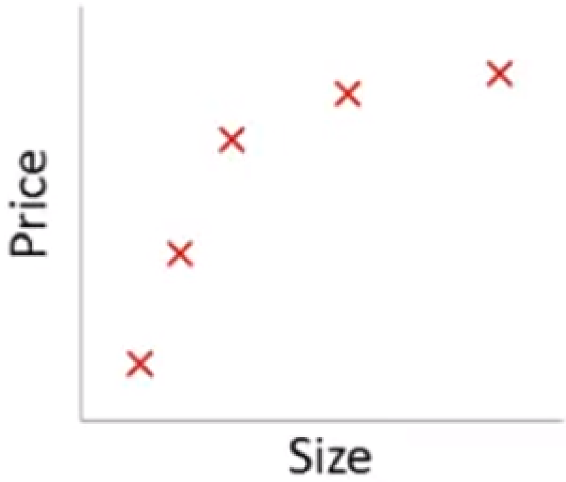


$\theta_0 + \theta_1 x + \theta_2 x^2$



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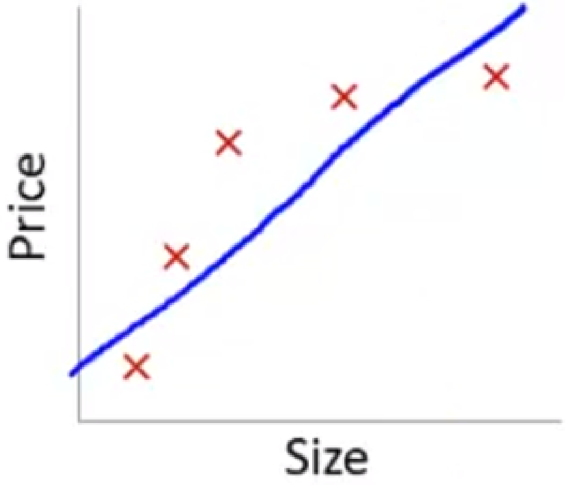
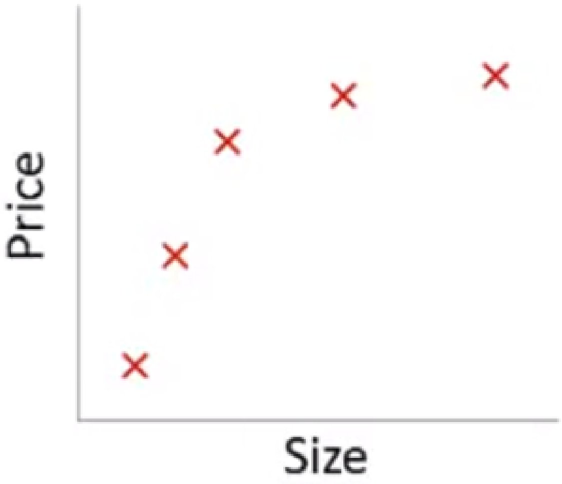
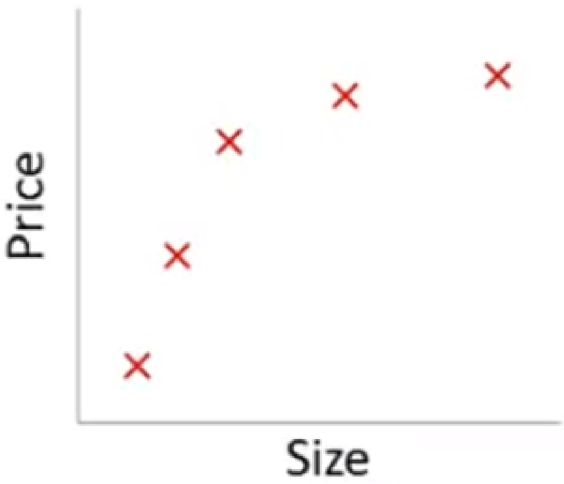


$\theta_0 + \theta_1 x$

"Underfit" "High bias"



