# Visual Goal-Step Inference using wikiHow

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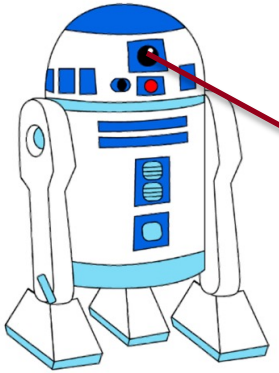
# Motivation

- Teach AI system to understand complex events.
- Reasoning relationship between high-level goals and the steps.
  - E.g., Goal: “change a tire” → Steps: “raise the jack”, “loosen the nuts”.
- Past work examined the goal-step relationship for **text**.




Make Tea?
Make Coffee?
Cook Noodles?

→ Recommendations

Get a slice of cake: take the cake out of the box → cut a slice → put it on a plate → take the plate to the user

(Reporting Bias)

# Introduction

- Learning goal-step relations in multimodal fashion.
- We propose the Visual Goal-Step Inference (VGSI)
  - Given given a textual goal
  - Infer which image represents a plausible step towards that goal
- More challenging than text-image matching
  - Text and objects are not closely matched

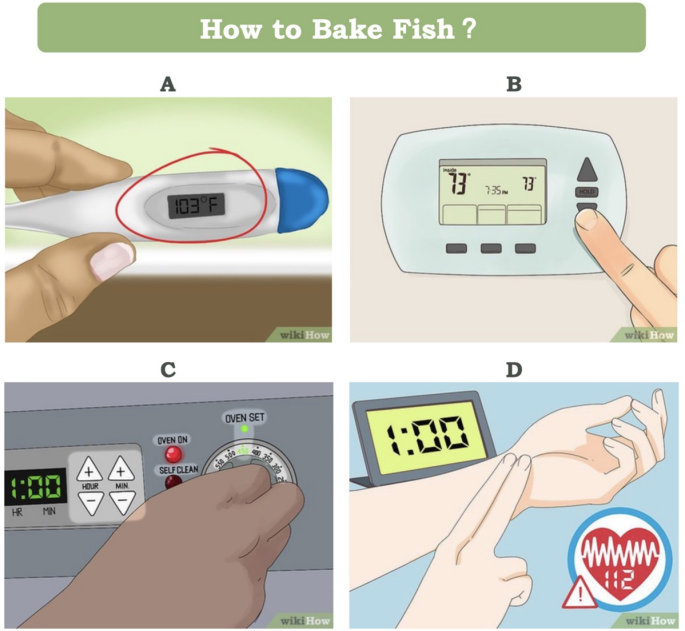



Figure 1: An example Visual Goal-Step Inference Task: given a text goal (*bake fish*), select the image (C) that represents a step towards that goal.

# Dataset

- Harvested from wikiHow
- Goal – Method – Step structure
- The corpus consists
  - 53,189 wikiHow articles across various categories
  - 155,265 methods, 772,294 steps/images

| Category | Goals | Methods | Steps | Images |
|---|---|---|---|---|
| Health | 7.8k | 19.1k | 97.5k | 111.8k |
| Home and Garden | 5.9k | 16.0k | 82.9k | 85.4k |
| Education & Communications | 4.7k | 12.4k | 61.2k | 66.1k |
| Food & Entertaining | 4.6k | 11.6k | 62.0k | 69.0k |
| Finance & Business | 4.4k | 11.8k | 59.3k | 66.8k |
| Pets & Animals | 3.5k | 9.5k | 45.3k | 48.0k |
| Personal Care & Style | 3.4k | 9.0k | 46.1k | 48.9k |
| Hobbies & Crafts | 2.8k | 7.5k | 40.9k | 42.7k |
| Computers & Electronics | 2.6k | 6.1k | 31.5k | 36.2k |
| Arts & Entertainment | 2.5k | 6.8k | 35.4k | 37.2k |
| Total | 53.2k | 155.3k | 772.3k | 772.3k |

Table 1: Number of goals, methods, steps and images in the top 10 wikiHow categories.

