Food Image Recognition Using Deep Convolutional Network with Pre-training and Fine-tuning

ICME Workshop on Multimedia for Cooking and Eating Activities (CEA)

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Introduction: Food & Deep

- Food image recognition :
  - One of important topics in CEA community
  - Helpful for food habit recording.

- Deep Convolutional Neural Network:
  - Best image classification method at present
    - ILSVRC, Pascal VOC, MIT-SUN, Caltech-101/256,..

How about food datasets such as UEC-Food101/256 and ETH Food-101 ?

http://foodcam.mobi/

FoodCam : [Kawano et al. MTA13]

- Real-time mobile food recognition
  Android application

Objectives of this work

- **[Experiments]**
  Introduce deep convolutional neural networks (DCNN) into food image classification task
- Examine its effectiveness

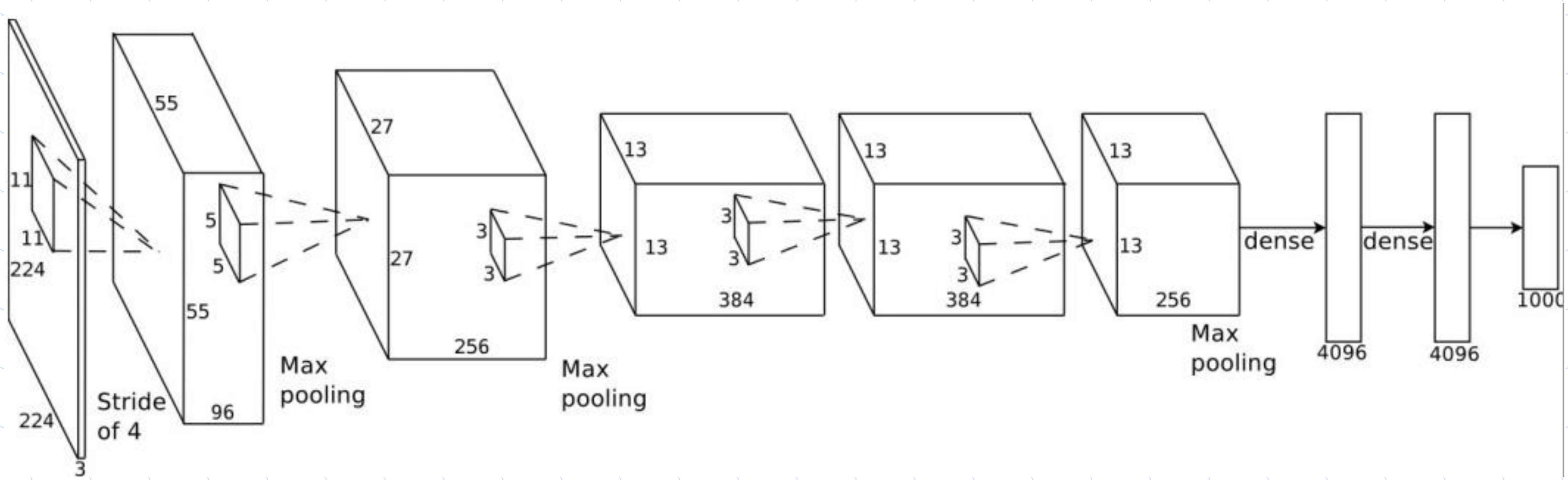
- **[Application]**
- Apply DCNN-based food classifier to Twitter food photo mining .

Deep Convolutional Neural Network（DCNN）

- The most common network architecture for image classification: **AlexNET** proposed by Alex Krizhevsky in ILSVRC2012.

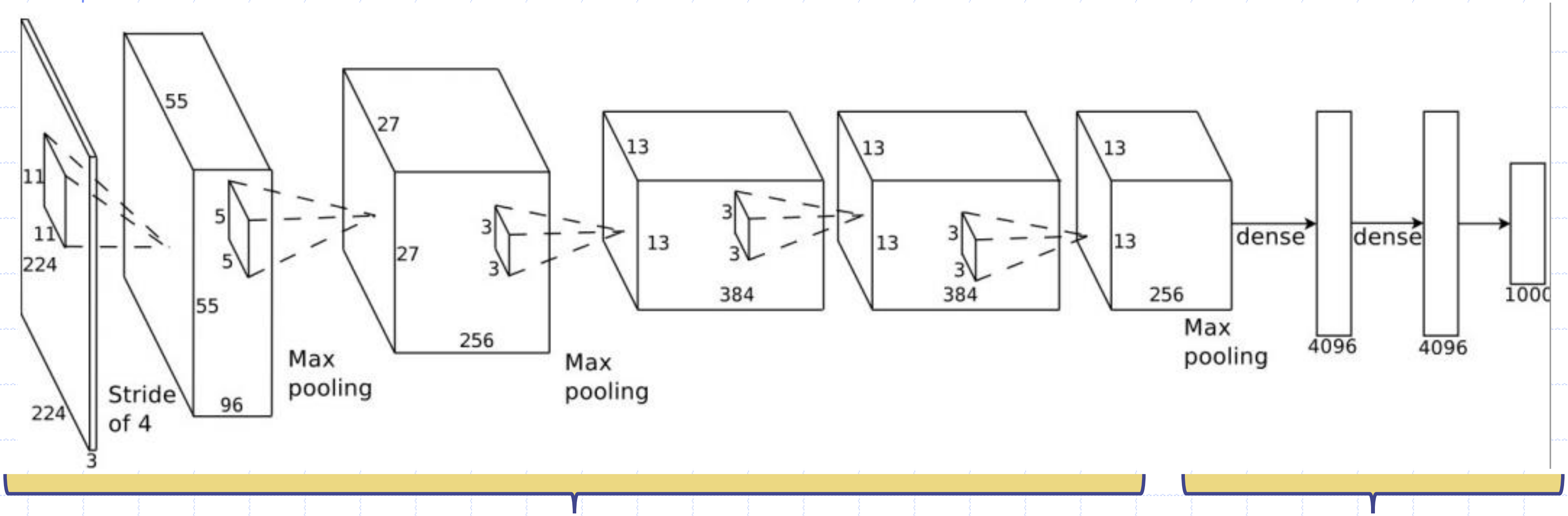
  Alex Krizhevsky, I.Sutskever, J. Hinton : ImageNet Classification with Deep Convolutional Neural Networks, NIPS 2012.

