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Abstract

Recent work by Isola et. al. (2011) has demonstrated that memorability is an intrinsic property of images that is consistent across viewers and can be predicted accurately with current computer vision techniques. Despite progress, a clear understanding of the specific components of an image that drive memorability are still unknown. While previous studies such as Khosla et. al. (2012) have tried to investigate computationally the memorability of image regions within individual images, no behavioral study has systematically explored which memorability of image regions. Here we study which region from an image is memorable or forgettable. Using a large image database, we obtained the memorability scores of the different visual regions present in every image. In our task, participants viewed a series of images, each of which were displayed for 1.4 seconds. After the sequence was complete, participants similarly viewed a series of image regions and were asked to indicate whether each region was seen in the earlier sequence of full images.

1. Introduction

Consider the image and its corresponding objects in Figure 1. Even though the person on the right is comparable in size to the left person, he is remembered far less by humans (indicated by their memorability scores of 0.18 and 0.64 respectively). People tend to remember the fish in the center and the person on the left, even after 30 minutes have passed (memorability score = 0.64). Interestingly, despite vibrant colors and considerable size, the boat is also remembered far less by humans (memorability = 0.18).

Just like aesthetics, interestingness, and other metrics of image importance, memorability quantifies something about the utility of a photograph toward our everyday lives. For many practical tasks, memorability is an especially desirable property to maximize. For example, this may be the case when creating educational materials, logos, advertisements, book covers, websites, and much more. Understanding memorability, and being able to automatically predict it,

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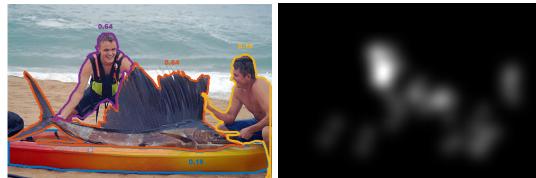


Figure 1: Not all objects are equally memorable. Figure (left) showing how objects in an image have different memorability scores and how this memorability differs from traditional saliency (right). For example, even humans look at the person on the right and find it salient, it's memorability is quite low.

lends itself to a wide variety of applications in each of these areas. Due to this, automatic prediction of intrinsic memorability of images using computer vision and machine learning techniques has received considerable attention in the recent years [5], [6], [4], [2], [7]. While these studies have shed light on what distinguishes the memorability of different images and the intrinsic and extrinsic properties that make those images memorable, the above example raises an interesting question: what exactly about an image is remembered? Despite progress in the computer vision literature on image memorability, a clear understanding of the memorability of the specific components of an image is still unknown. For example, not all objects in an image will be equally remembered by people and as the figure 1 seems to suggest, there exists significant and interesting differences in memorability of objects in an image. Furthermore, the memorability of complex images may be principally driven by the memorability of its objects. Can specific objects inside images be memorable to all us and how can we better understand what makes those objects more memorable?

In this paper, we systematically explore the memorability of objects within individual images and shed light on the various factors and properties that drive object memorability by augmenting both the images and object segmentations in the 850 existing images from PASCAL 2010 [3] dataset with memorability scores and class labels. By exploring the connection between object memorability,

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saliency, and image memorability, our paper makes several important contributions.

Firstly, we show that just like image memorability, object memorability is a property that is shared across subjects and objects remembered by one person are also likely to be remembered by others and vice versa. Secondly, we show that there exists a strong correlation between visual saliency and object memorability and demonstrate insights when can visual saliency directly predict object memorability and when does it fail to do so. While there have been a few studies that explore the connection between image memorability and visual saliency [2], [11], our work is the first to explore the connection between object memorability and visual saliency. Third, we explore the connection between image memorability and object memorability and show that the most memorable object inside an image can be a strong predictor of image memorability in certain cases. Studying these questions, help not only understand visual saliency, image and object memorability in more detail, but it can also have important contributions to computer vision. For example, understanding which regions and objects in an image are memorable would enable us to modify the memorability of images which can have applications in advertising, user interface design etc. With this in mind, as shown in the section 4, our proposed dataset serves as a benchmark for evaluating object memorability model algorithms and can help usher in future algorithms that try to predict memorability maps.

