

Contrast and Classify: Training Robust VQA Models

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Abstract

Recent Visual Question Answering (VQA) models have shown impressive performance on the VQA benchmark but remain sensitive to small linguistic variations in input questions. Existing approaches address this by augmenting the dataset with question paraphrases from visual question generation models or adversarial perturbations. These approaches use the combined data to learn an answer classifier by minimizing the standard cross-entropy loss. To more effectively leverage augmented data, we build on the recent success in contrastive learning. We propose a novel training paradigm (ConClat) that optimizes both cross-entropy and contrastive losses. The contrastive loss encourages representations to be robust to linguistic variations in questions while the cross-entropy loss preserves the discriminative power of representations for answer prediction.

We find that optimizing both losses – either alternately or jointly – is key to effective training. On the VQA-Rephrasings [45] benchmark, which measures the VQA model’s answer consistency across human paraphrases of a question, ConClat improves Consensus Score by 1.63% over an improved baseline. In addition, on the standard VQA 2.0 benchmark, we improve the VQA accuracy by 0.78% overall. We also show that ConClat is agnostic to the type of data-augmentation strategy used.

1. Introduction

Visual Question Answering (VQA) refers to the task of automatically answering free-form natural language questions about an image. For VQA systems to work reliably when deployed in the wild, for applications such as assisting visually impaired users, they need to be robust to different ways a user might ask the same question. For example, VQA models should produce the same answer for two paraphrased questions – “What is in the basket?” and “What is contained in the basket?” since their semantic meaning is the same. While significant progress has been made towards building more accurate VQA systems, these models remain

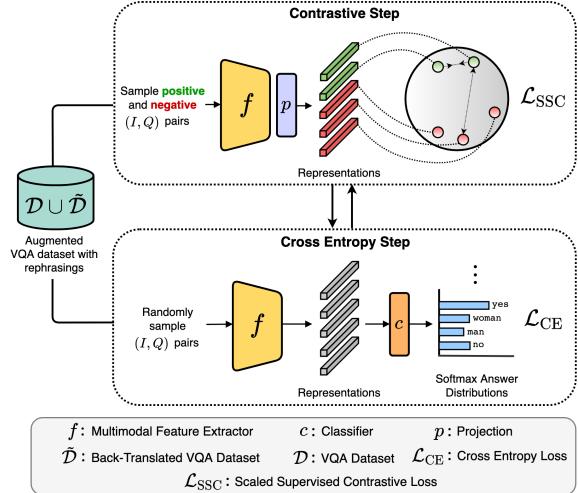


Figure 1: We make VQA model robust to question paraphrases using a training paradigm ConClat that minimizes contrastive and cross-entropy losses together. Contrastive learning step pulls representations of positive samples corresponding to paraphrased questions closer together while pushing those with different answers farther apart. Cross-entropy step makes these representations discriminative to help model answer visual questions accurately.

brittle to minor linguistic variations in the input question.

To make VQA systems robust, existing approaches [45, 48] have trained VQA systems [24] by augmenting the training data with different variations of the input question. For instance, VQA-CC [45] use a visual question generation (VQG) model to generate paraphrased question given an image and answer. Generally, these models fuse image and question features into a joint vision and language (V+L) representation followed by a standard softmax classifier to produce answer probabilities and are optimized by minimizing the cross-entropy loss. Unfortunately, cross-entropy loss treats every image-question pair independently and fails to exploit the information that some questions in the augmented dataset are paraphrases of each other.

We overcome this limitation by using a contrastive loss InfoNCE [36] that encourages joint V+L (Vision and Language) representations obtained from samples whose ques-

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tions are paraphrases of each other to be closer while pulling apart the V+L representations of samples with different answers. As we operate in a supervised setting, we choose Supervised Contrastive Loss (SCL) [26] which extends InfoNCE by utilizing the label information to bring samples from the same class (ground-truth answer) together. We introduce a variant of the SCL which emphasizes rephrased image-question pairs over pairs that are entirely different but have the same answer. Our proposed training paradigm, ConClaT (**C**ontrast and **C**lassify **T**raining), minimizes SCL and cross-entropy loss together to learn better vision and language representations as shown in Fig.1. Minimizing the contrastive loss encourages representations to be robust to linguistic variations in questions while the cross-entropy loss preserves the discriminative power of the representations for answer classification. Instead of pretraining with SCL, then fine-tuning with cross-entropy loss as in [26], we find that minimizing the two losses either alternately or jointly by constructing loss-specific mini-batches helps learn better representations. For contrastive loss, we carefully curate mini-batches by sampling various types of negatives and positives given a reference sample.

We show the efficacy of our training paradigm across two rephrasing (i.e., data-augmentation) strategies. Using rephrasings obtained from a VQG model proposed in [45], our approach outperforms a baseline that simply treats these rephrasings as additional samples and ignores the link between question and its paraphrases. We noticed that the VQG model fails to produce a diverse set of rephrasings for a question. Hence, we use Back-translation to obtain question rephrasings. Back-translation [15] involves translating an input sentence from one language to another and then translating it back into the original language using a pair of machine translation models (e.g. en-fr and fr-en). We find that Back-translation preserves the semantic meaning of the question while generating syntactically diverse question. Utilizing the publicly available collection of neural machine translation models in HuggingFace [53], we generate numerous rephrasings of every question. Then, we filter poor/irrelevant rephrasings with a sentence similarity model [42] and store 3 rephrasings per original question of VQA v2.0 dataset without any manual supervision.

We extensively ablate ConClaT with alternate [8], joint and pretrain-finetune [26] training schemes, and compare with previously proposed triplet [39] and margin-based losses [60]. We evaluate on the VQA Rephrasings benchmark [45] which measures the model’s answer consistency across several rephrasings of a question. ConClaT improves Consensus Score by 1.63% over an improved baseline. In addition, on the standard VQA 2.0 benchmark, we improve VQA accuracy by 0.78% overall. It is also worth noting that VQA models trained using ConClaT perform better than existing approaches across both the aforementioned data-

augmentation strategies – Back-translation and VQG.

2. Related Work

Models for VQA. Several models have been proposed for Visual Question Answering which fuse CNN grid features and LSTM features with different forms of attention [34, 56, 16, 23]. Bottom-Up and Top-Down [6] proposed to learn attention over object regions obtained from a pretrained object detector and subsequent works [27, 58, 24] introduced various ways to fuse image and language representations. Recent works [32, 33, 46, 29, 46, 47, 13] use multi-modal transformers to learn visuo-linguistic representations from object detector features and BERT question features [14]. We use the multi-modal transformer architecture similar to UNITER [13] for all our experiments.

Robustness of VQA Models. Robustness of VQA models with respect to multi-modal vision and language input has been studied in great detail. [18, 59] proposed balanced datasets to ensure models don’t overfit to language while answering visual questions. C-VQA [4] and VQA-CP [3] datasets were proposed to test robustness against changing question-answer distributions. SQuINT [44] encouraged consistency between reasoning questions and associated sub-questions. Our work focuses on robustness to question paraphrases in VQA-Rephrasings [45] that were collected from human annotators. VQA-CC [45] trained a Visual Question Generation (VQG) model to generate paraphrases of questions to augment the training dataset while VQA-Aug [48] augmented the training dataset by generating paraphrases of questions via back-translation. We show that these data augmentation techniques can be better utilized via ConClaT to build robust and accurate VQA models. Concurrent to our work, Whitehead *et al.* [51] propose a rule-based mechanism to generate question paraphrases for VQA. They constrain their model architecture to be modular [7] and use module-level loss to improve consistency. In contrast, our approach is agnostic to model architecture.

Various works [3, 2, 60, 39] made VQA models robust to language bias (For example, “What is the color of x ” will always produce ‘blue’ irrespective of x). Recent works [49, 1, 9, 37] also studied robustness from counterfactual answering lens – answer should change according to the change in semantic content of the question or image. Our work, on the other hand, focuses on robustness to *syntax*tic variations in questions.

Paraphrase Generation in NLP. There has been significant work in the area of Natural Language Processing (NLP) for generating paraphrases of a sentence using LSTM networks [40], Deep Reinforcement Learning [31], Variational Autoencoders [19] and Transformers [50]. However, these works require supervision in the form of paraphrase pairs. In order to mitigate this limitation of labelled data, Neural Machine Translation (NMT)

models have been used to generate paraphrases in a self-supervised fashion via back-translation [35, 52]. We build on top of these works and use state-of-the-art NMT models from HuggingFace [53] to generate paraphrases for visual questions without any supervision.