We use this in this work.



Deep Convolutional Neural Network

- Consists of convolutional layers and full connection layers.



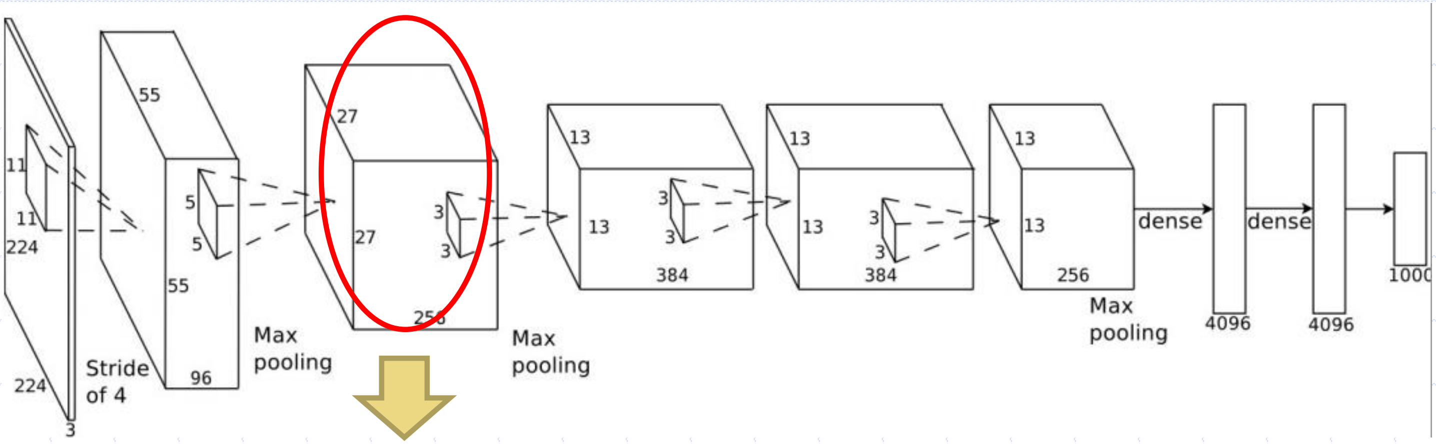
Convolutional layers

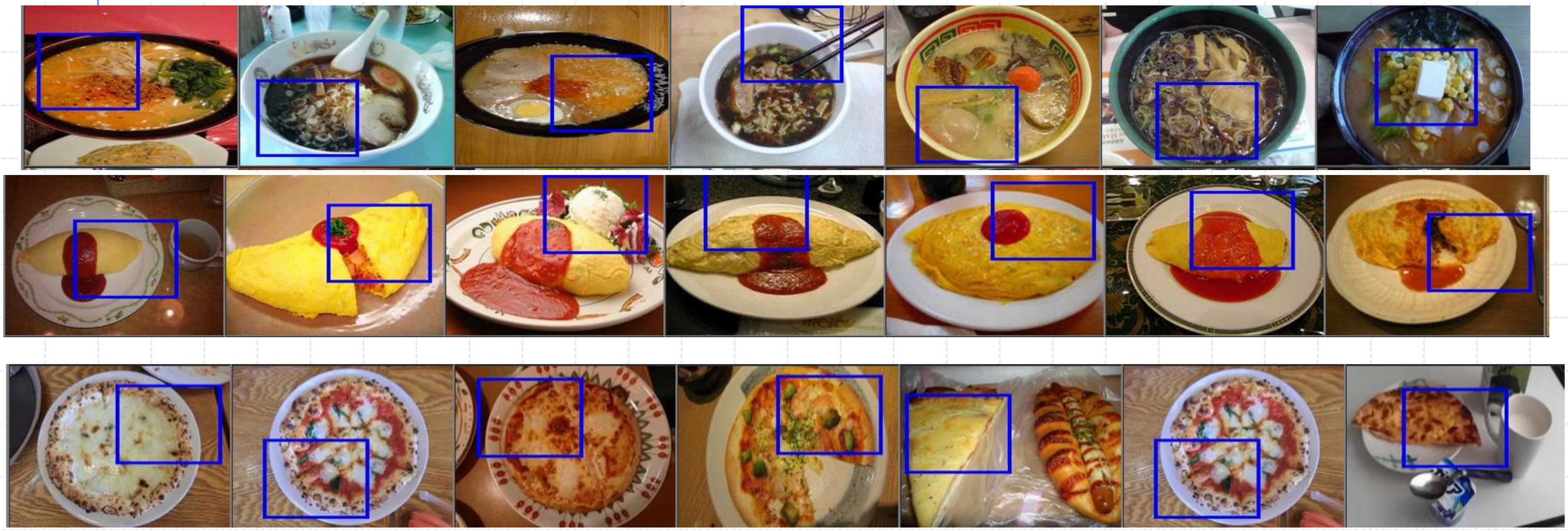
⇒ Feature extraction part

Full-connection layers

⇒ classification part

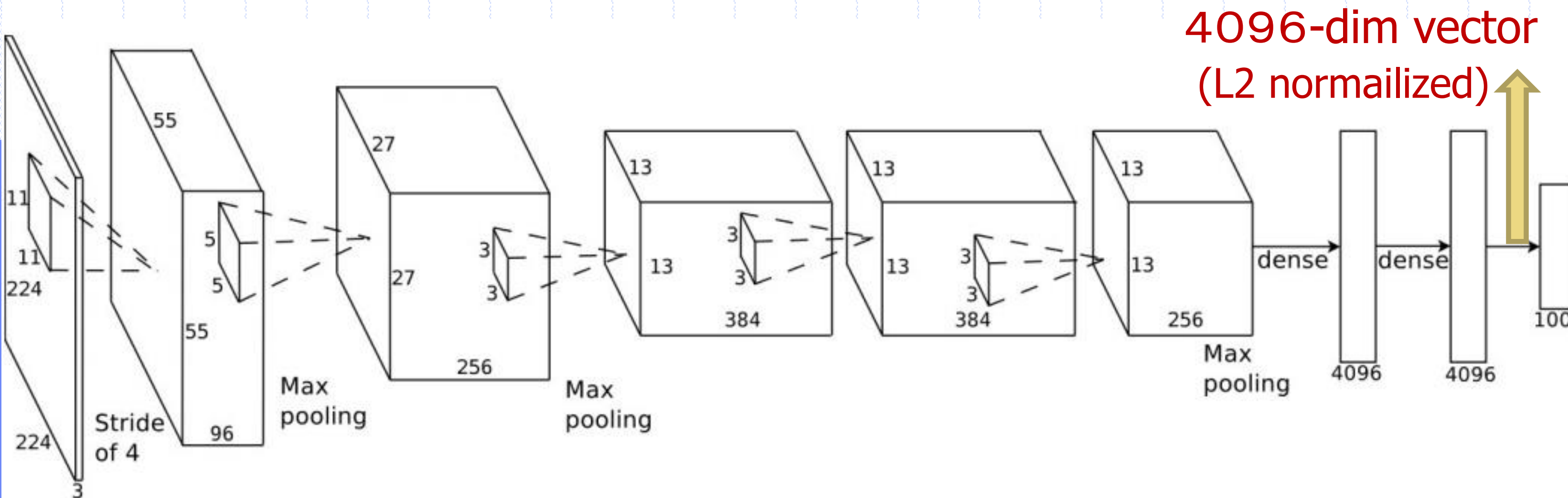
Most activated location on 3rd conv. layer





[Exisiting works] DCNN with Food Dataset

- [Kawano et al. CEA2014]
  - DCNN activation features (pre-trained with ILSVRC data)
  - UEC-FOOD100: FV: 65.32%
    - DCNN 57.87%, DCNN+FV: 72.26% (best so far)
- Other work:
  - [Kagaya et al. MM2014] 10 kinds of foods with DCNN trained from scratch
  - [Bossard et al. ECCV2014] ETH-Food101 with AlexNet from scratch



2. **Use activation features of pre-trained DCNN**
   - Extract activation signals from the previous layer of the last one, and use them as visual features
   - Easiest among three. (by using Caffe or Overfeat)
3. **Fine-tune a pre-trained DCNN using non-large-scale dataset**
   - Even small data can improve performance over (2)

