Deep-based Ingredient Recognition for Cooking Recipe Retrieval

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Introduction
Introduction

Dish

Ingredient composition

Corn Carrot Spareribs
Introduction

Dish

Ingredient composition

Recipe

**Corn spareribs soup**

**Material**

- Small spareribs (300g), Corn (1), Carrot (1).

**Procedure**

1. Chop corn into 4-6 pieces, and cut carrot into chunk.
2. Rinse spareribs until water is running clear, scald and drain. Set aside.
3. Boil water in a large pot, add in all ingredients except salt. Let it simmer over low heat for 1 hour.
4. Add salt to taste, serve warm.
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Why this problem is challenging?

Kung bao chicken

**Material**
- Chicken, cucumber, peanut, carrot

**Procedure**
1. Cut the chicken, cucumber, and carrot into small dices.
2. ..............................................................

Kung bao chicken

**Material**
- Chicken, peanut, white onion, dried chilli

**Procedure**
1. Dice the chicken, and cut the dried chilli on to sections.
2. ..............................................................
Why this problem is challenging?

Kung bao chicken

Material

**Chicken, cucumber, peanut, carrot**

Procedure

1. Cut the chicken, cucumber, and carrot into small dices.
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Kung bao chicken

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Kung bao chicken

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Chicken, cucumber, peanut, carrot

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Kung bao chicken

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Kung bao chicken

Material

**Chicken, peanut, white onion, dried chilli**

Procedure

1. Dice the chicken, and cut the dried chilli on to sections.
2. ..............................................................
Kung bao chicken

Material
Chicken, cucumber, peanut, carrot

Procedure
1. Cut the chicken, cucumber, and carrot into small dices.
2. ..........................................................

Cucumber
Carrot

White onion

Kung bao chicken

Material
Chicken, peanut, white onion, dried chilli

Procedure
1. Dice the chicken, and cut the dried chilli on to sections.
2. ..........................................................
Why this problem is challenging?

Kung bao chicken

Material

- Chicken, cucumber, peanut, carrot

Procedure

1. Cut the chicken, cucumber, and carrot into small dices.
2. ..........................................................

Kung bao chicken

Material

- Chicken, peanut, white onion, dried chilli

Procedure

1. Dice the chicken, and cut the dried chilli on to sections.
2. ..........................................................
Ingredient versus food categorization
Ingredient versus food categorization
Ingredient versus food categorization

Scaling up food recognition through ingredients
Problem-1: Ingredient recognition
Problem-1: Ingredient recognition

shape  color
Problem-1: Ingredient recognition

shape  color  size  occlusion
Problem-1: Ingredient recognition

- shape
- color
- size
- occlusion
- lighting
- viewpoint
…
Problem-2: Zero-shot recipe retrieval
Problem-2: Zero-shot recipe retrieval

Unknown category
Problem-2: Zero-shot recipe retrieval

Unknown category
Problem-2: Zero-shot recipe retrieval

Unknown category

Cucumber
Corn
Pea
Cashew
Carrot

Retrieval
Problem-2: Zero-shot recipe retrieval

Material
Cucumber, carrot, peas, corn, cashew

Procedure
1. Cut cucumber into sections, and make the sections into cucumber cup.
2. Cut carrot into small dices.
3. Boil the water, and put the peas, corn into boiling water for about 5 minutes.
4. ..............................................
Abstract

Food recognition is difficult because food items are deformable objects that exhibit significant variations in appearance. We believe the key to recognizing food is to exploit the spatial relationships between different ingredients (such as meat and bread in a sandwich). We propose a new representation for food items that calculates pairwise statistics between local features computed over a soft pixel-level segmentation of the image into eight ingredient types. We accumulate these statistics in a multi-dimensional histogram, which is then used as a feature vector for a discriminative classifier. Our experiments show that the proposed representation is significantly more accurate at identifying food than existing methods.

1. Introduction

Automatic food recognition is emerging as an important research topic in object recognition because of the demand for better dietary assessment tools to combat obesity. The goals of such systems are to enable people to better understand the nutritional content of their dietary choices and to provide medical professionals with objective measures of their patients' food intake [18]. People are not very accurate when reporting the food that they consume. As an alternative to manual logging, we investigate methods for automatically recognizing foods based on their appearance. Unfortunately, the standard object recognition approaches based on aggregating statistics of descriptive local features perform poorly on this task [5] because food items are deformable and exhibit significant intra-class variations in appearance; the latter is the case even for relatively standardized items from fast food menus.