Contrastive Learning. There has been recent interest in the use of Contrastive Learning for learning visual representations in a self-supervised manner [54, 22, 21, 10, 12, 11, 41]. Going beyond Image Classification, recently, [20] used contrastive learning for phrase grounding. They used the InfoNCE loss [36] to learn a compatibility function between a set of region features from an image and contextualized word representations. In contrast, we want to learn representations which are robust to linguistic variations in the question for VQA.

To utilize label information in contrastive losses, [26] proposed Supervised Contrastive Learning (SCL) loss for learning *visual* representations. We introduce a variant of the SCL which scales the contributions from augmented positive samples (rephrasings in our case) over intra-class positive samples (that have the same answer) using a scaling factor. Moreover, our training paradigm optimizes both (cross-entropy and SCL) losses together, whereas [26] follow the pretrain-finetune training scheme. Furthermore, [26] randomly sample positive and negative pairs based on label information, whereas we carefully curate batches by sampling hard-negatives from the dataset. We show how these differences affect performance through a series of ablations in our experiments section.

3. Preliminaries

In this section, we introduce the VQA task and the standard cross entropy training of VQA models. We then recap contrastive methods for learning representations [10] and the recently proposed Supervised Contrastive Learning (SCL) [26] setup. We describe our approach in section 4.

VQA. The task of Visual Question Answering (VQA) [5, 18] involves predicting an answer a for a question q about an image v . An instance of this problem in the VQA Dataset \mathcal{D} is represented via a tuple $x = (v, q, a), \forall x \in \mathcal{D}$. Recent VQA models [24, 6, 13] take image and question as input and output a joint vision and language (V+L) representation $\mathbf{h} \in \mathcal{R}^{d_h}$ using a multi-modal network f :

$$\mathbf{h} = f(v, q)$$

The V+L representation \mathbf{h} is then used to predict a probability distribution over the answer space \mathcal{A} with a softmax classifier $f^c(\mathbf{h})$ learned by minimizing the cross-entropy:

$$\mathcal{L}_{\text{CE}} = -\log \frac{\exp(f^c(\mathbf{h})[a])}{\sum_{a' \in \mathcal{A}} \exp(f^c(\mathbf{h})[a'])} \quad (1)$$

where $f^c(\mathbf{h})[a]$ is the logit corresponding to the answer a .

Contrastive Learning. Recent works in vision [10] have used contrastive losses to bring representations of two augmented views of the same image (called positives) closer together while pulling apart the representations of two different images (called negatives). The representation \mathbf{h} obtained from an image encoder is projected into a d_z dimensional hyper-sphere using a projection network g such that $\mathbf{z} = g(\mathbf{h}) \in \mathcal{R}^{d_z}$. Given a mini-batch of size K , the image representation \mathbf{h} is learned by minimizing the InfoNCE [36] loss which operates on a pair of positives $(\mathbf{z}_i, \mathbf{z}_p)$ and $K-1$ negative pairs $(\mathbf{z}_i, \mathbf{z}_k)$ such that $i, p, k \in [1, K], k \neq i$ as follows:

$$\mathcal{L}_{\text{NCE}}^i = -\log \frac{\exp(\Phi(\mathbf{z}_i, \mathbf{z}_p)/\tau)}{\sum_{k=1}^K \mathbb{1}_{k \neq i} \exp(\Phi(\mathbf{z}_i, \mathbf{z}_k)/\tau)}, \quad (2)$$

where $\Phi(\mathbf{u}, \mathbf{v}) = \mathbf{u}^\top \mathbf{v} / \|\mathbf{u}\| \|\mathbf{v}\|$ computes similarity between \mathbf{u} and \mathbf{v} and $\tau > 0$ is a scalar temperature parameter.

A generalization of InfoNCE loss to handle more than one positive-pair was proposed by [26] called Supervised Contrastive Loss (SCL). Given a reference sample x , SCL uses class-label information to form a set of positives $\mathcal{X}^+(x)$ that contains samples with the same label as x . $\mathcal{X}^+(x)$ also contains augmented views of the sample because they share the same label as x . For a minibatch with K samples, SCL is defined as:

$$\begin{aligned} \mathcal{L}_{\text{SC}}^i &= -\sum_{p=1}^{|\mathcal{X}^+(x_i)|} \log \frac{\exp(\Phi(\mathbf{z}_i, \mathbf{z}_p)/\tau)}{\sum_{k=1}^K \mathbb{1}_{k \neq i} \cdot \exp(\Phi(\mathbf{z}_i, \mathbf{z}_p)/\tau)} \\ \mathcal{L}_{\text{SC}} &= \sum_{i=1}^K \frac{\mathcal{L}_{\text{SC}}^i}{|\mathcal{X}^+(x_i)|} \end{aligned} \quad (3)$$

Overall, $\mathcal{L}_{\text{SC}}^i$ tries to bring the representation of samples in $\mathcal{X}^+(x_i)$ closer together compared to representations of samples with a different ground-truth label.

4. Approach

We now describe our approach, ConClaT, which uses contrastive and cross-entropy training to learn VQA models robust to question paraphrases.

4.1. Augmented Dataset with Back-translation

We augment the train set with question paraphrases using 88 different MarianNMT [25] Back-translation model pairs released by HuggingFace [53]. We produce 27 *unique* rephrasings per question with cosine similarity of 0.88 on average, the similarity is calculated by first encoding the questions via Sentence-BERT [42]. We only select paraphrases that have ≥ 0.95 similarity with the original question and choose three unique paraphrases randomly from this subset. We use three paraphrases to keep the compute

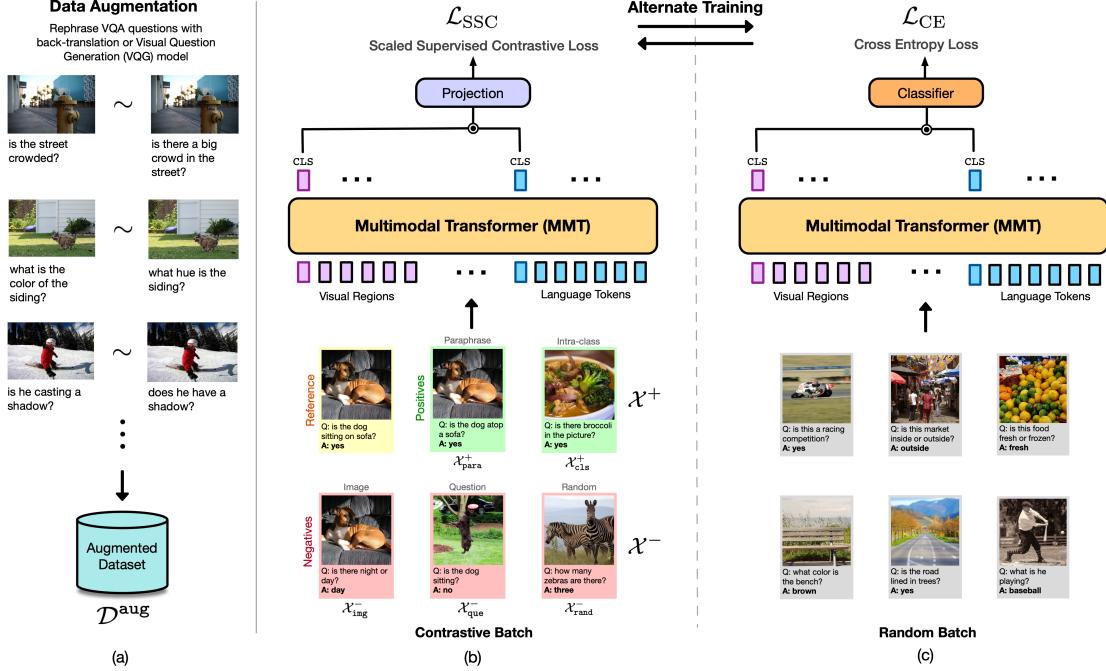


Figure 2: **Overview of ConClat.** (a) We augment the VQA dataset by paraphrasing every question via Back-translation or Visual Question Generation (VQG) model. (b) We carefully curate a contrastive batch by sampling different types of positives and negatives to learn joint V+L representations by minimizing scaled supervised contrastive loss \mathcal{L}_{SSC} . (c) Cross Entropy loss \mathcal{L}_{CE} is optimized with \mathcal{L}_{SSC} .

manageable. Overall, our augmented train set consists of $\sim 1.6\text{M}$ samples.

