

Regression Models

Taking our first steps to modelling data

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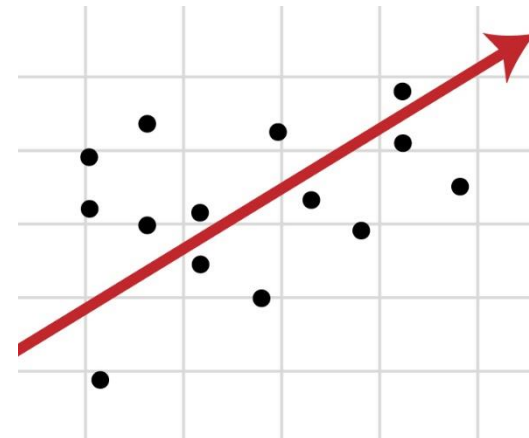


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Problem Overview

Types of modelling

Data Modelling

- As part of the data science process, we want to get a clear idea of what processes generate our data
 - Scientific method: Form a hypothesis and test it
 - Extension: Find a way to understand what's in the data
 - We already did this a lot of times: “mental models” captured our ideas
- A more strict way of modelling
 - Treat the data generating process as a function
 - “Black box”
 - Make some assumptions
 - Create a simplified version of reality under your assumptions
 - Check your model against reality
 - ⇒ Create better and more complex models



A Quick Peek at Machine Learning

- Machine learning is “making computers learn with experience, without being explicitly programmed”
 - Similar to how humans learn
- It's all about models
 - ML follows the same processes as we're going to do
 - ML algorithms are basically “function approximations”
 - Each algorithm does its own thing, i.e. has different assumptions, scope and performance
- It's also about selecting the best model
 - There are many “helper algorithms” to do so – either fully automated or semi-automated
 - Visualization algorithms,
 - Fine-tuning algorithms
 - Model selection algorithms, etc.

A Quick Peek at Machine Learning (2)

- There are a lot of classes of problems
- The most commonly used two
 - **Regression** – model a function which returns a number (i.e. returns a continuous variable)
 - Example: predict the temperature tomorrow
 - **Classification** – model a function which tries to differentiate between two (or more) predefined types of things
 - Example: predict if an image is of a cat or not
- The essence: once we assume a model, **we can make predictions** about function outputs
 - Thus, we can capture patterns in an otherwise unpredictable world

Linear Regression

**Predict continuous values...
and torture first-semester students**

Linear Regression Intuition

- Regression – predicting a continuous variable
- Problem statement
 - Given pairs of $(x; y)$ points, create a model
 - Under the assumption that y depends linearly on x (and nothing else)
- Linear regression model
 - $y = ax + b$
 - a, b – unknown parameters
 - Example: $y = 2x + 3$
 - Real case: we have many sources of error
 - So, the relationship we observe, cannot be perfect
 - There is some noise added to our data
 - $y = ax + b + \varepsilon$, ε – noise
 - We **don't want** to model the noise, only the “useful function”

Generating Data Points

- Generating a few “ideal” data points is easy

```
x = np.linspace(-3, 5, 10)
y = 2 * x + 3
plt.scatter(x, y)
plt.xlabel("x")
plt.ylabel("y")
plt.show()
```

- Adding noise – draw from a random distribution

```
y_noise = np.random.normal(size = len(y))
y_with_noise = y + y_noise
plt.scatter(x, y_with_noise)
plt.xlabel("x")
plt.ylabel("y")
plt.show()
```

- If we want, we can even configure the “size” of our noise
 - More noise = worse data = less accurate predictions