1.1. Related works

Image Memorability: Describe Isola's first paper n some insights that have been raised on image memorability thus far. Also describe Khosla's comp model but we are the first work to actually describe what humans actually remember and don't

Visual Saliency: Talk about visual attention and models that have been proposed. Also, talk about Pascal-S and how it has helped reduce dataset bias

Saliency and memorability: discuss some results related to saliency and image memorability.

and talk about our work plans on connecting and shedding light on all these phenomena together.

2. Measuring Object Memorability

As a first step towards understanding memorability of objects, we built an image database containing a variety of objects from a diverse range of categories, and measured the probability that every object in each image will be remembered by a large group of subjects after a single viewing. This helps provide ground truth memorability scores for the objects inside the images and allows for a precise analysis of the memorable elements within an image. For this task, we utilized the PASCAL-S dataset [8], a fully segmented



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Figure 2: Example stimuli from the memory game. Example filler, familiar, and control images and objects.

dataset built on the validation set of the PASCAL VOC 2010 [3] segmentation challenge. For improved segmentation purposes, we manually cleaned up and refined the segmentations from this dataset. While building the improved ground-truth of full segmentation, we removed all homogeneous non-object or background segments such as ground, grass, floor, sky etc, as well as imperceptible object fragments and excessively blurred regions. All remaining object segmentations were tested for memorability. In the end, our final dataset consisted of 850 images and 3414 object segmentations i.e. on average each image consisted of approximately 4 segments for which we gathered the ground truth memorability on.

2.1. Memory Game: Measuring Object Memorability

To measure the memorability of individual objects from our dataset, we created an alternate version of the Visual Memory Game following the basic design in [5], with the exception of a few key differences. We administered the game and collected data through Amazon Mechanical Turk. In our game, participants first viewed a sequence of images one at a time, with a 1.5 second gap in between image presentations. Subjects were asked to remember the contents and objects inside those images as much as they could. To ensure that subjects would not just only look at the salient or center objects, subjects had unlimited time to freely view the images. Once they were done viewing an image, they could press any key to advance to the next image. Following the initial image sequence, participants then viewed a sequence of objects, their task then being to indicate through a key press which of those objects was present in one of the previously shown images. Each object was displayed for 1.5 second, with a 1.5 second gap in between the object sequences. Pairs of corresponding image and object sequences were broken up into 10 blocks. Each block consisted of 80 total stimuli (35 images and 45 objects), and lasted approximately 3 minutes. At the end of each block, the subject could take a short break. Overall, the experiment took approximately took 30 minutes to complete.

Unknown to the subjects, inside each block, each sequence of images was pseudo-random and consisted of 3

'target' images taken from the Pascal-S dataset whose objects the participants were to later identify. The remaining images in the sequence consisted of 16 'filler' images and 16 'familiar' images. The 'filler' images were randomly selected from the DUT-OMRON dataset [12] and the 'familiar' images were randomly sampled from the MSRA dataset proposed in [10]. Similarly, the object sequence was also pseudo-random and consisted of 3 'target' objects (1 object taken randomly from each previously shown target image). The remaining objects in the sequence consisted of 10 'control' objects, 16 'filler' objects, and 16 'familiar' objects. The 'filler' objects were taken randomly from the 80 different object categories in the Microsoft COCO dataset [9] and the 'familiar' objects were the objects taken from the previously displayed 'familiar' images in the image sequence. The filler images and objects helped provide spacing between the target images and target objects, whereas the familiar images and objects allowed us to check if the subjects were paying attention to the task [1], [5]. While the fillers and familiars (both the images and objects) were taken from datasets resembling real world scenes and objects, the 'control' objects were artificial stimuli randomly sampled from the dataset proposed in [1] and helped serve as an additional control to test the attentiveness of the subjects. Repeats on targets i.e. the target images and target objects were spaced 70 – 79 stimuli apart, and repeats occurred on the familiars with a spacing of 1 – 79 stimuli (i.e. distance between familiar images and their objects). The images and objects appeared only once, and each subject was tested on only one object from each target image. Objects were centered within their parent frame and non-object pixels were set to grey. Participants were required to complete the entire task, which included 10 blocks (overall time approximately 30 minutes), and could not participate in the experiment a second time. After collecting the data, we assigned a 'memorability score' to each target object in our dataset, defined as the percentage of correct detections by subjects. In all our analysis, we removed all subjects whose accuracy on the control objects was below 75% and below 50% on familiar images/objects. A total of 2000 workers from Mechanical Turk ($> 95\%$ approval rate in Amazons system) performed the game and on average each object was scored by 20 subjects.