For a sample $x = (v, q, a) \in \mathcal{D}$, let's denote a set of paraphrases for question q by $\mathcal{Q}(q)$ and the corresponding set of VQA triplets as:

$$\mathcal{X}_{\text{para}}^+(x) = \{(v, q', a) \mid q' \in \mathcal{Q}(q)\} \quad (4)$$

As shown in Figure 2(a), we augment the VQA dataset \mathcal{D} with multiple paraphrased samples of a given question and denote the augmented dataset \mathcal{D}^{aug} as:

$$\mathcal{D}^{\text{aug}} = \mathcal{D} \bigcup_{x \in \mathcal{D}} \mathcal{X}_{\text{para}}^+(x) \quad (5)$$

4.2. Scaled Contrastive Loss for VQA

We would like our VQA model to produce the *same and correct* answer for a question and its paraphrase given an input image. This motivates us to map joint vision and language (V+L) representations of an original and paraphrased sample closer to each other. Moreover, since we operate in a supervised setting, following SCL [26] we also pull the joint representations for the questions with the same answer (intra-class positives) closer together while pulling apart the representations of questions with different answers. We define the set of all samples with the same ground truth answer

as x by:

$$\mathcal{X}^+(x) = \{(\hat{v}, \hat{q}, \hat{a}) \in \mathcal{D}^{\text{aug}} \mid \hat{a} = a\} \quad (6)$$

Note that $\mathcal{X}_{\text{para}}^+(x) \subset \mathcal{X}^+(x)$ as all question paraphrases have the same answer for a given image but not all questions with the same answer are paraphrases. We refer to samples in set $\mathcal{X}_{\text{cls}}^+(x) = \mathcal{X}^+(x) - \mathcal{X}_{\text{para}}^+(x)$ as *intra-class* positives and set $\mathcal{X}_{\text{para}}^+(x)$ as *paraphrased* positives w.r.t. x as depicted in Figure 2(b).

Following Eq. (3), all the samples in $\mathcal{X}^+(x_i)$ in \mathcal{L}_{SC} are treated the same. That is, representations from both the paraphrased positives and intra-class positives are brought closer together. To emphasize on the link between question and its paraphrase, we propose a variant of the SCL in Eq. (7) which assigns higher weight to paraphrased positives $\mathcal{X}_{\text{para}}^+(x)$ over intra-class positives $\mathcal{X}_{\text{cls}}^+(x)$. We introduce a scaling factor α_{ip} in the SCL (Eq. (3)) for a sample x_i as follows:

$$\mathcal{L}_{\text{SSC}}^i = - \sum_{p=1}^{|\mathcal{X}^+(x_i)|} \alpha_{ip} \cdot \log \frac{\exp(\Phi(\mathbf{z}_i \cdot \mathbf{z}_p)/\tau)}{\sum_{k=1}^K \mathbb{1}_{k \neq i} \cdot \exp(\Phi(\mathbf{z}_i \cdot \mathbf{z}_p)/\tau)} \quad (7)$$

$$\mathcal{L}_{\text{SSC}} = \sum_{i=1}^K \frac{\mathcal{L}_{\text{SSC}}^i}{\sum_p \alpha_{ip}} \quad (8)$$

Algorithm 1 ConClAT with alternate \mathcal{L}_{SSC} and \mathcal{L}_{CE}

input: steps N ; constant N_{ce} ; data \mathcal{D}^{aug} ; networks f, g

for all $i \in \{1, \dots, N\}$ **do**

- $\mathcal{B} = \emptyset$
- if** $i \pmod{N_{ce}} = 0$ **do**

 - # sscl iteration
 - $\mathcal{B} = \text{CURATE}(N_r, \mathcal{D}^{\text{aug}}, \mathbf{w}); \mathcal{L} = \mathcal{L}_{\text{SSC}}$

- else do**

 - # ce iteration
 - $\mathcal{B} \sim \mathcal{D}^{\text{aug}}; \mathcal{L} = \mathcal{L}_{\text{CE}}$
 - update $f(\cdot), g(\cdot)$ networks to minimize \mathcal{L} over \mathcal{B}

return network $f(\cdot)$; throw away $g(\cdot)$.

The scaling factor α_{ip} assigns a higher weight $s > 1$ to positive samples corresponding to question paraphrases compared to other intra-class positives. Intuitively, because of the higher weight, the loss will penalize the model strongly if it fails to bring the representations of a question and its paraphrase closer. We define α_{ip} as:

$$\alpha_{ip} = \begin{cases} s & \text{if } x_p \in \mathcal{X}_{\text{para}}^+(x_i), \\ 1, & \text{otherwise} \end{cases} \quad (9)$$

4.3. Training with \mathcal{L}_{SSC} and \mathcal{L}_{CE}

We experiment with various schemes of combining supervision from \mathcal{L}_{SSC} and \mathcal{L}_{CE} losses. Specifically, we try – alternate (Algorithm 1), joint, and pretrain-finetune [26] training schemes.

Our alternate training scheme is summarized in Algorithm 1. Specifically, given N total training iterations, we update our model with \mathcal{L}_{SSC} after every $N_{ce}-1$ updates with \mathcal{L}_{CE} , where N_{ce} is a hyper-parameter. In the joint training scheme, we curate loss-specific batches for \mathcal{L}_{SSC} and \mathcal{L}_{CE} but jointly update the model by accumulating the gradients of these two losses. Training alternately or jointly with the two losses simplifies the optimization procedure compared to two-stage training (pretrain-finetune as in [26]) which requires double the hyper-parameters and longer training iterations. Please refer to supplementary for the exact algorithms of joint and pretrain-finetune training schemes. Empirically, we see that alternate training works slightly better than joint-training, and much better than pretrain-finetune training approach. Figure 2 depicts our training strategy (ConClAT).

4.4. Negative Types and Batch Creation

SCL operates with multiple negative samples. For a given reference sample $x = (v, q, a) \in \mathcal{D}^{\text{aug}}$, we define a corresponding set of negatives as samples with ground truth different than the reference x :

$$\mathcal{X}^-(x) = \{(\bar{v}, \bar{q}, \bar{a}) \in \mathcal{D}^{\text{aug}} \mid \bar{a} \neq a\}$$

Algorithm 2 Batch Curation Strategy for \mathcal{L}_{SSC}

input: number of references N_r ; data \mathcal{D} ; weights \mathbf{w}

function CURATE($N_r, \mathcal{D}, \mathbf{w}$)

- $\mathcal{B} = \emptyset, \mathcal{B}_r = \emptyset$ # initialize batches
- for all** $i \in \{1, \dots, N_r\}$ **do**

 - $x_i \sim \mathcal{D}$ # reference
 - $\hat{x}_i \sim \mathcal{X}_{\text{cls}}^+(x_i)$ # intra-class positive
 - $t \sim \text{Cat}(\mathcal{T}|\mathbf{w})$ # negative type
 - $\bar{x}_i \sim \mathcal{X}_t^-(x_i)$ # negative
 - append $\mathcal{B} = \mathcal{B} \cup \{x_i, \hat{x}_i, \bar{x}_i\}$

- for all** $i \in \{1, \dots, |\mathcal{B}|\}$ **do**

 - $x'_i \sim \mathcal{X}_{\text{para}}^+(x_i)$ # paraphrased positive
 - append $\mathcal{B}_r = \mathcal{B}_r \cup \{x'_i\}$

return $\mathcal{B} \cup \mathcal{B}_r$

We carefully curate batches for \mathcal{L}_{SSC} by sampling different types of negatives. We classify a negative sample $\bar{x} = (\bar{v}, \bar{q}, \bar{a}) \in \mathcal{X}^-(x)$ into one of three negative categories defined below.

- **Image Negatives**, $\mathcal{X}_{\text{img}}^-(x)$: Image negatives are samples that have the same image ($v = \bar{v}$) as the reference (x) but different answer. Since VQA dataset has multiple questions (~ 5.4) per image, finding image negatives is trivial.
- **Question Negatives**, $\mathcal{X}_{\text{que}}^-(x)$: Question negatives are samples that have questions similar to the reference but different answer. We measure the similarity between the questions by computing their cosine distance in the vector space of the Sentence-BERT [42] model, i.e. $\text{sim}(q, \bar{q}) > \epsilon$, where ϵ is a similarity threshold.
- **Random Negatives**, $\mathcal{X}_{\text{rand}}^-(x)$: Random negatives are samples that do not fall under either Image or Question negative categories *i.e.* any image and question pair that has a different answer than the reference.