$\theta_0 + \theta_1 x + \theta_2 x^2$



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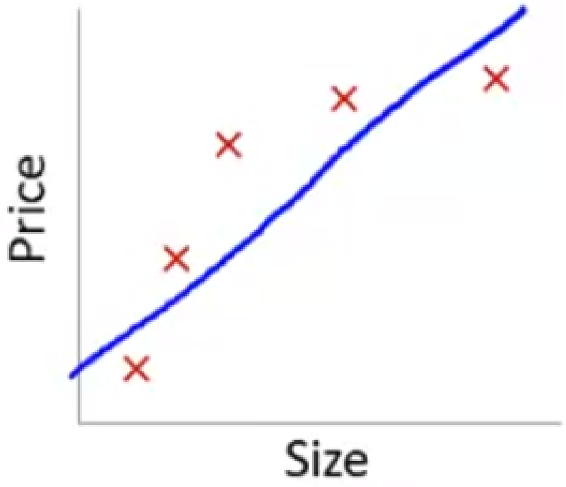
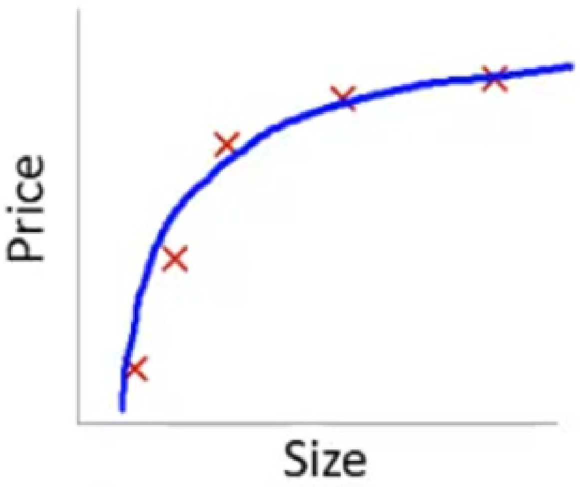
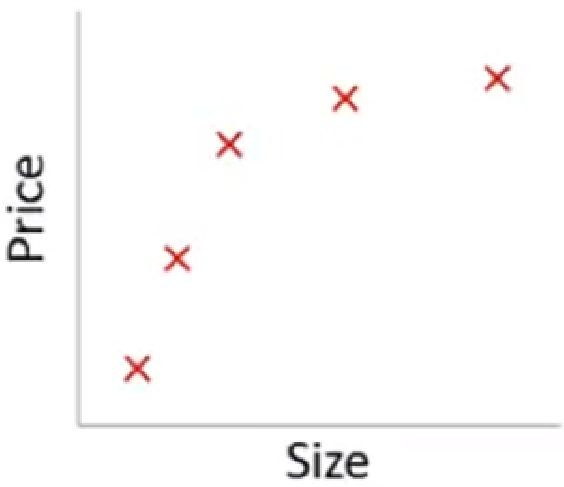
Example: Linear regression (housing prices)







$\rightarrow \theta_0 + \theta_1 x$

"Underfit" "High bias"

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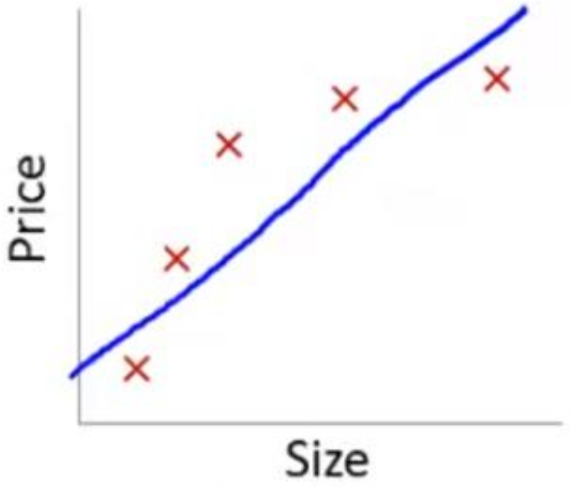