First Attempt at Modelling

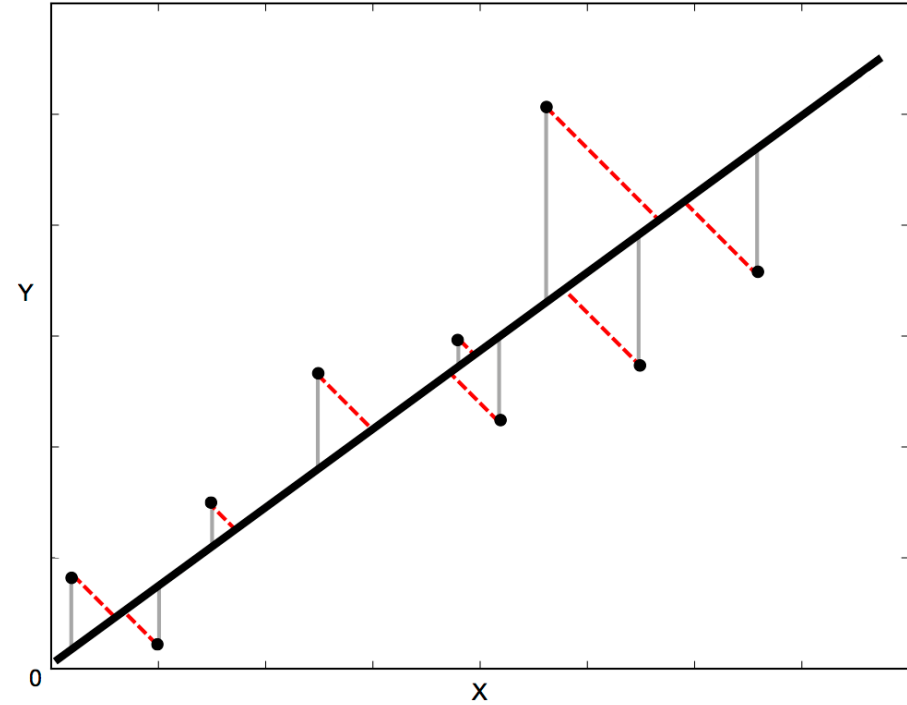
- We know the process was linear
 - Why don't we simply guess a few functions?
 - Remember: what we need to know are the parameters a and b

```
for y_guess in [3 * x + 8, 4 * x + 3, -2 * x]:  
    plt.scatter(x, y_with_noise)  
    plt.plot(x, y_guess)  
plt.show()
```

- We can see that some functions perform much better than others
 - Idea: the best function lies “closest” to all points
 - Meaning
 - Try to measure the distances from all points to the line
 - See when these distances are smallest
 - This will be the best line

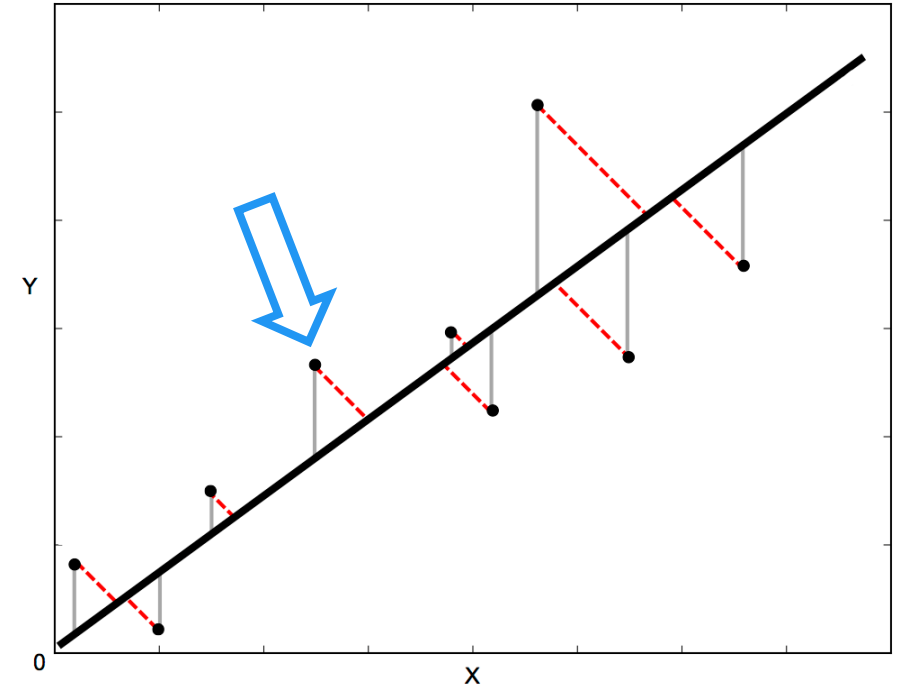
Distances

- By definition, the distance from a point A to the line l is measured on the perpendicular from A to l
 - Red dashed lines
 - This is correct but very computationally expensive
- Another approach: consider vertical distances
 - Gray solid lines
 - Equivalent measures (for our purposes)
 - You can prove it to yourself



Distances (2)

