Machine Learning

Dmytro Fishman (dmytro.fishman@ut.ee)

Performance metrics
## Deadlines

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Date of assignment</th>
<th>Deadline (midnight 23:59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW1</td>
<td>Sep 6</td>
<td>Sep 19</td>
</tr>
<tr>
<td>HW2</td>
<td>Sep 20</td>
<td>Oct 3</td>
</tr>
<tr>
<td>HW3</td>
<td>Oct 4</td>
<td>Oct 17</td>
</tr>
<tr>
<td>Paper summary</td>
<td>Oct 11</td>
<td>Oct 31</td>
</tr>
<tr>
<td>HW4</td>
<td>Oct 18</td>
<td>Oct 31</td>
</tr>
<tr>
<td>HW5</td>
<td>Nov 1</td>
<td>Nov 14</td>
</tr>
<tr>
<td>HW6</td>
<td>Nov 22</td>
<td>Dec 5</td>
</tr>
<tr>
<td>Project</td>
<td>Oct 12</td>
<td>Dec 13 - 15</td>
</tr>
</tbody>
</table>

*All deadlines are subject to change, check out CampusWire and website for updates*
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes...”

The Random Forest algorithm

Random Forest

Boosting (AdaBoost and GBM)

Stacking and Blending

Form several bags (using bootstrapping)

For each bag build a tree

For each node in the tree choose random set of features

Merge predictions using majority vote or averaging
Multiple models are built on training data

\[ y = 1.6 + 0.79x + 3.28 + 0.14x + 1.94 + 0.64x + 0.14x \]

**Ridge Regression**

**Linear Regression**

**Lasso Regression**

Multiple models are built on training data. The table summarizes the predictions:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>3.18</td>
<td>5.55</td>
</tr>
<tr>
<td>Ridge</td>
<td>3.23</td>
<td>5.17</td>
</tr>
<tr>
<td>Lasso</td>
<td>3.57</td>
<td>4.00</td>
</tr>
<tr>
<td>Average</td>
<td>3.32</td>
<td></td>
</tr>
</tbody>
</table>

\[ X_1 = 2 \quad X_2 = 5 \]

The average predictions are:

**Average the predictions**

\[ \text{mean}(3.18, 3.23, 3.57) \]
Multiple models are built on training data.

Training data

<table>
<thead>
<tr>
<th>Test</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Ensemble</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dog</td>
<td>Dog</td>
<td>Cat</td>
<td>Dog</td>
</tr>
</tbody>
</table>

Majority voting
Multiple models are built on training data.

<table>
<thead>
<tr>
<th>Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>Dog</td>
</tr>
<tr>
<td>Model 2</td>
<td>Dog</td>
</tr>
<tr>
<td>Model 3</td>
<td>Cat</td>
</tr>
<tr>
<td>Ensemble</td>
<td>TRUE</td>
</tr>
</tbody>
</table>

Dog - 2, Cat - 1

Majority voting
Multiple models are built on training data.

Training data

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Dog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 2</td>
<td>Dog</td>
</tr>
<tr>
<td>Model 3</td>
<td>Cat</td>
</tr>
<tr>
<td>Ensemble</td>
<td>Dog</td>
</tr>
</tbody>
</table>

Test

Dog wins!

Majority voting
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes…”

Random Forest

Boosting (AdaBoost and GBM)

Stacking and Blending
We can estimate the weight of each model based on **CV** on training data.

Previously each model was given only **one vote**.

Now each model has **different number of votes**.

- **M1** for Dog: 2 votes
- **M2** for Dog: 1 vote
- **M3** for Cat: 33 votes
- **M1** for Dog: 37 votes
- **M2** for Dog: 30 votes
- **M3** for Cat: 70 votes
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes…”

Random Forest

Boosting (AdaBoost and GBM)

Stacking and Blending
Bootstrapping + Aggregation = Bagging

Aggregating predictions produced by models trained on random bootstraps of data
Bootstrapping + Aggregation = Bagging

Aggregating predictions produced by models trained on random bootstraps of data
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes…”
We add a **new step** into the tree building algorithm:

0. Choose a **random set** of features

1. Evaluate **all possible splits**

2. Choose the **best split**

---

**Heads**, means we keep \( X_2 \)

**Tail**, means we keep \( X_1 \)
We can build an ensemble

Red
Blue
Red

Blue
Blue
Blue

66% Red
66% Blue
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes…”

Random Forest

Boosting (AdaBoost and GBM)

Stacking and Blending
Both methods train ensembles **sequentially** (one model after another).
We modified importance scores.

Both methods train ensembles **sequentially** (one model after another).

AdaBoost

Gradient Boosting
**Basic ensembling**

**Weighted ensembling**

**Bagging ensembling**

“In previous episodes…”

---

**Random Forest**

**Boosting**

*(AdaBoost and GBM)*

**Stacking and Blending**
Stacking or blending

Meta-model

Final predictions
Basic ensembling

Weighted ensembling

Bagging ensembling

“In previous episodes…”

Random Forest

Boosting (AdaBoost and GBM)

Stacking

Blending
Supervised Learning
- Classification
- Regression

Unsupervised Learning
- Dimensionality reduction
- Clustering

Reinforcement Learning

Machine Learning
Classification

Regression
Everything is easy, here we calculate the proportion of correctly guessed instances.
Everything is easy, here we calculate the proportion of correctly guessed instances.

Accuracy = $\frac{4}{5}$
Everything is easy, here we calculate the proportion of correctly guessed instances.

Accuracy = \frac{4}{5}

Correctly guessed instances

The number of all instances
The good thing about **accuracy** is that it is easily interpretable.
The good thing about **accuracy** is that it is easily interpretable.

Accuracy = 80%
The good thing about **accuracy** is that it is easily interpretable.
The good thing about **accuracy** is that it is easily interpretable.

**Accuracy = 80%**

**Accuracy ~ 50%**
The good thing about **accuracy** is that it is easily interpretable.

You can easily estimate the **added value** of your classifier over a query to [https://www.random.org/](https://www.random.org/)
It is not always informative to use random generator as a baseline.

Accuracy = 80%

Random Generator

Accuracy ~ 50%
What if we have slightly different situation?
What if we have slightly different situation?

Only one instance of opposite class
What if we have slightly different situation?

Only one instance of opposite class

Classifier the predicts all instances as blue
What if we have slightly different situation?

Only one instance of opposite class

Classifier the predicts all instances as blue

Majority class (most frequent class)
What if we have slightly different situation?

Only one instance of **opposite** class

Classifier the predicts all instances as **blue**

Accuracy = ?%
What if we have slightly different situation?

Only one instance of opposite class

Classifier the predicts all instances as blue

Accuracy = 80%
What if we have slightly different situation?

Accuracy = ?%
What if we have slightly different situation?

Accuracy = $\frac{9}{10}$
What if we have slightly different situation?

Accuracy = 90%
What if we have slightly different situation?

Accuracy = 90%

What is the accuracy of the random generator in this case?

~?%
What if we have slightly different situation?

Accuracy = 90%

What is the accuracy of the random generator in this case?

∼50%
Sometimes being better than random guess is not enough!

Accuracy = 90%

What is the accuracy of the random generator in this case?

