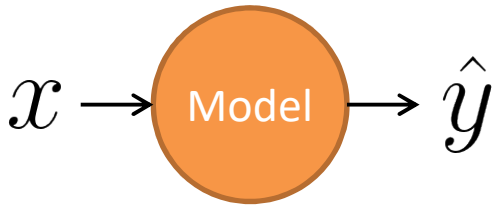
Computer Vision with Embedded Machine Learning

Review of Neural Networks

Supervised Learning

Training data:

$$(x_0, y_0)$$
$$(x_1, y_1)$$
$$(x_2, y_2)$$
$$\vdots$$



Inference: using the trained machine learning model to make predictions with new, unseen data

Goal:

$$f(x_n) = \hat{y_n}$$

where

$$\hat{y_n} = y_n$$

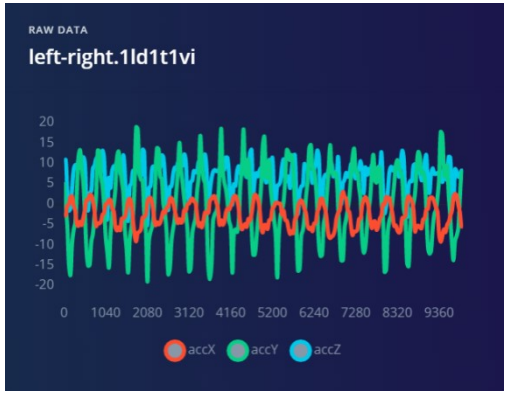
Features

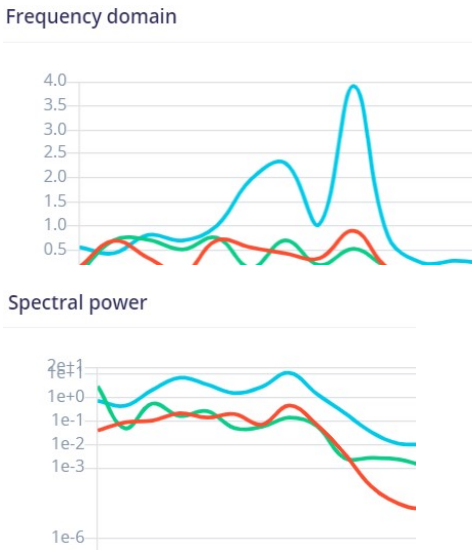
Feature: individual measurable property or characteristic of a phenomenon

Single 3-axis accelerometer measurement

$$x_{0_x} = -1.02\ [m/s^2]$$
$$x_{0_y} = 5.19\ [m/s^2]$$
$$x_{0_z} = 9.81\ [m/s^2]$$