We hypothesize that discriminating between joint V+L representations of above negatives and the reference would lead to more robust V+L representations as it requires the model to preserve relevant information from both modalities in the learnt representation. Negative samples belonging to each of the above types are depicted in Figure 2(b).

Batch Curation. To create mini-batches for \mathcal{L}_{SSC} , as described in Algorithm 2, we start by filling our batch with triplets of reference x_i , a intra-class positive \hat{x}_i and a negative sample \bar{x}_i of type t . The negative type t is sampled from a categorical distribution $\text{Cat}(\mathcal{T}|\mathbf{w})$ where $\mathbf{w} = (w_{\text{img}}, w_{\text{que}}, w_{\text{rand}})$ are the probability weights of selecting different types of negatives defined by $\mathcal{T} = \{\text{que}, \text{img}, \text{rand}\}$. This procedure is repeated for specified number of times N_r to create a batch \mathcal{B} . Finally, for every sample

in \mathcal{B} we add a corresponding paraphrased positive x'_i sample. For \mathcal{L}_{CE} , we sample mini-batches randomly from the dataset \mathcal{D}^{aug} .

Importance of Scaling Factor. VQA Dataset has a skewed distribution of answer labels and since we sample references for SCL minibatch independently of each other (see Algorithm 2) quite often we end up with multiple intra-class positives but only a single paraphrased positive for given a reference in a minibatch. To balance this trade-off we choose to scale the loss corresponding to paraphrased positive sample from the intra-class positive samples. We call this loss Scaled Supervised Contrastive Loss (\mathcal{L}_{SSC}).

5. Experiments

5.1. Datasets and Metrics

We use the VQA v2.0 [18] and the VQA-Rephrasings [45] datasets for experiments. VQA contains nearly 443K train, 214K val and 453K test instances. VQA-Rephrasings was collected to evaluate the robustness of VQA models towards human rephrased questions. Specifically, the authors collected 3 human-provided rephrasings for 40k image-question pairs from the VQA v2.0 validation dataset.

Shah *et al.* [45] also introduced Consensus Score (CS) as an evaluation metric to quantify the agreement of VQA models across multiple rephrasings of the same question. Amongst all subsets of paraphrased questions of size k , the consensus score $CS(k)$ measures the fraction of subsets in which *all* the answers have non-zero VQA-Score. For a set of paraphrases Q , the consensus score $CS(k)$ is defined as:

$$CS(k) = \sum_{Q' \subset Q, |Q'|=k} \frac{\mathcal{S}(Q')}{^n C_k} \quad (10)$$

$$\mathcal{S}(Q') = \begin{cases} 1 & \text{if } \forall q \in Q', \text{ VQA-Score}(q) > 0, \\ 0 & \text{else} \end{cases} \quad (11)$$

Where $^n C_k$ is number of subsets of size k sampled from a set of size n . $CS(k)$ is zero for a group of questions Q when the model answers at least k questions correctly.

When reporting results on the val split and VQA-Rephrasings, we train on the VQA 2.0 train split and when reporting results on the VQA 2.0 test-dev and test-std we train on both VQA 2.0 train and val splits. The VQA Rephrasings dataset [45] is never used for training and used only for evaluation.

5.2. Baselines and Training Details

VQA Model. For f , we use a multimodal transformer (MMT) inspired from [13], with 6 layers and 768-dim embeddings. It takes as input two different modalities. The

question tokens are encoded using a pre-trained three layer BERT [14] encoder which is fine-tuned along with the multimodal transformer. Object regions are encoded by extracting features from a frozen ResNeXT-152 [55] based Faster R-CNN model [43]. The projection module g consists of two linear layers and a L-2 normalization function. We choose MMT as representative of current SoTA models [23, 32, 13, 30, 17] in VQA that rely heavily on some form of multi-modal transformer architecture. Also note that our approach (ConClaT) is *agnostic* to the choice of the model.

Question Paraphrases using VQG. Apart from training with question paraphrases generated via Back-translation, we also experiment with generating question paraphrases using the VQG module from [45]. We input the VQG module with 88 random noise vectors to keep the generation comparable with Back-translation approach. For filtering, we use the gating mechanism used by the authors and sentence similarity score of ≥ 0.85 and keep a maximum of 3 unique rephrasings for each question.

Training Details. We train our models using Adam optimizer [28] with a linear warmup and with a learning rate of 1e-4 and a staircase learning rate schedule, where we multiply the learning rate by 0.2 at 10.6K and at 15K iterations. We train for 5 epochs of train + augmented dataset on 4 NVIDIA Titan XP GPUs and use a batch-size of 420 when using \mathcal{L}_{SSC} and \mathcal{L}_{CE} both and 210 otherwise. We put remaining hyperparameters in the supplementary.

Existing state-of-the-art methods. Previous work [45] in VQA-Rephrasings trained a VQG model using a cycle-consistent training scheme along with the VQA model. The approach involved generating questions by a VQG model such that the answer for the original and the generated question are consistent with each other. For their experiments, they build on top of Pythia [24] and BAN [6] as base VQA models. We treat these approaches as baselines for our experiments.

6. Results

In this section, we carefully ablate each component of ConClaT, and also compare results with previous methods (Pythia+CC, BAN+CC) from [45]. We report the Consensus Score ($CS(k)$) for $k = 3, 4$ on VQA-Rephrasings [45] and VQA Accuracy on VQA 2.0 [18] datasets. We omit $CS(1)$ and $CS(2)$ for brevity, and provide them in the supplementary.

6.1. ConClaT

Our baseline architecture MMT without any additional data (Table 2, Row 5) and trained using cross-entropy (\mathcal{L}_{CE}) outperforms previous best (BAN+CC, Table 2, Row 4) by +3.64% on $CS(4)$ while being -0.31% worse on VQA 2.0

	Model	Loss(es)	Scaling	N-Type	Train Scheme	CS(3)	CS(4)	VQA val
1	MMT	\mathcal{L}_{CE}	-	-	-	55.53	52.36	66.31
2	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	R	Alternate	56.53	53.42	66.62
3	MMT	$\mathcal{L}_{SC} \& \mathcal{L}_{CE}$	✓	RQ	Alternate	56.88	53.77	66.97
4	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RI	Alternate	56.91	53.79	66.93
5	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	QI	Alternate	57.00	53.90	66.95
6	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RQI	Alternate	57.08	53.99	66.98
7	MMT	$\mathcal{L}_{SC} \& \mathcal{L}_{CE}$	✗	RQI	Alternate	56.49	53.36	66.60
8	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	Dynamic (Eq. 12)	RQI	Alternate	57.01	53.92	66.95
9	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RQI	Joint	56.59	53.63	66.23
10	MMT	$\mathcal{L}_{SSC} \rightarrow \mathcal{L}_{CE}$ [26]	✗	RQI	Pretrain-Finetune	52.63	49.20	64.21
11	MMT	\mathcal{L}_{DMT} [60] & \mathcal{L}_{CE}	✗	RQI	Alternate	56.23	53.10	66.59

Table 1: **Ablations Study.** **Scaling** denotes whether scaling factor α (defined in Eq. 9 or Eq. 12) was used. **N-Type** defines the type of negatives used from Image (I), Question (Q) and Random (R). All experiments are run with Back-translation data.

Model	DA	Consensus Scores		VQA Scores		
		CS(3)	CS(4)	val	test-dev	test-std
1 Pythia [24]	-	45.94	39.49	65.78	68.43	-
2 BAN [27]	-	47.45	39.87	66.04	69.64	-
3 Pythia + CC [45]	-	50.92	44.30	66.03	68.88	-
4 BAN + CC [45]	-	51.76	48.18	66.77	69.87	-
5 MMT	-	55.10	51.82	66.46	-	-
6 MMT	VQG [45]	54.92	51.85	64.50	-	-
7 MMT + ConClaT	VQG [45]	55.33	52.31	64.74	-	-
8 MMT	BT	55.53	52.36	66.31	69.51	69.22
9 MMT + ConClaT	BT	57.08	53.99	66.98	69.80	70.00

Table 2: ConClaT vs existing methods / baselines on VQA-Rephrasings and VQA 2.0. **DA** denotes the source of augmented data from either Back Translation (BT) or Visual Question Generation (VQG). For test-dev and test-std, we train our model on train+val set of VQA 2.0.

validation. Training MMT with Back-translated data (Table 2, Row 8) using only \mathcal{L}_{CE} further improves **CS(4)** by +0.54% while slightly degrading performance on VQA 2.0 by -0.15%, we treat this as our new baseline.