- Look at a point and its projection
 - x -coordinate: the same
 - y -coordinate
 - Point: we know it from the start
 - Projection: we can calculate it
- Calculating the projection y
 - It's whatever the model function produces for x
 - $\Rightarrow \tilde{y} = ax + b$
- Distance becomes a very simple difference
 - $d = y - \tilde{y}$
 - But... now distances can be negative



Distances (3)

- To make distances positive, we can do a lot of things
- Simplest: take the absolute value
 - This is used sometimes (and it's called mean absolute error, MAE)
 - Although it works quite well, there are a few problems with it
 - E.g. the distance becomes 0 when the perfect line
- Better: square the distance
 - It's also non-negative everywhere but...
 - Is almost always > 0
 - Emphasizes bigger errors more (can be good or bad)
 - This is called mean square error (MSE)
- New definition of distance
 - $d = (y - \tilde{y})^2$

Loss Function

- We want to somehow account for all points
 - We can simply sum all distances to get a measure of “the total distance” from all points to the line
 - Since we can have 4, 10, 100 or 10^9 points, we also need to normalize the error
- The sum of distances now becomes
 - $J = \frac{1}{n} \sum_{i=1}^n (y_i - \tilde{y}_i)^2$
 - This is what we call our **total loss function**
 - This is an estimation of the total distance
 - **Minimizing this function will produce the best line**

Calculating the Loss Function

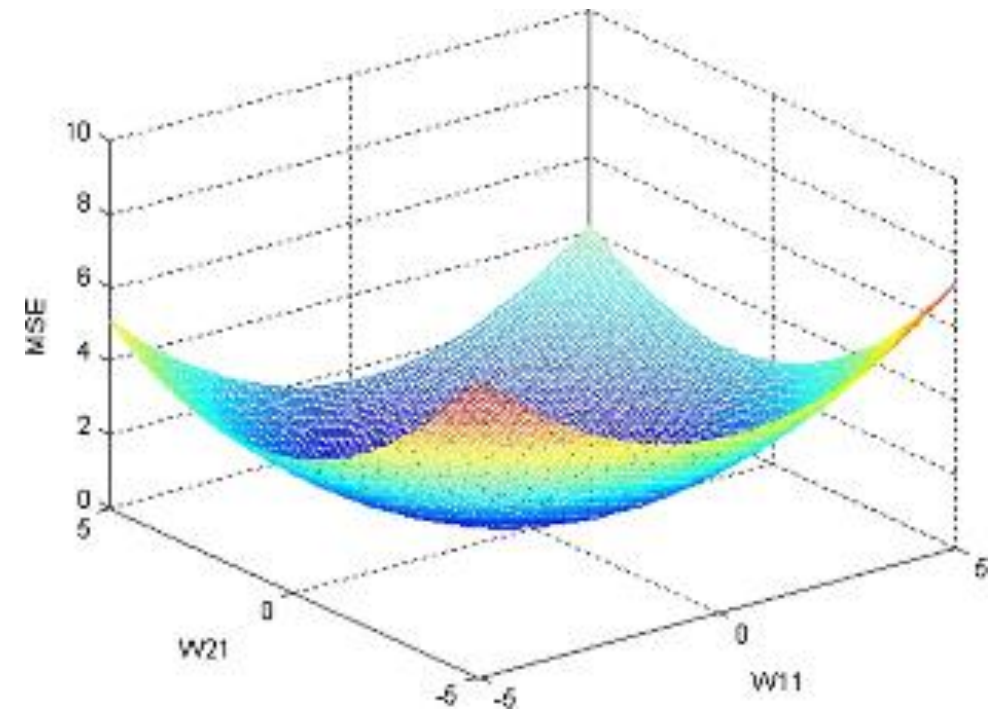
- The code is pretty simple
- Given points x, y and a line with parameters a, b we can simply substitute in the formula above
 - First, for each x , compute $\tilde{y} = ax + b$
 - After that, compute the distances $(y - \tilde{y})^2$
 - Return the sum of all distances, divided by the number of points

```
def calculate_loss(x, y, a, b):  
    y_predicted = a * x + b  
    distances = (y - y_predicted) ** 2  
    return np.sum(distances) / len(x)
```

- Now that we have a quantifier, we can go back to our three guessed lines and calculate their loss functions
 - It will give us the intuition of what we're dealing with