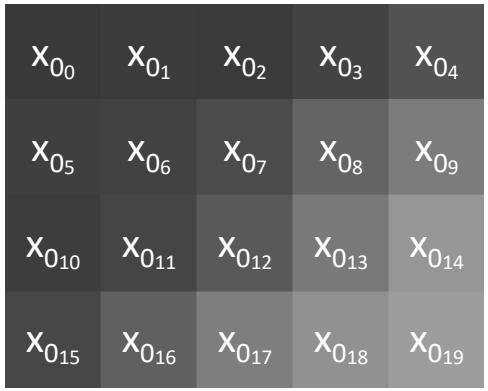
Accelerometer measurements over time





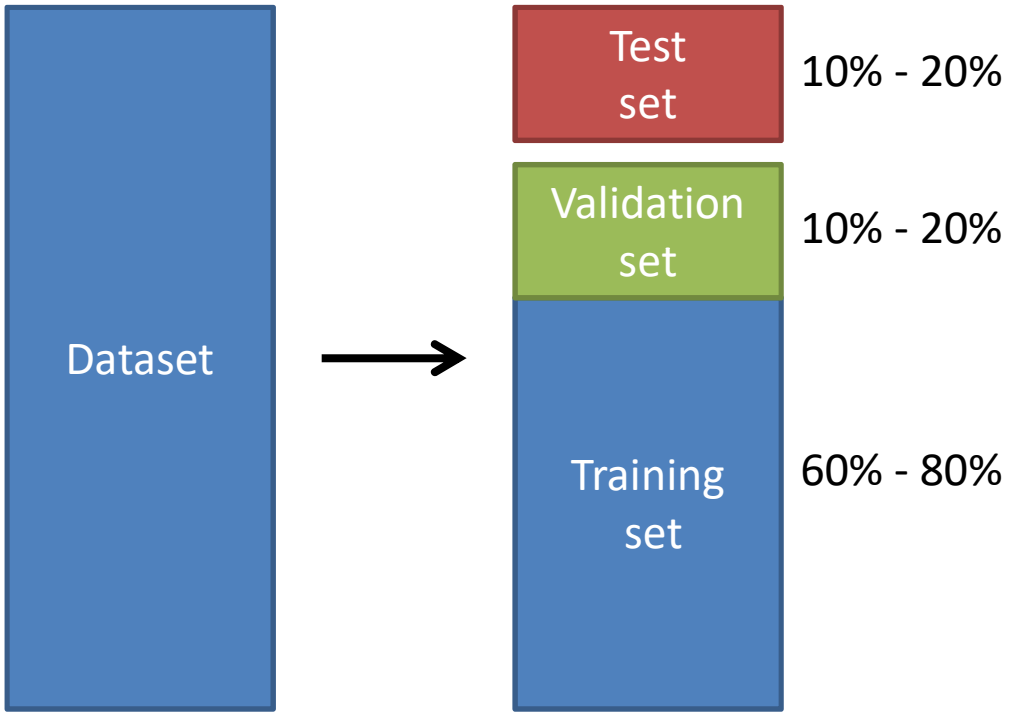
Features

Example of sample x_0

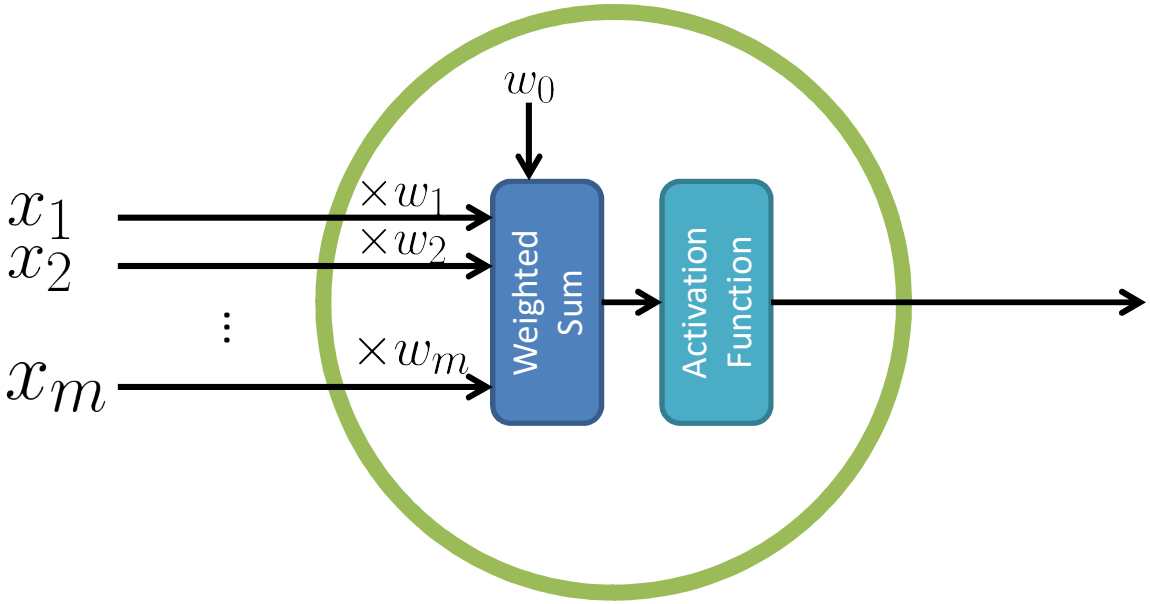


$x_{0_0} = 0.22$
$x_{0_1} = 0.23$
$x_{0_2} = 0.23$
$x_{0_3} = 0.26$
$X_{0_4} = 0.32$
$x_{0_5} = 0.25$
$x_{0_6} = 0.26$
⋮