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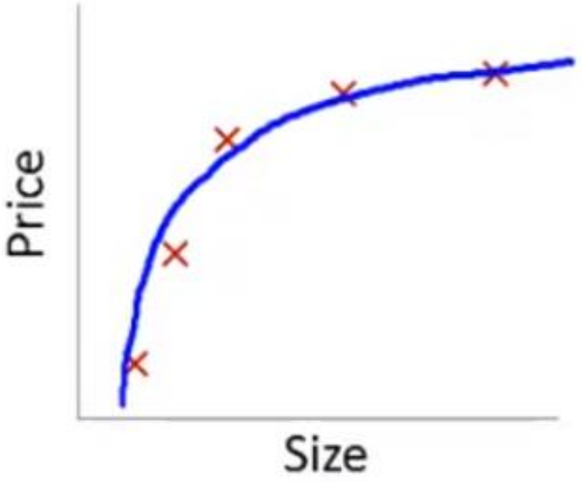
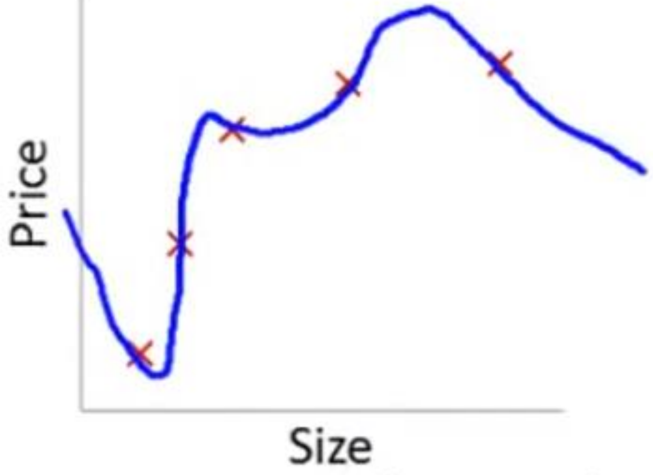
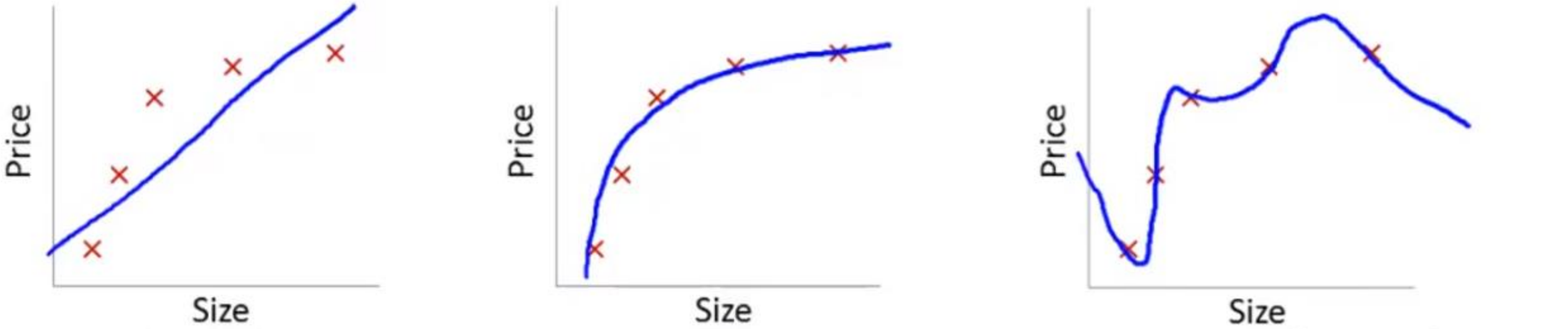


$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2$



$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$

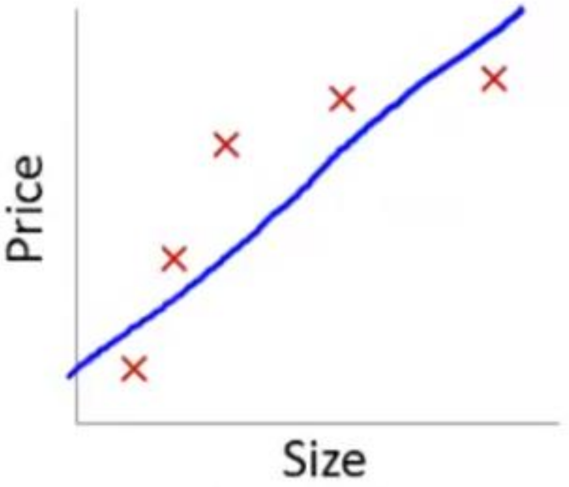
Example: Linear regression (housing prices)



$\rightarrow \theta_0 + \theta_1 x$ $\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2$ $\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$

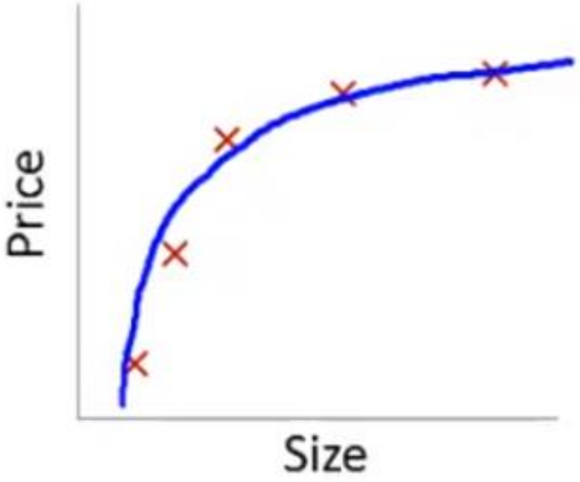
"Underfit" "High bias" "Overfit" "High variance"

Example: Linear regression (housing prices)