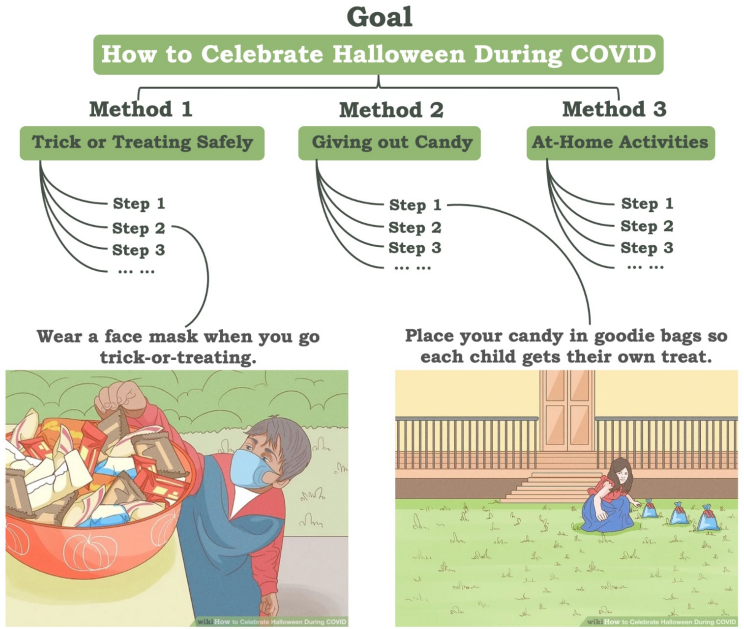



Figure 2: Hierarchical multimodality of wikiHow.

# Sampling Strategies

- 4-way Choice Format
- Sampling Strategies
  - Random Sampling:
    - randomly pick three different articles
    - select one image by chance from each article
  - Similarity Sampling
    - greedily select the most similar images based on the feature vectors
    - use FAISS to retrieve the top-3 most similar images
  - Category Strategy
    - randomly select three different articles within the same wikiHow category as the goal
    - select one image by chance from each article

# Qualitative Examples

(C) Category Sampling


(C.1) Correct Answer is **A**

(C.2) Correct Answer is **D**

# Methods

- Problem Formulation:
  - Input: a high-level goal $G$, an Image $I$
  - The model outputs the matching score:

$$match(G, I) = F(X_G, X_I) \qquad (1)$$

- Baseline Models:
  - **DeViSE**:
    - maps the source vector onto the span of the target vector.
  - **Similarity Network**:
    - 2 branches with pointwise multiplication, train as binary classifier.
  - **Triplet Network**:
    - 3 branches, minimize the positive pair distance, maximize negative pair distance.
  - **LXMERT**:
    - transformer encoders, attention layers to ground text to objects.

# Experimental Setup

- Human Annotation
  - 100 examples from each test set
  - A pair of annotators complete each test and take the average
- Modified VGSI
  - Replace the goal prompt with method/step
  - More detailed/lower-level prompt
  - Validate VGSI is challenging


(C.1) Correct Answer is **A**

# Results

| Model | Sampling Strategy (Test Size) | | |
|---|---|---|---|
| | **Random** (153,961) | **Similarity** (153,770) | **Category** (153,961) |
| Random | .2500 | .2500 | .2500 |
| DeViSE | .6719 | .3364 | .4558 |
| Similarity Net | .6895 | .6226 | .4983 |
| LXMERT | .7175 | .4259 | .2886 |
| Triplet Net (GloVe) | .7251 | .7450 | .5307 |
| Triplet Net (BERT) | **.7280** | **.7494** | **.5360** |
| Human | .8450 | .8214 | .7550 |

-13.8% -8.77% -29.0%

Table 2: Accuracy of SOTA models on the wikiHow VGSI test set with different sampling strategies (sample size is shown in parentheses).