Datasets

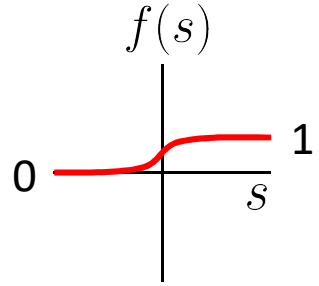


Node (Neuron)

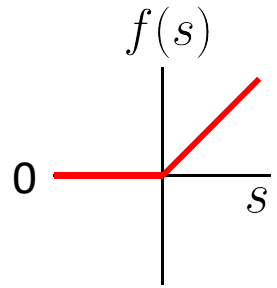


$$f(w_0 + w_1 x_1 + w_2 x_2 + ...)$$

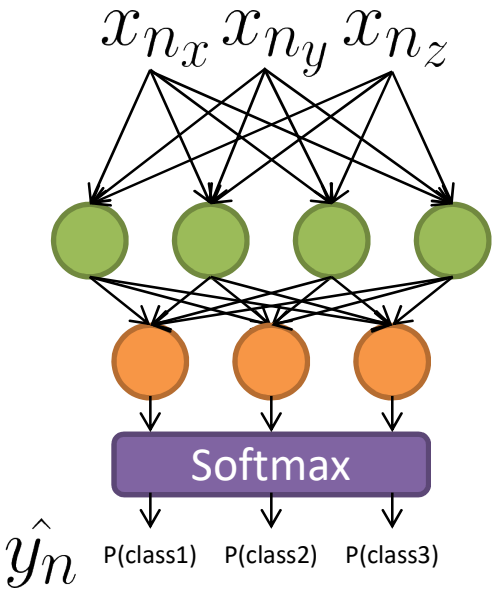
Sigmoid function



ReLU function



Dense Neural Network (DNN)



Input layer

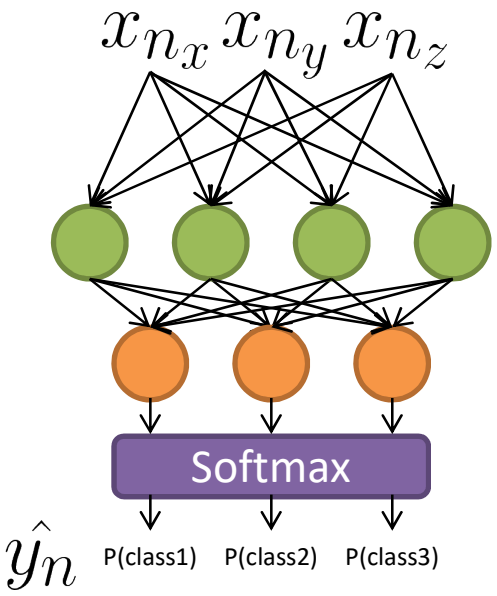
Example:
- Accelerometer: -20…20 m/s^2
- Light sensor: 0...120,000 lux

Hidden layer

Normalize input: [0, 255] → [0.0, 1.0]

Output layer

Training



1. Initialize weights with random values
2. Input features from training sample
3. Perform forward pass
4. Calculate loss
5. Perform backpropagation
6. Repeat 2-5 until desired/acceptable performance

Terminology

Gradient descent: Algorithm to adjust parameters in a model to minimize loss during backpropagation