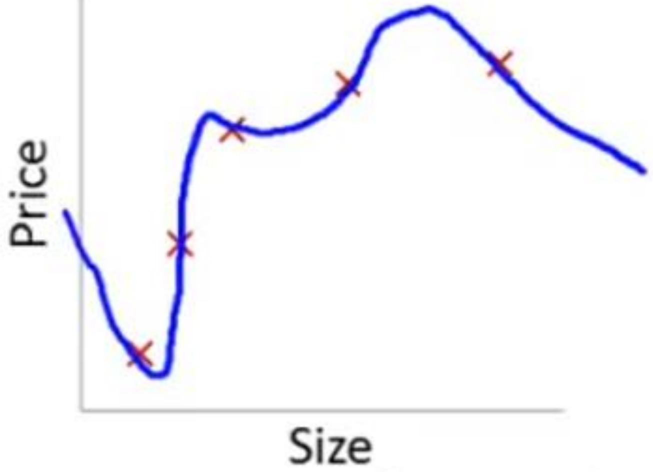
$\rightarrow \theta_0 + \theta_1 x$

"Underfit" "High bias"



$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2$

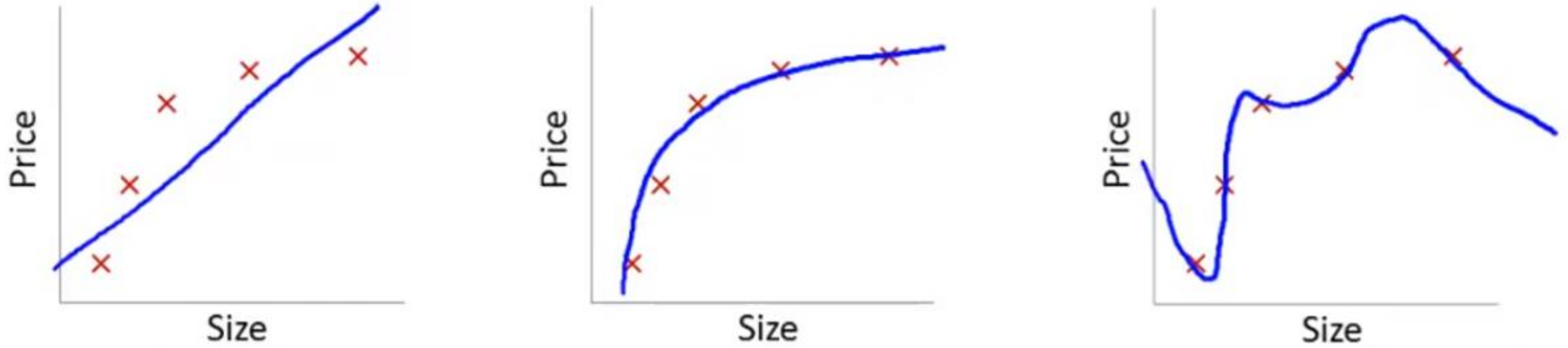
"Just right"



$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$

"Overfit" "High variance"

Example: Linear regression (housing prices)



$\rightarrow \theta_0 + \theta_1 x$ "Underfit" "High bias"

$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2$ "Just right"

$\rightarrow \theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$ "Overfit" "High variance"

Overfitting: If we have too many features, the learned hypothesis may fit the training set very well ($J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^{(i)}) - y^{(i)})^2 \approx 0$), but fail to generalize to new examples (predict prices on new examples).

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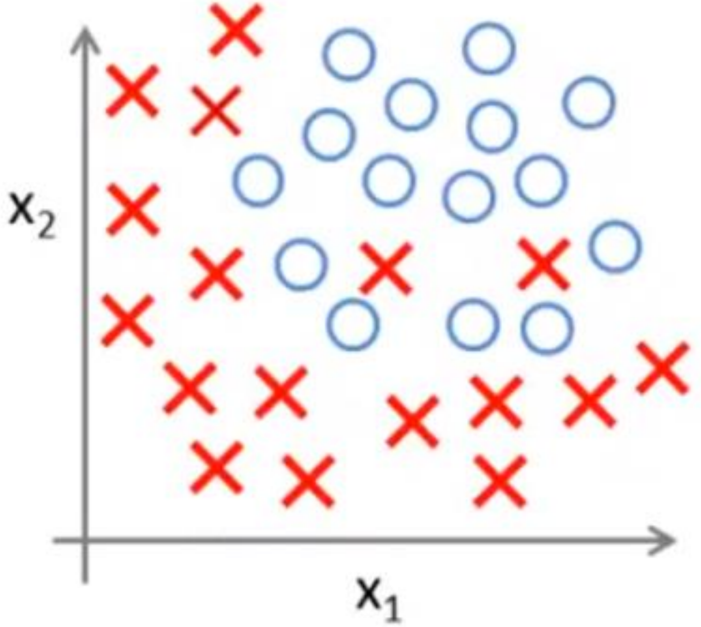
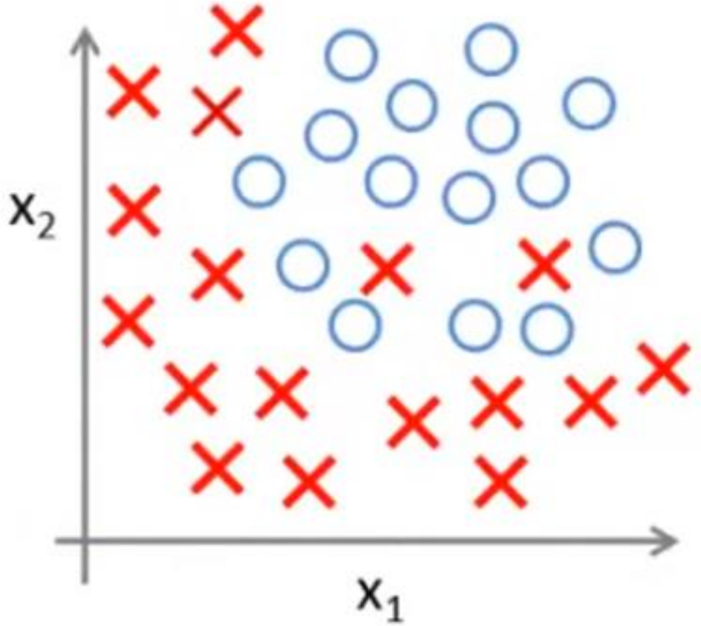
Example: Logistic regression