~50%
Segmentation problem - predicting **class** for each pixel in the image (in this case **pedestrian** and **background**).
Segmentation problem - predicting class for each pixel in the image (in this case pedestrian and background)
Segmentation problem - predicting class for each pixel in the image (in this case pedestrian and background)
Segmentation problem - predicting class for each pixel in the image (in this case pedestrian and background)
**Segmentation** problem - predicting **class** for each pixel in the image (in this case **pedestrian** and **background**)

Background > **90%** pixels

Person < **10%** pixels
Segmentation problem - predicting class for each pixel in the image (in this case pedestrian and background)

Background > 90% pixels

**Majority** class prediction is +90% accurate
Segmentation problem - predicting class for each pixel in the image (in this case pedestrian and background)

Background > 90% pixels

Majority class prediction is +90% accurate

Random guess is only 50% accurate
Sometimes being simply better than random guess **is not good enough!**
Ok, so what can we do? (if not **accuracy** then who?)
Ok, so what can we do? (if not **accuracy** then who?)
Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not **accuracy** then who?)
Ok, so what can we do? (if not **accuracy** then who?)
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Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not accuracy then who?)
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called “positive” and the other “negative”. This division is arbitrary.
Ok, so what can we do? (if not **accuracy** then who?)

One of the classes is called **positive** and the other **negative**. This division is arbitrary.

Let's call the red class **negative**.
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called “positive” and the other “negative”. This division is arbitrary.

Let’s call the red class “negative”. And the blue class will call “positive”.

Predicted

Actual
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called “positive” and the other “negative”. This division is arbitrary.
One of the classes is called “positive” and the other “negative”. This division is arbitrary.
Ok, so what can we do? (if not **accuracy** then who?)

One of the classes is called “**positive**” and the other “**negative**”. This division is arbitrary