2.2. Is object memorability a shared property across subjects?

Previous work on image memorability has found human consistency to be fairly high. That is, people tend to remember the same images, and exhibit similar performance in doing so. Despite variability due to individual differences and other sources of noise, this level of consistency provides evidence that memorability is an intrinsic property of images that can be predicted. In contrast to full images,

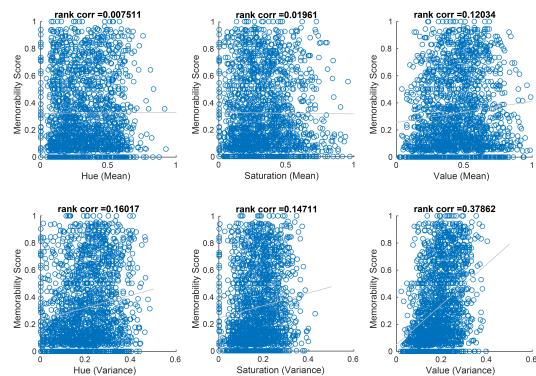


Figure 3: **Correlations between simple color features and object memorability.** Color features were computed from HSV representations of the objects.

this paper focuses primarily on the memorability of individual objects in an image, which may or may not exhibit the same level of human consistency as full images, which often contain complex arrangements of several objects. High consistency in object memorability would indicate that, like full images, objects can potentially be predicted with high accuracy. To assess human consistency in remembering objects, we repeatedly divided our entire subject pool into two equal halves and quantified the degree to which memorability scores for the two sets of subjects were in agreement using Spearmans rank correlation (ρ) . We computed the average correlation over 25 of these random split iterations, yielding a final value of 0.76. Such a result confirms that human consistency in remembering particular objects is at least as strong as that of images.

3. Understanding Object Memorability

In this section, we aim to better understand object memorability and the factors that make an object more memorable or forgettable to humans. We first investigate if simple color and geometric factors like simple object features like color etc can predict if an object would be memorable or not.

3.1. Can simple color features explain object memorability?

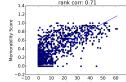
While simple image features are traditionally poor predictors of memorability in full images [Oliva, CVPR 2011], and with good reason [cite [11] from Oliva, CVPR 2011]], it is important to verify that this finding generalizes to individual objects. To do this, we first examined a number of simple color statistics. We decomposed each image into its hue, saturation, and value components and calculated the mean and standard deviation of each channel. Essentially no relationship existed between memorability and either mean hue ($\rho = 0$) or mean saturation ($\rho = 0.02$). This deviates somewhat from the findings related to images that

