1 Face detection

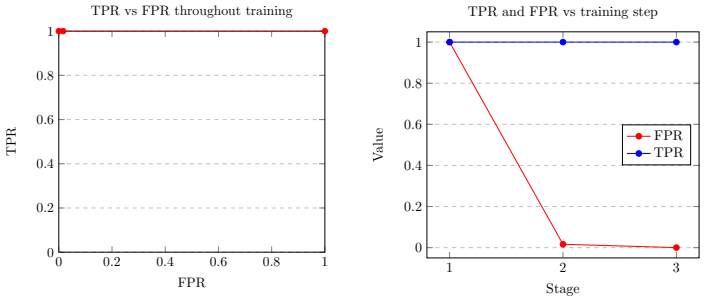
TOGO Limitation of TPR. Difficult to define "true" values. The bouding region of a face is discrete and we may choose not to detect side on faces. Example below shows 2 possible "true" values for a detection. One give a IOU of under 0.7 but the other gives over 0.9.

Figure 1: Viola-Jones face detection (green) with ground truth (red)

Frontal face detection results		
Image name	TPR	F1-SCORE
dart4	1	1
dart5	1	0.88
dart13	1	0.666667
dart14	1	0.5
dart15	1	0

The results show that the true positivity rate, TPR, for all images is 1. Despite this we often see far lower F1 scores. This reveals the limitation of the TPR as a detector can always achieve a high TPR by having a low tolerance to classify something as a face. This would result in a very low F1 score as many false positives would arise yet the true positivity rate would remain high.
The image dart-15 reveals another limitation of these metrics. It can often to difficult to classify the ground truth. This classifier was created to detect frontal faces and therefore in dart15 I have claimed no frontal face present. Despite this the classifier has detected on of the faces brining its F1 score down. Similarly there is no clear boundry for a face and therefore the exact area that should be detected can vary resulting in the need for a larger tolerance for the intersection over area, IOU.

2 Dart board detection



2
Figure ?? shows the change in FPR and TPR throughout the training process. At the beginning of the training all images are accepted throughout the stages more layers are added to the cascade. Each layer will remove of the regions classified as a dart board. This results in a drop in FPR as the training takes place. Throughout the training process the TPR remains and 1. However if more layers were added (and therefore the classifier removed more classified regions) then the TPR could also be reduced. This could still result in the classifiers F1 score increasing as the FPR would also be decreasing.

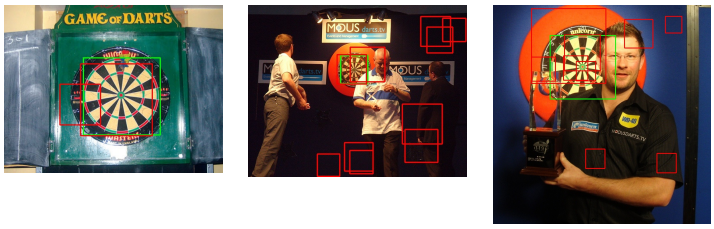


Figure 2: Viola-Jones dartboard detection with true values

Frontal face detection results		
Image name	TPR	F1-SCORE
dart1	1	0.666667
dart2	1	0.25
dart3	1	0.4
dart4	0	0
dart5	0	0
dart6	1	0.181818
dart7	0	0
dart8	0	0
dart9	0	0
dart10	0	0
dart11	0	0
dart12	0	0
dart13	0	0
dart14	0	0
dart15	1	0.5
Average	0.333333	0.133232

Table 1: Viola-Jones face detection (green) with ground truth (red)
The average values in Table 2, show the unreliable results of the cascade for detecting dart boards. It not only has a very

low TPR and also a very low F1-score suggesting there are many missed dart boards as well as regions falsely classified. The images in Figure 2 show the wide range of results from the classifier. a and b show successful classifications yet b and c show the high number of false positives. It is also noteworthy that the TPR values achieved during training were far higher than the average achieved during testing. This is as a result of the method used to generate positive images. These took one image of a dart board and generated variations (via movements/rotations) on that image. This means when classifying different types of dartboards of those with objects in the way (such as 2 c) the classifier performs far worse.

3 Combining Viola-Jones with hough circle detection

From the above section it is clear that the Viola Jones detector is not well suited to detecting dart boards and especially not to detecting the circular shape of the dart board. In order to overcome this limitation the results from the Viola-Jones detector can be combined with a circle hough transform. This circle hough transform can then be used to shrink the results set and increase the F1 score of the detector. The combination step is as follows:

- Run Viola-Jones and hough circles.
- For every Viola-Jones results find the maximum IOU with the circles from hough.
- If the IOU is greater than a specified threshold (0.4 in this case) add results from the hough to the set of final results.

The use of IOU with hough resulted in a large reduction in the set of results. For the required IOU a relatively low threshold was chosen (0.4) as often the Viola-Jones detector would find a section of the dart board (matching the expected pattern) but no the circle. For this reason the final result used the bounding box from the hough circle rather than the Viola-Jones detector as this was more likely to encompass the full dartboard. This removed many of the original Viola-Jones false positives and therefore increased the F1-score dramatically. However the limitation of this approach are clear in **??** which shows the circle detector failing to detect circles with large angles to the camera or with objects blocking sections of the circle. This can result in a reduction in the TPR rate of the overall detector in exchange for the reduction in the number of false positives.

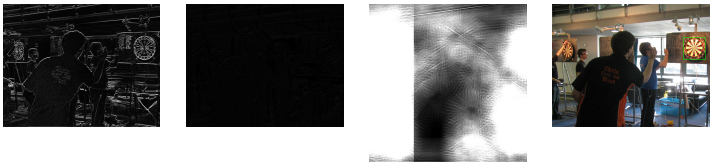


Figure 3: Hough circle detection on dart8.jpg

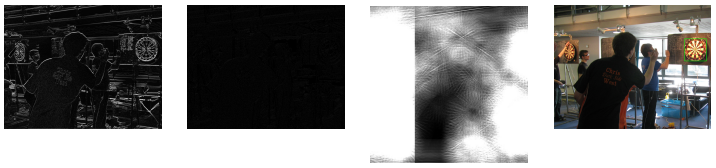


Figure 4: Hough circle detection on dart8.jpg

Frontal face detection results				
Image name	TPR	F1	Δ TPR	Δ F1
dart1	1	1		
dart2	1	0.5		
dart3	1	0.5		
dart4	0	0		
dart5	1	1		
dart6	0	0		
dart7	1	0.5		
dart8	0.5	0.666667		
dart9	0	0		
dart10	0	0		
dart11	0.333333	0.5		
dart12	0	0		
dart13	1	0.4		
dart14	1	0.5		
dart15	1	1		
Average	0.333333	0.133232		

Table 2: Viola-Jones face detection (green) with ground truth (red)