Inspecting the Loss Function

- Note that J does not depend on x and y
 - x and y are already fixed – we don't touch the data at all when we try to model it
 - $\Rightarrow J$ depends only on the line parameters a, b
 - In math jargon, J is a function of a and b : $J = f(a, b)$
- Also note the form of J : it's $(\dots)^2$
 - This is a paraboloid (3D parabola)
 - See how varying a and b gives us a different output number for J
 - It has exactly one min value
 - And we can see it
 - Our task: find the parameters a, b which make J as small as possible



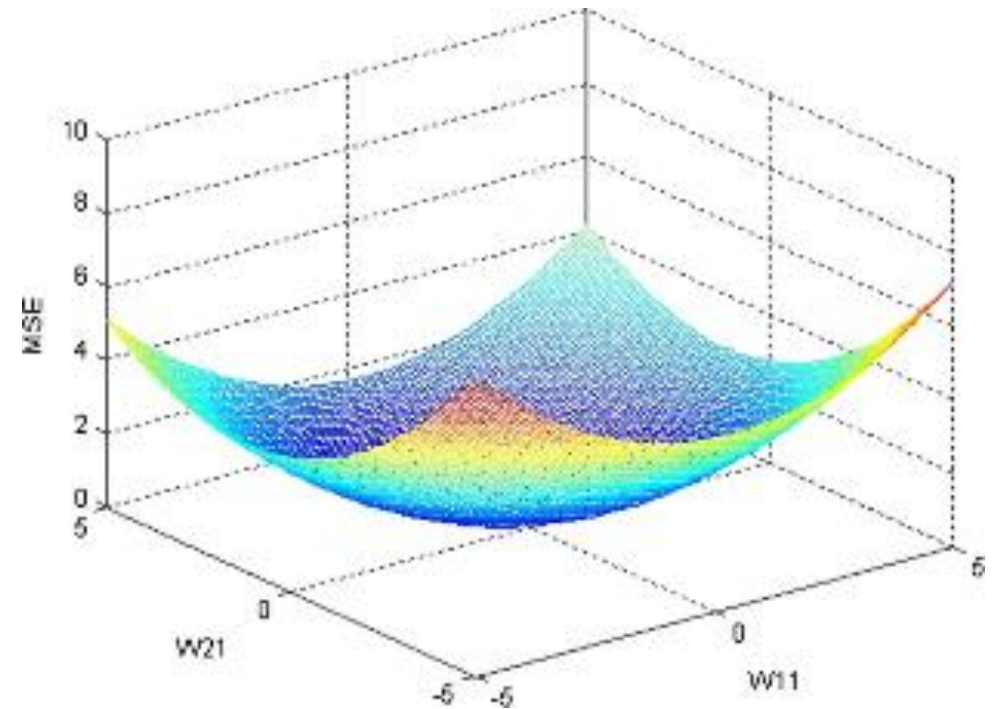
Minimizing the Loss Function (1)

■ Intuition

- If the plot was a real object (say, a sheet of some sort), we could slide a ball bearing on it
- After a while, the ball bearing will settle at the “bottom” due to gravity
- We could measure the position of the ball and that’s it :)

■ More “nerd speak”

- This is the same task – we have a gravity potential energy that the ball tries to minimize
- When it’s minimal, the ball remains in stable equilibrium