Not explored yet

Introducing pre-training with non-ILSVRC and Fine-tuning

- Existing works: training from scratch or using pre-trained model with ILSVRC

Two kinds of extensions

- **Pre-training with food-related ImageNet categories**
- **Fine-tuning**

DCNN pre-training Datasets

- ILSVRC2012
  - Large Scale Visual Recognition Challenge
  - one thousand training images per category
  - Generic 1000 categories
  - few food categories

DCNN pre-trained with the dataset containing more food-related categories is desirable.

DCNN pre-training Datasets containing more foods

- Select 1000 food-related categories from ImageNet
  - List up all the word under “food” in the ImageNet hierarchy
  - 1526 synsets related to “food”
  - Exclude synsets included in ILSVRC dataset
  - Select the top 1000 synsets in terms of # of images in ImageNet

* ImageNet 2011 Fall release

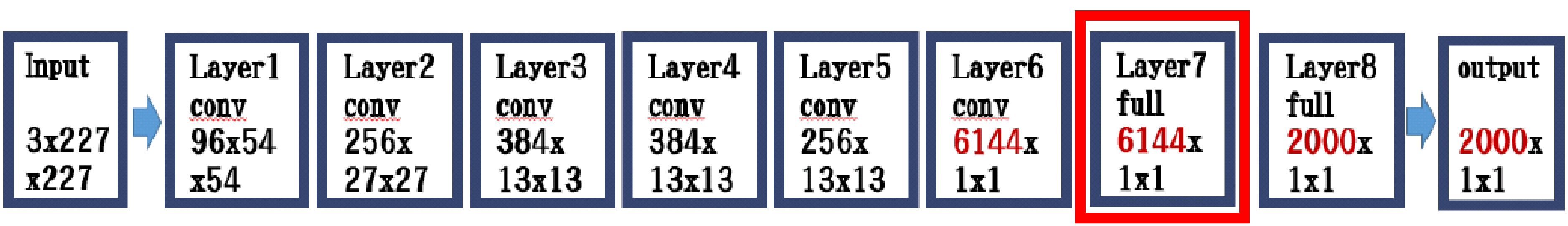
DCNN pre-training Datasets

- ImageNet2000 categories
  - 1000 food-related categories from ImageNet
  - ImageNet1000 (ILSVRC) categories