324 show hue to be weakly predictive of memorability. However, this makes sense since the effect has been speculated to
325 be due to the blue and green outdoor landscapes being less
326 memorable than warmly colored human faces and indoor
327 scenes. While our dataset contained plenty of indoor ob-
328 jects and people, outdoor scene-related image regions such
329 as sky and ground were not included as objects. This may
330 explain why the effect was not present in our dataset. Look-
331 ing at the variance of each channel, we see that variance
332 in hue ($= 0.16$) and saturation ($= 0.15$) are weakly corre-
333 lated with memorability, while value has a medium corre-
334 lation ($= 0.38$). This suggests that variation in the color
335 hue and color purity of an object contribute somewhat to
336 object memorability. This may be because people are mem-
337 orable regardless of the color of their clothing, or simply
338 that color inhomogeneity draws ones attention. The find-
339 ing that variation in value contributes considerably to object
340 memorability indicates that high contrast objects are more
341 memorable. Although the correlation seems high compared
342 to the performance of past simple features in past research,
343 the scatterplot in FIGURE X suggests that it may not pro-
344 duce reliable predictions. Next, we computed image size,
345 calculated by the number of pixels that make up the object
346 normalized by the total number of pixels in the parent im-
347 age. Not surprisingly, this metric correlated strongly with
348 object memorability ($= 0.53$). This makes sense given that
349 large objects, especially that take up the majority of the par-
350 ent image frame, are more likely to be seen and identified.
351

3.2. What is the relationship between visual saliency and object memorability?

356 Note: add in small intro about past work

357 To examine the relationship between visual saliency and
358 object memorability, we used two indexes of saliency to de-
359 scribe each object. The first was calculated as the number
360 of unique fixation points within the area of each object. The
361 correlation between object memorability and number of fixa-
362 tions within those objects was quite high ($= 0.71$). How-
363 ever, this correlation decreases significantly as the number
364 of total fixations within the object increases. In figure X,
365 we show the correlation between object memorability and
366 number of fixations for subsets of the objects that have at
367 least some minimum number of fixations. On the leftmost
368 side of the plot, the correlation is at it's highest since the
369 set of objects with a fixation count greater than or equal to
370 zero includes all objects and so the correlation is identical to
371 FIGURE FIX-CORR. However, as the minimum number of
372 fixations increases, we look only at objects that contain an
373 increasingly higher number of distinct fixation points, and
374 the correlation decreases. By the time we reach a minimum
375 fixation count of around 35, the correlation falls to around
376 0.2. This may mean that the predictive value of saliency de-
377 creases when there are many areas of interest within a single



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Figure 4: Correlation between object memorability and number of fixations. add-in later.

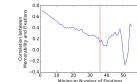


Figure 5: Relationship between memorability and saliency by minimum number of fixations. add-in later.

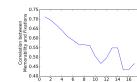


Figure 6: Relationship between memorability and saliency by minimum number of objects. add-in later.

object. (NOTE: We may want to show examples of images with lots of fixation points that were not well predicted. We could just plot the fixation locations as points on the image) The reason for this decline may be that...[make arguments here] Toward the right end of the plot, few objects contain large numbers of fixations, and so the correlations become sporadic. The red line marks the point for which the correlations cease to be statistically significant, just at the end of the main trend line. Alternatively, FIGURE Z shows a similar relationship in which the correlation between memorability and fixation count is plotted as a function of minimum number of objects present in the parent image of the object. In a similar pattern, we see that as the minimum number of objects increases, the correlation between fixation count and object memorability decreases. This follows from the fact that fixation count and number of parent image objects are negatively correlated ($= -0.38$), meaning that if there are more objects in an image, there are less fixation points in any one object, which may a consequence of needing to distribute attention across the objects in the scene. In both scenarios, the ability to predict object memorability sharply decreases.

The second metric we used... (put map method here?)

The second metric we used... (put map method here?)

3.3. What is the relationship between object memorability and object categories?

In the previous sections, we showed that simple features have little predictive power over object memorability and there exists a weak relationship between visual saliency and object memorability. In this section, we show that object memorability is heavily influenced by it's category and investigate the possible reasons behind the same.

