

Visual Semantic Role Labeling

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Abstract

In this paper we introduce the problem of Visual Semantic Role Labeling: given an image we want to detect people doing actions and localize the objects of interaction. Classical approaches to action recognition either study the task of action classification at the image or video clip level or at best produce a bounding box around the person doing the action. We believe such an output is inadequate and a complete understanding can only come when we are able to associate objects in the scene to the different semantic roles of the action. To enable progress towards this goal, we annotate a dataset of 16K people instances in 10K images with actions they are doing and associate objects in the scene with different semantic roles for each action. Finally, we provide a set of baseline algorithms for this task and analyze error modes providing directions for future work.

1. Introduction

Current state of the art on action recognition consists of classifying a video clip containing the action, or marking a bounding box around the approximate location of the agent doing the action. Most current action recognition datasets classify each person into doing one of k different activities and focus on coarse activities (like ‘playing baseball’, ‘cooking’, ‘gardening’). We argue that such a coarse understanding is incomplete and a complete visual understanding of an activity can only come when we can reason about fine grained actions constituting each such activity (like ‘hitting’ the ball with a bat, ‘chopping’ onions with a knife, ‘mowing’ the lawn with a lawn mower), reason about people doing multiple such actions at the same time, and are able to associate objects in the scene to the different semantic roles for each of these actions.

Figure 1 shows our desired output. We want to go beyond coarse activity labels such as ‘playing baseball’, and be able to reason about fine-grained actions such as ‘hitting’ and detect the various semantic roles for this action namely: the agent (pink box), the instrument (blue box) and the object (orange box). Such an output can help us answer



Figure 1: **Visual Semantic Role Labeling:** We want to go beyond classifying the action occurring in the image to being able to localize the agent, and the objects in various semantic roles associated with the action.

various questions about the image. It tells us more about the current state of the scene depicted in the image (association of objects in the image with each other and with actions happening in the image), helps us better predict the future (the ball will leave the image from the left edge of the image, the baseball bat will swing clockwise), help us to learn commonsense about the world (naive physics, that a bat hitting a ball impacts momentum), and in turn help us in understanding ‘activities’ (a baseball game is an outdoor sport played in a field and involves hitting a round ball with a long cylindrical bat).

We call this problem as ‘Visual Semantic Role Labeling’. Semantic Role Labeling in a Natural Language Processing context refers to labeling words in a sentence with different semantic roles for the verb in the sentence [5]. NLP research on this and related areas has resulted in FrameNet [4] and VerbNet [33] which catalogue verbs and their semantic roles. What is missing from such catalogues is visual grounding. Our work here strives to achieve this grounding of verbs and their various semantic roles to images. The set of actions we study along with the various roles are listed in Table 1.



Figure 2: Visualizations of the images in the dataset: We show examples of annotations in the dataset. We show the agent in the blue box and objects in various semantic roles in red. People can be doing multiple actions at the same time. First row shows: person skateboarding, person sitting and riding on horse, person sitting on chair and riding on elephant, person drinking from a glass and sitting on a chair, person sitting on a chair eating a doughnut.

Visual semantic role labeling is a new task which has not been studied before; thus we start by annotating a dataset of 16K people instances with action labels from 26 different action classes and associating objects in various semantic roles for each person labeled with a particular action. We do this annotation on the challenging Microsoft COCO (Common Objects in COntext) dataset [24], which contains a wide variety of objects in complex and cluttered scenes. Figure 2 shows some examples from our dataset. Unlike most existing datasets which either have objects or actions labeled, as a result of our annotation effort, COCO now has detailed action labels in addition to the detailed object instance segmentations, and we believe will form an interesting test bed for studying related problems. We also provide baseline algorithms for addressing this task using CNN based object detectors, and provide a discussion on future directions of research.

2. Related Work

There has been a lot of research in computer vision to understand activities and actions happening in images and

videos. Here we review popular action analysis datasets, exact tasks people have studied and basic overview of techniques.

PASCAL VOC [8] is one of the popular datasets for static action classification. The primary task here is to classify bounding box around people instances into 9 categories. This dataset was used in the VOC challenge. Recently, Gkioxari *et al.* [12] extended the dataset for action detection where the task is to detect and localize people doing actions. MPII Human Pose dataset is a more recent and challenging dataset for studying action [3]. The MPII Human Pose dataset contains 23K images containing over 40K people with 410 different human activities. These images come from YouTube videos and in addition to the activity label also have extensive body part labels. The PASCAL dataset has enabled tremendous progress in the field of action classification, and the MPII human pose dataset has enabled studying human pose in a very principled manner, but both these datasets do not have annotations for the object of interaction which is the focus of our work here.