= 2000 categories

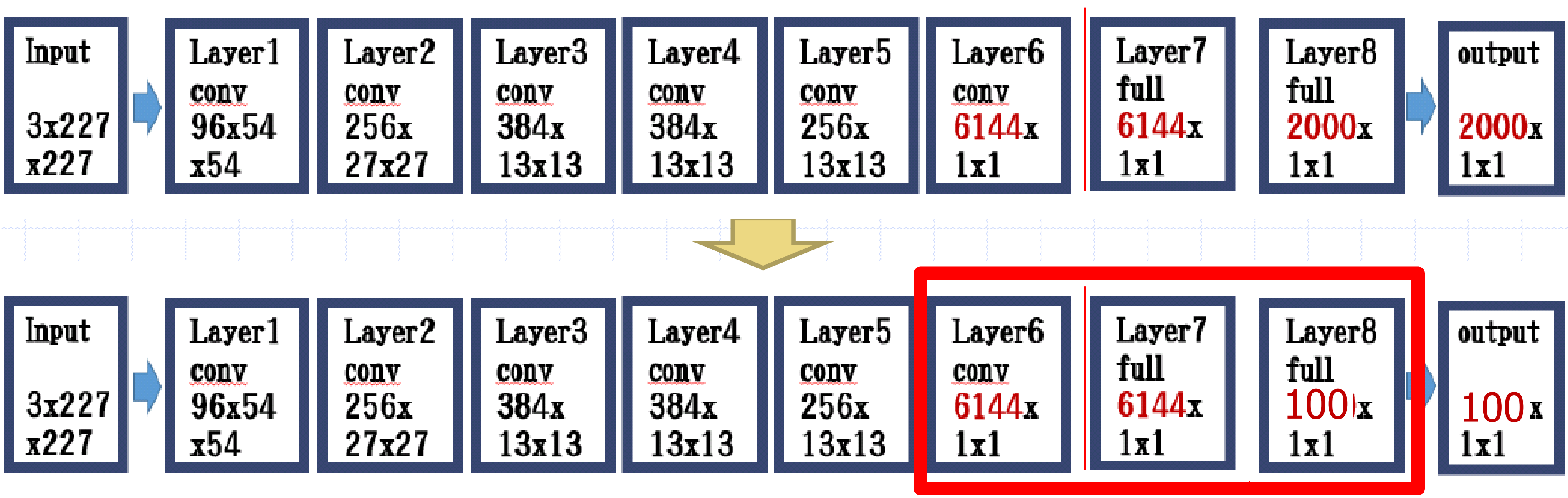
Pre-training with ImageNet2000

- DCNN Features with ImageNet 2000 categories
  - Using Caffe
  - The dimension of full connection layers is modified from 4096 to 6144, since the output dimension is raised from 1000 to 2000.
- Training time
  - About one week (training from scratch)
  - GPU, Nvidia Geforce TITAN BLACK, 6GB



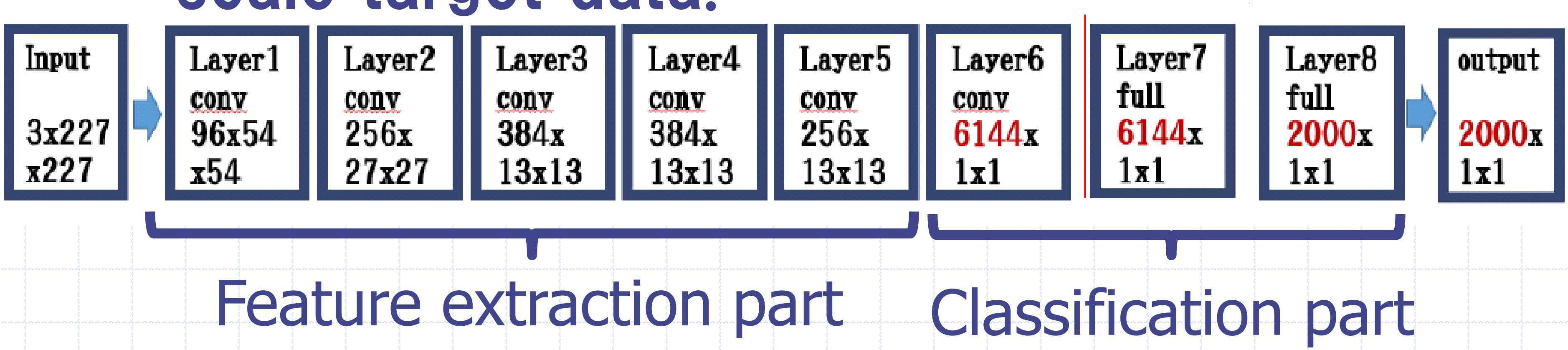
Fine-tuning with small dataset

- Modify the size of the last layer (2000⇒100)
- Re-train only weight parameters of full connection layers (L6,7,8)
- Weights from L1-5 are fixed



Fine-tuning

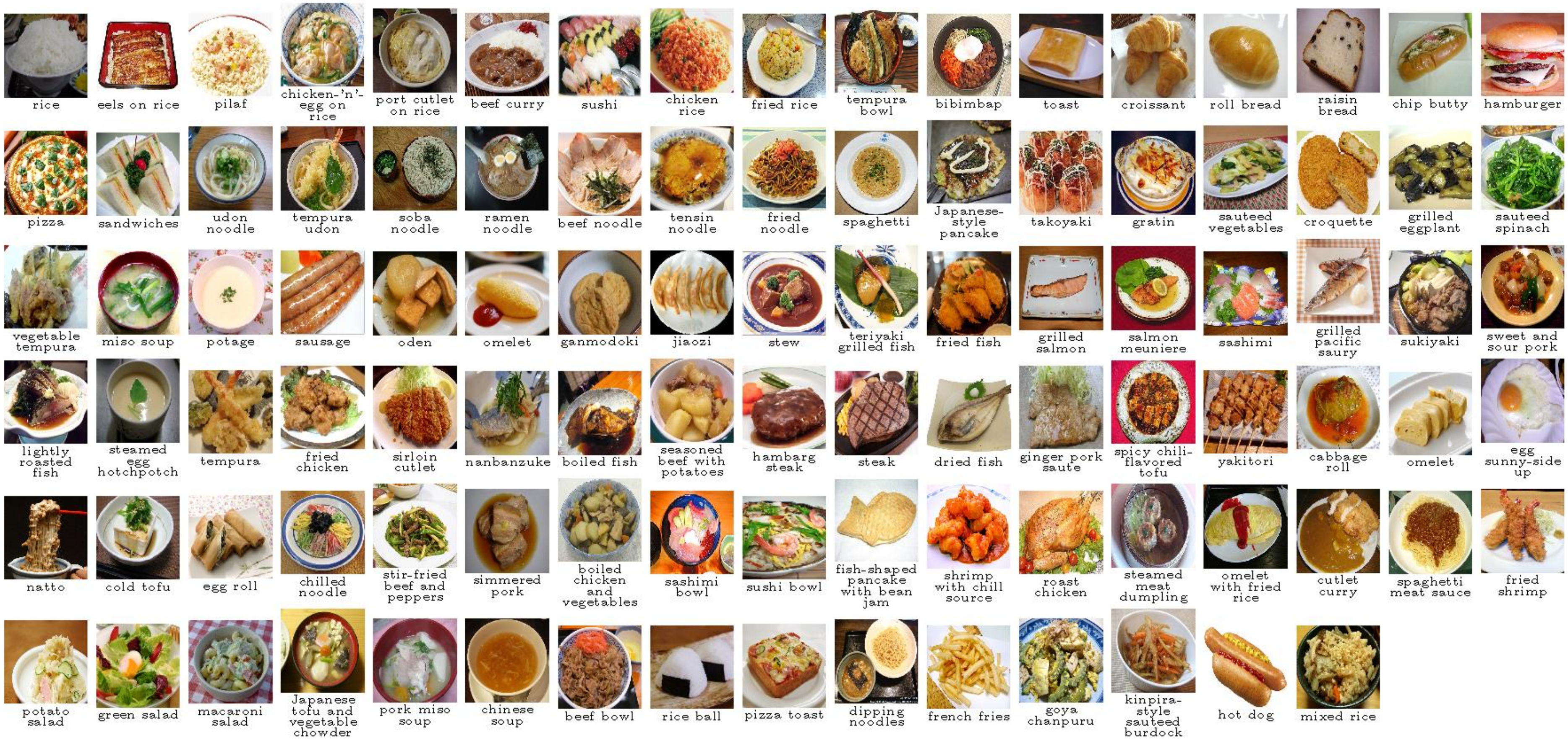
- It enables DCNN to be trained with small data.
- Feature extraction parts are trained with large-scale data such as ImageNet.
- Classification parts are trained with small-scale target data.