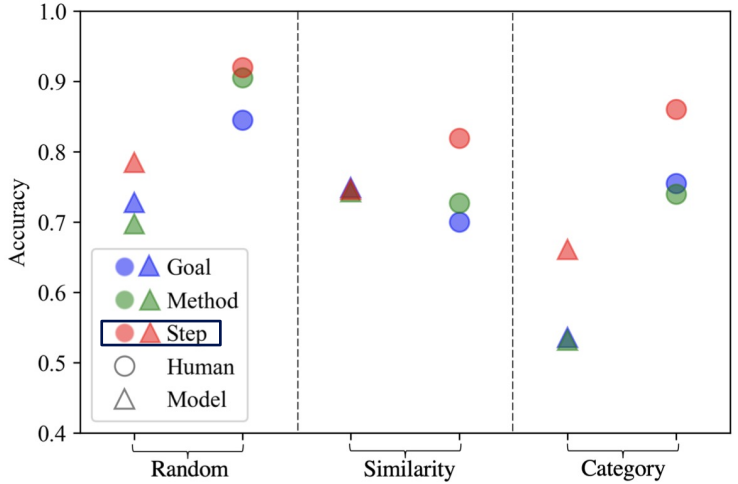



Figure 3: Accuracy of human (circles) and model (triangles) on the modified wikiHow VGSI test set with different textual input (e.g., in Fig 1, the *goal* prompt will be replaced by *method* - "Baking the Fish." or *step* - "Preheat the oven.").

# Transfer Learning

- Most wikiHow images are drawings.
- Can we apply the knowledge learned from wikiHow to real photos?
- Target dataset (Instructional Videos + Keyframe extraction)
  - Howto100m
    - randomly select 1,000 goals, one video per goal
    - k-means clustering to select key frames,
    - Split goals into 8:2 for training and testing
  - COIN
    - 180 goals, 5 videos per goal for testing, the remaining 9,709 videos for training
    - The videos in COIN are segmented into clips, we randomly pick one frame per clip
- Caption-based dataset for comparison
  - Flickr30K
  - MSCOCO

# Transfer Learning

| PT-Data | FT? | Sampling Strategy | | |
|---|---|---|---|---|
| | | Random | Similarity | Category |
| - | ✓ | .6649 | .5085 | .5216 |
| Flickr30K | ✗ | .4903 | .5103 | .3919 |
| | ✓ | .7006 | .5823 | .5495 |
| MSCOCO | ✗ | .5349 | .5401 | .4071 |
| | ✓ | .7481 | .6180 | .5536 |
| Howto100m | ✗ | .5694 | .5811 | .3989 |
| | ✓ | .6948 | .6104 | .5436 |
| wikiHow | ✗ | **.6245** | **.6309** | **.4586** |
| | ✓ | **.7639** | **.6854** | **.5659** |
| Human | - | .9695 | .8500 | .8682 |

Table 3: Transfer performance (4-way multiple choice accuracy) on COIN. PT stands for pre-training, FT for fine-tuning. FT results are obtained by fine-tuning the model on 5 examples of the COIN training set (i.e., 5-shot). **Red** numbers indicate the best zero-shot performance. **Blue** numbers are the best fine-tuned results.

| PT-Data | FT? | Sampling Strategy | | |
|---|---|---|---|---|
| | | Random | Similarity | Category |
| - | ✓ | .6005 | .6096 | .4434 |
| Flickr30K | ✗ | .4837 | .5398 | .3856 |
| | ✓ | .6207 | .6408 | .4740 |
| MSCOCO | ✗ | .5099 | .5715 | .3958 |
| | ✓ | .6340 | .6640 | .4794 |
| COIN | ✗ | .5067 | .5161 | .3978 |
| | ✓ | .6170 | .6343 | .4638 |
| wikiHow | ✗ | **.6556** | **.6754** | **.4750** |
| | ✓ | **.6855** | **.7249** | **.5143** |
| Human | - | .8300 | .7858 | .7550 |

Table 4: Transfer performance (4-way multiple choice accuracy) on Howto100m. FT results are obtained by fine-tuning the model on the full training set.

# Conclusion

- We propose the novel Visual Goal-Step Inference task (VGSI), a multimodal challenge for reasoning over procedural events.
- We construct a dataset from wikiHow and show that SOTA models struggle on it.
- The knowledge harvested from our dataset could be transferred to other datasets.
- The multimodal representation learned from VGSI has strong potential to be useful for NLP applications such as multimodal dialog systems, multimodal schema induction systems.

# Thank you!

Dataset and code are available at
https://github.com/YueYANG1996/wikiHow-VGSI