Gupta *et al.* [16, 15], Yao *et al.* [38, 37, 39], Prest *et al.* [28] collect and analyze the Sports, People Playing Musi-

cal Instruments (PPMI) and the Trumpets, Bikes and Hats (TBH) datasets but the focus of these works is on modeling human pose and object context. While Gupta *et al.* and Yao *et al.* study the problem in supervised contexts, Prest *et al.* also propose weakly supervised methods. While these methods significantly boost performance over not using human object context and produce localization for the object of interaction as learned by their model, they do not quantify performance at the joint task of detecting people, classifying what they are doing and localizing the object of interaction. Our proposed dataset will be a natural test bed for making such quantitative measurements.

There are also a large number of video datasets for activity analysis. Some of these study the task of full video action classification [32, 14, 23, 26, 20, 31], while some [40, 18, 29] also study the task of detecting the agent doing the action. In particular the J-HMDB [29] and UCF Sports dataset [18] are popular test beds for algorithms that study this task [13]. More recently, [30] proposed a new video dataset where annotations come from DVS scripts. Given annotations can be generated automatically, this will be a large dataset, but is inadequate for us as it does not have the visual grounding which is our interest here.

There have been a number of recent papers which generate captions for images [9, 19, 36, 21, 25, 35, 22, 7, 6]. Some of them also produce localization for various words that occur in the sentence [9, 36]. While this maybe sufficient to generate a caption for the image, the understanding is often limited only to the most salient action happening in the image (based on biases of the captions that were available for training). A caption like ‘A baseball match’ is completely correct for the image in Figure 1, but it is far from the detailed understanding we are striving for here: an explicit action label for each person in the image along with accurate localization for all objects in various semantic roles for the action.

3. V-COCO Dataset

In this section, we describe the Verbs in COCO (V-COCO) dataset. Our annotation process consisted of the following stages. Example images from the dataset are shown in Figure 2.

We build off the COCO dataset, for the following reasons, a) COCO is the most challenging object detection dataset, b) it has complete annotations for 160K images with 80 different object classes along with segmentation mask for all objects and five human written captions for each image, c) V-COCO will get richer if COCO gets richer *e.g.* with additional annotations like human pose and key points.

Identifying verbs The first step is to identify a set of verbs to study. We do this in a data driven manner. We use the captions in the COCO dataset and obtain a list of words for which the subject is a person (we use the Stan-

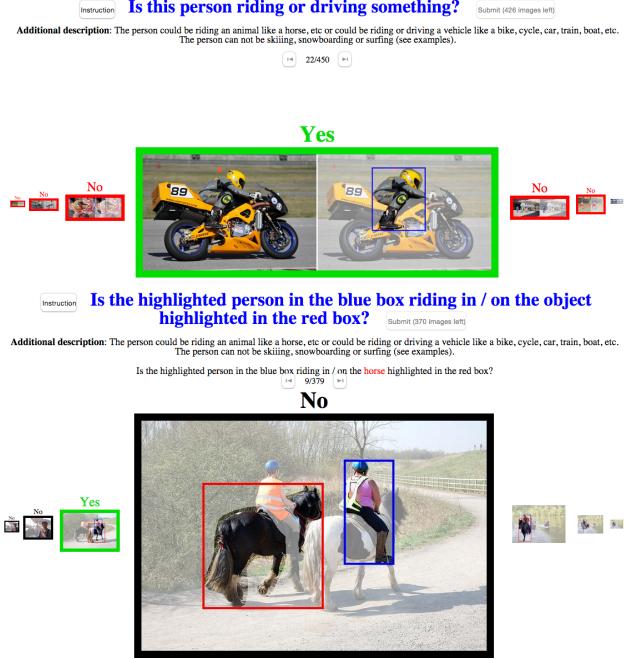


Figure 3: **Interface for collecting annotations:** The top row shows the interface for annotating the action the person is doing, and the bottom row shows the interface for associating the roles.

ford dependency parser to determine the subject associated with each verb and check this subject against a list of 62 nouns and pronouns to determine if the subject is a person). We also obtain counts for each of these verbs (actions). Based on this list, we manually select a set of 30 basic verbs (actions). We picked these words with the consideration if these would be in the vocabulary of a 5-year old child. The list of verbs is tabulated in Table 1. Based on visual inspection of images with these action words, we dropped pick, place, give, take because they were ambiguous from a single image.