Experiments: Food dataset

- UEC-FOOD100/256 dataset
  - 100 / 256 food categories (Japanese and Asian)
  - More than 100 images for each category
  - Bounding box information for all the images
- ETH Food-101 [Bossard et al. ECCV2014]
  - 101 categories, 1000 images for each category (mainly western and partly Japanese)
  - Collecting from http://www.foodspotting.com/
  - 20 categories are overlapped with UEC-FOOD100

UEC-FOOD 100


rice
eels on rice
pilaf
chicken-'n'-egg on rice
port cutlet on rice
beef curry
sushi
chicken rice
fried rice
tempura bowl
bibimbap
toast
croissant
roll bread
raisin bread
chip butty
hamburger
pizza
sandwiches
udon noodle
tempura udon
soba noodle
ramen noodle
beef noodle
tensin noodle
fried noodle
spaghetti
Japanese-style pancake
takoyaki
gratin
sauteed vegetables
croquette
grilled eggplant
sauteed spinach
vegetable tempura
miso soup
potage
sausage
oden
omelet
ganmodoki
jiaozi
stew
teriyaki grilled fish
fried fish
grilled salmon
salmon meuniere
sashimi
grilled pacific saury
sukiyaki
sweet and sour pork
lightly roasted fish
steamed egg hotchpotch
tempura
fried chicken
sirloin cutlet
nanbanzuke
boiled fish
seasoned beef with potatoes
hambarg steak
steak
dried fish
ginger pork saute
spicy chili-flavored tofu
yakitori
cabbage roll
omelet
egg sunny-side up
natto
cold tofu
egg roll
chilled noodle
stir-fried beef and peppers
simmered pork
boiled chicken and vegetables
sashimi bowl
sushi bowl
fish-shaped pancake with bean jam
shrimp with chill source
roast chicken
steamed meat dumpling
omelet with fried rice
cutlet curry
spaghetti meat sauce
fried shrimp
potato salad
green salad
macaroni salad
Japanese tofu and vegetable chowder
pork miso soup
chinese soup
beef bowl
rice ball
pizza toast
dipping noodles
french fries
goya chanpuru
kinpira-style sauteed burdock
hot dog
mixed rice

UEC-FOOD 100

rice
eels on rice
pilaf
chicken-'n'-egg on
pork cutlet on rice
beef curry
sushi
chicken rice
fried rice
tempura bowl
bibimbap
toast
croissant
roll bread
raisin bread
chip butty
hamburger
pizza
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natto
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stew
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sweet and sour pork
egg sunny-side up
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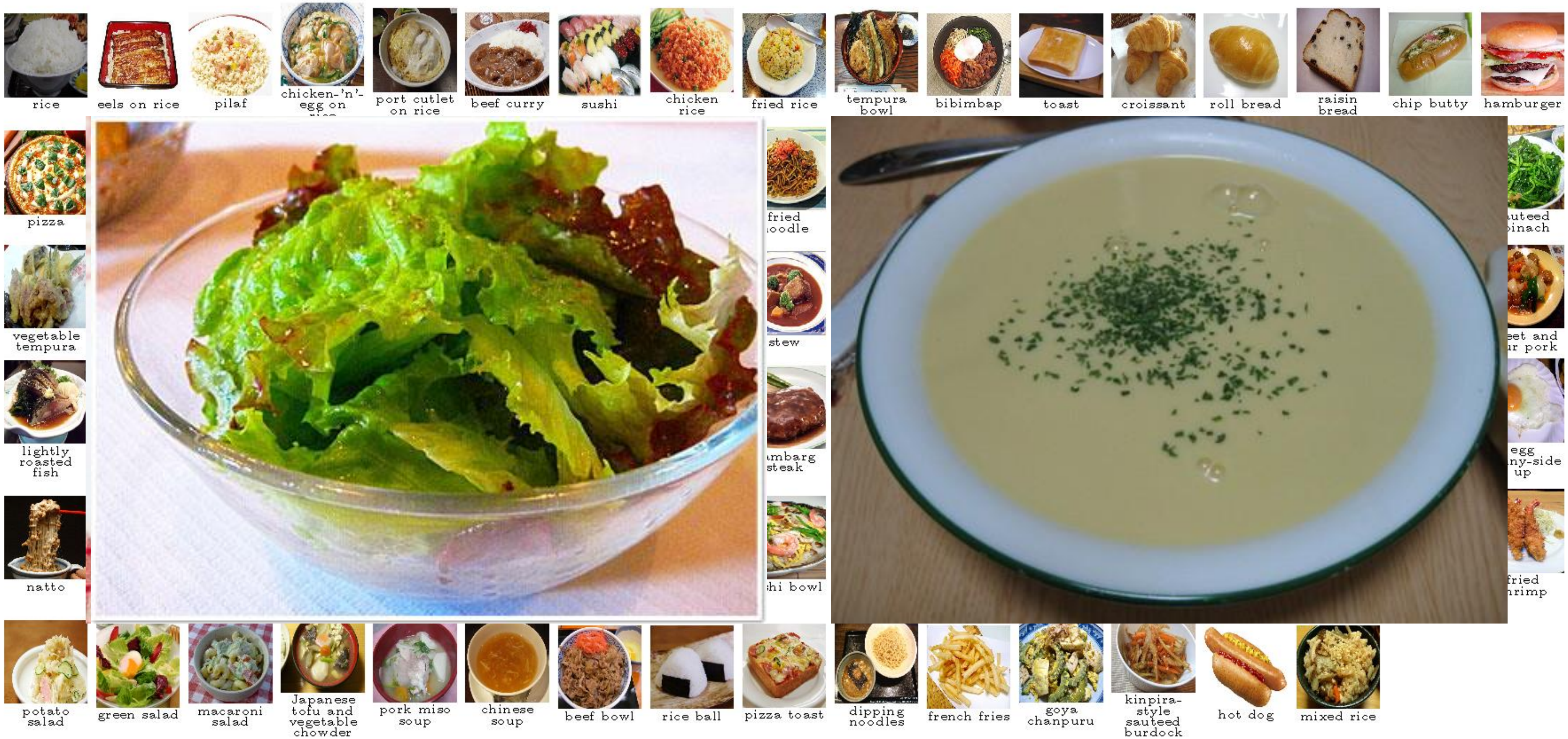