432 **3.3.1 Are some object classes more memorable than
433 others?**
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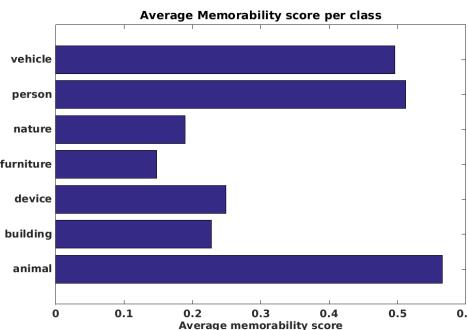
438 Our dataset contains 3414 object segmentations from the
439 Pascal-S dataset. For this analysis, we first assigned three
440 in-house annotators the task of assigning class labels to each
441 object segmentation in our dataset. The annotators were
442 given the original image (for reference) and the object seg-
443 mentation and asked to assign 1 category to the segment out
444 of 7 possible categories: animal, building, device, furniture,
445 nature, person, and vehicle. We choose these high-level cat-
446 egories such that a wide range of object classes could be
447 covered under these categories. For example, device in-
448 cluded object segments like utensils, bottle, tv, computer
449 etc, nature included segments like tree, mountain, flowers,
450 and vehicle covered segments like car, bike, bus, aeroplane
451 etc. **add a small table here which shows stats of the object
452 classes n their frequency in the dataset.**

453
454
455 Figure 7 shows the average memorability score for the all
456 7 different object classes in our dataset. This visualisation
457 gives a sense of how the memorability of different object
458 classes differs. Animal, person, and vehicle are all highly
459 memorable classes with each of them having an average
460 memorability score greater than 0.5. Interestingly, all the
461 other object categories have an average memorability score
462 lower than 0.25 indicating that humans do not remember
463 objects from these categories very well. In particular, fur-
464 niture has an average memorability score of only 0.18 and
465 is the least memorable object class. This could be possibly
466 due to the fact that most objects from classes like furniture,
467 nature, and building either appear mostly in the background
468 or are occluded which could decrease their memorability
469 significantly. On the contrary, objects from animal, person,
470 and vehicle classes appear mostly in the foreground leading
471 to a higher memorability score on average. Table 1 shows
472 the average memorability of the top 20 most memorable ob-
473 jects for each object class. This analysis is particularly in-
474 teresting as these top objects are not occluded and most of
475 them tend to appear in the foreground. The top 20 most
476 memorable objects from person, animal and vehicle have
477 memorability higher than 0.90 whereas the average memo-
478 rability of the top 20 objects from building, furniture, and
479 nature is lesser than 0.70. While the differences in the mem-
480 orability of different classes could be driven primarily due
481 to factors like occlusion, size, background/foreground, the
482 results in table 1 suggest that memorability could be an in-
483 trinsic property of an object class and some object classes
484 like person, animal, vehicle are in general intrinsically more
485 memorable than classes like furniture, nature etc.

Object Class	Memorability of top 20 objects
Animal	0.94
Building	0.65
Device	0.86
Furniture	0.63
Nature	0.67
Person	0.93
Vehicle	0.96

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Table 1: Average memorability of top 20 objects for each class

Figure 7: **Average memorability per object class.** Figure showing some object classes are more memorable than others.514 **3.3.2 Why are some objects not memorable within a
515 class?**
516

517 As demonstrated above, some object classes like animal,
518 person, vehicle are more than others either due to their
519 intrinsic property or external factors like occlusion, fore-
520 ground/background etc. However, not all objects in a class
521 are equally memorable. The examples in figure 8 show the
522 most memorable and least memorable objects for each ob-
523 ject class. A common property between these objects is that
524 the least memorable objects within each object class tend
525 to be occluded and obstructed by other objects. What other
526 possible factors could influence the memorability of an ob-
527 ject within a class?