We find that alternate training (ConClaT) with \mathcal{L}_{SSC} and \mathcal{L}_{CE} (Table 2, Row 9) improves **CS(4)** by +1.63% and VQA Accuracy by +0.67 % on validation. ConClaT outperforms previous state-of-the-art approach BAN+CC by +5.81% on **CS(4)** while performing competitively on VQA 2.0 validation (+0.22%) and test-dev (-0.07%) splits. We present this as our main result, which shows that training with both the losses together leads to models that are accurate (higher VQA score) and robust (higher Consensus score).

ConClaT with VQG data. We also experiment by augmenting the data generated from VQG model of [45]. Similar to Back-translation data, we find that using ConClaT (Table 2, Row 7) leads to +0.46% and +0.24% gains on **CS(4)** and VQA 2.0 validation over the baseline (Table 2,

Row 8). We attribute the relatively smaller gains from VQG data to the lower quality and lesser quantity of paraphrases generated by the VQG module. We discuss more about the quality of generated data in Supplementary Section 5.

6.2. Ablations

Training schemes. We try three different ways of combining \mathcal{L}_{CE} and \mathcal{L}_{SSC} losses. Training alternately performs the best (Table 1, Row 6), whereas training jointly performs worse by -0.36% and -0.75% on **CS(4)** and VQA validation accuracy respectively (Table 1, Row 9). Following the approach taken in [26], we try pre-training the model with \mathcal{L}_{SSC} and then finetuning it on \mathcal{L}_{CE} (Table 1, Row 10) and we find this to perform the worst with -4.79% and -2.77% in **CS(4)** and VQA validation accuracy respectively .

Contrastive vs Triplet Losses. Previous works have explored the use of triplet losses [60, 39] for learning robust VQA models. Specifically, we experiment by replacing our \mathcal{L}_{SSC} with Dynamic-margin Triplet loss (\mathcal{L}_{DMT}) proposed in [60] for mitigating the tendency of VQA models to ignore the image and rely solely on question for answering (also known as knowledge-inertia) . It is also worth noting that \mathcal{L}_{DMT} is an improved version of the vanilla triplet loss used in [39]. We find that ConClaT outperforms this ablation (Table 1, Row 11) by +0.89% and +0.39% **CS(4)** and VQA validation accuracy respectively.

Scaling in \mathcal{L}_{SSC} . We see improvement on both VQA validation (+0.56%) and **CS(4)** (+0.35%) when using our proposed variant Scaled Supervised Contrastive Loss (\mathcal{L}_{SSC}) when compared to using unscaled \mathcal{L}_{SC} (Table 1, Rows 6, 7). Beyond the constant scaling factor defined in Eq. 9, we also experimented with using a dynamic scaling factor de-

			
<p>Q How many slices are there on the plate? 1</p> <p>Q1 What number of slices can be seen on the plate? 2</p> <p>Q2 What is the total amount of slices on the plate? 4</p> <p>Q3 The plate has what number of slices on it? 2</p> <p>GT 1</p> <p>Avg. CS 0.06 / 1.00</p>	<p>What is in the case? flowers</p> <p>The vase has what item in it? vase</p> <p>The vase what is it? glass</p> <p>What item is placed inside the vase? flowers</p> <p>flowers</p> <p>0.16 / 1.00</p>	<p>What word is written in white? stop</p> <p>What's the word that is in white? bus</p> <p>The word in white is what? stop</p> <p>In white, what word is it? stop</p> <p>stop</p> <p>0.16 / 1.00</p>	<p>What is the main color in the photo? green</p> <p>What is the photo's main color? white</p> <p>What color dominates the picture? green</p> <p>What is the dominant color in the photo? green</p> <p>green</p> <p>0.16 / 1.00</p>
			
<p>Q Is it taken in a church? no</p> <p>Q1 Is it taken in a house of worship? yes</p> <p>Q2 Is it taken in a house of God? yes</p> <p>Q3 Is it taken in a Christian center for worship? no</p> <p>GT no</p> <p>Avg. CS 0.16 / 1.00</p>	<p>What animals are there? horses</p> <p>What would you say these animals are? horses</p> <p>Can you tell me the name of this animal? nothing</p> <p>What kind of animal is this? horse</p> <p>horses</p> <p>0.16 / 1.00</p>	<p>What kind of landscape is this? desert</p> <p>What sort of scene is this? beach</p> <p>What kind of scenery would you call this? beach</p> <p>What kind of scenery is this? beach</p> <p>beach</p> <p>0.16 / 1.00</p>	<p>What pattern is the person's shirt? striped</p> <p>What is on the shirt? nothing</p> <p>Do you know what pattern is there? stripes</p> <p>What pattern is on the shirt? no</p> <p>stripes</p> <p>0.37 / 0.37</p>
█ Ours █ Baseline			

Figure 3: **Qualitative Examples.** Predictions of ConClat (Table 1, Row 1) and our baseline (Table 1, Row 6) on several image-question pairs and their corresponding rephrased questions. Average Consensus Scores (k=1-4) are also shown at the bottom (higher the better).

fined as follows:

$$\alpha_{ip} = \begin{cases} s \cdot \Phi(\mathbf{z}_i \cdot \mathbf{z}_p) & \text{if } x_p \in \mathcal{X}_{\text{para}}^+(x_i), \\ \Phi(\mathbf{z}_i \cdot \mathbf{z}_p), & \text{otherwise} \end{cases} \quad (12)$$

Where $\Phi(\mathbf{u}, \mathbf{v}) = 1 - \mathbf{u}^\top \mathbf{v} / \|\mathbf{u}\| \|\mathbf{v}\|$ computes the cosine distance between \mathbf{u} and \mathbf{v} . We did not find significant improvements using dynamic scaling (Table 1, Row 8).

Negative Sampling Strategy. Furthermore, we find that our proposed negative sampling strategy (Algorithm 2) where we carefully curate batches for \mathcal{L}_{SSC} loss (Table 1, Row 6) helps improve **CS(4)** (+0.57%) and VQA accuracy (+0.36%) over random-sampling (Table 1, Row 2). We find that adding either `que`-type negatives (Table 1, Row 3) or `img`-type negatives (Table 1, Row 4) lead to gains in **CS(4)** and VQA validation accuracy. Using only `img`-type and `que`-type negatives (Table 1, Row 5) leads to significant gains, showing that use of both the types is crucial.

6.3. Qualitative Analysis

We qualitatively visualize few samples in Figure 3. We compare our final approach (Table 1, Row 6) with our baseline (Table 1, Row 1). As evident from samples, ConClat improves the consistency in answers across the rephrasings.

(2,2) shows an interesting example where ConClat yields a singular answer for one question paraphrase and produces the original plural answer for other paraphrased question. In (2,3), baseline incorrectly answers the original VQA question but correctly answers some of the rephrasings whereas our approach gets all the questions right. (2,4) illustrates a failure case where both the approaches fail to answer all the paraphrased questions correctly.

7. Conclusion

To summarize, we have three main contributions. First, we propose a novel training paradigm (ConClat) that optimizes contrastive and cross-entropy losses to learn joint vision and language representations that are robust to question paraphrases. Minimizing the contrastive loss encourages representations to be robust to linguistic variations in questions while the cross-entropy loss preserves the discriminative power of the representations for answer classification. Second, we introduce Scaled Supervised Contrastive Loss (\mathcal{L}_{SSC}), that assigns higher weight to positive samples associated with question paraphrases over samples that just have the same answer boosting the performance further. Finally, we propose a negative sampling strategy to curate

loss-specific batches which improves performance over random sampling strategy. Compared to previous approaches, VQA models trained with ConClat achieve higher consistency scores on the VQA-Rephrasings dataset as well as higher VQA accuracy on the VQA 2.0 dataset across a variety of data augmentation strategies. We also qualitatively demonstrate that our approach yields correct and consistent answers for VQA questions and their rephrasings.