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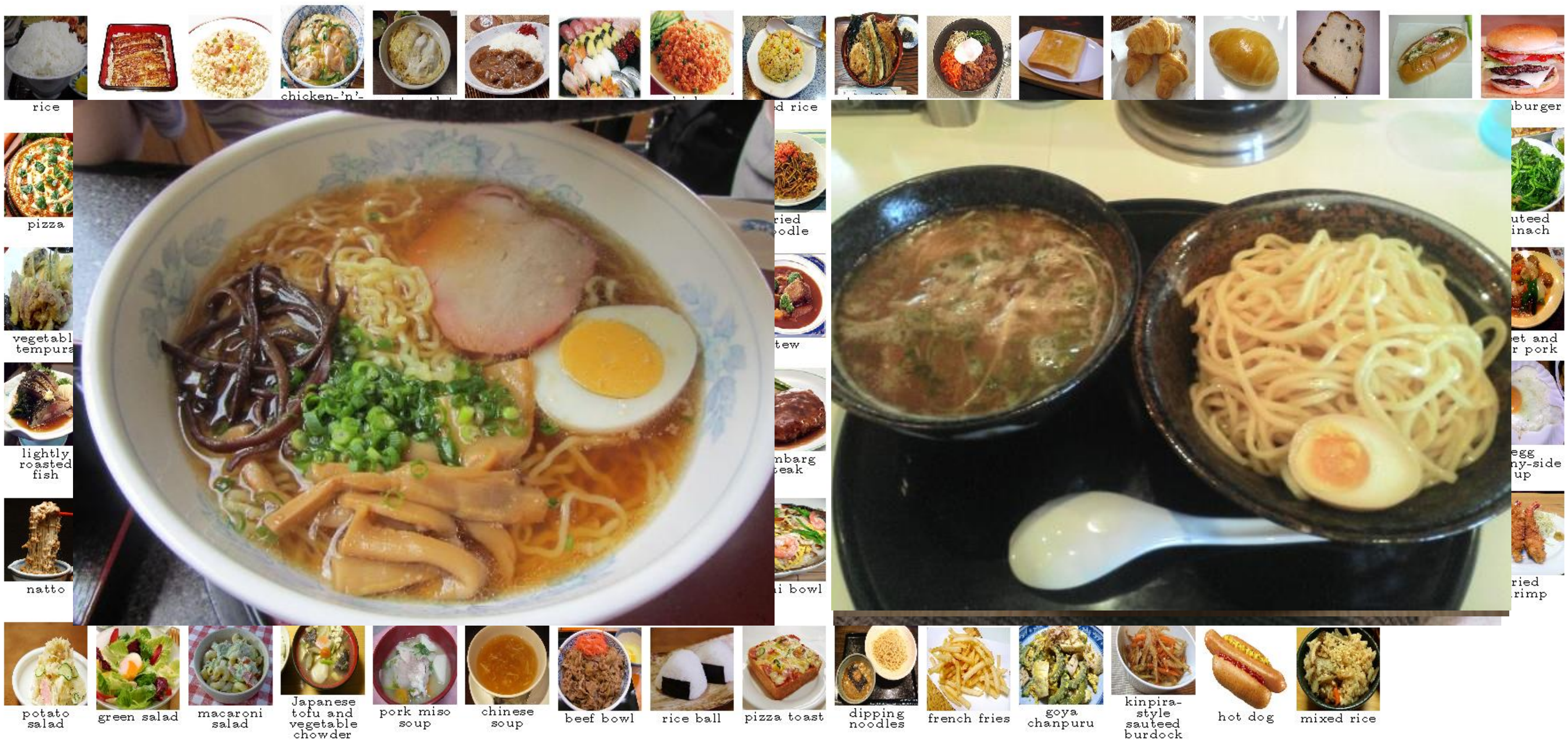
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mixed rice

FoodRec: foodrec app with UECFOOD100
by Hamlyn Centre-Imperial College (UK)