528 **Relationship with number of objects in an image:** We
529 first tested how the memorability of each object class is af-
530 fected by the number of objects inside an image. We took in
531 all images that had at least 'n' objects (where $1 \leq n \leq$
532 10) inside them and computed the average memorability of
533 each object class. Figure 9 shows the change in average
534 memorability of the different object classes with respect to
535 the increase in number of objects in an image. This fig-
536 ure shows that the number of objects present in an image
537 is an important factor that results in the variation in the
538 memorability of objects within a class. As the number of
539 objects in an image increase, the memorability of the ob-

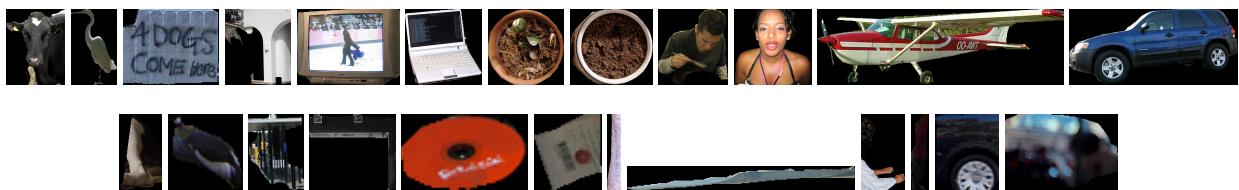


Figure 8: Qual Results. Figure showing top and bottom objects for each class.

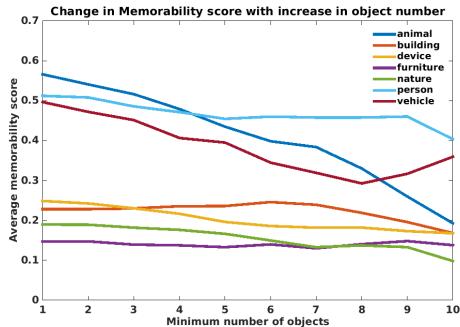


Figure 9: Correlation between object class and number of objects. add-in later.

ject classes decreases. In particular, the memorability of objects belonging to highly memorable classes like animal, person, and vehicle decreases significantly with the increase in number of objects in an image. Intuitively, this could mean that with an increase in number of objects, humans cannot concentrate on a single object in an image and have a difficulty remembering objects in those images. Thus, if a person, animal or vehicle is present in a highly cluttered image, humans can not remember those objects very well.

Relationship of inter-class memorability: While the previous analysis sheds light on how the memorability of an object class is effected by factors such as occlusion, and number of objects in an image, how does the presence of a particular object class effect the memorability of another object class? To investigate this, for each possible pair of object categories we took all images that contained at least one object from both the categories and computed the average memorability scores for the two object categories. This way we were able to capture the relationship between pairs of object categories and how their presence effects their respective memorability scores. Figure 10 plots these results and for each object class, shows how it's memorability is effected in the presence of other object classes. The red mark on each line shows the over all average memorability of that class. Firstly, the memorability of low memorable classes i.e. nature, furniture, device, and building is not effected a lot in the presence of other object categories and their memorability tends to be low throughout. The memorability of person class also remains close to it's average memorability score and tends to be unaffected by the pres-

ence of most object categories. However, the memorability of person does get effected in the presence of buildings as the average memorability of person class drops below 0.4 for images containing both persons and buildings. This could be due to the fact that there exists images wherein the building is quite large and the persons in those images are usually smaller or less significant in contrast to the building (also illustrated in figure 11). The memorability of the animal class remains close to it's average memorability in presence of most classes, however it drops significantly to below 0.4 in presence of the person class (also shown in figure 11). The memorability of vehicle class is strongly affected by the presence of other object categories. In particular, it's memorability drops significantly in presence of person and animal classes also shown in figure 11.

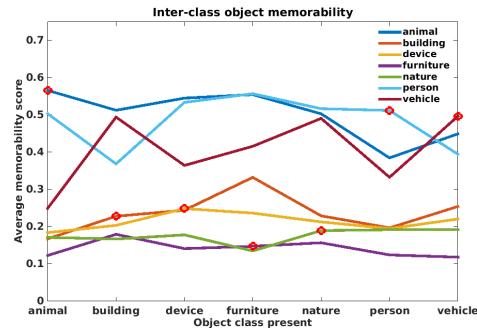


Figure 10: inter-class object memorability relationship. add-in later.