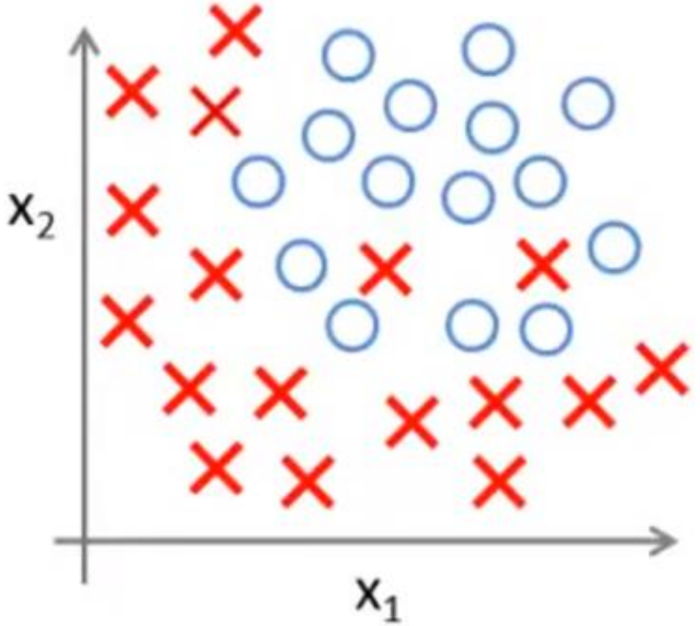


$$h_\theta(x) = g(\theta_0 + \theta_1 x_1 + \theta_2 x_2)$$

(g = sigmoid function)



$$g(\theta_0 + \theta_1 x_1 + \theta_2 x_2 \\ + \theta_3 x_1^2 + \theta_4 x_2^2 \\ + \theta_5 x_1 x_2)$$



$$g(\theta_0 + \theta_1 x_1 + \theta_2 x_1^2 \\ + \theta_3 x_1^2 x_2 + \theta_4 x_1^2 x_2^2 \\ + \theta_5 x_1^2 x_2^3 + \theta_6 x_1^3 x_2 + \dots)$$

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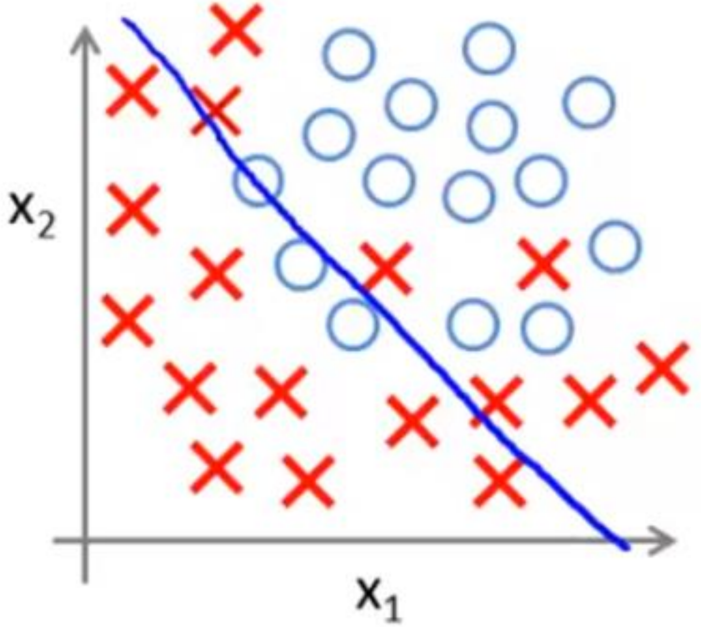
Example: Logistic regression