Identifying interesting images With this list of verbs, the next step is to identify a set of images containing people doing these actions. We do this independently for each verb. We compute two scores for each image: a) does this image have a person associated with the target verb (or its synonyms) (based on the captions for the image), b) does this image contain objects associated with the target verb (using the COCO object instance annotations, the list of associated objects was picked manually). Query expansion using the set of objects associated with the target verb was necessary to obtain enough examples.

We sum these scores to obtain a ranked list of images for each verb, and consider the top 8000 images independently for each verb (in case the above two scores do not yield enough images we take additional images that contain people). We then use AMT to obtain annotations for people in

these 8000 images (details on the mechanical turk annotation procedure are provided in Section 3.1). We thus obtain a set of positive instances for each verb. The next step is to come up with a common set of images across all action categories. We do this by solving an integer program. This step of obtaining annotations separately for each action and then merging positive instances into a common pool of images was important to get enough examples for each action class.

Salient People Given this task requires detailed reasoning (consider localizing the spoon and fork being used to eat), instead of working with all people in the image, we work with people instances which have sufficient pixel area in the image. In addition, we also discard all people with pixel area less than half the pixel area of the largest person in the image. This helps with images which have a lot of by-standers (who may not be doing anything interesting). Doing this speeds up the annotation process significantly, and allows us to use the annotation effort more effectively. Note that we can still study the VSRL problem in a detection setting. Given the complete annotations in COCO, even if we don't know the action that a non salient person is doing, we still know its location and appropriately adjust the training and evaluation procedures to take this into account.

Annotating salient people with all action labels Given this set of images we annotate all ‘salient people’ in these images with binary label for each action category. We again use AMT for obtaining these annotations but obtain annotations from 5 different workers for each person for each action.

Annotating object in various roles Finally, we obtain annotations for objects in various roles for each action. We first enumerate the various roles for each verb, and identify object categories that are appropriate for these roles (see Table 1). For each positively annotated person (with 3 or more positive votes from the previous stage) we obtain YES/NO annotation for questions of the form: ‘Is the *person* in the blue box *holding* the *banana* in the red box?’

Splits To minimize any differences in statistics between the different splits of the data, we combined 40K images from the COCO training set with the COCO validation set and obtained annotations on this joint set. After the annotation, we construct 3 splits for the V-COCO dataset: the images coming from the validation set in COCO were put into the V-COCO *test* set, the rest of the images were split into V-COCO *train* and *val* sets.

3.1. Annotation Procedure

In this section, we describe the Amazon Mechanical Turk (AMT) [2] annotation procedure that we use during the various stages of dataset annotation.

We follow insights from Zhou *et al.* [41] and use their annotation interface. We frame each annotation task as a

binary YES/NO task. This has the following advantages: the user interface for such a task is simple, it is easy to insert test questions, it is easy to asses consensus, and such a task ends up getting done faster on AMT.

User Interface We use the interface from Zhou *et al.* [41]. The interface is shown in Figure 3. We show two images: the original image on the left, and the image highlighting the person being annotated on the right. All images were marked with a default NO answer and the turker flips the answer using a key press. We inserted test questions to prevent spamming (see below) and filtered out inaccurate turkers. We composed HITs (Human Intelligence Tasks) with 450 questions (including 50 test questions) of the form: ‘Is the person highlighted in the blue box *holding* something?’ In a given HIT, the action was kept fixed. On average turkers spent 15 minutes per HIT, although this varied from action to action. For annotating the roles, an additional box was highlighted corresponding to the object, and the question was changed appropriately.

Test Questions We had to insert test questions to ensure reliability of turker annotations. We inserted two sets of test questions. The first set was used to determine accuracy at the time of submission and this prevented turkers from submitting answers if their accuracy was too low (below 90%). The second set of questions were used to guard from turkers who hacked the client side testing to submit incorrect results (surprisingly, we did find turkers who did this). HITs for which the average accuracy on the test set was lower than 95% were relaunched. The set of test questions were bootstrapped from the annotation process, we started with a small set of hand labeled test questions, and enriched that set based on annotations obtained on a small set of images. We manually inspected the annotations and augmented the test set to penalize common mistakes (skiing *vs.* snowboarding) and excluded ambiguous examples.