UEC-FOOD as a Fine-Grained Image Classification Dataset

arXiv.org > cs > arXiv:1502.07802

Search or Article-id

Computer Science > Computer Vision and Pattern Recognition

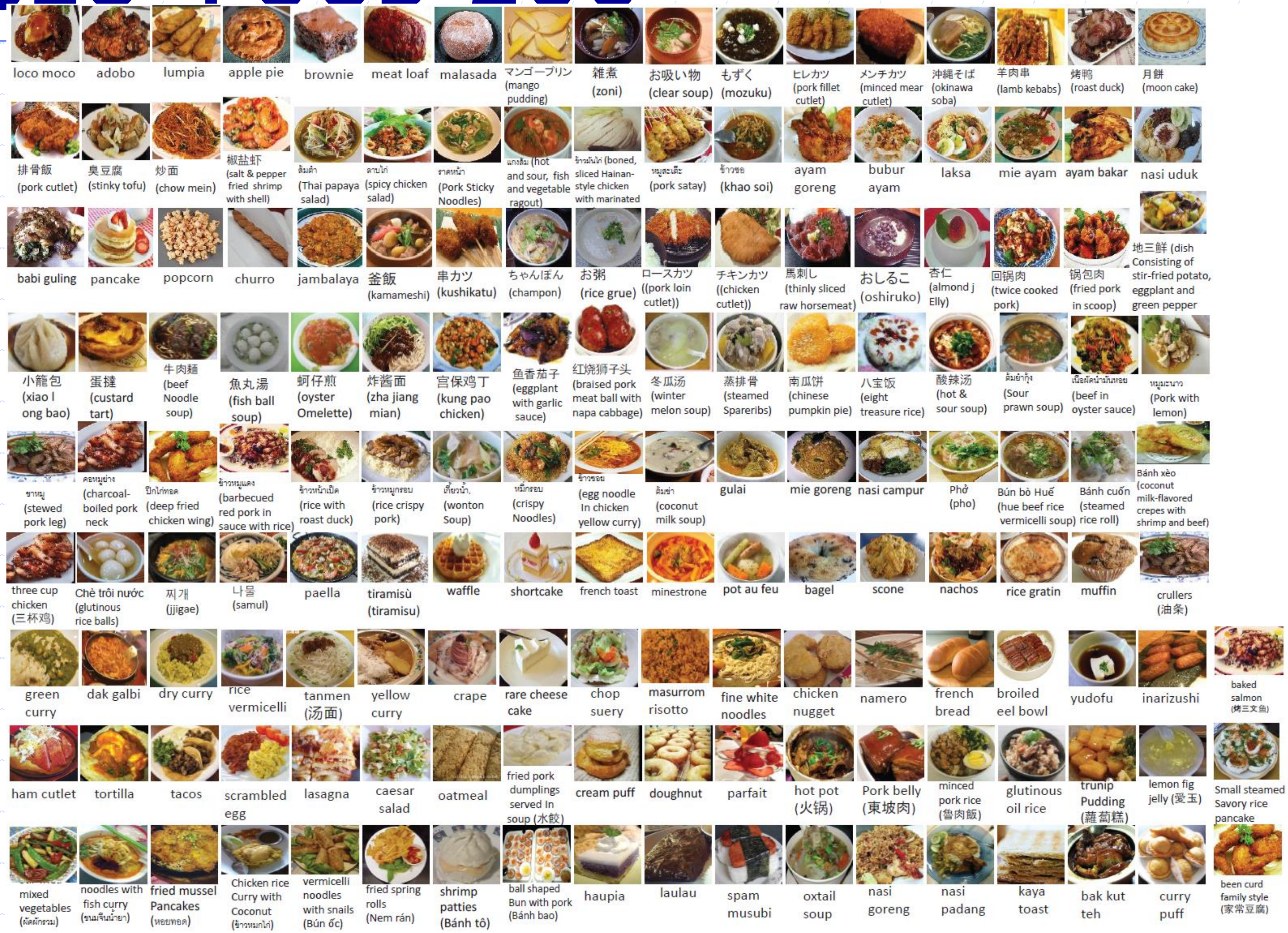
Modelling Local Deep Convolutional Neural Network Features to Improve Fine-Grained Image Classification

ZongYuan Ge, Chris McCool, Conrad Sanderson, Peter Corke

(Submitted on 27 Feb 2015)

We propose a local modelling approach using deep convolutional neural networks (CNNs) for fine-grained image classification. Recently, deep CNNs trained from large datasets have considerably improved the performance of object recognition. However, to date there has been limited work using these deep CNNs as local feature extractors. This partly stems from CNNs having internal representations which are high dimensional, thereby making such representations difficult to model using stochastic models. To overcome this issue, we propose to reduce the dimensionality of one of the internal fully connected layers, in conjunction with layer-restricted retraining to avoid retraining the entire network. The distribution of low-dimensional features obtained from the modified layer is then modelled using a Gaussian mixture model. Comparative experiments show that considerable performance improvements can be achieved on the challenging Fish and UEC FOOD-100 datasets.

UEC-FOOD 256


loco moco
adobo
lumpia
apple pie
brownie
meat loaf
malasada
マンゴープリン (mango pudding)
雑煮 (zoni)
お吸い物 (clear soup)
もずく (mozuku)
ヒレカツ (pork fillet cutlet)
メンチカツ (minced mear cutlet)
沖縄そば (okinawa soba)
羊肉串 (lamb kebabs)
烤鸭 (roast duck)
月餅 (moon cake)
排骨飯 (pork cutlet)
臭豆腐 (stinky tofu)
炒面 (chow mein)
椒盐虾 (salt & pepper fried shrimp with shell)
(Thai papaya salad)
(spicy chicken salad)
(Pork Sticky Noodles)
(hot and sour, fish and vegetable ragout)
(boned, sliced Hainan-style chicken with marinated
(pork satay)
(khao soi)
ayam goreng
bubur ayam
laksa
mie ayam
ayam bakar
nasi uduk
babi guling
pancake
popcorn
churro
jambalaya
釜飯 (kamameshi)
串カツ (kushikatu)
ちゃんぽん (champon)
お粥 (rice grue)
ロースカツ ((pork loin cutlet))
チキンカツ ((chicken cutlet))
馬刺し (thinly sliced raw horsemeat)
おしるこ (oshiruko)
杏仁 (almond j Elly)
回锅肉 (twice cooked pork)
锅包肉 (fried pork in scoop)
地三鮮 (dish Consisting of stir-fried potato, eggplant and green pepper
小籠包 (xiao l ong bao)
蛋撻 (custard tart)
牛肉麵 (beef Noodle soup)
魚丸湯 (fish ball soup)
蚵仔煎 (oyster Omelette)
炸酱面 (zha jiang mian)
宫保鸡丁 (kung pao chicken)
鱼香茄子 (eggplant with garlic sauce)
红烧狮子头 (braised pork meat ball with napa cabbage)
冬瓜汤 (winter melon soup)
蒸排骨 (steamed Spareribs)
南瓜饼 (chinese pumpkin pie)
八宝饭 (eight treasure rice)
酸辣汤 (hot & sour soup)
(Sour prawn soup)
(beef in oyster sauce)
(Pork with lemon)
(stewed pork leg)
(charcoal-boiled pork neck
(deep fried chicken wing)
(barbecued red pork in sauce with rice)
(rice with roast duck)
(rice crispy pork)
(wonton Soup)
(crispy Noodles)
(egg noodle In chicken yellow curry)
(coconut milk soup)
gulai
mie goreng
nasi campur
Phở (pho)
Bún bò Huế (hue beef rice vermicelli soup)
Bánh cuốn (steamed rice roll)
Bánh xèo (coconut milk-flavored crepes with shrimp and beef)
three cup chicken (三杯鸡)
Chè trôi nước (glutinous rice balls)
찌개 (jjigae)
나물 (samul)
paella
tiramisù (tiramisu)
waffle
shortcake
french toast
minestrone
pot au feu
bagel
scone
nachos
rice gratin
muffin
crullers (油条)
green curry
dak galbi
dry curry
rice vermicelli
tanmen (汤面)
yellow curry
crape
rare cheese cake
chop suery
masurrom risotto
fine white noodles
chicken nugget
namero
french bread
broiled eel bowl
yudofu
inarizushi
baked salmon (烤三文鱼)
ham cutlet
tortilla
tacos
scrambled egg
lasagna
caesar salad
oatmeal
fried pork dumplings served In soup (水餃)
cream puff
doughnut
parfait
hot pot (火锅)
Pork belly (東坡肉)
minced pork rice (魯肉飯)
glutinous oil rice
trunip Pudding (蘿蔔糕)
lemon fig jelly (愛玉)
Small steamed Savory rice pancake
mixed vegetables
noodles with fish curry
fried mussel Pancakes
Chicken rice Curry with Coconut
vermicelli noodles with snails (Bún ốc)
fried spring rolls (Nem rán)
shrimp patties (Bánh tôm)
ball shaped Bun with pork (Bánh bao)
haupia
laulau
spam musubi
oxtail soup
nasi goreng
nasi padang
kaya toast
bak kut teh
curry puff
been curd family style (家常豆腐)

