Stocastic Gradient Descent for Logistic Regression

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EXAMPLE

Slides adapted from William Cohen

Reminder: Logistic Regression

$$P(Y=0|X) = \frac{1}{1+\exp\left[\beta_0 + \sum_i \beta_i X_i\right]} \tag{1}$$

$$P(Y=1|X) = \frac{\exp\left[\beta_0 + \sum_i \beta_i X_i\right]}{1+\exp\left[\beta_0 + \sum_i \beta_i X_i\right]} \tag{2}$$

- Discriminative prediction: $p(y\,|\,x)$
- Classification uses: ad placement, spam detection
- What we didn't talk about is how to learn β from data

Logistic Regression: Objective Function

$$\mathscr{L} \equiv \ln p(Y \mid X, \beta) = \sum_j \ln p(y^{(j)} \mid x^{(j)}, \beta) \tag{3}$$

$$= \sum_j y^{(j)} \left(\beta_0 + \sum_i \beta_i x_i^{(j)} \right) - \ln \left[1 + \exp \left(\beta_0 + \sum_i \beta_i x_i^{(j)} \right) \right] \tag{4}$$

Algorithm

1. Initialize a vector B to be all zeros
2. For $t = 1, \dots, T$
   - For each example $\vec{x}_i, y_i$ and feature j:
     - Compute $\pi_i \equiv \Pr(y_i = 1 \mid \vec{x}_i)$
     - Set $\beta[j] = \beta[j]' + \lambda(y_i - \pi_i)x_{i,j}$
3. Output the parameters $\beta_1, \dots, \beta_d$.

Example Documents

$$\beta[j] = \beta[j] + \lambda(y_i - \pi_i)x_{i,j}$$

$$\vec{\beta} = \langle \beta_{bias} = 0, \beta_A = 0, \beta_B = 0, \beta_C = 0, \beta_D = 0 \rangle$$

$y_1 = 1$	$y_2 = 0$
A A A A B B B C	B C C C D D D D

(Assume step size $\lambda = 1.0$.)

You first see the positive example. First, compute π_1

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$\pi_1 = \Pr(y_1 = 1 \mid \vec{x}_1) = \frac{\exp \beta^T x_i}{1 + \exp \beta^T x_i} =$

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$\pi_1 = \Pr(y_1 = 1 \,|\, \vec{x}_1) = \frac{\exp \beta^T x_i}{1 + \exp \beta^T x_i} = \frac{\exp 0}{\exp 0 + 1} = 0.5$

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$\pi_1 = 0.5$ What's the update for β_{bias}?

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$$\beta_{bias} = \beta'_{bias} + \lambda \cdot (y_1 - \pi_1) \cdot x_{1,bias} = 0.0 + 1.0 \cdot (1.0 - 0.5) \cdot 1.0$$

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What's the update for β_D?

$\beta_D = \beta'_D + \lambda \cdot (y_1 - \pi_1) \cdot x_{1,D} = 0.0 + 1.0 \cdot (1.0 - 0.5) \cdot 0.0$

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$$\beta[j] = \beta[j] + \lambda(y_i - \pi_i)x_{i,j}$$
$$\vec{\beta} = \langle .5, 2, 1.5, 0.5, 0 \rangle$$

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(Assume step size $\lambda = 1.0$.)

Now you see the negative example. What's π_2?

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$\pi_2 = \Pr(y_2 = 1 \mid \vec{x}_2) = \frac{\exp \beta^T x_i}{1 + \exp \beta^T x_i} = \frac{\exp\{.5 + 1.5 + 1.5 + 0\}}{\exp\{.5 + 1.5 + 1.5 + 0\} + 1} =$

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$\beta_{bias} = \beta'_{bias} + \lambda \cdot (y_2 - \pi_2) \cdot x_{2,bias} = 0.5 + 1.0 \cdot (0.0 - 0.97) \cdot 1.0$

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$$\beta[j] = \beta[j] + \lambda(y_i - \pi_i)x_{i,j}$$

$$\vec{\beta} = \langle -0.47, 2, 0.53, -2.41, -3.88 \rangle$$

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