3.2. Dataset Statistics

In this section we list statistics on the dataset. The V-COCO dataset contains a total of 10346 images containing 16199 people instances. Each annotated person has binary labels for 26 different actions. The set of actions and the semantic roles associated with each action are listed in Table 1. Table 1 also lists the number of positive examples for each action, the set of object categories for various roles for each action, the number of instances with annotations for the object of interaction.

We split the V-COCO dataset into a *train*, *val* and *test* split. The *train* and *val* splits come from the COCO *train* set while the *test* set comes from the *val* set. Number of images and annotated people instances in each of these splits are tabulated in Table 3.

Note that all images in V-COCO inherits all the annotations from the COCO dataset [24], including bounding boxes

Table 1: List of actions in V-COCO. We list the different actions, number of semantic roles associated with the action, number of examples for each action, the different roles associated with each action along with their counts and the different objects that can be take each role. Annotations for cells marked with * are currently underway.

Action	Roles	#	Role	#	Objects in role
carry	1	970	obj	*	
catch	1	559	obj	457	sports ball, frisbee,
cut	2	569	instr	477	scissors, fork, knife,
			obj	*	
drink	1	215	instr	203	wine glass, bottle, cup, bowl,
eat	2	1198	obj	737	banana, apple, sandwich, orange, carrot, broccoli, hot dog, pizza, cake, donut,
			instr	*	
hit	2	716	instr	657	tennis racket, baseball bat,
			obj	454	sports ball
hold	1	7609	obj	*	
jump	1	1335	instr	891	snowboard, skis, skateboard, surfboard,
kick	1	322	obj	297	sports ball,
lay	1	858	instr	513	bench, dining table, toilet, bed, couch, chair,
look	1	7172	obj	*	
point	1	69	obj	*	
read	1	227	obj	172	book,
ride	1	1044	instr	950	bicycle, motorcycle, bus, truck, boat, train, airplane, car, horse, elephant,
run	0	1309	-	-	
sit	1	3905	instr	2161	bicycle, motorcycle, horse, elephant, bench, chair, couch, bed, toilet, dining table, suitcase, handbag, backpack,
skateboard	1	906	instr	869	skateboard,
ski	1	924	instr	797	skis,
smile	0	2960	-	-	
snowboard	1	665	instr	628	snowboard,
stand	0	8716	-	-	
surf	1	984	instr	949	surfboard,
talk on phone	1	639	instr	538	cell phone,
throw	1	544	obj	475	sports ball, frisbee,
walk	0	1253	-	-	
work on computer	1	868	instr	773	laptop,

for non-salient people, crowd regions, allowing us to study all tasks in a detection setting. Moreover, each image also has annotations for 80 object categories which can be used to study the role of context in such tasks.

Figure 4 (left) shows the distribution of the number of people instances in each image. Unlike past datasets which mostly have only one annotated person per image, the V-COCO dataset has a large number of images with more than one person. On average these have 1.57 people annotated with action labels per image. There are about 2000 images with two, and 800 images with three people annotated.

Figure 4 (right) shows a distribution of the number of different actions a person is doing in V-COCO. Unlike past datasets where each person can only be doing one action, people in V-COCO do on average 2.87 actions at the same time. Table 2 lists the set of actions which co-occur more

Table 2: List and counts of actions that co-occur in V-COCO.

597 look, stand	411 carry, hold, stand, walk
340 hold, stand, ski	329 ride, sit
324 look, sit, work on computer	302 look, jump, skateboard
	296 hold, ride, sit
280 look, surf	269 hold, stand
259 hold, smile, stand	253 stand, walk
238 smile, stand	230 look, run, stand
	209 hold, look, stand, hit
193 hold, smile, stand, ski	189 look, sit
189 look, run, stand, kick	183 smile, sit
160 look, stand, surf	159 hold, look, sit, eat
	152 hold, stand, talk on phone
150 stand, snowboard	140 hold, look, smile, stand, cut
129 hold, stand, throw	128 look, stand, jump, 127 hold, smile, sit, eat skateboard
124 hold, look, stand, cut	121 hold, look, sit, work on computer
115 look, jump, snowboard	115 look, stand, skateboard
107 hold, look, run, stand, 105 look, stand, throw	104 hold, look, stand, ski hit

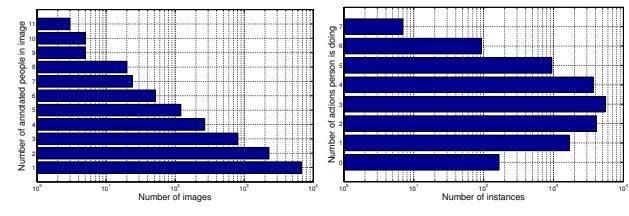


Figure 4: Statistics on V-COCO: The bar plot on left shows the distribution of the number of annotated people per image. The bar plot on right shows the distribution of the number of actions a person is doing. Note that X-axis is on log scale.