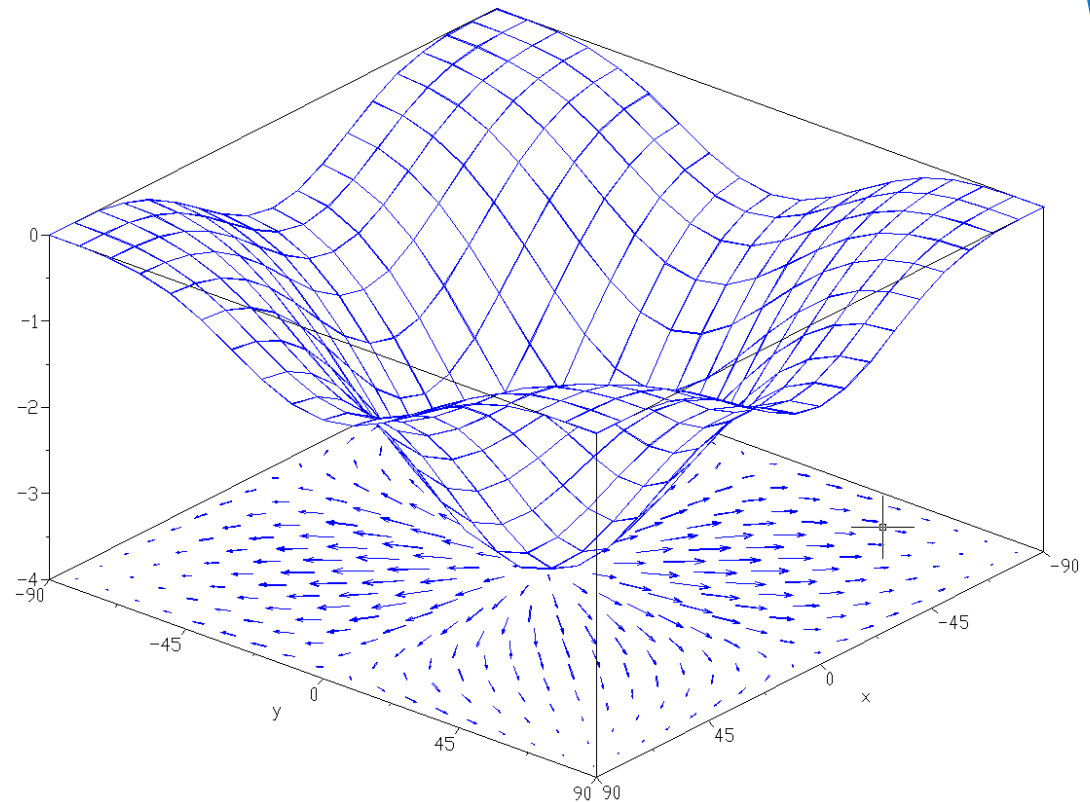


Minimizing the Loss Function (2)

- Turns out, we can also do this using calculus
 - In many dimensions
- We can find the optimal parameters right away
 - Because the function is really simple
 - But we'll stick to another approach because this is what is useful for all other ML tasks
- We'll try to replicate the example with the ball
 - Basically, we'll try to slide (descend) over the function surface until we reach the minimum
 - This method is called **gradient descent**

Gradient Descent

- We know what **descent** is
 - How about **gradient**?
- The gradient (let's call it g for now) is a vector function
 - Like J , g accepts two values a and b
 - g returns a vector which shows where **the steepest ascent** is
 - g is all arrows on the picture
 - Interpretation
 - The length of the vector tells us how steep the maximum is
 - Long vector = very, very steep;
short vector = relatively flat
 - The direction of the vector tells us where to go in order to get there



Gradient Descent (2)

- Gradients will almost work
 - Except they show us the highest point, and we're looking for the lowest one
 - Solution: just take the negative gradient $-g$
 - Ascending on $-g$ is the same as descending on g
- This is good now, but how is the gradient defined?
 - We saw from the picture that it's related to a function
 - The gradient of a function $J(a, b)$ is a vector $g(a, b)$ with the following components
 - $g_a = \frac{\partial J}{\partial a}, g_b = \frac{\partial J}{\partial b}$
 - The ∂ symbol means "partial derivative"
 - If you don't understand this, you only need to know that partial derivatives are quite easy to calculate

Gradient Descent (3)

- Remember that $J = \frac{1}{n} \sum (y_i - \tilde{y}_i)^2$
 - We can prove (and we're not going to :D) that
 - $\frac{\partial J}{\partial a} = -\frac{2}{n} \sum x_i (y_i - \tilde{y}); \frac{\partial J}{\partial b} = -\frac{2}{n} \sum (y_i - \tilde{y})$
- This can be implemented easily

```
a_gradient = -2 / len(x) * np.sum(x * (y - (a * x + b)))  
b_gradient = -2 / len(y) * np.sum(y - (a * x + b))
```

- Note how this code makes use of numpy and its extremely easy operations on arrays
- Now, if we know x, y, a, b we can calculate the gradient vector
 - You'll also see the gradient of J being denoted as ∇J
 - This is simply math notation

Gradient Descent (4)