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Appendix

A. Ablations with Joint Training

In the joint training experiment (Table 2, Row 8), we use a weighing parameter (β) to combine the \mathcal{L}_{SC} and \mathcal{L}_{CE} losses. We ablate on the choice of weight (β) used, and we represent the overall loss in this experiment as:

$$\mathcal{L}_{\text{joint}} = \beta \mathcal{L}_{\text{SSC}} + (1 - \beta) \mathcal{L}_{\text{CE}}$$

We also find that the VQA-Accuracy and Consensus Scores hit a sweet-spot at $\beta = 0.5$ and we use this configuration as our baseline.

Model	β	CS(4)	VQA val
1 MMT	0.25	52.97	66.14
2 MMT	0.50	53.63	66.23
3 MMT	0.75	48.53	61.34
4 MMT	0.90	40.68	51.03
5 MMT + ConClaT	-	53.99	66.98

Table A: Ablations on the choice of our hyper-parameter β for joint training.

B. Joint and Pretrain-Finetune Training

As mentioned in Section 4.3 of the manuscript, we respectively provide the training schemes used to jointly optimize in Algorithm 3 and the scheme used to pretrain-finetune in Algorithm 4 with the \mathcal{L}_{SSC} and \mathcal{L}_{CE} losses.

C. Gradient Surgery of \mathcal{L}_{SSC} and \mathcal{L}_{CE}

To know whether the gradients of both the losses (\mathcal{L}_{SSC} and \mathcal{L}_{CE}) are aligned with each other during training, we follow the gradient surgery setup of [57] for multi-task learning. During joint-training, we take the dot-products of gradients from both the losses and plot them to see how well they are aligned *i.e.* whether the dot product is positive or negative. In Figure A we plot the un-normalized dot product between the gradients corresponding to \mathcal{L}_{CE} and \mathcal{L}_{SSC}

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Algorithm 3 ConClaT with joint \mathcal{L}_{SSC} and \mathcal{L}_{CE}

```

input: steps  $N$ ; constant  $N_r, \beta$ ; data  $\mathcal{D}^{\text{aug}}$ ; networks  $f, g$ 

for all  $i \in \{1, \dots, N\}$  do
    # initialize batches
     $\mathcal{B}_{\text{SSC}} = \text{CURATE}(N_r, \mathcal{D}^{\text{aug}}, \mathbf{w})$ ;  $\mathcal{B}_{\text{CE}} \sim \mathcal{D}^{\text{aug}}$ 
    # compute gradients separately
     $\nabla_{\text{SSC}} = \nabla \mathcal{L}_{\text{SSC}}(f, g, \mathcal{B}_{\text{SSC}}) \cdot \beta$ 
     $\nabla_{\text{CE}} = \nabla \mathcal{L}_{\text{CE}}(f, g, \mathcal{B}_{\text{CE}}) \cdot (1 - \beta)$ 
    # joint update
    update  $f(\cdot), g(\cdot)$  networks with  $\nabla = \nabla_{\text{CE}} + \nabla_{\text{SSC}}$ 
return network  $f(\cdot)$ ; throw away  $g(\cdot)$ 

```

Algorithm 4 ConClaT with pre-train \mathcal{L}_{SSC} and fine-tune \mathcal{L}_{CE}

```

input: steps  $N_p, N_f$ ; data  $\mathcal{D}^{\text{aug}}$ ; networks  $f, g$ 
    # pretrain with SSCL
     $\mathcal{B} = \text{CURATE}(N_r, \mathcal{D}^{\text{aug}}, \mathbf{w})$ 
    update  $f(\cdot), g(\cdot)$  networks to minimize  $\mathcal{L}_{\text{SSC}}$  over  $\mathcal{B}$ 
    # finetune with CE
    for all  $i \in \{1, \dots, N_f\}$  do
         $\mathcal{B} \sim \mathcal{D}^{\text{aug}}$ 
        update  $f(\cdot)$  network to minimize  $\mathcal{L}_{\text{CE}}$  over  $\mathcal{B}$ 
    return network  $f(\cdot)$ ; throw away  $g(\cdot)$ 

```

losses. We find that except for initial few steps the gradients of both the losses are aligned (dot product is positive) and thus the updates are complementary with respect to each other.

D. Training

Hyperparameters. All the models have $\sim 100M$ trainable parameters. We train our models using Adam optimizer [28] with a linear warmup and with a learning rate of 1e-4 and a staircase learning rate schedule, where we multiply the learning rate by 0.2 at 10.6K and at 15K iterations. We train for 5 epochs of augmented train dataset \mathcal{D}^{aug} on 4 NVIDIA Titan XP GPUs and use a batch-size of 420 when using \mathcal{L}_{SSC} and \mathcal{L}_{CE} both and 210 otherwise. We use Py-

Table B: Hyperparameter choices for models.

#	Hyperparameters	Value	#	Hyperparameters	Value
1	Maximum question tokens	23	2	Maximum object tokens	101
3	$\mathcal{L}_{CE}:\mathcal{L}_{SSC}$ iterations ratio	3:1	4	Number of TextBert layers	3
5	Embedding size	768	6	Number of Multimodal layers	6
7	Multimodal layer intermediate size	3072	8	Number of attention heads	12
9	Negative type weights (\mathbf{w})	(0.25, 0.25, 0.5)	10	Multimodal layer dropout	0.1
11	Similarity Threshold (ϵ)	0.95	12	Optimizer	Adam
13	Batch size	210/420	14	Base Learning rate	2e-4
15	Warm-up learning rate factor	0.1	16	Warm-up iterations	4266
17	Vocabulary size	3129	18	Gradient clipping (L-2 Norm)	0.25
19	Number of epochs	5/20	20	Learning rate decay	0.2
21	Learning rate decay steps	10665, 14931	22	Number of iterations	25000
23	Projection Dimension (\mathcal{R}^{d_z})	128	24	Scaling Factor (s)	20
25	N_{ce}	4	26	N_r	70

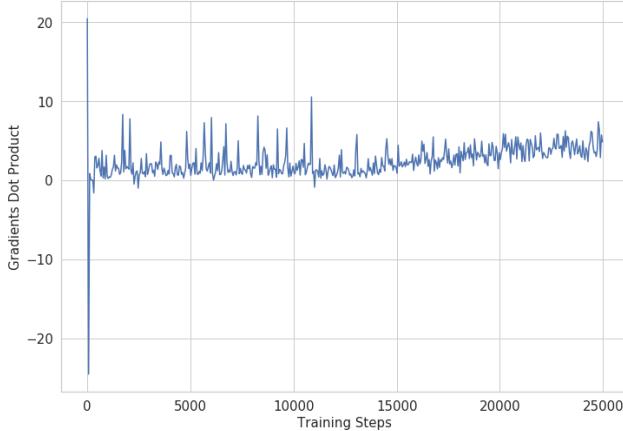


Figure A: Gradient Alignment between the \mathcal{L}_{SSC} and \mathcal{L}_{CE} losses. The dot-product is positive indicating that the gradients from the two losses are aligned.

Torch [38] for all the experiments. Hyperparameters are summarized in Table B.

E. Frequently Asked Questions

Why use different sampling rates for different negative types?

The different types of negatives – same-image-different-question (img) and same-question-different-image (que) – encourages the model to be sensitive to both modalities. We use different sampling weights to emphasize more on these two types of negatives over the ones which just have different answers. We obtain the weights (Table B, Row 9) through hyper-parameter tuning on the validation set.

Why should questions dealing with different concepts but same answer (e.g., questions in Fig 2b, “Is the dog

atop a sofa?” and “Is there broccoli in the picture?”) have similar representations?

We clarify that we do not impose any supervision at the level of MMT layers but only at the penultimate layer before answer prediction. Hence, the model is able to perform different reasoning steps (needed to process entirely different visual/textual inputs) for arriving at the same final answer.

F. Augmented Data

Back-translation: We use 88 different MarianNMT [25] Back-translation model pairs released by Hugging Face [53] to generate question paraphrases. We use Sentence-BERT [42] to filter out paraphrases that cosine similarity of ≥ 0.95 with the original question and choose three unique paraphrases randomly from the filtered set. After filtering duplicates we end up with 2.89 paraphrases per original question on average.