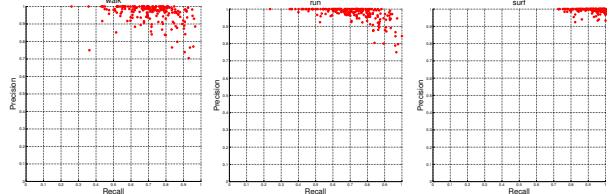


Figure 5: Human Agreement

than 100 times along with their counts. We also analyse human agreement for different actions to quantify the ambiguity in labeling actions from a single image by benchmarking annotations from one turker with annotations from the other turkers for each HIT for each action and produce points on precision and recall plot. Figure 5 presents these plots for the `walk`, `run` and `surf` actions. We can see that there is high human agreement for actions like `surf`, whereas there is lower human agreement for verbs like `walk` and `run`, as expected.

Table 3: Statistics of various splits of V-COCO.

	<i>train</i>	<i>val</i>	<i>test</i>	<i>all</i>
Number of Image	2533	2867	4946	10346
Number of People Instance	3932	4499	7768	16199

3.3. Tasks and Metrics

These annotations enable us to study a variety of new fine grained tasks about action understanding which have not been studied before. We describe these tasks below.

Agent Detection The agent detection task is to detect instances of people engaging in a particular action. We use the standard average precision metric as used for PASCAL VOC object detection [8] to measure performance at this task - people labeled positively with the action category are treated as positive, un-annotated non-salient people are marked as difficult.

Role Detection The role detection task is to detect the agent and the objects in the various roles for the action. An algorithm produces as output bounding boxes for the locations of the agent and each semantic role. A detection is correct if the location of the agent and each role is correct (correctness is measured using bounding box overlap as is standard). As an example, consider the role detection task for the action class ‘hold’. An algorithm will have to produce as output a bounding box for the person ‘holding’, and the object being ‘held’, and both these boxes must be correct for this detection to be correct. We follow the same precision recall philosophy and use average precision as the metric.

4. Methods

In this section, we describe the baseline approaches we investigated for studying this task. As a first step, we train object detectors for the 80 different classes in the COCO dataset. We use R-CNN [11] to train these detectors and use the 16-layer CNN from Simonyan and Zisserman [34] (we denote this as VGG). This CNN has been shown to be very effective at a variety of tasks like object detection [11], image captioning [9], action classification [1]. We finetune this detector using the fast version of R-CNN [10] and train on 77K images from the COCO train split (we hold out the 5K V-COCO *train* and *val* images). We use the precomputed MCG bounding boxes from [27].

Agent detection model Our model for agent detection starts by detecting people, and then classifies the detected people into different action categories. We train this classification model using MCG bounding boxes which have an

intersection over union of more than 0.5 with the ground truth bounding box for the person. Since each person can be doing multiple actions at the same time, we frame this as a multi-label classification problem, and finetune the VGG representation for this task. We denote this model as *A*.

At test time, each person detection (after non-maximum suppression), is scored with classifiers for different actions, to obtain a probability for each action. These action probabilities are multiplied with the probability from the person detector to obtain the final score for each action class.

Regression to bounding box for the role Our first attempt to localize the object in semantic roles associated with an action involves training a regression model to regress to the location of the semantic role. This regression is done in the coordinate frame of the detected agent (detected using model *A* as described above). We use the following 4 regression targets [11]. (\bar{x}_t, \bar{y}_t) denotes the center of the target box *t*, (\bar{x}_o, \bar{y}_o) denotes the center of the detected person box *o*, and (w_t, h_t) , (w_o, h_o) are the width and height of the target and person box.

$$\delta(t, o) = \left(\frac{\bar{x}_t - \bar{x}_o}{w_o}, \frac{\bar{y}_t - \bar{y}_o}{h_o}, \log \left(\frac{w_t}{w_o} \right), \log \left(\frac{h_t}{h_o} \right) \right) \quad (1)$$

We denote this model as *B*.

