The Dartboard Challenge

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ABSTRACT

In subtask 1 we ran the existing Viola-Jones detector to find faces in the image. We then go on to train our own Viola-Jones detector on samples of a dartboard in subtask 2. This yielded a high true positive rate but also a high false positive rate, leading to a low F1-score. To improve the F1-score in subtask 3 we combined the Viola-Jones detector with the circle Hough transform to reduce the number of false positives and therefore increase the F1-score.

Subtask 1: The Viola-Jones Object Detector

The picture below shows the ground truths (annotated as green bounding boxes) and the faces detected (annotated as the red bounding boxes):

(a) Faces 4 **(b)** Faces 5 **(c)** Faces 13 **(d)** Faces 14 **(e)** Faces 15

Figure 1. Annotation of ground truths and detections of faces using Viola-Jones

The true positive rates (TPRs) for the five images are shown in tabular form below, in particular the TPRs for faces 5 and faces 15 are 0.818 and 0.333 respectively. The true positive rate is hard to calculate accurately because there is ambiguity in the ground truth. It is not clear what defines a face, whether the bounding box should just surround the eyes, mouth and nose or whether features like the ears and forehead should be included. This becomes even more difficult for side profile faces, such as in faces 15. To evaluate the true positive rate we calculated the intersection over union (IoU) between the ground truth and detected bounding boxes. We set the threshold to the conventional value of 0.5, resulting in some seemingly correct detections to fall just below the threshold. In faces 5, IoU values of around 0.48 caused the TPR to be lower than expected.

	Faces 4	Faces 5	Faces 13	Faces 14	Faces 15	Average
TPR	1	0.818	1	1	0.333	0.830
F1-score	1	0.720	0.667	0.5	0.286	0.635

$$\text{F1-score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (1)$$

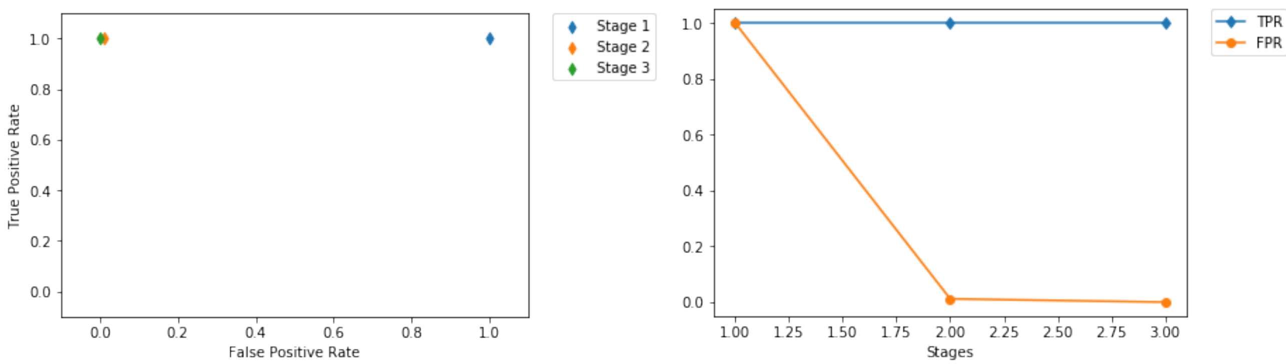
Where precision is the number of correct positives divided by the total number of positives and recall is just the TPR.

If a detector detects faces everywhere in the picture then all faces will be successfully detected so the true positive rate would be 100%, however the false positive rate would be extremely high so this detector would have no practical use.

Subtask 2: Building & Testing our own Detector

$$\mathrm{TPR} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}} \qquad \mathrm{FPR} = \frac{\mathrm{FP}}{\mathrm{FP}+\mathrm{TN}} \tag{2}$$

The figures below shows the TPR and FPR after each stage of training the strong classifier. Each stage of training adds further Haar-like features to the classifier, which reduces the FPR rapidly.



(a) Scatter plot showing TPR against FPR

(b) Line graph showing TPR and FPR

Figure 2. Graphs showing how TPR and FPR change after each stage of training

(a) Dart 1

(b) Dart 3

(c) Dart 11

(d) Dart 12

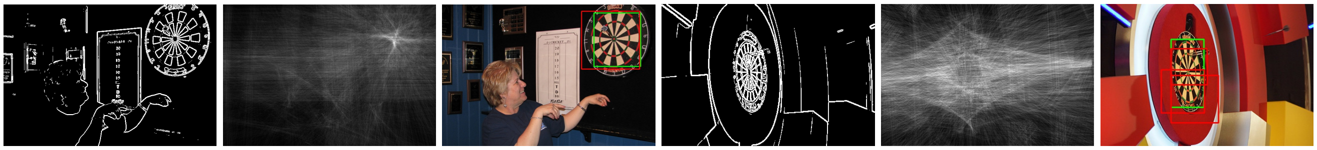
Figure 3. Annotation of ground truths and detections of dartboards using Viola-Jones

The average TPR in part b was 61.5%, this is lower than in part a which was 100%. The FPR in part b would be much higher than in part a because there are many false positives. The performance in part b is clearly worse than in part a.