- **True Negative** - negative class predicted as negative

```
<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th></th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

\text{X}_1 \text{X}_2
One of the classes is called **positive** and the other **negative**. This division is arbitrary.
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called "positive" and the other "negative". This division is arbitrary.

False Positive - negative class predicted as positive
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called “positive” and the other “negative”. This division is arbitrary.

Correct guesses
Ok, so what can we do? (if not accuracy then who?)

One of the classes is called “positive” and the other “negative”. This division is arbitrary.
One of the classes is called "**positive**" and the other "**negative**". This division is arbitrary.
Type I Error

You’re pregnant!

Type II Error

You’re not pregnant!
*provided that pregnant is a positive class
**Confusion matrix** is a powerful tool to analyse the performance of machine learning algorithms.
**Confusion matrix** is a powerful tool to analyse the performance of machine learning algorithms.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
</tr>
<tr>
<td></td>
<td>FN</td>
</tr>
</tbody>
</table>

The confusion matrix is illustrated with a scatter plot, where each point represents a data instance classified by the model. The scatter plot shows the distribution of points in the feature space defined by $X_1$ and $X_2$. The points in the plot correspond to the actual and predicted classes, with different colors indicating the true and false positives and negatives.
**Confusion matrix** is a powerful tool to analyze the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.

Problematic classifiers usually manifest themselves in empty columns.
What about this example?
What about this example?

Predicted

Actual

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms. Problematic classifiers usually manifest themselves in empty columns.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
**Confusion matrix** is a powerful tool to analyse the performance of machine learning algorithms.

How to **interpret** this number?
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithm.
Confusion matrix is a powerful tool to analyze the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyze the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms. How to interpret this number?
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithm.
**Confusion matrix** is a powerful tool to analyse the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
Confusion matrix is a powerful tool to analyse the performance of machine learning algorithms.
These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
**Recall** and **Precision** can help summarise the confusion matrix.

Recall = $\frac{TP}{TP + FN}$

These are **four** numbers ($TN$, $TP$, $FN$ and $FP$), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Number of correctly predicted as positive

Recall = \( \frac{TP}{TP + FN} \)

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

- **Number of correctly predicted as positive**
- **The total number of actual positive**

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Number of correctly predicted as positive

Recall = \( \frac{TP}{TP + FN} \)

The total number of actual positive

Precision = \( \frac{TP}{TP + FP} \)

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

Number of correctly predicted as positive

The total number of actual positive

Precision = \( \frac{TP}{TP + FP} \)

Number of correctly predicted as positive

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

These are four numbers (TN, TP, FN, and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix

Recall = \( \frac{TP}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Number of correctly predicted as positive

Recall = \( \frac{TP}{TP + FN} \)

The total number of actual positive

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive

These are four numbers (TN, TP, FN and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Recall = \frac{TP}{TP + FN}

Precision = \frac{TP}{TP + FP}

100 people, 20 had a disease. Our algorithm diagnosed 15 people with a disease. What is precision and recall?
Recall and Precision can help summarise the confusion matrix.

Number of correctly predicted as positive

Recall = \( \frac{TP}{TP + FN} \)

The total number of actual positive

Number of correctly predicted as positive

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive

100 people, 20 had a disease. Our algorithm diagnosed 15 people with a disease and 5 did not.

What is precision and recall?

These are four numbers (TN, TP, FN, and FP), can we have fewer indicators?
Recall and Precision can help summarise the confusion matrix.

Recall = \frac{TP}{TP + FN}

Precision = \frac{TP}{TP + FP}

The total number of actual as positive

The total number of points predicted as positive

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

- **Recall** = Number of correctly predicted as **positive**
- **Recall** = The total number of actual **positive**

Precision = \( \frac{TP}{TP + FP} \)

- **Precision** = Number of correctly predicted as **positive**
- **Precision** = The total number of points predicted as **positive**
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

The total number of actual positive

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

| Predicted | Actual | Sum
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FN</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>TP</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

Number of correctly predicted as positive

Recall = \( \frac{TP}{TP + FN} \)

The total number of actual as positive

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{9}{(TP + FN)} \)

Precision = \( \frac{TP}{(TP + FP)} \)

The total number of points predicted as positive:

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

The total number of actual as positive:

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

The total number of actual as positive:

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{9}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

The total number of actual positive

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

**Recall**

\[
\text{Recall} = \frac{9}{(TP + FN)}
\]

The **total number** of actual positive

**Precision**

\[
\text{Precision} = \frac{TP}{(TP + FP)}
\]

The **total number** of points predicted as positive

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TP</td>
<td>9</td>
</tr>
<tr>
<td>TN</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
</tr>
</tbody>
</table>

\[
\sum \text{Actual} = 0 \quad \sum \text{Predicted} = 10
\]

\[
\sum = 9
\]
Recall and Precision can help summarise the confusion matrix.

Recall = \frac{9}{(TP + FN)}

The total number of actual positive

Precision = \frac{TP}{(TP + FP)}

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{9}{9 + 0} \)

The total number of actual positive

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive

Number of correctly predicted as positive

\[
\begin{array}{ccc}
\text{Actual} & \text{TN} & \text{FP} \\
\text{FN} & 0 & 1 \\
\text{TP} & 9 & 0 \\
\end{array}
\]
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{9}{9} \)

The total number of actual positive points.

Precision = \( \frac{TP}{TP + FP} \)

Number of correctly predicted as positive.

Number of correctly predicted as positive.

The total number of points predicted as positive.

The total number of points predicted as positive.

\[
\begin{array}{ccc}
\text{Actual} & \text{Predicted} \\
\hline
\text{TN} & \text{FP} & \sum \\
\hline
\text{FN} & \text{TP} & \sum \\
\hline
\sum & 0 & 10 \\
\sum & 9 & \sum \\
\end{array}
\]
**Recall** and **Precision** can help summarise the confusion matrix.

Recall = \(9 / 9\)

Precision = \(\frac{TP}{TP + FP}\)

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Actual</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FP</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>FN</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

The total number of points predicted as positive is 9.
Recall and Precision can help summarise the confusion matrix

Recall = 1.0

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive

Number of correctly predicted as positive
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive.
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive.
Recall and Precision can help summarise the confusion matrix.

Recall = \(1.0\)

- We correctly predicted 100% of actual positive cases.
- Number of correctly predicted as positive.

Precision = \(\frac{TP}{TP + FP}\)

- The total number of points predicted as positive.
- The confusion matrix:

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>TN</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FN</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

\[ \sum 10 \]
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Precision = \( \frac{TP}{TP + FP} \)

The total number of points predicted as positive.
Recall and Precision can help summarise the confusion matrix

Recall $= 1.0$

We correctly predicted 100% of actual positive cases

Number of correctly predicted as positive

Precision $= \frac{9}{(TP + FP)}$

The total number of points predicted as positive
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Number of correctly predicted as positive.

Precision = \( \frac{9}{(TP + FP)} \)

The total number of points predicted as positive.

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TN 0</td>
</tr>
<tr>
<td></td>
<td>FN 0</td>
</tr>
<tr>
<td></td>
<td>TP 9</td>
</tr>
<tr>
<td></td>
<td>FP 1</td>
</tr>
</tbody>
</table>

The confusion matrix:

\[\sum_0^{10} \quad \sum_0^{1} \quad \sum_{9} \quad \sum_{10} \]
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Precision = \( \frac{9}{TP + FP} \)

The total number of points predicted as positive.
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0