Using Object Detectors Our second method for localizing these objects uses object detectors for the categories that can be a part of the semantic role as described in Table 1. We start with the detected agent (using model *A* above) and for each detected agent attach the highest scoring box according to the following score function:

$$P_D(\delta(t_c, o)) \times sc_c(t_c) \quad (2)$$

where *o* refers to the box of the detected agent, box *t_c* comes from all detection boxes for the relevant object categories *c* $\in \mathcal{C}$ for that action class, and *sc_c(t_c)* refers to the detection probability for object category *c* for box *t_c*. *P_D* is the probability distribution of deformations *δ* computed from the training set, using the annotated agent and role boxes. We model this probability distribution using a Gaussian. The detection probabilities for different object categories *c* $\in \mathcal{C}$ are already calibrated using the softmax in the Fast R-CNN training [10]. We denote this model as *C*.

5. Experiments

We summarize our results here. We report all results on the V-COCO *val* set. Since we use bounding box proposals, we analyze the recall for these proposals on the objects that are part of various semantic roles. For each semantic role for each action class, we compute the coverage (measured as the intersection over union of the best overlapping



Figure 6: Visualizations of detections from our best performing baseline algorithm. We show the detected agent in the blue box and the detected object in the semantic role in the red box and indicate the inferred action class in the test at the bottom of the image. We show some correct detections in the top two rows, and common error modes in subsequent rows. ‘Incorrect Class’: when the inferred action class label is wrong; ‘Mis-Grouping’: correctly localized and semantically feasible but incorrectly matched to the agent; and ‘Mis-localization’ and ‘Hallucination’ of the object of interaction.

Table 4: Performance on actions in V-COCO. We report the recall for MCG candidates for objects that are part of different semantic roles for each action, AP for agent detection and role detection for 4 baselines using VGG CNN (with and without finetuning for this task). See Section 5 for more details.

Action	Role	MCG Recall			Average Precision						
		mean	R[0.5]		R[0.7]	A		B ₀	B	C ₀	C
			agent	role		role	role	role	role		
carry	obj*					54.2					
catch	obj	73.7	91.6	67.2		41.4	1.1	1.2	24.1	22.5	
cut	instr	58.6	61.4	30.7		44.5	1.6	2.3	4.6	3.9	
	obj*										
drink	instr	69.5	82.1	58.2		25.1	0.3	0.7	3.1	6.4	
eat	obj	84.4	97.8	89.7		70.2	8.0	11.0	37.0	46.2	
	instr*										
hit	instr	72.0	88.1	60.5		82.6	0.2	0.7	31.0	31.0	
	obj	62.0	73.8	53.3			11.3	11.8	41.3	44.6	
hold	obj*					73.4					
jump	instr	76.0	88.7	68.7		69.2	4.0	17.0	33.9	35.3	
kick	obj	82.7	100.0	94.4		61.6	0.3	0.8	48.8	48.3	
lay	instr	94.6	100.0	97.7		39.3	19.9	28.0	32.8	34.3	
look	obj*					65.0					
point	obj*					1.4					
read	obj	83.5	96.2	82.7		10.6	0.9	2.1	2.2	4.7	
ride	instr	84.7	99.1	87.9		45.4	1.2	9.7	12.5	27.6	
run	-					59.7					
sit	instr	82.2	94.7	82.6		64.1	20.0	22.3	24.3	29.2	
skateboard	instr	73.2	87.3	63.7		83.7	3.0	12.2	32.7	40.2	
ski	instr	49.1	46.5	20.9		81.9	4.9	5.5	5.9	8.2	
smile	-					61.9					
snowboard	instr	67.8	75.1	51.7		75.8	4.3	13.6	20.2	28.1	
stand	-					81.0					
surf	instr	66.7	76.0	53.2		94.0	1.5	4.8	28.1	27.3	
talk on phone	instr	59.9	69.3	37.3		46.6	1.1	0.6	5.8	5.8	
throw	obj	72.5	88.0	73.6		50.1	0.4	0.5	25.7	25.4	
walk	-					56.3					
work on computer	obj	85.6	98.6	88.5		56.9	1.4	4.9	29.8	32.3	
mean		73.6	85.0	66.4		57.5	4.5	7.9	23.4	26.4	