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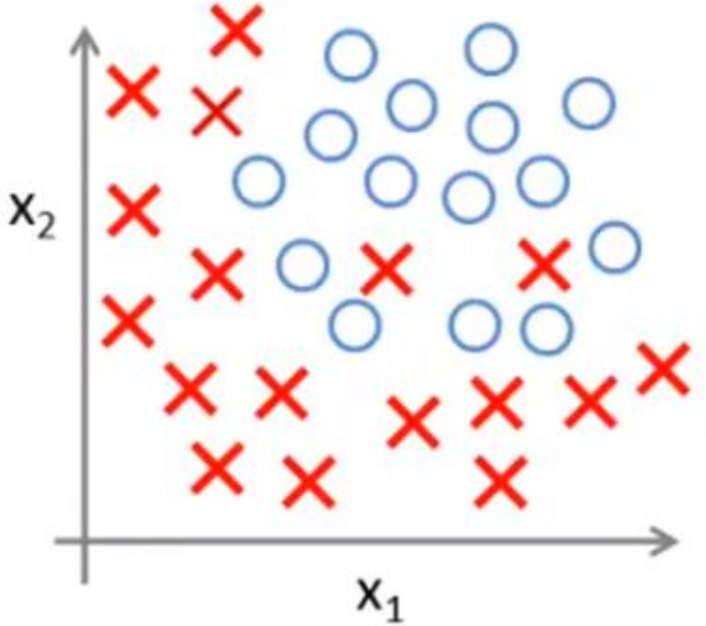
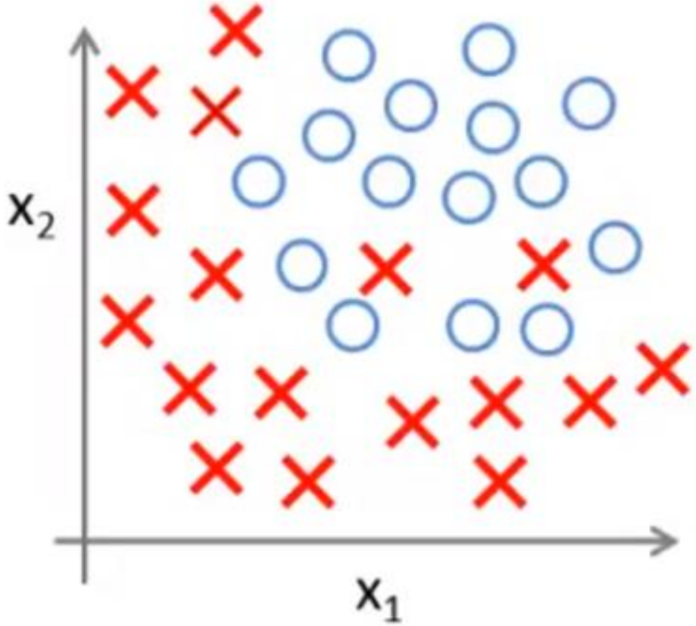


$$g(\theta_0 + \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_1^2 + \theta_4 x_2^2 + \theta_5 x_1 x_2)$$



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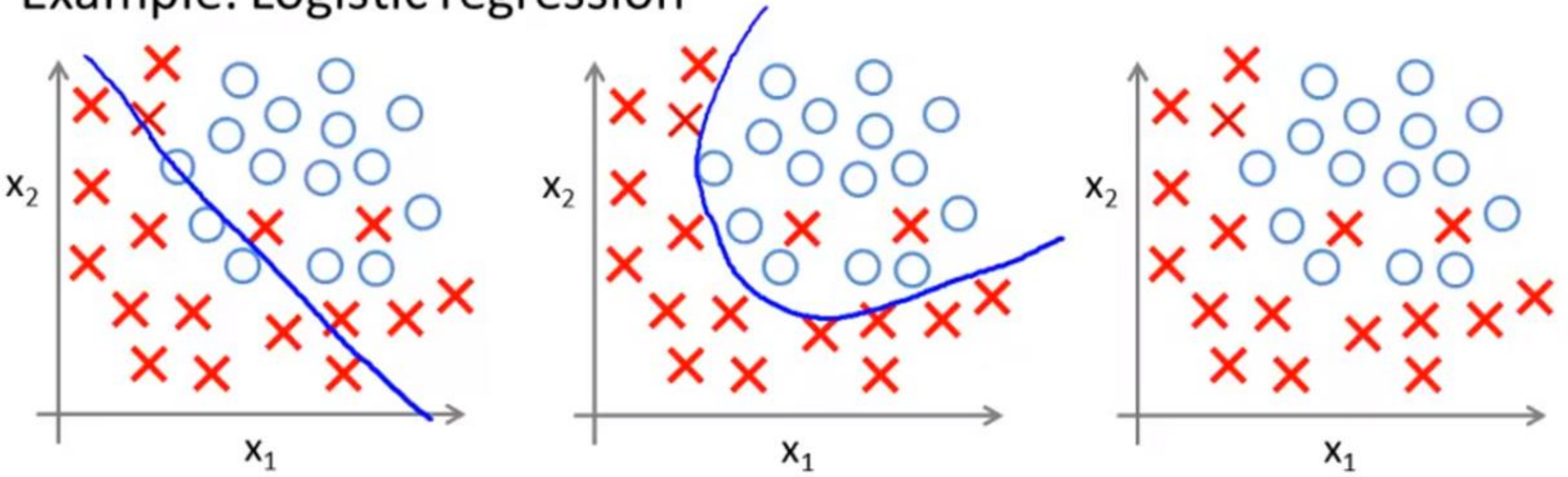
Example: Logistic regression



