# Support Vector Classifier: Loss function

In concept, the SVC is quite similar to the Logistic Regression model.

The main difference between the two is the Loss function

- Cross Entropy for Logistic Regression
- Hinge Loss for the Support Vector Classifier

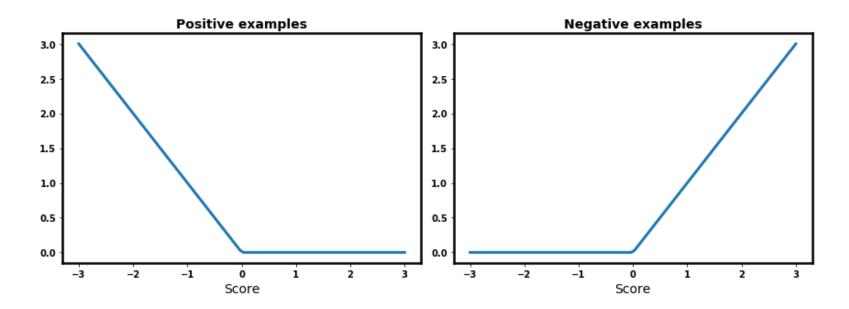
It is the Hinge Loss that makes this model quite interesting.

## **Hinge Loss function**

The Hinge Loss function is best described by a plot.

Here are the two sides of the per-example Hinge Loss

In [4]: | svmh.plot\_hinges()



That is: it is a function of a "score"  $\hat{s}$ 

- ullet for Positive examples: the loss is  $\max(0,-\hat{s})$
- ullet for Negative examples: the loss is  $\max(0,\hat{s})$

The plot resembles a hinge.

## **SVC Loss versus Binary Cross Entropy**

For Binary Logistic Regression

- We computed a score s as a linear function of the features
- We converted the linear score into a probability via the logistic function

$$\hat{p}^{(\mathbf{i})} = \sigma(s(\hat{\mathbf{x}}^{(\mathbf{i})}))$$

By encoding the Positive labels  $\mathbf{y^{(i)}}$  with the number 1 and Negative labels with the number 0

• We were able to combine the two sides (Positive, Negative) of the per-example loss into a single equation

$$\mathcal{L}^{(\mathbf{i})} = -\left(\mathbf{y^{(i)}} * \log(\hat{p}^{(\mathbf{i})}) + (1 - \mathbf{y^{(i)}}) * \log(1 - \hat{p}^{(\mathbf{i})})\right)$$

This is the equation for per-example Binary Cross Entropy Loss.

### For the Binary SVC:

- We compute a score as linear function of the features
- We use Hinge Loss instead of Log Loss

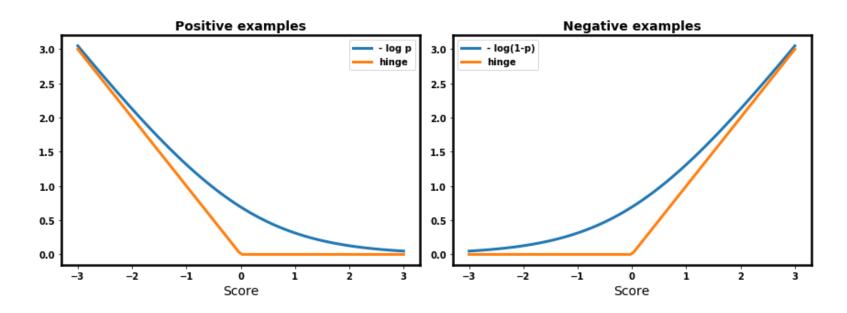
By analogy with Cross Entropy, we can combine the two sides (Positive, Negative) of the

per-example loss into a single equation 
$$\mathcal{L}^{(\mathbf{i})} = \left(\mathbf{y^{(i)}} \max(0, -s(\hat{\mathbf{x}})) + (1 - \mathbf{y^{(i)}}) \max(0, s(\hat{\mathbf{x}}))\right)$$

You can see the similarity with Cross Entropy.

The similarity between the SVM Classification Loss and Cross Entropy becomes more apparent if we plot them together
• Note: the horizontal scale for the Cross Entropy plots are $\hat{p}$ rather than $\hat{s}$

In [5]: svmh.plot\_log\_p(x\_axis="Score", hinge\_pt=0)



### For SVC loss

- We can eliminate the asymmetry in the two sides
- With a slightly different encoding of Positive/Negative
- Into integers +1 and -1 (rather than +1 and 0)

To make this unusual encoding clear, we will place a "dot" over  ${f y}$ 

$$\dot{\mathbf{y}^{(i)}} = egin{cases} +1 & ext{if Positive } \mathbf{y^{(i)}} \\ -1 & ext{if Negative } \mathbf{y^{(i)}} \end{cases}$$

This allows us to simplify the per-example SVC loss to

$$\mathcal{L}^{(\mathbf{i})} = \max(0, -\dot{\mathbf{y}}^{(\mathbf{i})} * s(\hat{\mathbf{x}}))$$

This is the equation for per-example Hinge Loss, when the "hinge point" is 0.