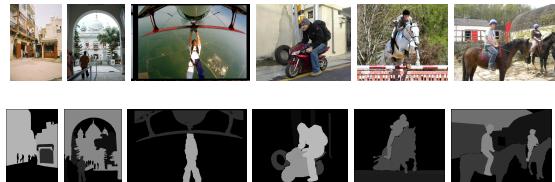


Figure 11: Qual Results. Figure showing how memorability of different classes is effected in presence of other classes. Bottom row is the memorability map

Taken together, the results from this section show that the memorability an object within a particular class is greatly effected by occlusion, number of objects present in an image and presence of other object classes in the image.

648 3.4. What is the relationship between object and 649 image memorability? 650

651 [Note: only the skeleton of this section is added, this still
652 needs significant work]
653

654 While in the previous sections, we have investigated the
655 various factors that could effect object memorability, an im-
656 portant question remembers. Now that we know what ob-
657 jects people remember and the factor that influence their
658 memorability, how does the memorability of objects effect
659 the overall image memorability? To shed light on the re-
660 lationship between image memorability and object mem-
661 orability, we conducted another large-scale experiment on
662 Amazon Mechanical turk for the images in our dataset to
663 gather their respective memorability scores. For this ex-
664 periment, we followed the exact paradigm as the memory game
665 experiment proposed in [5]. [add details about the fillers,
666 add details about the experiment including number of work-
667 ers, number of times each image was viewed by workers and
668 explain the consistency analysis]

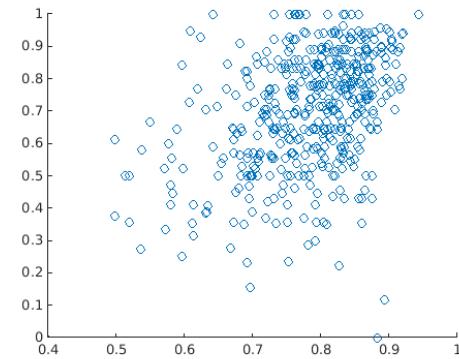
669 After collecting the image memorability scores, we con-
670 ducted several analysis to answer - if an image is highly
671 memorable, what happens to memorability of objects in-
672 side the image (and vice versa)? For each image in the
673 dataset, we firstly computed the maximum object mem-
674 orability within the image. Figure 12 shows the high corre-
675 lation of maximum object memorability with image mem-
676 orability ($\rho = 0.43$). Although there is a high correlation
677 between maximum object and image memorability, it still
678 doesn't predict image memorability completely. However,
679 table 2 also demonstrates that maximum object memorabil-
680 ity is a very strong predictor of whether an image is highly
681 memorable or low memorability. If we only take the top-
682 most 20 and bottommost 20 images from the dataset, then
683 their average max object memorability is highly correlated
684 with the image memorability scores. Similar trend is ob-
685 served for 50 most and 100 most top and bottom mem-
686 orable images. This is also shown via the figure XX [show
687 the qualitative examples here to show memorable images
688 contain memorable objects and non-memorable images do
689 not]. This shows although simply the max object mem-
690 orability cannot predict whether an image is medium mem-
691 orable, max object memorability serves as a strong features
692 in predicting if an image is highly memorable or not. Im-
693 ages that are lowly memorable, is possibly due to the fact
694 that they do not contain a single highly memorable object
695 [refer to qual figure again].
696

697 4. Predicting Object Memorability 698

699 here the benchmarking and baseline code comes up
700

Top and bottom images	max object memorability correlation	702
20	0.8	703
50	0.6	704
100	0.5	705

706
707 Table 2: correlation for top and bottommost images
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711 Figure 12: Correlation between max object memorability and image
712 memorability. add-in later.
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