- Let's now get to the real descent
- Iterative algorithm – perform as long as needed
 - Start from some point in the $(a; b)$ space: $(a_0; b_0)$
 - Decide how big steps to take: number α
 - Called “learning rate” in ML terminology
 - Use the current a, b and x, y to compute ∇J
 - $-\nabla J_a$ tells us how much to move in the a direction in order to get to the minimum
 - Similar for $-\nabla J_b$
 - Take a step with size α in each direction
 - $a_1 = a_0 - \nabla J_a; b_1 = b_0 - \nabla J_b$
 - $(a_1; b_1)$ are the new coordinates
 - Repeat the two preceding steps as needed
 - Usually, we do this for a fixed number of iterations

Gradient Descent Code

■ Gradient descent step

```
def perform_gradient_descent(x, y, a, b, learning_rate):  
    a_gradient = -2 / len(x) * np.sum(x * (y - (a * x + b)))  
    b_gradient = -2 / len(y) * np.sum(y - (a * x + b))  
    new_a = a - a_gradient * learning_rate  
    new_b = b - b_gradient * learning_rate  
    return (new_a, new_b)
```

■ Entire process: 1000 iterations

```
model_a, model_b = -10, 20 # Start somewhere  
alpha = 0.01 # Learning rate  
for step in range(1001):  
    model_a, model_b = perform_gradient_descent(  
        data_x, data_y, model_a, model_b, alpha)  
    if step % 100 == 0:  
        error = calculate_loss(data_x, data_y, model_a, model_b)  
        print("Step {}: a = {}, b = {}, J = {}".format(  
            step, model_a, model_b, error))  
print("Final line: {} * x + {}".format(model_a, model_b))
```

Results and Interpretation

- Going through the entire process, we now have a line $y = ax + b$ which describes our data in the best way
 - We could plot the evolution of J to see that it always decreases
 - If it doesn't, this indicates a problem with our algorithm
- This was a lot of work
 - Thankfully, there are libraries that hide away all that complexity for us
 - `scikit-learn` is the most popular of them
 - Arguably, the most popular of the `scikits` as well
 - Also, generalizes trivially to more dimensions

```
from sklearn.linear_model import LinearRegression

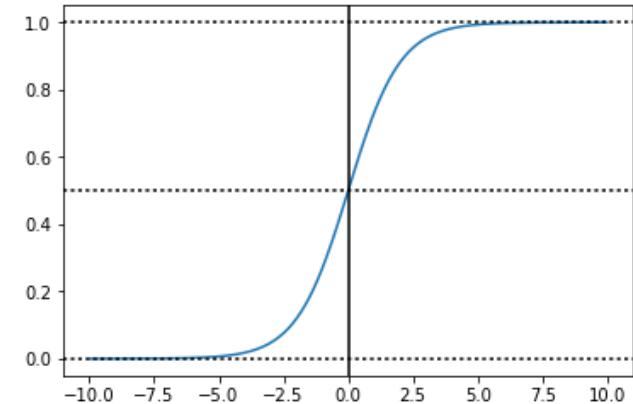
model = LinearRegression()
model.fit(data_x.reshape(-1, 1), data_y)
print(model.coef_, model.intercept_)
```


Logistic Regression

Use a regression model to classify

Logistic Regression

- The name is a bit misleading
 - This is used for classification
- Two classes, 0 and 1
 - Can generalize to more classes using a “trick”
- A function to discriminate: **sigmoid**
 - $x < 0 \Rightarrow y = 0; x > 0 \Rightarrow y = 1$
 - We'll look at the implementation later
- Loss function
 - Similar to the linear regression cost function
- Gradient descent
- Usage in scikit-learn



```
from sklearn.linear_model import LogisticRegression
```

Overview of the Process

- We dealt mainly with the modelling part
 - It's only a piece of the puzzle
- Many algorithms to choose from
 - Each with its own features and drawbacks
- Many ways to test that we're on a correct path
- The end result depends mainly on
 - The person working on the dataset
 - The data quality
 - Less prominent but also worth mentioning
 - Data size (bigger usually is better)
 - Data acquisition and sampling processes

Summary

- Problem overview
 - Regression, classification
 - Machine learning: putting it all together
- Linear regression
 - Motivation, derivation, usage
 - More involved example
- Logistic regression
 - Motivation, usage

The image features a white background with two blue decorative bars. The top bar is a solid blue band at the very top. Below it is a white space containing the text. At the bottom, there is another white space, followed by a dark blue band and a final solid blue band at the very bottom. The text 'Questions?' is centered in the white space.

Questions?