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"Underfit"

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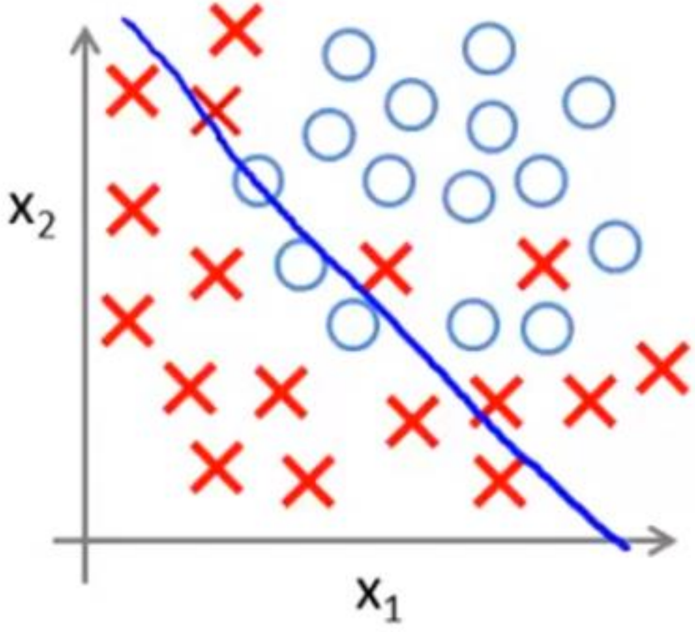
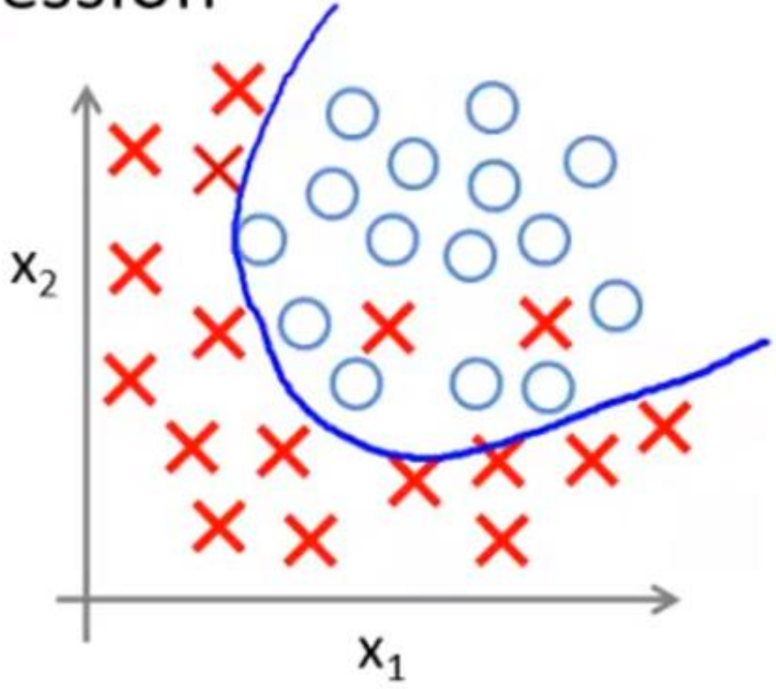
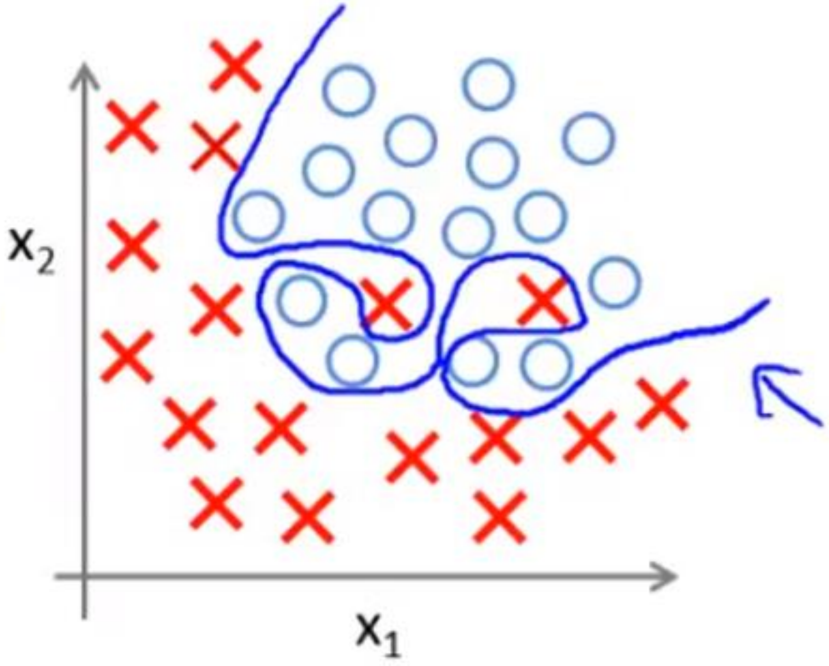
$+\theta_5 x_1^2 x_2^3 + \theta_6 x_1^3 x_2 + \ldots)$