Our research is motivated by the observation that a food item can largely be characterized by its ingredients and their relative spatial relationships. For instance, sandwiches are often composed of a layer of meat surrounded on either side by slices of bread, while salads consist of assorted greens!
Existing works

- food categorization

- PFD
- FoodLog
- food-101
- MenuMatch
- TADA
- FoodCam
- Im2calories
- MealSnap
- myfitnesspal
Existing works

- food categorization
- no or little use of ingredients
- ignore ingredient composition in wild (e.g., Chinese food)
Existing works

- FoodLog
- food categorization
- no or little use of ingredients
- ignore ingredient composition in wild (e.g., Chinese food)
- zero-shot recipe retrieval has not been studied
Existing works

- food categorization
- no or little use of ingredients
- ignore ingredient composition in wild (e.g., Chinese food)
- zero-shot recipe retrieval has not been studied
Existing works

- food categorization
- Large scale recognition and modelling
- no or little use of ingredients
- ignore ingredient composition in wild (e.g., Chinese food)
- zero-shot recipe retrieval has not been studied
Framework
Framework
Framework
Framework
Framework
Framework

Multi-task DCNN

Scores

Ingredients

External knowledge

Carrot

Dry dates

Baby cabbage

Bacon

Pepper

Black fungus

Yuba

Sausage

Bamboo shoot

Beef

Pork
Framework
Framework
Framework
Framework
Framework

Multi-task DCNN

(a) Multi-task DCNN

Scores

Ingredients

(b) Zero-shot recipe retrieval

Recipe

Materials: Lean meat 250 grams, Green bell peppers 30 grams, Carrots 2 each, Dry dates 30 grams, onion 2, ginger 1 snack, garlic 5 slices, Sesame oil, Sweet Vinegar, Salt, white sugar, Chicken essence.

Procedure:
1st, slice the lean meat; cut the semi-finished yam, abundant in the bowl, add the salt and the water starch mixes well.
2nd, add the onion and garlic, then cut the date with a knife.
3rd, the bell pepper, sweet vinegar, and the carrot cut the slice and separate them.
4th, the water sauce, the oil sauce, the aromatic vinegar, the oil, and the sauce. 

External knowledge

Carrot
Dry dates
Baby cabbage
Bacon
Pork
Black fungus
Pepper
Sausage
Bamboo shoot
Beef
Yuba
Multi-task DCNN

172 food
Single label learning

353 ingredients
Multi label learning
Multi-task learning

- Exploiting joint relationship
- Keep high-level features common to food and ingredients.
- Learn specialized features.
Variants of architectures
Variants of architectures

- Error propagation
- Slow convergence
Variants of architectures

- Error propagation
- Slow convergence

- Sharing the same features
- No privacy
Variants of architectures

Arch-A
Stacked version
- Error propagation
- Slow convergence

Arch-B
Layer sharing
- Sharing the same features
- No privacy

Arch-C
No sharing
- Independent tasks
- Act like two-DCNN
Variants of architectures

Arch-A
Stacked version
- Error propagation
- Slow convergence

Arch-B
Layer sharing
- Sharing the same features
- No privacy

Arch-C
No sharing
- Independent tasks
- Act like two-DCNN

Arch-D
Partial sharing
- Keeps the high-level features common between two tasks.
- Learn specialized features.
Zero-shot recipe retrieval
— for unknown food category

Training examples
Zero-shot recipe retrieval
— for unknown food category

Training examples
Zero-shot recipe retrieval
— for unknown food category

Training examples

Tomato & scamped eggs

tomato
egg
green chilli
Ingredient graph
Ingredient graph

Model ingredient relationship
Ingredient graph

Model ingredient relationship
Ingredient graph

Model ingredient relationship
Connect to ingredient unknown to model
Ingredient graph

Model ingredient relationship
Connect to ingredient unknown to model

\[ E(y) = \sum_{c\in\mathcal{N}} \psi_u(y_c) + \sum_{(c,v)\in\varepsilon} \psi_p(y_c, y_v) \]
Ingredient graph

Model ingredient relationship
Connect to ingredient unknown to model

Multi-task DCNN

\[ E(y) = \sum_{c \in N} \psi_u(y_c) + \sum_{(c, v) \in \varepsilon} \psi_p(y_c, y_v) \]
Model ingredient relationship
Connect to ingredient unknown to model

$$E(y) = \sum_{c \in N} \psi_u(y_c) + \sum_{(c,v) \in \varepsilon} \psi_p(y_c, y_v)$$

Recipe #: 65,284
Ingredient #: 3,567
Conditional Random field
Conditional Random field

- Tomato
- Green onion
- Rice noodle
- Chilli oil
- Beef
- Fried yuba
- Noodle
- Water
- Green veg.
- Mushroom
- Egg
- Rice noodle
- Tomato
- Green onion
- Egg
- Chilli oil
- Fried yuba
Conditional Random field

- Rice noodle
- Chilli oil
- Fried yuba
- Egg
- Tomato
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- Beef
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16
Conditional Random field

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- Rice noodle
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- Fried yuba
- Water
- Green onion
Conditional Random field