We correctly predicted 100% of actual positive cases.

Precision = 9 / 10
The total number of points predicted as positive.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TN</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
</tr>
<tr>
<td>TP</td>
<td>9</td>
</tr>
</tbody>
</table>

The confusion matrix is shown with TP, TN, FP, and FN values.
Recall and Precision can help summarise the confusion matrix.

**Recall** = 1.0

We correctly predicted 100% of actual **positive** cases.

**Precision** = \( \frac{9}{10} \)

The total number of points predicted as **positive**.
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0
We correctly predicted 100% of actual positive cases.

Precision = 0.9
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0

We correctly predicted 100% of actual positive cases.

Precision = 0.9

Of all points predicted positive, 90% were actually positive.
Recall and Precision can help summarise the confusion matrix.

Recall = \(1.0\)

We correctly predicted 100% of actual positive cases.

Precision = \(0.9\)

Of all points predicted positive, 90% were actually positive.
Recall and Precision can help summarise the confusion matrix

<table>
<thead>
<tr>
<th>Actual</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
</tr>
<tr>
<td></td>
<td>FP</td>
</tr>
<tr>
<td></td>
<td>FN</td>
</tr>
<tr>
<td></td>
<td>TP</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

Recall = \[1.0\]

Both Recall and Precision are high, does it automatically mean that our classifier is good?

Precision = \[0.9\]
Recall and Precision can help summarise the confusion matrix.

Recall = 1.0
Precision = 0.9
Recall and Precision can help summarise the confusion matrix.

This classifier completely ignores the second class.

We got high Recall and Precision just because we defined blue class as positive.
Ok, so what can we do? (if not accuracy then who?)

Let’s call the red class “negative”
And the blue class will call “positive”

How Recall and Precision are going to change if we flip the positive/negative assignment?
Ok, so what can we do? (if not accuracy then who?)

Let’s call the blue class “negative.”
And the red class will call “positive.”

How Recall and Precision are going to change if we flip the positive/negative assignment?
How **Confusion Matrix** is going to change if we flip the **positive/negative** assignment?
How **Confusion Matrix** is going to change if we flip the positive/negative assignment?
How **Confusion Matrix** is going to change if we flip the **positive/negative** assignment?
How **Confusion Matrix** is going to change if we flip the positive/negative assignment?
Recall and Precision can help summarise the confusion matrix.

Recall = \frac{TP}{TP + FN}

Number of correctly predicted as positive

The total number of actual positive

Precision = \frac{TP}{TP + FP}

Number of correctly predicted as positive

The total number of points predicted as positive

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>1</td>
</tr>
<tr>
<td>TN</td>
<td>9</td>
</tr>
</tbody>
</table>

\[\sum\begin{array}{cccc}
\text{Actual} & \text{FN} & \text{TP} \\
\text{TN} & 9 & 0 \\
\text{FP} & 0 & 0 \\
\end{array}\]
Recall and Precision can help summarise the confusion matrix.

Recall = \frac{0}{TP + FN}

Precision = \frac{0}{TP + FP}

The total number of points predicted as positive

The total number of actual positive

Number of correctly predicted as positive

Number of correctly predicted as positive

Actual

Predicted

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>TP</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>TN</td>
<td>FP</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>∑</td>
<td>∑</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>
Recall and Precision can help summarise the confusion matrix.

**Recall**

\[
\text{Recall} = \frac{0}{0 + \text{FN}}
\]

- Number of correctly predicted as **positive**
- The total number of actual positive

**Precision**

\[
\text{Precision} = \frac{0}{0 + \text{FP}}
\]

- Number of correctly predicted as **positive**
- The total number of points predicted as **positive**

**Confusion Matrix**

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
<td>FN</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Recall and Precision can help summarise the confusion matrix.

Recall = \[ \frac{0}{0 + 1} \]

The total number of actual positive

Precision = \[ \frac{0}{0 + 0} \]

The total number of points predicted as positive

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Actual</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
<td>FP</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>FN</td>
<td>TP</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>∑</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Recall and Precision can help summarise the confusion matrix

Recall = 0.0

Precision = NaN
Recall and Precision can help summarise the confusion matrix

Recall = 0.0

We correctly predicted 0% of actual positive cases

NaN% of all predicted positive were actually positive

Precision = NaN
Recall and Precision for class red

Recall = 0.0

We correctly predicted 0% of actual positive cases

NaN% of all predicted positive were actually positive

Precision = NaN
Recall and Precision for class red

Recall = 0.0

We correctly predicted 0% of actual positive cases

NaN% of all predicted positive were actually positive

Precision = NaN

Recall and Precision for class blue

Recall = 1.0

We correctly predicted 100% of actual positive cases

90% of all predicted positive were actually positive

Precision = 0.9
Recall and Precision for class red

Recall = 0.0
Precision = NaN

We correctly predicted 0% of actual positive cases
NaN% of all predicted positive were actually positive

Recall and Precision for class blue

Recall = 1.0
Precision = 0.9

We correctly predicted 100% of actual positive cases
90% of all predicted positive were actually positive

Calculate **recall** and **precision** for each class to get a more complete picture of classifier’s performance.
Recall and Precision for class red

Recall = 0.0
Precision = NaN
We correctly predicted 0% of actual positive cases
NaN% of all predicted positive were actually positive

Recall and Precision for class blue

Recall = 1.0
Precision = 0.9
We correctly predicted 100% of actual positive cases
90% of all predicted positive were actually positive

Calculate **recall** and **precision** for each class to get a more complete picture of classifier’s performance

*Is it possible to combine **recall** and **precision** in one value?
for class red

Recall = 0.0
Precision = NaN

for class blue

Recall = 1.0
Precision = 0.9
for class red

Recall = 0.0

Precision = NaN

for class blue

Recall = 1.0

Precision = 0.9

F1-score

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]
for class **red**

Recall = 0.0

Precision = **NaN**

F1-score = ?

for class **blue**

Recall = 1.0

Precision = 0.9

F1-score = ?

\[ F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} \]
for class \textcolor{red}{red}

Recall = 0.0

Precision = \textcolor{red}{NaN}

\textbf{F1-score} = \textcolor{red}{NaN}

\[ F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} \]

for class \textcolor{blue}{blue}

Recall = 1.0

Precision = 0.9

\textbf{F1-score} = \textcolor{blue}?
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

for class blue

Recall = 1.0
Precision = 0.9
F1-score = ?

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]
for class red

Recall = 0.0

Precision = NaN

F1-score = NaN

for class blue

Recall = 1.0

Precision = 0.9

F1-score = ?

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

for class blue

Recall = 1.0
Precision = 0.9
F1-score = ?

\[
F1 = 2 \times \frac{1.0 \times 0.9}{1.0 + 0.9}
\]
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

\[ F1 = 2 \times \frac{0.9}{1.9} \]

for class blue

Recall = 1.0
Precision = 0.9
F1-score = ?
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

\[ F1 = \frac{1.8}{1.9} \]

for class blue

Recall = 1.0
Precision = 0.9
F1-score = ?
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

\[ F1 = 0.947 \]

for class blue

Recall = 1.0
Precision = 0.9
F1-score = ?
for class red

Recall = 0.0
Precision = NaN
F1-score = NaN

for class blue

Recall = 1.0
Precision = 0.9
F1-score = 0.947

F1 = 0.947
for class **red**

- Recall = 0.0
- Precision = NaN
- \( F1 \)-score = NaN

for class **blue**

- Recall = 1.0
- Precision = 0.9
- \( F1 \)-score = 0.947

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]
F1-score is a **harmonic mean** between recall and precision

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]
F1-score is a **harmonic mean** between recall and precision

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]

F1-score is **also known** as …
F1-score is a **harmonic mean** between recall and precision

\[ F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} \]

F1-score is **also known** as the **Sørensen-Dice** coefficient.
F1-score is a **harmonic mean** between recall and precision.

\[
F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}}
\]

F1-score is **also known** as the **Dice** coefficient.
F1-score is a harmonic mean between recall and precision

\[ F1 = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} \]

F1-score is also known as the Dice coefficient

\[ \text{Dice} = \frac{2 \times TP}{2 \times TP + FP + FN} \]
Is this even possible?

\[
2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \times \text{TP}}{2 \times \text{TP} + \text{FP} + \text{FN}}
\]

- F1-score
- Dice coefficient
Is this even possible?

$$\frac{2 \cdot \text{Recall} \cdot \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \cdot TP}{2 \cdot TP + FP + FN}$$

Dice coefficient
Is this even possible?

\[
2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Recall = \( \frac{TP}{TP + FN} \)

Dice coefficient
Is this even possible?

\[ 2 \left( \frac{TP}{TP + FN} \right) \times \text{Precision} + \text{Precision} = \frac{2 \times TP}{2 \times TP + FP + FN} \]

Recall = \[ \frac{TP}{TP + FN} \]

Dice coefficient