Example: Logistic regression







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"Underfit"

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"Overfit"

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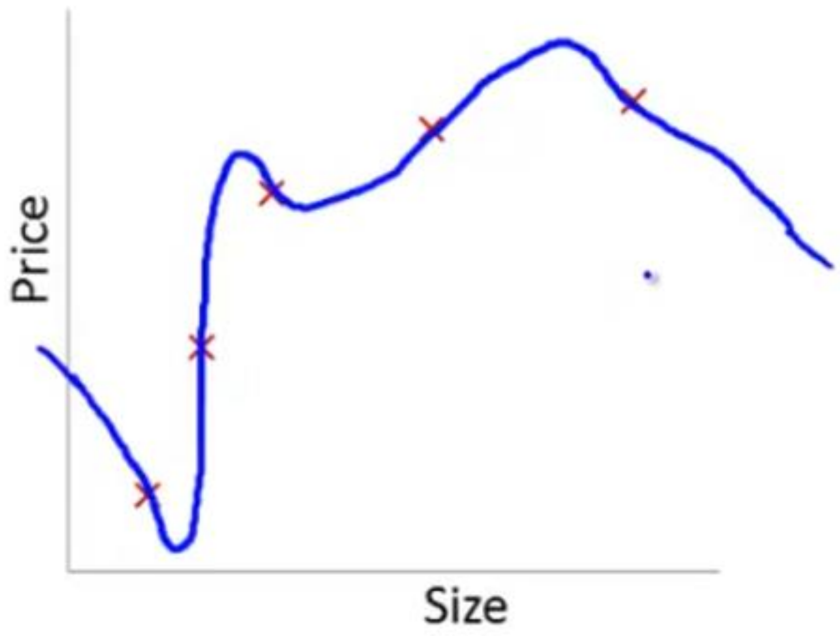
Exercise

- Consider the medical diagnosis problem of classifying tumors as malignant or benign. If a hypothesis $h(x)$has overfit the training set, it means that:
  - It makes accurate predictions for examples in the training set and generalizes well to make accurate predictions on new, previously unseen examples.
  - It does not make accurate predictions for examples in the training set, but it does generalize well to make accurate predictions on new, previously unseen examples.
  - It makes accurate predictions for examples in the training set, but it does not generalize well to make accurate predictions on new, previously unseen examples.
  - It does not make accurate predictions for examples in the training set and does not generalize well to make accurate predictions on new, previously unseen examples.

Addressing overfitting:

$$x_1 = \text{ size of house}$$
$$x_2 = \text{ no. of bedrooms}$$
$$x_3 = \text{ no. of floors}$$
$$x_4 = \text{ age of house}$$
$$x_5 = \text{ average income in neighborhood}$$
$$x_6 = \text{ kitchen size}$$
$$\vdots$$
$$x_{100}$$



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Addressing overfitting:

Options:

1. Reduce number of features.
   - Manually select which features to keep.
   - Model selection algorithm (later in course).

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1. Reduce number of features.
   - Manually select which features to keep.
   - Model selection algorithm (later in course).
2. Regularization.
   - Keep all the features, but reduce magnitude/values of parameters θ_j.
   - Works well when we have a lot of features, each of which contributes a bit to predicting y.