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Conditional Random field

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- Tomato
- Rice noodle
- Chilli oil
- Fried yuba

Water

Green veg.
Kung bao chicken

**Material**
- Chicken, cucumber, peanut, carrot

**Procedure**
1. Cut the chicken, cucumber, and carrot into small dices.
2. Season the chicken for about 20 minutes.
3. .................................................................
Kung bao chicken

Material
- Chicken
- Cucumber
- Peanut
- Carrot
- Onion
- Chilli

Procedure
1. Cut the chicken, cucumber, and carrot into small dices.
2. Season the chicken for about 20 minutes.
3. ..........................................................
Recipe Retrieval

Top-K predictions

Chicken, cucumber, peanut, carrot

Kung bao chicken

Material

- Chicken
- Cucumber
- Peanut
- Carrot
- Onion
- Chilli

Procedure

1. Cut the chicken, cucumber, and carrot into small dices.
2. Season the chicken for about 20 minutes.
3. .................................................................
Recipe Retrieval

Top-K predictions

Kung bao chicken

Material
- **Chicken, cucumber, peanut, carrot**

Procedure
1. Cut the chicken, cucumber, and carrot into small dices.
2. Season the chicken for about 20 minutes.
3. .................................................................
Fusion
Kung bao chicken

Material: Chicken, cucumber, peanut, carrot
Seasoning: soy sauce, pepper, cooking wine, salt.

Procedure:
1). Cut the chicken, cucumber, and carrot into small dices.
2). Combine chicken, salt, pepper, soy sauce, and wine in a medium bowl and toss to coat. Set aside for 20 minutes.
3). ..................................................
Material:

- Chicken
- Cucumber
- Peanut
- Carrot

Seasoning:

- Soy sauce
- Pepper
- Cooking wine
- Salt

Procedure:

1. Cut the chicken, cucumber, and carrot into small dices.
2. Combine chicken, salt, pepper, soy sauce, and wine in a medium bowl and toss to coat. Set aside for 20 minutes.
3. ...
Fusion

Kung bao chicken

Material: Chicken, cucumber, peanut, carrot, soy sauce, pepper, salt.

Seasoning: soy sauce, pepper, cooking wine, salt.

Procedure: 1). Cut the chicken, cucumber, and carrot into small dice.
2). Combine chicken, salt, pepper, soy sauce, and wine in a medium bowl and toss to coat. Set aside for 20 minutes.
3).
Fusion

Kung bao chicken

Material: Chicken, cucumber, peanut, carrot

Seasoning: soy sauce, pepper, cooking wine, salt

Procedure:
1. Cut the chicken, cucumber, and carrot into small dice.
2. Combine chicken, salt, pepper, soy sauce, and wine in a medium bowl and toss to coat. Set aside for 20 minutes.
3. (Continue with the remaining steps.)
Fusion

Kung bao chicken
Material: Chicken, cucumber, peanut, carrot
Seasoning: soy sauce, pepper, cooking wine, salt
Procedure: 1). Cut the chicken, cucumber, and carrot into small sizes.
2). Blend the chicken, salt, pepper, soy sauce, and wine to coat. Let marinate for 20 minutes.
3).
**Dataset**

**VIREO FOOD-172**

- 172 food categories
- 353 visible ingredients
- 110,214 web images

from “Go Cooking”
labeled by 10 homemakers

## DATASET

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Food category #</th>
<th>Ingredient label #</th>
<th>Image #</th>
<th>Domain</th>
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<td>VIREO Food-172</td>
<td>172</td>
<td>353</td>
<td>110,241</td>
<td>Chinese</td>
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<td>100</td>
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<td>-</td>
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<td>Western</td>
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<td>101</td>
<td>-</td>
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<td>Fast food</td>
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Ingredient recognition
Ingredient recognition

VIRO FOOD-172

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<th>Method</th>
<th>Micro F1 (%)</th>
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<tr>
<td>FC7</td>
<td>42.94</td>
</tr>
<tr>
<td>Gist</td>
<td>23.01</td>
</tr>
<tr>
<td>CM</td>
<td>21.08</td>
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<tr>
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22
Ingredient recognition

**VIREO FOOD-172**

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**UEC FOOD-100**

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**Significance test:** multi-task >> single-task.
Food categorization
Food categorization

VIREO FOOD-172

Top-1 Accuracy (%)

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<tr>
<th>Model</th>
<th>Accuracy</th>
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<tr>
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Food categorization

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## Food categorization

### VIREO FOOD-172

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**Significance test:** multi-task $>>$ single-task.
Zero-shot recipe retrieval
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes

Image retrieval
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes

Image retrieval

Deep food feature
Deep ingredient feature
Convolutional layers

Arch-D
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes

Image retrieval

- Gist
- Color moment
- Single task
- VGG(FC7)
- Deep food features
- Deep ingredient features