# **Hinge Loss interpretation**

From the previous plot of Cross Entropy Loss (log p) versus Hinge Loss, we can see the similarity.

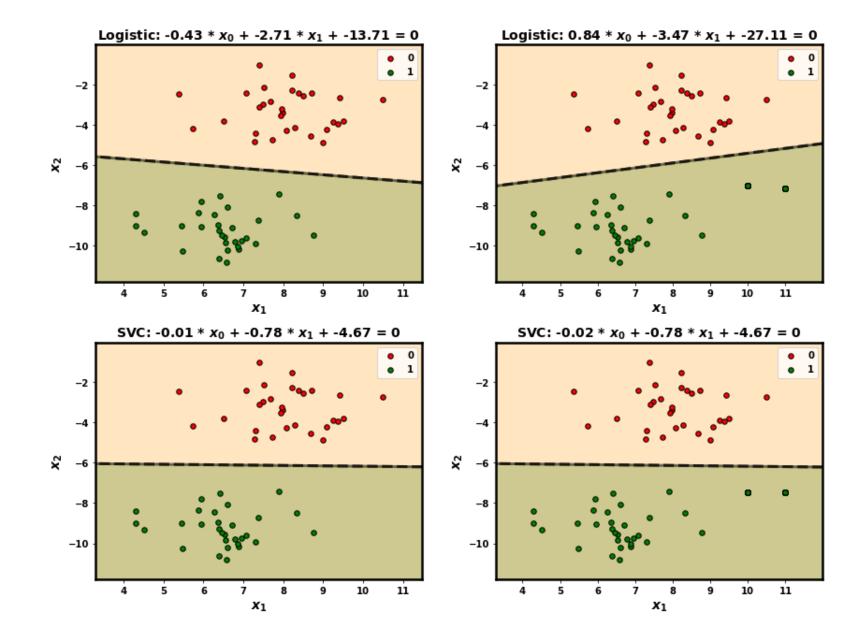
The key difference is that

- A correctly classified example has a per-example Hinge Loss of 0
- A correctly classified example has a positive per-example Log Loss

An optimizer seeking the  $\Theta$  that minimizes Average Loss will be sensitive to non-zero per-example loss.

- Using Log Loss: once an example is correctly classified, the example contributes to Average Loss
- Using Hinge Loss: once an example is correctly classified, the example *does not* contribute to Average Loss.





The chart compares Logistic Regression to SVC on an original and augmented set of examples

- The original examples are the plots on the left
- The original examples are augmented by a cluster of examples and plotted on the right
  - The new examples are correctly classified and located just below the boundary near the right edge
  - Although hard to see: there are many instances of each added example (all identical)

The additional examples are relatively close to the separating boundary.

- For Logistic Regression:
  - Each example incurs a relatively high Log Loss  $\mathcal{L}^{(i)}$  since it is close to the boundary
  - There are a lot of such examples, each contributing a positive amount to Average Loss

$$\mathcal{L} = rac{1}{m} \sum_{i=1}^m \mathcal{L^{(i)}}$$

 Minimizing Average Loss when these new examples are present means moving the boundary away from them

### For SVC:

- The additional examples are on the correct side of the boundary and incur zero Hinge Loss
- Hence the additional examples do not affect the fit.

### The key difference

- ullet One the Hinge Loss for an example reaches 0
- There is no benefit (i.e., reduction of Average Loss)
- To improving the parameters to make the example be "further" from the boundary

### For Cross Entropy Loss

- There is always benefit until per example loss reaches 0
- Hence, in the absence of other constraints, the optimizer will try to "improve" the fit

#### For a Classification task

- Cross Entropy Loss continues to try to improve the probability  $\hat{p}^{(i)}$  long after  $\hat{p}^{(i)}$  has crossed the prediction threshold (e.g., 0.5)
  - This might lead to overfitting (high variance)
- Hinge Loss will not try to improve prediction once we cross the threshold
  - this might lead to a fit that is "good" but not "best" (high bias)

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In [7]: print("Done")
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Done