Is this even possible?

\[
2 \times \frac{TP}{TP + FN} \times \text{Precision} + \text{Precision} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
2 \left( \frac{TP}{TP + FN} \right) \cdot \text{Precision} + \text{Precision} = \frac{2 \cdot TP}{2 \cdot TP + FP + FN}
\]

\[
\text{Precision} = \frac{TP}{TP + FP}
\]

Dice coefficient
Is this even possible?

\[ 2 \ast \frac{TP}{TP + FN} \ast \frac{TP}{TP + FP} \]

\[ \text{Precision} = \frac{TP}{TP + FP} \]

\[ \frac{2 \ast TP}{2 \ast TP + FP + FN} \]
Is this even possible?

\[
2 \ast \frac{TP}{TP + FN} \ast \frac{TP}{TP + FP} + \frac{TP}{TP + FN} \frac{TP}{TP + FP} = \frac{2 \ast TP}{2 \ast TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
2 \times \frac{\frac{TP}{TP + FN}}{\frac{TP}{TP + FN}} \times \frac{TP}{TP + FP} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[ \frac{2 \times TP \times TP}{(TP + FN) \times (TP + FP)} = \frac{2 \times TP}{2 \times TP + FP + FN} \]

Dice coefficient
Is this even possible?

\[
2 \cdot \frac{TP \cdot TP}{(TP + FN) \cdot (TP + FP)} = \frac{2 \cdot TP}{2 \cdot TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[ \frac{2 \times TP}{2 \times TP + FP + FN} \]

Dice coefficient
Is this even possible?

\[
\begin{align*}
2^* & \frac{TP \times TP}{(TP + FN) \times (TP + FP)} \\
& \frac{TP \times (TP + FP) + TP \times (TP + FN)}{(TP + FN) \times (TP + FP)} \\
& = \frac{2 \times TP}{2 \times TP + FP + FN}
\end{align*}
\]

Dice coefficient
Is this even possible?

\[
\frac{2 \times TP}{2 \times TP + FP + FN} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even **possible**?

\[
\frac{2 \times TP}{\frac{TP \times TP}{(TP + FN) \times (TP + FP)}} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

**Dice coefficient**
Is this even possible?

\[
\frac{2 \times TP \times TP}{TP \times (TP + FP) + TP \times (TP + FN)} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]
Is this even possible?

\[
\frac{2 \times TP \times TP}{TP \times (TP + FP) + TP \times (TP + FN)} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
2 \times \frac{TP \times TP}{TP \times (TP + FP + TP + FN)} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
\frac{2 \times TP \times TP}{TP \times (TP + FP + TP + FN)} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even **possible**?

\[
\frac{2 \times TP \times TP}{TP \times (TP + FP + TP + FN)} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

**Dice coefficient**
Is this even possible?

\[
2 \times \frac{TP}{TP + FP + TP + FN} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
2 \times \frac{TP}{2 \times TP + FP + FN} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

Dice coefficient
Is this even possible?

\[
\frac{2 \times TP}{2 \times TP + FP + FN} \quad \text{F1-score}
\]

\[
= \frac{2 \times TP}{2 \times TP + FP + FN} \quad \text{Dice coefficient}
\]
Is this even possible?

\[
\frac{2 \times TP}{2 \times TP + FP + FN} = \frac{2 \times TP}{2 \times TP + FP + FN}
\]

F1-score

Dice coefficient
for class **red**

Recall = 0.0

Precision = NaN

**F1-score/Dice = NaN**

\[
F1/Dice = 2 \times \frac{Recall \times Precision}{Recall + Precision}
\]

for class **blue**

Recall = 1.0

Precision = 0.9

**F1-score/Dice = 0.947**

\[
F1/Dice = \frac{2 \times TP}{2 \times TP + FP + FN}
\]
for class red

Recall = 0.0

Precision = NaN

F1-score/Dice = NaN

\[
\text{F1/Dice} = 2 \times \frac{\text{Recall} \times \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \times \text{TP}}{2 \times \text{TP} + \text{FP} + \text{FN}}
\]
for class red

Recall = 0.0

Precision = NaN

F1-score/Dice = 0.0

\[
F1/Dice = 2 \cdot \frac{\text{Recall} \cdot \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \cdot \text{TP}}{2 \cdot \text{TP} + \text{FP} + \text{FN}}
\]
for class **red**

Recall = 0.0

Precision = **NaN**

F1-score/Dice = 0.0

for class **blue**

Recall = 1.0

Precision = 0.9

F1-score/Dice = 0.947
So far...
So far...

The good thing about accuracy is that it is easily interpretable.

Accuracy = 80%
So far...

**Accuracy** does not help to detect **lazy** (majority class) classifier

Both are dummy and can be harmful
So far…

**Confusion matrix** is a powerful tool to analyse the performance of machine learning algorithms.

One of the classes is completely ignored.
Recall and Precision can help summarise the confusion matrix.

Recall = \( \frac{TP}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

The total number of actual positive

The total number of points predicted as positive
Values of **Recall** and **Precision** depend on the definition of the “positive” class

Recall = 0.0

We correctly predicted 0% of actual positive cases

NaN% of all predicted positive were actually positive

Precision = NaN

Recall = 1.0

We correctly predicted 100% of actual positive cases

90% of all predicted positive were actually positive

Precision = 0.9
F1-score is a harmonic mean between recall and precision.

\[
\frac{2 \cdot \text{Recall} \cdot \text{Precision}}{\text{Recall} + \text{Precision}} = \frac{2 \cdot \text{TP}}{2 \cdot \text{TP} + \text{FP} + \text{FN}}
\]

F1-score is also known as the Dice coefficient.
Accuracy = 80%

Confusion matrix

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>FP</td>
</tr>
<tr>
<td>FN</td>
<td>TP</td>
</tr>
</tbody>
</table>

Recall = 1.0

Precision = 0.75

F1-score/Dice = 6/7
Can we please have just one number?
Can we please have just one number?
Let's assume that we have a classifier that assigned the following probabilities of a data point to be positive (i.e. blue)

A bit more balanced example

Can we please have just one number?
Can we please have just one number?

Let’s assume that we have a classifier that assigned the following probabilities of a data point to be positive (i.e. blue)
Can we please have just **one** number?

Let's assume that we have a classifier that assigned the following probabilities of a data point to be **positive** (i.e. **blue**)
Probability for the point to belong to positive class

Where these probabilities or scores come from?
Where these **probabilities** or **scores** come from?

**Probability** for the point to belong to **positive class**

Decision tree

[Graph showing points with probabilities]
Where these **probabilities** or **scores** come from?

**Probability** for the point to belong to **positive class**

What is the **probability** of this point to be **blue**?
Where these **probabilities** or **scores** come from?

**Probability** for the point to belong to **positive class**

What is the **probability** of this point to be **blue**?
Where these **probabilities** or **scores** come from?

The **Probability** for the point to belong to **positive class** is 0.9.

What is the **probability** of this point to be **blue**?

Decision tree

3/4
Where these **probabilities** or **scores** come from?

**Probability** for the point to belong to a **positive class**

What is the **probability** of this point to be **blue**?
Almost every **model** can output **probability** for each point to belong to a **certain class**

Where these **probabilities** or **scores** come from?

- Probability for the point to belong to **positive class**

What is the **probability** of this point to be **blue**?
Let’s assume that we have a classifier that assigned the following probabilities of a data point to be **positive** (i.e. **blue**).
Can we please have just one number?

Classifier scores (probabilities) of being positive:

Let's assume that we have a classifier that assigned the following probabilities of a data point to be positive (i.e. blue):
Can we please have just **one** number?

Classifier scores (probabilities) of bing **positive**:

0.9  0.8  0.7  0.6  0.5
Can we please have just **one** number?

Classifier scores (probabilities) of being **positive**:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Above what probability will we consider the point to be predicted as **positive**?
Can we please have just one number?

Classifier scores (probabilities) of being positive:

0.9  0.8  0.7  0.6  0.5

Above what probability we will consider point to be predicted as positive?

We shall consider all possible threshold values!
Can we please have just **one** number?

Classifier scores (probabilities) of being **positive**:

0.9  0.8  0.7  0.6  0.5

If probability is \( \geq 1.0 \) the data point is predicted **positive**.
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☺</td>
<td>☧</td>
<td>☦</td>
<td>☩</td>
</tr>
</tbody>
</table>

If probability is $\geq 1.0$ the data point is predicted positive.
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

\[ \geq 1.0 \]

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>⬜️</td>
<td>□</td>
<td>□</td>
<td>⬜️</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>0.8</td>
<td>🔄</td>
<td>✗</td>
</tr>
<tr>
<td>0.7</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>0.6</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>0.5</td>
<td>✓</td>
<td>✗</td>
</tr>
</tbody>
</table>

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>Threshold</th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

What are the values in the confusion matrix for such threshold?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th></th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Actual | Predicted
--- | ---
FN | TP
FP |
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Threshold</th>
<th>TN</th>
<th>FP</th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 1.0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

What are the values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Predicted

Actual

<table>
<thead>
<tr>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Can we please have just **one** number?

This threshold is associated with **one** point on this graph.

Classifier scores (probabilities) of bing **positive**:

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Blue Square]</td>
<td>![Red Circle]</td>
<td>![Blue Square]</td>
<td>![Blue Square]</td>
<td>![Red Circle]</td>
</tr>
</tbody>
</table>

Predicted

<table>
<thead>
<tr>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Actual