Arch-D

Deep food feature

Deep ingredient feature

Convolutional layers

Hit rate @ 10

- 0.039
- 0.035
- 0.439
- 0.521
- 0.523
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes

Image retrieval

Hit rate @ 10

- Gist: 0.039
- Color moment: 0.035
- Single task VGG(FC7): 0.439
- Deep food features: 0.521
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Arch-D

Deep food feature
Deep ingredient feature
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Image retrieval

Ingredient matching

Hit rate @ 10

0.039 0.035 0.439 0.521 0.523

Gist Color moment Single task VGG(FC7) Deep food features Deep ingre. features
Zero-shot recipe retrieval

Queries from **20** unknown food categories
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Image retrieval

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Ingredient matching

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Image retrieval

- Gist
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Ingredient matching Fusion

Convolutional layers

Arch-D
Zero-shot recipe retrieval

Queries from 20 unknown food categories
Search against 65,284 recipes

Image retrieval

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Ingredient matching

Fusion
Top-3 retrieved recipes

Noodles with tomato & egg

Material
Noodle (100g), egg (1), tomato (0.5), green vegetables (a few)

Procedure
1. Heat up oil in wok; add tomato cubes.
2. ..................................................

Noodles with tomato & egg

Material
Noodle, tomato, egg, garlic, green onion

Procedure
1. Cut the tomato into slices.
2. Heat up oil in wok, and ..... 
3. ..................................................

Noodles with tomato & egg

Material
Noodle, tomato, egg, black fungus, daylily

Procedure
1. Boil dried noodles in boiling water for around 5 minutes.
2. ..................................................
Noodles with tomato & egg

Material
Noodle (100g), egg (1), tomato (0.5), green vegetables (a few)

Procedure
1. Heat up oil in wok; add tomato cubes.
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Top-3 retrieved recipes
Best-match recipe retrieval

**Noodles with tomato & egg**

**Material**
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**Procedure**
1. Heat up oil in wok; add tomato cubes.
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**Noodles with tomato & egg**

**Material**
Noodle, tomato, egg, garlic, green onion

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Noodles with tomato & egg

Material
Noodle, tomato, egg, garlic, green onion

Procedure
1. Cut the tomato into slices.
2. Heat up oil in wok, and ..... 
3. .................................................

Green veg. Noodle Egg Tomato

Top-3 retrieved recipes
Best-match recipe retrieval

500 queries with >=10 relevant recipes
Best-match recipe retrieval

500 queries with >=10 relevant recipes

Assorted corn  
Braised noodles with lentil  
Corn, carrot & ribs soup  
Loopah egg soup  
Mustard pork noodles  
Sichuan cold noodles  
Soybeans & pork leg soup  
Sausage claypot  
Spicy crab  
Tomato & egg noodles  
Average

Hit rate @ 10

Relevant recipe  
Best-match recipe
Best-match recipe retrieval
Best-match recipe retrieval

Cooking methods required

Fried egg with leek

Scrambled egg with leek
Best-match recipe retrieval

**Cooking methods required**
- Fried egg with leek
- Scrambled egg with leek

**Cutting methods required**
- Green pepper with potato shreds
- Green pepper with potato slices
# Generalization

<table>
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<th>Food</th>
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**Ingredient**

Known

Unknown

Unknown
### Generalization

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- Known: 90%
## Generalization

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Unknown Ingredient

- 63% hit-rate
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Generalization
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Conclusion
Conclusion

**Ingredient recognition**

**Contribution-1**

Multi-task DCNN (partial sharing)

- VIREO-172: +6%
- UEC-100: +13%

**Limitation**

Non-observed and non-visible ingredients
Conclusion

**Ingredient recognition**

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---

**Recipe retrieval**

**Contribution-2**

Deep features + semantic labels

**Best-match retrieval**

> 50% of chance within top-10

**Limitation**
Require knowledge in cooking and cutting methods

---

**Kung bao chicken**

**Material**
Chicken, cucumber, peanut, carrot

**Procedure**
1. ........................................

---

**Kung bao chicken**

**Material**
Chicken, peanut, white onion, dried chilli

**Procedure**
1. ........................................
Conclusion

Ingredient recognition

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Generalisability

**Contribution-3**
Ingredient graph
* recognition: +2%; retrieval: +9%

**Working case**
Ingredients are known

**Marginal case**
Some ingredients are unknown

---

Kung bao chicken

**Material**
Chicken, cucumber, peanut, carrot

**Procedure**
1. """"""""
Conclusion

**Ingredient recognition**

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**Marginal case**
Some ingredients are unknown

🌟 *VIREO Food-172: the only dataset with hundreds of ingredient labels and focuses on Chinese Food*