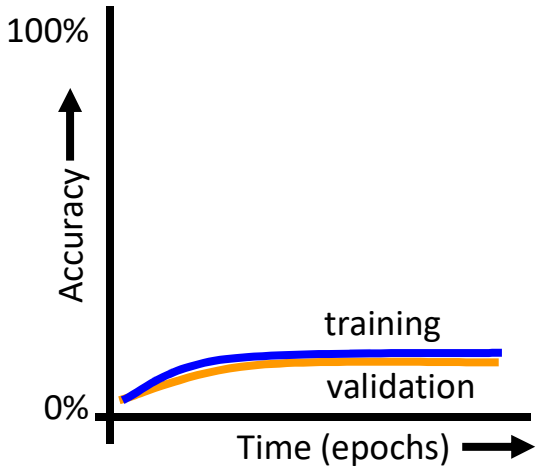
Epoch: All training samples have been passed through the model to compute the loss and gradient(s)

Batch gradient descent: Update parameters with gradient descent once after computing the average gradient from all training data (1 iteration of gradient descent for 1 epoch)

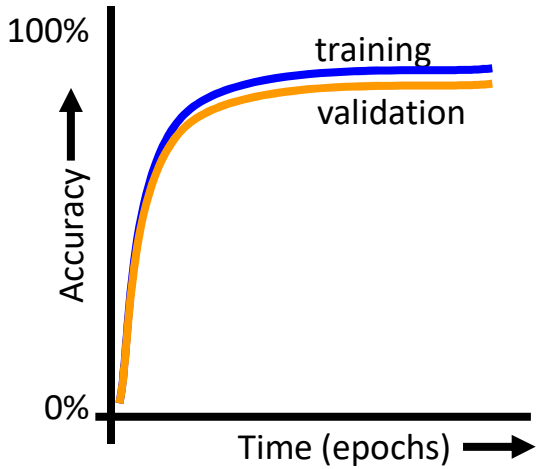
Stochastic gradient descent (SGD): Update parameters with gradient descent once after computing the gradient from one training sample (1 iteration of gradient descent for 1 sample)

Mini-batch gradient descent: Update parameters with gradient descent once per group of training samples (1 iteration of gradient descent for 2..(n-1) samples, where n is the number of training samples.

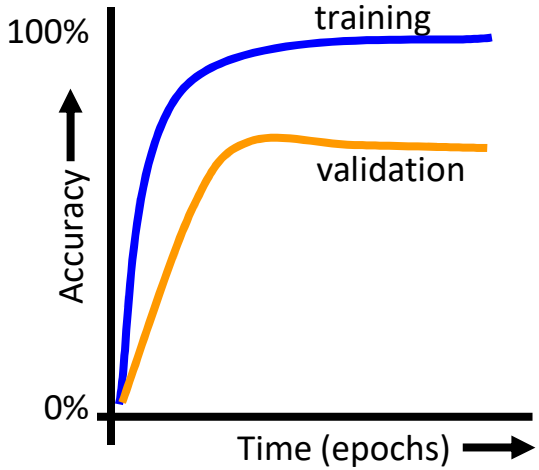
Spotting Underfitting and Overfitting



Underfit: Model performs poorly on training and validation data

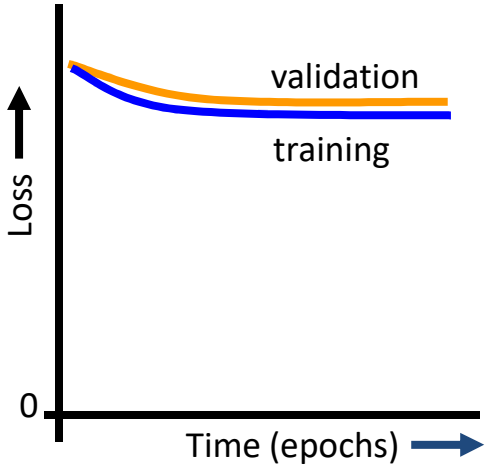


Good fit: Model generalizes well from training to validation data



Overfit: Model predicts training data well but fails to generalize to validation data