<table>
<thead>
<tr>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- >= 1.0
- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Actual

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Predicted

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Where is this point?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>True Positive Rate (TP/TP + FN)</th>
<th>False Positive Rate (FP/FP + TN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Where is this point?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

$\begin{array}{cccc}
0.9 & 0.8 & 0.7 & 0.6 & 0.5 \\
\end{array}$

Where is this point?

Actual
\begin{tabular}{|c|c|}
\hline
FN & 3 \\
\hline
\end{tabular}

Predicted
\begin{tabular}{|c|c|}
\hline
TN & 2 \\
FP & 0 \\
\hline
\end{tabular}
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th></th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where is this point?

Actual

Predicted

<table>
<thead>
<tr>
<th></th>
<th>TP</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

\[
\begin{array}{cccccc}
0.9 & 0.8 & 0.7 & 0.6 & 0.5 \\
\end{array}
\]

\[
\begin{array}{cc}
>= 1.0 \\
\end{array}
\]

$\geq 1.0$ threshold is associated with point (0,0) on this graph.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>0</td>
</tr>
<tr>
<td>FN</td>
<td>3</td>
</tr>
<tr>
<td>TP</td>
<td>0</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

TP/(TP + FN) ≥ 1.0
FP/(FP + TN)
Can we please have just **one** number?

Classifier scores (probabilities) of bing **positive**:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Time to choose another **threshold**. What it could be?
Can we please have just one number?

Classifier scores (probabilities) of being positive:

If probability is $\geq 0.9$ the data point is predicted positive.
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Probability</th>
<th>&gt;= 0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>✔️</td>
</tr>
<tr>
<td>0.8</td>
<td>✔️</td>
</tr>
<tr>
<td>0.7</td>
<td>✔️</td>
</tr>
<tr>
<td>0.6</td>
<td>✔️</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of being positive:

What are the new values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of bing **positive**:

<table>
<thead>
<tr>
<th></th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Actual</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

What are the new values in the confusion matrix for such **threshold**?
Can we please have just **one** number?

Classifier scores (probabilities) of bing **positive**:

![Confusion Matrix Diagram](image)

What are the new values in the confusion matrix for such **threshold**?

True Positive Rate

\[
\text{TP/(TP + FN)}
\]

False Positive Rate

\[
\text{FP/(FP + TN)}
\]
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th></th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What are the new values in the confusion matrix for such threshold?

True Positive Rate = TP / (TP + FN)

False Positive Rate = FP / (FP + TN)

Predicted

Actual

FP

FN

TP

2
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Probability</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 1.0</td>
<td>2</td>
<td>FN</td>
</tr>
<tr>
<td>&gt;= 0.9</td>
<td>0.9</td>
<td>TP</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
<td>TP</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>TP</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>TP</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>TP</td>
</tr>
</tbody>
</table>

What are the new values in the confusion matrix for such threshold?
Can we please have just **one** number?

What are the new values in the confusion matrix for such **threshold**?

Classifier scores (probabilities) of bing **positive**:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

- **True Positive Rate**: $\frac{TP}{TP + FN}$
- **False Positive Rate**: $\frac{FP}{FP + TN}$

Where $TP$ = True Positive, $FN$ = False Negative, $FP$ = False Positive, and $TN$ = True Negative.
Can we please have just one number?

Classifier scores (probabilities) of being positive:

>= 0.9

0.9 0.8 0.7 0.6 0.5

What are the new values in the confusion matrix for such threshold?

Predicted

Actual

FP

TP

2

2

0.5

0.6

0.7

0.8

0.9
Can we please have just one number?

Classifier scores (probabilities)
of bing positive:

>= 0.9

[0.9, 0.8, 0.7, 0.6, 0.5]

What are the new values in the confusion matrix for such threshold?

Predicted

Actual

0 2 0

2 2 TP
Can we please have just one number?

Classifier scores (probabilities) of bing **positive**:

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.9</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
</tr>
</tbody>
</table>

What are the new values in the confusion matrix for such **threshold**?

**Predicted**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Actual**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TP**
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

>= 0.9

What are the new values in the confusion matrix for such threshold?
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>True Positive Rate</th>
<th>False Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.9</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

What are the new values in the confusion matrix for such a threshold?

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FP</td>
</tr>
<tr>
<td></td>
<td>True Negative</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Actual

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Predicted

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>■</td>
<td>■</td>
<td>◯</td>
<td>■</td>
<td>◯</td>
</tr>
</tbody>
</table>

Where is this point?

True Positive Rate: $\frac{TP}{TP + FN}$

False Positive Rate: $\frac{FP}{FP + TN}$
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Predicted

<table>
<thead>
<tr>
<th>Actual</th>
<th>TP</th>
<th>FN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

True Positive Rate: \[ \frac{1}{1 + 2} \]

False Positive Rate: \[ \frac{0}{0 + 2} \]

Where is this point?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>TN</th>
<th>FP</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.7</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.6</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0.5</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Where is this point?
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Predicted:

<table>
<thead>
<tr>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

$\geq 0.9$ threshold is associated with point $(0, 1/3)$ on this graph.
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>TN</th>
<th>FP</th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

True Positive Rate: $\frac{1}{3}$
False Positive Rate: $0.5$
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

True Positive Rate: $\frac{TP}{TP + FN}$

False Positive Rate: $\frac{FP}{FP + TN}$
Can we please have just **one** number?

Classifier scores (probabilities) of being **positive**:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

If probability is $\geq 0.8$ the data point is predicted **positive**.
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

True Positive Rate: \( \frac{TP}{TP + FN} \)
False Positive Rate: \( \frac{FP}{FP + TN} \)

Actual:
- TN: 1
- FN: 2

Predicted:
- FP: 1
- TP: 1

 >= 0.8
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>➡️</td>
<td>1</td>
</tr>
<tr>
<td>0.8</td>
<td>➡️</td>
<td>1</td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

True Positive Rate: \( \frac{1}{(1 + 2)} \)

False Positive Rate: \( \frac{1}{(1 + 1)} \)
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Probability</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.8</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
</tr>
</tbody>
</table>

True Positive Rate

False Positive Rate

Predicted

Actual

TN 1
FP 1
FN 2
TP 1
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>&gt;= 0.8</td>
</tr>
<tr>
<td>0.6</td>
<td>&gt;= 0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>&gt;= 0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>&gt;= 0.9</td>
</tr>
<tr>
<td>0.9</td>
<td>&gt;= 1.0</td>
</tr>
</tbody>
</table>

Threshold of 0.8 is associated with point (1/2, 1/3) on this graph.

Actual

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Predicted

<table>
<thead>
<tr>
<th></th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Actual | Predicted
--- | ---
| TN | FP |
| 1 | 1 |
| FN | TP |
| 2 | 1 |
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

0.9  0.8  0.7  0.6  0.5

True Positive Rate: $\frac{TP}{TP + FN}$
False Positive Rate: $\frac{FP}{FP + TN}$

$\geq 1.0$ $\geq 0.9$ $\geq 0.8$
Can we please have just **one** number?

Classifier scores (probabilities) of bing **positive**: 

<table>
<thead>
<tr>
<th>Score</th>
<th>True Positive Rate</th>
<th>False Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>&gt;= 0.9</td>
<td>&gt;= 0.7</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Actual**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Predicted**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Graph**

- True Positive Rate: TP/(TP + FN)
- False Positive Rate: FP/(FP + TN)
- >= 0.7
- >= 0.8
- >= 0.9
- >= 1.0
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

\[ \begin{array}{cccc}
0.9 & 0.8 & 0.7 & 0.6 & 0.5 \\
\text{True Positive Rate} & \geq 0.7 & \\
\text{False Positive Rate} & \frac{1}{1+1} & \frac{1}{1+1} & \frac{1}{1+1} & \frac{1}{1+1} & \frac{1}{1+1} \\
\text{Actual} & \text{TN} & \text{FP} & \text{FN} & \text{TP} & \\
\text{Predicted} & \text{ } & \circ & \square & \text{ } & \\
\end{array} \]
Can we please have just **one** number?

Classifier scores (probabilities) of bing **positive**:

<table>
<thead>
<tr>
<th>Score</th>
<th>True Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>2/3</td>
</tr>
<tr>
<td>0.8</td>
<td>&gt;= 0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>&gt;= 0.8</td>
</tr>
<tr>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
</tr>
<tr>
<td>FP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
</tr>
<tr>
<td>TP</td>
</tr>
</tbody>
</table>