VQG: We use the VQG model introduced by previous work [45] that takes as input the image and answer to generate a paraphrased question. We input the VQG module with 88 random noise vectors to keep the generation comparable with Back-translation approach. For filtering, we use the gating mechanism used by the authors and sentence similarity score of ≥ 0.85 and keep a maximum of 3 unique rephrasings for each question. Since, VQG produces fewer unique rephrasings per question than Back-translation, we used a lower similarity threshold. After filtering duplicates we end up with only 0.96 paraphrases per original question on average, far fewer than Back-translation. Qualitatively, we find the VQG paraphrases worse when compared against Back-translated ones.

Evaluation: During training, we evaluate our models using the Back-translated rephrasings on a subset of questions from validation set which do not overlap with VQA-

Rephrasings [45] dataset.

G. Code and Result Files

We share the code for running the baseline and the best experiments (Table 1, Rows 5, 9). Please find the released code at: [https://www.github.com/yashkant\(concat-vqa](https://www.github.com/yashkant(concat-vqa)

H. Full Ablations

For brevity and conciseness, we omitted **CS(1)** and **CS(2)** scores in the main ablation table, we provide the these scores in Table B.

I. Qualitative Samples

Figures B, C, D, E show many more qualitative samples comparing the baseline and ConClaT. We visualize the data generated via Back-translation and mined triplets in Figures F, G, H.

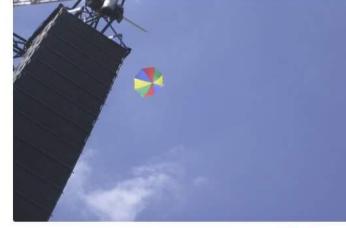
	Model	Loss(es)	Scaling	N-Type	Train Scheme	CS(1)	CS(2)	CS(3)	CS(4)	VQA val
1	MMT	\mathcal{L}_{CE}	-	-	-	67.58	60.04	55.53	52.36	66.31
2	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	R	Alternate	68.19	60.92	56.53	53.42	66.62
3	MMT	$\mathcal{L}_{SC} \& \mathcal{L}_{CE}$	✓	RQ	Alternate	68.41	61.24	56.88	53.77	66.97
4	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RI	Alternate	68.47	61.28	56.91	53.79	66.93
5	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	QI	Alternate	68.65	61.40	57.00	53.90	66.95
6	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RQI	Alternate	68.62	61.42	57.08	53.99	66.98
7	MMT	$\mathcal{L}_{SC} \& \mathcal{L}_{CE}$	✗	RQI	Alternate	68.20	60.90	56.49	53.36	66.60
8	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	Dynamic	RQI	Alternate	68.60	61.38	57.01	53.92	66.95
9	MMT	$\mathcal{L}_{SSC} \& \mathcal{L}_{CE}$	✓	RQI	Joint	67.75	60.79	56.59	53.63	66.23
10	MMT	$\mathcal{L}_{SSC} \rightarrow \mathcal{L}_{CE}$ [26]	✗	RQI	Pretrain-Finetune	65.33	57.39	52.63	49.20	64.21
11	MMT	\mathcal{L}_{DMT} [60] & \mathcal{L}_{CE}	✗	RQI	Alternate	68.11	60.70	56.23	53.10	66.59

Table B: **Ablations Study of ConClaT.** **Scaling** denotes whether scaling factor α was used. **N-Type** defines the type of negatives used from Image (I), Question (Q) and Random (R). All experiments are run with Back Translation data.



- Q** Who is sniffing who?
Q1 Somebody is being sniffed by who?
Q2 Who is doing the sniffing?
Q3 What is doing the sniffing?
- GT** dog
Avg. CS 0.16 / 1.00

- What color is the clock?
 Can you tell me what color the clock is?
 What color is the pictured clock?
 What is the color of the clock?
- orange**
 0.37 / 1.00



- What color is the umbrella?
 The color of the umbrella is what?
 The umbrella's color is what?
 The umbrella is what color?
- rainbow**
 0.16 / 1.00



- Q** How many skis are on the ground?
Q1 What is the number of skis on the ground?
Q2 What is the ski count on the ground?
Q3 What's the exact number of skis on the ground?
- GT** 0
Avg. CS 0.16 / 1.00



- Which corner of the table is in the frame?
 What corner of the table is shown?
 Which corner of this table is visible?
 Which corner of the table is in the shot?
- left**
 0.00 / 1.00



- Is the cat able to access the toilet water?
 Is toilet water something the cat has access to?
 Does the cat have access to the toilet water?
 Is accessing the toilet water something the cat can do?
- no**
 0.16 / 1.00



- Q** Are these fruit or vegetable?
Q1 Are these classified as fruit or vegetable?
Q2 Would these be called fruit or vegetable?
Q3 Do these count as fruit or vegetable?
- GT** vegetable
Avg. CS 0.00 / 1.00



- Is this food sweet?
 Does this food have a sweet taste?
 Does this food taste sweet?
 Is this a food that tastes sweet?
- yes**
 0.16 / 1.00



- How many sheep are there?
 What is the total of sheep?
 What is the number of sheep?
 How many sheep?
- 2**
 0.37 / 1.00

■ Ours ■ Baseline

Figure B: Qualitative Examples. Predictions of ConClaT and MMT+CE baseline on several image-question pairs and their corresponding rephrased questions. Average Consensus Scores (k=1-4) are also shown at the bottom (higher the better).

		
<p>Q Is there cheese on the sandwich? yes no</p> <p>Q1 Does the sandwich have cheese? yes no</p> <p>Q2 The sandwich, does it have cheese? yes no</p> <p>Q3 Is there cheese on it? yes no</p> <p>GT no</p> <p>Avg. CS 0.00 / 1.00</p>	<p>How many cows? 2 2 2</p> <p>What is the count of cows in this picture? 4 4 2</p> <p>How many cows are there in this picture? 2 2 2</p> <p>How many cows can be seen? 2 2 2</p> <p>2 0.37 / 1.00</p>	<p>How many dogs are there? 2 2 2</p> <p>What is the count for the amount of dogs? 10 2 2</p> <p>What is the number of dogs? 2 2 2</p> <p>What is the amount of dogs? 2 2 2</p> <p>2 0.37 / 1.00</p>
		
<p>Q Do these flowers have yellow leaves? no</p> <p>Q1 Are there yellow leaves on these flowers? no no</p> <p>Q2 Can yellow covered leaves be found on these flowers? yes no</p> <p>Q3 Are any of the leaves on these flowers yellow in color? no no</p> <p>GT no</p> <p>Avg. CS 0.37 / 1.00</p>	<p>Is this planes color black? yes yes no</p> <p>Is the color of this plane black? yes yes no</p> <p>Is the plane's color black? yes yes no</p> <p>Is the color associated with the plane black? yes no no</p> <p>0.00 / 1.00</p>	<p>What is in the vase? flowers flowers glass</p> <p>The vase has what in it? flowers flowers vase</p> <p>What item is placed inside the vase? flowers flowers vase</p> <p>The vase has what item in it? flowers flowers vase</p> <p>0.16 / 1.00</p>
		
<p>Q What color is the table? green green nothing</p> <p>Q1 Out of all the colors of the rainbow, which applies to the table? green green</p> <p>Q2 The table is what color? green green</p> <p>Q3 Can you name what color the table is? green green</p> <p>GT green</p> <p>Avg. CS 0.37 / 1.00</p>	<p>Do the pillows match the bedspread? yes yes no</p> <p>Are the pillows matching the bedspread? yes yes yes</p> <p>Does the bedspread match the pillows? yes yes yes</p> <p>Is the pattern on pillows and bedspread similar? yes yes yes</p> <p>0.37 / 1.00</p>	<p>Is this a vase? yes yes no</p> <p>Does the picture depict a vase? yes yes yes</p> <p>Is this a flower vase? yes yes yes</p> <p>Does the photo show a vase? yes yes yes</p> <p>0.37 / 1.00</p>

Figure C: Qualitative Examples. Predictions of ConClaT and MMT+CE baseline on several image-question pairs and their corresponding rephrased questions. Average Consensus Scores (k=1-4) are also shown at the bottom (higher the better).