Spotting Underfitting and Overfitting



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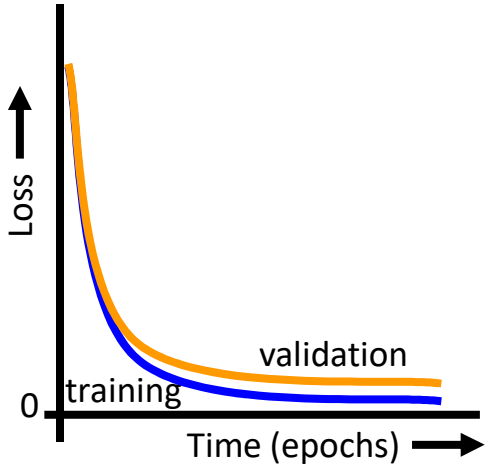

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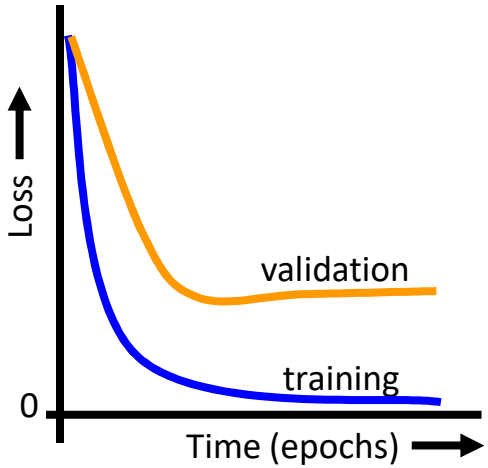

Overfit: Model predicts training data well but fails to generalize to validation data

Confusion Matrix

Actual Label \ Predicted Label	Cat	Dog	Bird	Human
Cat	205	10	1	46
Dog	6	199	0	32
Bird	9	17	223	34
Human	21	8	3	186

True Positive (TP): Predicted positive matches actual positive

True Negative (TN): Predicted negative matches actual negative

False Positive (FP) (“Type I Error”): Predicted positive does not match actual negative

False Negative (FN) (“Type II Error”): Predicted negative does not match actual positive

Confusion Matrix

Predicted Label

Actual Label	Cat	Dog	Bird	Human
Cat	205	10	1	46
Dog	6	199	0	32
Bird	9	17	223	34
Human	21	8	3	186

Total accuracy: $$\frac{\sum correct}{\sum all} = \frac{813}{1000} = 0.813$$

Confusion Matrix

Predicted Label

Actual Label	Cat	Dog	Bird	Human
Cat	205	10	1	46
Dog	6	199	0	32
Bird	9	17	223	34
Human	21	8	3	186

$$ACC = \frac{TP + TN}{P + N} = \frac{TP + TN}{TP + TN + FP + FN} = \frac{\square + \square}{\text{Total}}$$

$$= \frac{199 + 728}{1000} = 0.927$$

Confusion Matrix

Actual Label \ Predicted Label	Cat	Dog	Bird	Human
Cat	205	10	1	46
Dog	6	199	0	32
Bird	9	17	223	34
Human	21	8	3	186

$$F_1 = \frac{2TP}{2TP + FP + FN} = \frac{2 \times \square}{2 \times \square + \square + \square}$$

$$F_1 = \frac{2(199)}{2(199) + (35) + (38)} = 0.845$$

Confusion Matrix

Actual Label \ Predicted Label	Cat	Dog	Bird	Human
Cat	205	10	1	46
Dog	6	199	0	32
Bird	9	17	223	34
Human	21	8	3	186
Per-class accuracy	0.907	0.927	0.936	0.856
F1 scores	0.815	0.845	0.875	0.721

Total accuracy: 0.813

F1 average: 0.818