```
<table>
<thead>
<tr>
<th>Score</th>
<th>True Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>2/3</td>
</tr>
<tr>
<td>0.8</td>
<td>&gt;= 0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>&gt;= 0.8</td>
</tr>
<tr>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
```
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

True Positive Rate: \( \frac{TP}{TP + FN} \)

False Positive Rate: \( \frac{FP}{FP + TN} \)
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

True Positive Rate: \[\frac{TP}{TP + FN}\]

False Positive Rate: \[\frac{FP}{FP + TN}\]
Can we please have just one number?

Classifier scores (probabilities) of being positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>TN</th>
<th>FP</th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

True Positive Rate: 3/(3 + 0)
False Positive Rate: 1/(1 + 1)
Can we please have just one number?

Classifer scores (probabilities) of bing positive: 

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

True Positive Rate

False Positive Rate

Predicted

Actual

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>TP</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.6</td>
<td>[0.9, 0.8, 0.7, 0.6, 0.5]</td>
</tr>
</tbody>
</table>

Actual:

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>1</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
</tr>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TP</td>
<td>3</td>
</tr>
</tbody>
</table>

True Positive Rate: 1
False Positive Rate: 1/2
Can we please have just **one** number?

**Classifier scores (probabilities) of bing positive:**

<table>
<thead>
<tr>
<th>Probability</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>&gt;= 0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>&gt;= 0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>&gt;= 0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>&gt;= 0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

![Graph showing ROC curve with threshold values and classifier scores]
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- >= 1.0
- >= 0.9
- >= 0.8
- >= 0.7
- >= 0.6

Legend:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Legend:

- True Positive Rate $\frac{TP}{TP + FN}$
- False Positive Rate $\frac{FP}{FP + TN}$

Graph:

- Points for classifier scores
- Grid for True Positive Rate and False Positive Rate
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th></th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Actual

<table>
<thead>
<tr>
<th>FN</th>
<th>0</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Predicted

<table>
<thead>
<tr>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Probability</th>
<th>True Positive Rate</th>
<th>False Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>3/3 = 1.0</td>
<td>2/2 = 1.0</td>
</tr>
<tr>
<td>0.8</td>
<td>3/3 = 1.0</td>
<td>2/2 = 1.0</td>
</tr>
<tr>
<td>0.7</td>
<td>3/3 = 1.0</td>
<td>2/2 = 1.0</td>
</tr>
<tr>
<td>0.6</td>
<td>3/3 = 1.0</td>
<td>2/2 = 1.0</td>
</tr>
<tr>
<td>0.5</td>
<td>3/3 = 1.0</td>
<td>2/2 = 1.0</td>
</tr>
</tbody>
</table>

Actual

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TN</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>2</td>
</tr>
<tr>
<td>TP</td>
<td>3</td>
</tr>
</tbody>
</table>
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

Predicted

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

True Positive Rate

False Positive Rate
Can we please have just one number?

Classifier scores (probabilities) of bing positive:

<table>
<thead>
<tr>
<th>Score</th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Actual

<table>
<thead>
<tr>
<th></th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
Can we please have just **one** number?

Let's connect these points with a **line**.
Can we please have just one number?

Let's connect these points with a line.
Can we please have just one number?

Let's connect these points with a line
Can we please have just one number?

Let's connect these points with a line.
Can we please have just **one** number?

Let's connect these points with a **line**
Can we please have just one number?

Let's connect these points with a line.
Can we please have just one number?

This line is called Receiver Operating Characteristic.
Can we please have just one number?

This line is called the Receiver Operating Characteristic.
Can we please have just **one** number?

This **line** is called **ROC curve**
Can we please have just one number?

True Positive Rate

\[
\frac{TP}{TP + FN}
\]

False Positive Rate

\[
\frac{FP}{FP + TN}
\]

This line is called ROC curve.
Can we please have just **one** number?

This line is called **ROC curve**
Can we please have just one number?

This line is called ROC curve

Different thresholds

True Positive Rate

\[ \frac{TP}{TP + FN} \]

False Positive Rate

\[ \frac{FP}{FP + TN} \]
ROC itself is not meaningful, the area under this curve is what we are after.

This line is called ROC curve.
ROC itself is not meaningful, the area under this curve is what we are after.

This line is called ROC curve.
ROC itself is not meaningful, the area under this curve is what we are after.

Let's compute the area under the curve (AUC).
ROC itself is not meaningful, the area under this curve is what we are after.

Let’s compute the area under the curve (AUC)
**ROC** itself is not meaningful, the **area under this curve** is what we are after.

Let's compute the **area under the curve (AUC)**

We are interested in the area of this **polygon**
ROC itself is not meaningful, the area under this curve is what we are after.

In the meantime we know that the area of this square is $1 \times 1 = 1$.

Let's compute the area under the curve (AUC).
In the meantime we know that the area of this square is $1 \times 1 = 1$. 

Area is $\ ?$
ROC itself is not meaningful, the area under this curve is what we are after.

Let's compute the area under the curve (AUC).

How to find this area?

We are interested in the area of this polygon.

True Positive Rate: $\frac{TP}{TP + FN}$

False Positive Rate: $\frac{FP}{FP + TN}$

We are interested in the area of this polygon.
ROC itself is not meaningful, the area under this curve is what we are after.
ROC itself is not meaningful, the **area under** this **curve** is what we are after.

Let's compute the **area under** the **curve** (AUC).

We are interested in the area of this polygon.

How to find this **area**?

\[
\text{True Positive Rate} = \frac{\text{TP}}{\text{TP} + \text{FN}} \\
\text{False Positive Rate} = \frac{\text{FP}}{\text{FP} + \text{TN}}
\]

1/3
1/2
2/3
>= 1.0
>= 0.9
>= 0.7
>= 0.6
>= 0.5
>= 0.4
>= 0.3
>= 0.2
>= 0.1
0
0
0.5
1
0
1
1.0

False Positive Rate
FP/(FP + TN)
We are interested in the area of this **polygon**.
ROC itself is not meaningful, the area under this curve is what we are after.

Let's compute the area under the curve (AUC).

We are interested in the area of this polygon:

\[ \frac{1}{2} \times \frac{2}{3} \]

\[ \frac{1}{3} \times \frac{1}{2} \]
ROC itself is not meaningful, the area under this curve is what we are after.

Let’s compute the area under the curve (AUC).

We are interested in the area of this polygon.
In the meantime we know that the area of this square is \(1 \times 1 = 1\).
In the meantime we know that the area of this square is $1 \times 1 = 1$.

Area is $1/3$

Area is $2/3$
In the meantime we know that the area of this square is $1 \times 1 = 1$

Area is 0.33

Area is 0.66