Q What covering everything?

snow

- Q1** What is that thing covering everything?
Q2 What is the substance covering everything?
Q3 What is covering everything?

snow
snow
bench
snow
snow
snow
snow
snow

GT snow
Avg. CS 0.37 / 1.00

What colors are the stripes on the left?
Can you name the colors on the far left?
The left side has which colors?
What colors do you see on the left?
red and white

red and white
red and white
yes
red and white
red and white
red and white
red and white

What kind of road is the truck parked on?
For the truck, what kind of road is it parked on?
Can you identify the type of road the truck is parked on?
Name the kind of road that truck is parked on?
parking lot

paved
asphalt
concrete
asphalt
no
no
paved
asphalt

0.00 / 0.37



Q What is on the plate?

food

- Q1** The plate has what on it?
Q2 Can you tell me what is on top of the plate?
Q3 What does the plate contain?

table
food
no
no
food

GT food
Avg. CS 0.16 / 0.37

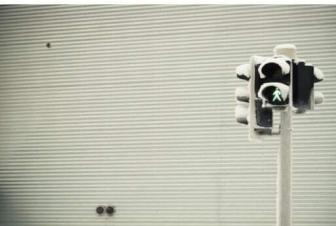
How many people are there?
What number of people are there?
What is the count of people?
What is the amount of people?

1
2
1
1
1
2

How many slices is this pizza cut into?
The pizza has been cut into how many slices?
What amount of slices make up the cut pizza?
The amount of slices the pizza has been cut into is what?

4
6
1
1
1
8
6
4

0.00 / 0.16



Q Are the flowers all one color?

no

- Q1** Do the flowers come in one color?
Q2 Are the flowers one color?
Q3 Are the flowers in a single color?

yes
yes
no
no
no

GT no
Avg. CS 0.37 / 0.37

What does the sign say?

go

What is on the sign?
What does the sign indicate?
What is written on the sign?

go
walk
go
walk
go

How many vehicles could use this object?
How many vehicles use this object?
Can you tell me how many vehicles use this object?
Will you tell me how many vehicles can use this object?

2
2
1
1
no
yes

2
0.16 / 0.37

Ours

Baseline

Figure D: Qualitative Examples. Predictions of ConClaT and MMT+CE baseline on several image-question pairs and their corresponding rephrased questions. Average Consensus Scores (k=1-4) are also shown at the bottom (higher the better).



Q Is this a male or female?	male male yes no	What shape is cut out of the wood?	square square square triangle	Is it evening?	yes
Q1 Is this a male?	yes	The shape cut out of the wood is what?	triangle	Is it night time?	no
Q2 Do you know if this is a girl?	yes	Tell me the shape that is cut out of the wood.	no	Is it dark outside?	yes
Q3 What is the gender of the person?	male male	Cut out of the wood is what shape?	square rectangle	Does it appear to be evening?	yes
GT female	female	square	rectangle		no
Avg. CS	0.16 / 0.16	0.37 / 0.06		yes	1.00 / 0.06



Q What color is his jacket?	white white white white white white no	Where is the food?	table table	How was the food served?	plate baked
Q1 I want to know what color is his jacket?	white	What is the location of the food?	table table	How did they serve the food?	plate baked
Q2 I would like to know What color is his jacket?	white	Where is the morsels?	table table	In what way was the food served?	plate bowl
Q3 Can I know what color is his jacket?	white	Where is the sustenance?	shelf on table	What was the food served on?	plate plate
GT white	white	table	on table	on plate	1.00 / 0.06
Avg. CS	1.00 / 0.37	1.00 / 0.16			



Q How many minutes are depicted on the sign?	10 2 20 2	What is the date on the photo?	unknown 0	What text is on the computer?	unknown flickr
Q1 The number of minutes depicted on the sign are what?	20 2	The date on the photo is what?	unknown 0	What is that written on the computer?	words words
Q2 Can you tell me the amount of minutes on the sign?	no no	What is the date that can be seen on the photo?	2016 0	What are the writings on the computer?	facebook words
Q3 So what's on the sign?	stop go	The photo has what date on it?	2010 2010	What is written on the computer?	yes words
GT 30	30	19.12.2007	0.00 / 0.00	icon names	website
Avg. CS	0.00 / 0.00			0.00 / 0.00	

Ours Baseline

Figure E: Qualitative Examples. Predictions of ConClaT and MMT+CE baseline on several image-question pairs and their corresponding rephrased questions. Average Consensus Scores (k=1-4) are also shown at the bottom (higher the better).

	Reference Sample	Image Negative	Question Negative
Image			
Original Question	Where is the dog laying?	What is the dog doing?	The dog's lying on a rug?
Back Translated Questions	Where's the dog lay? Where's the dog lying down? Where's the dog lying?	What's the dog doing? What is a dog doing? What's that dog doing?	Is the dog laying on a rug? Is the dog lying on a rug? Is the dog lying on a carpet?
Ground Truth Answers	outside, street, yes, sidewalk, ground	resting, lying down, laying down, sleeping	yes
Image			
Original Question	What are the men sitting on?	What are the ranks of the military members?	What are men sitting on?
Back Translated Questions	What are these men sitting on? What are men sitting on? What were these men sitting on?	What are the ranks of military members? What are the ranks of the military? What is the rank of military members?	What are the men sitting on? What are these men sitting on? What were these men sitting on?
Ground Truth Answers	bench	low	bed
Image			
Original Question	What's in the oven?	What storage is open?	What is in the oven?
Back Translated Questions	What is in the oven? What is there in the oven? What is inside the oven?	What kind of storage is open? Which storage is open? What storage place is open?	What's in the oven? What was in the oven? What is the meaning of the oven?
Ground Truth Answers	pot	oven	turkey

Figure F: Visualizing the triplets of samples from VQA dataset with corresponding mined Image and Question Negatives.

	Reference Sample	Image Negative	Question Negative
Image			
Original Question	How high is the plane in the sky?	Are there clouds?	What's the altitude of the plane?
Back Translated Questions	How high is the plane in the air? How high is the plane of the sky? How high is the flying plane?	Are There Clouds? Is there clouds? Is there a clouds?	What is the altitude of the plane? What is the plane's altitude? How high is the altitude of the plane?
Ground Truth Answers	medium, very, high, very high	yes	unknown, high
Image			
Original Question	What is the woman taking a picture of?	What color is the grass?	Is that woman taking pictures?
Back Translated Questions	What's the woman taking a picture of? What is the woman taking a picture of it? What's that woman taking a picture of?	What color is grass? What color is this grass? What color does the grass have?	Is this woman taking a picture? Is the woman taking a picture? Does this woman take a picture?
Ground Truth Answers	goose, swan, bird	green, no grass	yes
Image			
Original Question	Is the catcher wearing safety gear?	What is the name of the teams?	Is the athlete wearing safety gear?
Back Translated Questions	Is the catcher wearing safety equipment? Is the catcher wearing the safety equipment? Does the catcher wear safety equipment?	What's the name of the teams? What's the name of these teams? What is the name of teams?	Is the athlete wearing a safety gear? Is the athlete wearing safety equipment? Does the athlete wear safety equipment?
Ground Truth Answers	yes	cubs	no

Figure G: Visualizing the triplets of samples from VQA dataset with corresponding mined Image and Question Negatives.

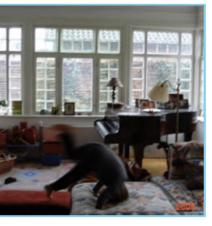
	Reference Sample	Image Negative	Question Negative
Image			
Original Question	What is the elephant doing?	How many elephants are there?	What is the elephant doing?
Back Translated Questions	What's the elephant doing? What's an elephant doing? What's that elephant doing?	How many elephants is there? How many elephants do you have? How many elephants exist?	What's the elephant doing? What's an elephant doing? What's that elephant doing?
Ground Truth Answers	drinking water, drinking	3, 4	eating, kissing, playing
Image			
Original Question	What is the equipment in the background?	How many birds?	What instrument is in the background?
Back Translated Questions	What's the equipment in the background? What are the equipment in the background? What kind of equipment is in the background?	How many birds are? How many birds are there? How much birds?	What instrument in the background? Which instrument is in the background? What is the instrument in the background?
Ground Truth Answers	building, oil, cranes, boats	3, 2	piano
Image			
Original Question	What brand are the catcher's shoes?	What game are they playing?	What brand are the batter's shoes?
Back Translated Questions	What brand is the catcher's shoes? What brand are the shoes of the catcher? What brand are the catcher shoes?	What kind of game are they playing? What game do they play? Which game are they playing?	What are the batter's shoes brand? What brand are the shoes of the batter? What brand are the batter shoes?
Ground Truth Answers	puma, black and white, asics, nike	baseball	clear, adidas, nike

Figure H: Visualizing the triplets of samples from VQA dataset with corresponding mined Image and Question Negatives.