MCG bounding box with the ground truth bounding box for the object in the role) for each instance and report the mean coverage, recall at 50% overlap and recall at 70% overlap (Table 4 columns three to five). We see reasonable recall whenever the object in the semantic role is large (*e.g.* bed, bench for `lay`, horse, elephant, train, buses for `ride`) or small but highly distinctive (*e.g.* football for `kick`, doughnuts, hot dogs for `eat obj`) but worse when the object can be in drastic motion (*e.g.* tennis rackets and baseball bats for `hit instr`), or small and not distinctive (*e.g.* tennis ball for `hit obj`, cell phone for `talk on phone`, ski for `ski`, scissors and knife for `cut`).

Given that our algorithms start with a person detection, we report the average precision of the person detector we are using. On the V-COCO *val* set our person detector which uses the 16-layer VGG network in the Fast R-CNN [10]

framework gives an average precision of 62.54%.

We next report the performance at the task of agent detection (Table 4) using model *A* as described in Section 4. We observe a mean average precision of 57.5%. Performance is high for action classes which occur in a distinctive scene like `surf` (94.0%, occurring in water) `ski`, `snowboard` (81.9% and 75.8%, occurring in snow) and `hit` (82.6%, occurring in sports fields). Performance is also high for classes which have a distinctive object associated with the action like `eat` (70.2%). Performance for classes which are identified by an object which is not easy to identify is lower *e.g.* wine glasses for `drink` (25.1%), books for `read` (10.6%), *e.g.* object being `cut` and the instrument being used for `cut` (44.5). Performance is also worse for action classes which require reasoning about large spatial relationships *e.g.* 61.6% for `kick`, and fine grained reasoning of human pose *e.g.* 41.4%, 50.1% for `catch` and `throw`. Finetuning the VGG representation for this task improves performance significantly and just training a SVM on the VGG `fc7` features (finetuned for object detection on COCO) performs much worse at 46.8%.

We now report performance of the two baseline algorithms on the role detection task. We first report performance of algorithm *B*₀ which simply pastes the box at the mean deformation location and scale (determined using the mean of the δ vector as defined in Eq. 1 across the training set for each action class separately). This does poorly and gives a mean average precision for the role detection task of 4.5%. Using the regression model *B* as described in Section 4 to predict the location and scale of the semantic role does better giving a mAP of 7.9%, with high performing classes being `sit`, and `lay` for which the object of interaction is always below the person. Using object detector output from VGG and using the location of the highest scoring object detection (from the set of relevant categories for the semantic roles for the action class) without any spatial model (denoted as *C*₀) gives a mAP of 23.4%. Finally, model *C* which also uses a spatial consistency term in addition to the score of the objects detected in the image performs the best among these four baseline algorithms giving a mAP of 26.4%. Modeling the spatial relationship helps for cases when there are multiple agents in the scene doing similar things *e.g.* performance for `eat` goes up from 37.0% to 46.2%, for `ride` goes up from 12.5% to 27.6%.

Visualizations Finally, we visualize the output from our best performing baseline algorithm in Figure 6. We show some correct detections and various error modes. One of the common error modes is incorrect labeling of the action (`ski vs.snowboard`, `catch vs.throw`). Even with a spatial model, there is very often a mis grouping for the incorrect role with the agent. This is common when there are multiple people doing the same action in an image *e.g.* multiple

people riding horses, or skateboarding, or working on a laptops. Finally, a lot of errors are also due to mislocalization and hallucination of object of interaction in particular when the object is small *e.g.* ski for *skiing*, books for *reading*.

Error Modes Having such annotations also enables us to analyze different error modes. Following [17], we consider the top *num_inst* detections for each class (*num_inst* is the number of instances for that action class), and classify the false positives in these top detections into the following error modes:

1. **bck**: when the agent is detected on the background. (IU with any labeled person is less than 0.1).
2. **bck person**: when the agent is detected on the background, close to people in the background. Detections on background people are not penalized, however detections which have overlap between 0.1 and 0.5 with people in the background are still penalized and this error mode computes that fraction.
3. **incorrect label**: when the agent is detected around a person that is labeled to be not doing this action.
4. **person misloc**: when the agent is detected around a person doing the action but is not correctly localized (IU between 0.1 and 0.5) (the object is correctly localized).
5. **obj misloc**: when the object in the semantic role is not properly localized (IU between 0.1 and 0.5) (the agent is correctly localized).
6. **both misloc**: when both the object and the agent are improperly localized (IU for both is between 0.1 and 0.5).
7. **mis pairing**: when the object is of the correct semantic class but not in the semantic role associated with this agent.
8. **obj hallucination**: when the object is detected on the background.