ROC itself is not meaningful, the area under this curve is what we are after.

Let's compute the area under the curve (AUC).
ROC itself is not meaningful, the area under this curve is what we are after.

**AUC** is a measure from 0 to 1.
ROC itself is not meaningful, the area under this curve is what we are after

True Positive Rate
\[
\frac{TP}{TP + FN}
\]

False Positive Rate
\[
\frac{FP}{FP + TN}
\]

Area of 1.0 is a perfect classifier

AUC is a measure from 0 to 1
ROC itself is not meaningful, the area under this curve is what we are after.

AUC is a measure from 0 to 1.

Area of 0.5 is a random classifier.
True Positive Rate
\[ \frac{TP}{TP + FN} \]

False Positive Rate
\[ \frac{FP}{FP + TN} \]

Area of 0.5 is a random classifier

Area is 0.66
So our classifier is better than random
(AUC 0.66 > AUC 0.5)
So our **classifier** is better than **random**

(AUC 0.66 > AUC 0.5)

Hey! Did not you say that **being better than random** is **not enough**? Would **AUC** help to detect **majority** class prediction?
Coming back to unbalanced example
Coming back to unbalanced example

What do you think are classifier scores in this case?
What do you think are classifier scores in this case?

Scores are the same and usually very high (1.0) for each point.
What do you think are classifier scores in this case?
What do you think are classifier scores in this case?

If score is $\geq 1.0$ the data point is predicted **positive**.
What do you think are classifier scores in this case?

If score is $\geq 1.0$ the data point is predicted \textit{positive}

\[
\begin{array}{c|c|c}
\text{Actual} & \text{Predicted} & \text{True Positive Rate} \\ 
\hline 
\text{TN} & ? & \frac{TP}{TP + FN} \\ 
\text{FP} & ? & \frac{FP}{FP + TN} \\ 
\text{FN} & ? & \\ 
\text{TP} & ? & \\
\end{array}
\]
What do you think are classifier scores in this case?

If score is $\geq 1.0$ the data point is predicted positive.
What do you think are classifier scores in this case?

If score is \( \geq 1.0 \) the data point is predicted positive.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>0</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
</tr>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TP</td>
<td>9</td>
</tr>
</tbody>
</table>
What do you think are classifier scores in this case?

If score is $\geq 1.0$ the data point is predicted \textit{positive}.
What do you think are classifier **scores** in this case?

What other thresholding option we can use?
What do you think are classifier scores in this case?

If score is $> 1.0$ the data point is predicted **positive**
What do you think are classifier **scores** in this case?

If score is $\geq 1.0$ the data point is predicted **positive**.
What do you think are classifier scores in this case?

If score is $> 1.0$ the data point is predicted **positive**

True Positive Rate

$\frac{TP}{TP + FN}$

False Positive Rate

$\frac{FP}{FP + TN}$
What do you think are classifier scores in this case?

If score is > 1.0 the data point is predicted **positive**

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FN</td>
<td>9</td>
</tr>
<tr>
<td>TP</td>
<td>0</td>
</tr>
<tr>
<td>TN</td>
<td>1</td>
</tr>
<tr>
<td>FP</td>
<td>0</td>
</tr>
</tbody>
</table>

True Positive Rate: \[
\frac{TP}{TP + FN}
\]

False Positive Rate: \[
\frac{FP}{FP + TN}
\]
What do you think are classifier scores in this case?

1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0

If score is > 1.0 the data point is predicted positive

Predicted

<table>
<thead>
<tr>
<th>Actual</th>
<th>TN</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual</th>
<th>FN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>
What do you think are classifier scores in this case?

If score is $> 1.0$ the data point is predicted **positive**

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>TN</td>
<td>FP</td>
</tr>
<tr>
<td>FN</td>
<td>TP</td>
</tr>
</tbody>
</table>

True Positive Rate 0
False Positive Rate 0
True Positive Rate
\( \frac{TP}{TP + FN} \)

False Positive Rate
\( \frac{FP}{FP + TN} \)

\( >= 1.0 \)

\( > 1.0 \)
True Positive Rate: \( \frac{TP}{TP + FN} \)

False Positive Rate: \( \frac{FP}{FP + TN} \)

Graph shows the relationship between True Positive Rate and False Positive Rate.
True Positive Rate = \( \frac{TP}{TP + FN} \)

False Positive Rate = \( \frac{FP}{FP + TN} \)

ROC

\( > 1.0 \)

\( \geq 1.0 \)
True Positive Rate

$$\frac{TP}{TP + FN}$$

False Positive Rate

$$\frac{FP}{FP + TN}$$

ROC

$$\geq 1.0$$

$$> 1.0$$
True Positive Rate \[\frac{TP}{TP + FN}\]

False Positive Rate \[\frac{FP}{FP + TN}\]

AUC is 0.5

ROC
If AUC is close to 0.5 the classifier should not be trusted
If AUC is close to 0.5 the classifier should not be trusted.

AUC is 0.5

Our classifier:

Area is 0.66
What if you have **multiclass** classification?
What if you have **multiclass** classification?

Things get more interesting…
What if you have **multiclass** classification?

![Diagram of a classifier and a confusion matrix](image)
What if you have **multiclass** classification?

Classifiers X

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 1 0</td>
</tr>
<tr>
<td>0 3 0 0</td>
<td></td>
</tr>
<tr>
<td>0 1 1 1</td>
<td></td>
</tr>
</tbody>
</table>
Confusion matrix remains informative for multiclass problems.
How do you calculate **recall**, **precision** and **F1-score**?
How do you calculate **recall**, **precision** and **F1-score**?

First fix your “positive” class.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
How do you calculate recall, precision and F1-score?
How do you calculate **recall**, **precision** and **F1-score**?

First fix your “**positive**” class.

![Diagram showing a classifier and a confusion matrix](image.png)
How do you calculate recall, precision and F1-score?

First fix your “positive” class.
How do you calculate recall, precision and F1-score?

Recall = \( \frac{TP}{TP + FN} \)

Precision = \( \frac{TP}{TP + FP} \)

F1 = \( \frac{2 \times (\text{Recall} \times \text{Preciision})}{\text{Recall} + \text{Precision}} \)

First fix your “positive” class.

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{FP} )</td>
<td>0</td>
</tr>
<tr>
<td>( \text{TN} )</td>
<td>5</td>
</tr>
<tr>
<td>( \text{TP} )</td>
<td>1</td>
</tr>
<tr>
<td>( \text{FN} )</td>
<td>1</td>
</tr>
</tbody>
</table>
First fix your "positive" class

<table>
<thead>
<tr>
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<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>FN</td>
</tr>
<tr>
<td>FP</td>
<td>TN</td>
</tr>
</tbody>
</table>

You can also compute ROC/AUC for each class

- TP (True Positive) = 1
- FN (False Negative) = 1
- FP (False Positive) = 0
- TN (True Negative) = 5
So far...

Accuracy = 80%

Confusion matrix

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>TN</td>
<td>1</td>
</tr>
<tr>
<td>FP</td>
<td>1</td>
</tr>
<tr>
<td>FN</td>
<td>0</td>
</tr>
<tr>
<td>TP</td>
<td>3</td>
</tr>
</tbody>
</table>

Recall = 1.0

Precision = 0.75

F1-score/Dice = 6/7
So far...

Classifier $\mathbf{X}$

AUC is 0.66
So far…

Area of 1.0 is a **perfect** classifier

AUC is 1
So far…

**True Positive Rate**
\[
\frac{TP}{TP + FN}
\]

**False Positive Rate**
\[
\frac{FP}{FP + TN}
\]

**Area of 1.0 is a perfect classifier**

If AUC is close to **0.5** the classifier should not be trusted

AUC is **1**

AUC is **0.5**
So far…

**ROC (AUC)** is not necessarily instead of other metrics (accuracy, recall, confusion matrix etc). It can be used **in addition**.
That's all Folks!