	Dart 0	Dart 1	Dart 2	Dart 3	Dart 4	Dart 5	Dart 6	Dart 7
F1-score	0.333	0.5	0.4	0.333	0.667	0.333	0	0

Dart 8	Dart 9	Dart 10	Dart 11	Dart 12	Dart 13	Dart 14	Dart 15	Average
0	0.4	0.111	0.667	0	0	0.0952	0.5	0.325

Subtask 3: Integration with Shape Detectors



(a) Thresholded magnitude 0 **(b)** Circle Hough space 0 **(c)** Improved detections 0 **(d)** Thresholded magnitude 12 **(e)** Circle Hough space 12 **(f)** Improved detections 12

Figure 4. Images showing the result of the Sobel filter, circle Hough Transform and also annotation of ground truths and detections of dartboards using our combined detector

Our average F1-score after combining Viola-Jones with the circle Hough Transform is 0.470, calculated by our function with a recall of 0.552 and precision of 0.409. The increased precision is due to removing Viola-Jones detections which do not have bright pixels in the Hough space.

	Dart 0	Dart 1	Dart 2	Dart 3	Dart 4	Dart 5	Dart 6	Dart 7
F1-score	1	0.5	0.667	1	1	0.667	0	0

Dart 8	Dart 9	Dart 10	Dart 11	Dart 12	Dart 13	Dart 14	Dart 15	Average
0	1	0.286	0	0	0	0.4	1	0.470

Merits

- Images of circular dartboards (front profile) produce good results
- Improved F1-score due to a reduced number of false positives
- Fast runtime due to limiting the angles which need to be searched
- Noisy images can be dealt because of Gaussian blurring step
- Partially obscured dartboards can still be detected

Limitations

- Images of elliptical dartboards (taken at an angle) produce worse results
- If Viola-Jones outputs no detections, then our combined detector will also output no detections
- Detections with too small or too large bounding boxes don't always get removed
- Rarely, but in one case a true positive gets removed, reducing the TPR

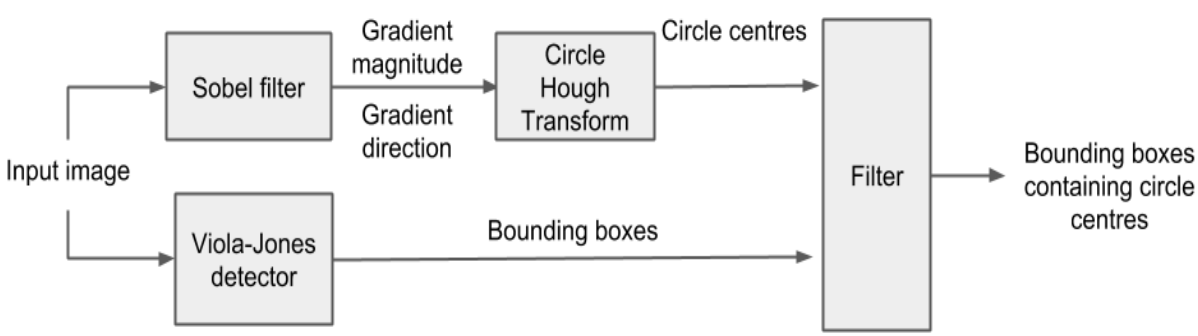


Figure 5. Flow chart depicting how we combined evidence from the Hough Transform and Viola-Jones detector to build an improved detector

The rationale behind the way we combined our evidence was based on trying to increase the F1-score by reducing the number of false positives. We filtered out false positives by checking inside each bounding box in the circle Hough Space for the brightest points, those with high votes (above a threshold), and throwing away bounding boxes that surrounded areas with low votes.

Subtask 4: Improving our Detector

If we had more time to improve our detector we could have used an alternative feature descriptor, instead of Haar-like. For example the Histograms of Oriented Gradients (HOG) feature descriptor may have performed better than Haar-like on dartboards, because it is designed for general purpose object detection. HOG represents objects as a single feature vector rather than a set of feature vectors that represent a segment of the image. Other feature detectors include Scale-invariant feature transform (SIFT) and Speeded up robust features (SURF).

Another approach we could have taken would be to integrate not only the circle Hough Transform but also the line Hough Transform. We chose to use the circle Hough Transform because we thought this was a better identifying feature of dartboards, whereas lines (or even intersecting lines) are more likely to appear elsewhere in the image. Despite this, the addition of using the line Hough Transform would help to detect dartboards that were elliptical rather than circular due to the image being taken at an angle.

Increasing the number of samples of a dartboard than we trained the Viola-Jones detector on from 500 to 1000 decreased the FPR so, in theory, we could have trained on a much larger number for better results, however this was not practical due to the time it would have taken.