Figure 7 shows the distribution of these errors for the 2 best performing baselines that we experimented with, model C_0 and C .

The most dominant error mode for these models is incorrect classification of the action, Figure 6 shows some examples. Another error mode is mis localization of the object for categories like *ski*, *surf*, *skateboard*, and *snowboard*. This is also evident from the poor recall of the region proposals for objects categories associated with these actions. A large number of errors also come from ‘person

misloc’ for categories like *lay* which is because of unusual agent pose. We also observe that the ‘mis pairing’ errors decrease as we start modeling the deformation between the agent and the object. Finally, a large number of error for *cut* and *hit-obj* come from hallucinations of the object in the background.

Conclusions and Future Directions In this work, we have proposed the task of visual semantic role labeling in images. The goal of this task is to be able to detect people, classify what they are doing and localize the different objects in various semantic roles associated with the inferred action. We have collected an extensive dataset consisting of 16K people in 10K images. Each annotated person is labeled with 26 different actions labels and has been associated with different objects in the different semantic roles for each action. We have presented and analyzed the performance of four simple baseline algorithms. Our analysis shows the challenging nature of this problem and points to some natural directions of future research. We believe our proposed dataset and tasks will enable us to achieve a better understanding of actions and activities than current algorithms.

Concepts without percepts are empty, percepts without concepts are blind.

Immanuel Kant

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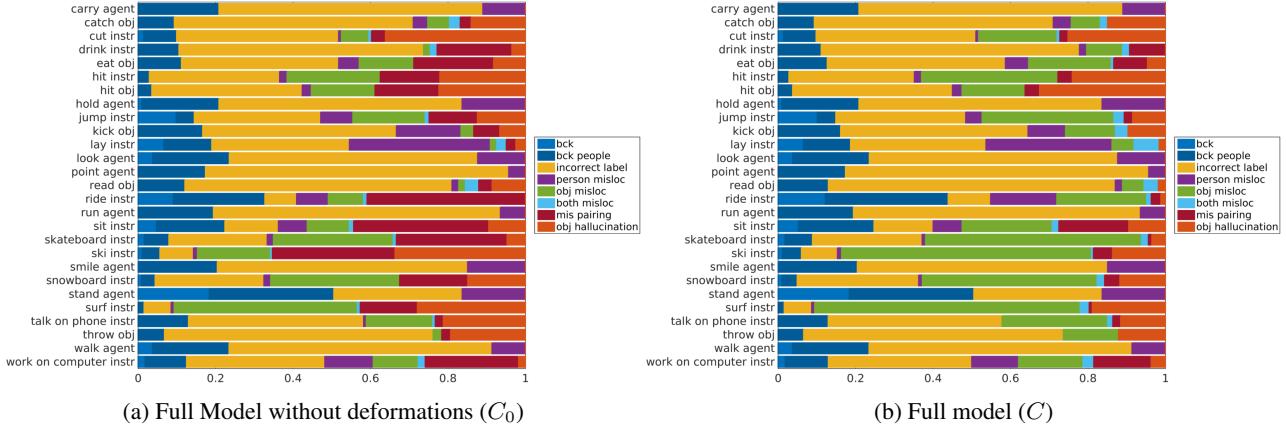


Figure 7: Distribution of the false positives in the top num_inst detections for each action class (with roles if applicable). ‘bck’ and ‘bck person’ indicate when the detected agent is on background (IU with any person less than 0.1) or around people in the background (IU with background people between 0.1 and 0.5), ‘incorrect label’ refers to when the detected agent is not doing the relevant action, ‘person misloc’ refers to when the agent detection is mis localized, ‘obj misloc’ refers to when the object in the specific semantic role is mis localized, ‘both misloc’ refers to when both the agent and the object are mis localized (mis localization means the IU is between 0.1 to 0.5). Finally, ‘mis pairing’ refers to when the object of interaction is of the correct semantic class but not in the semantic role for the detected agent, and ‘obj hallucination’ refers to when the object of interaction is hallucinated. The first figure shows the distribution for the C_0 model (which does not model deformation between agent and object), and the second figure shows the distribution for model C (which models deformation between the agent and the object).

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