UEC-FOOD 256

loco moco
adobo
lumpia
apple pie
brownie
meat loaf
malasada
マンゴープリン (mango pudding)
雑煮 (zoni)
お吸い物 (clear soup)
もずく (mozuku)
ヒレカツ (pork fillet cutlet)
メンチカツ (minced mear cutlet)
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月餅 (moon cake)
排骨飯 (pork cutlet)
臭豆腐 (stinky tofu)
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椒盐虾 (salt & pepper fried shrimp with shell)
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ayam goreng
bubur ayam
laksa
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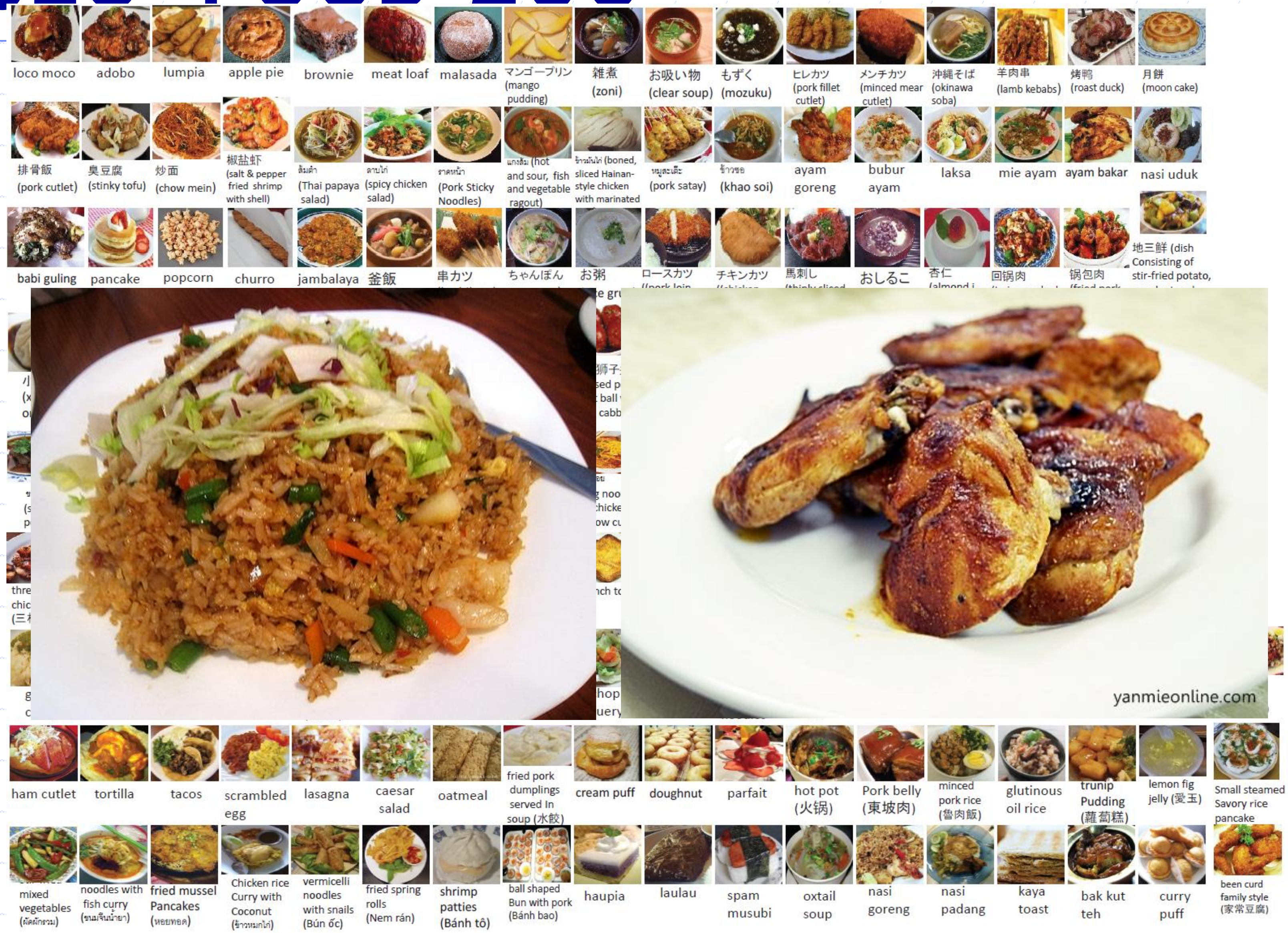
UEC-FOOD 256



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ちゃんぽん
お粥
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チキンカツ
馬刺し
おしるこ
杏仁
回锅肉
锅包肉
地三鮮 (dish Consisting of stir-fried potato,
yanmieonline.com
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ETH-Food101

- Sushi

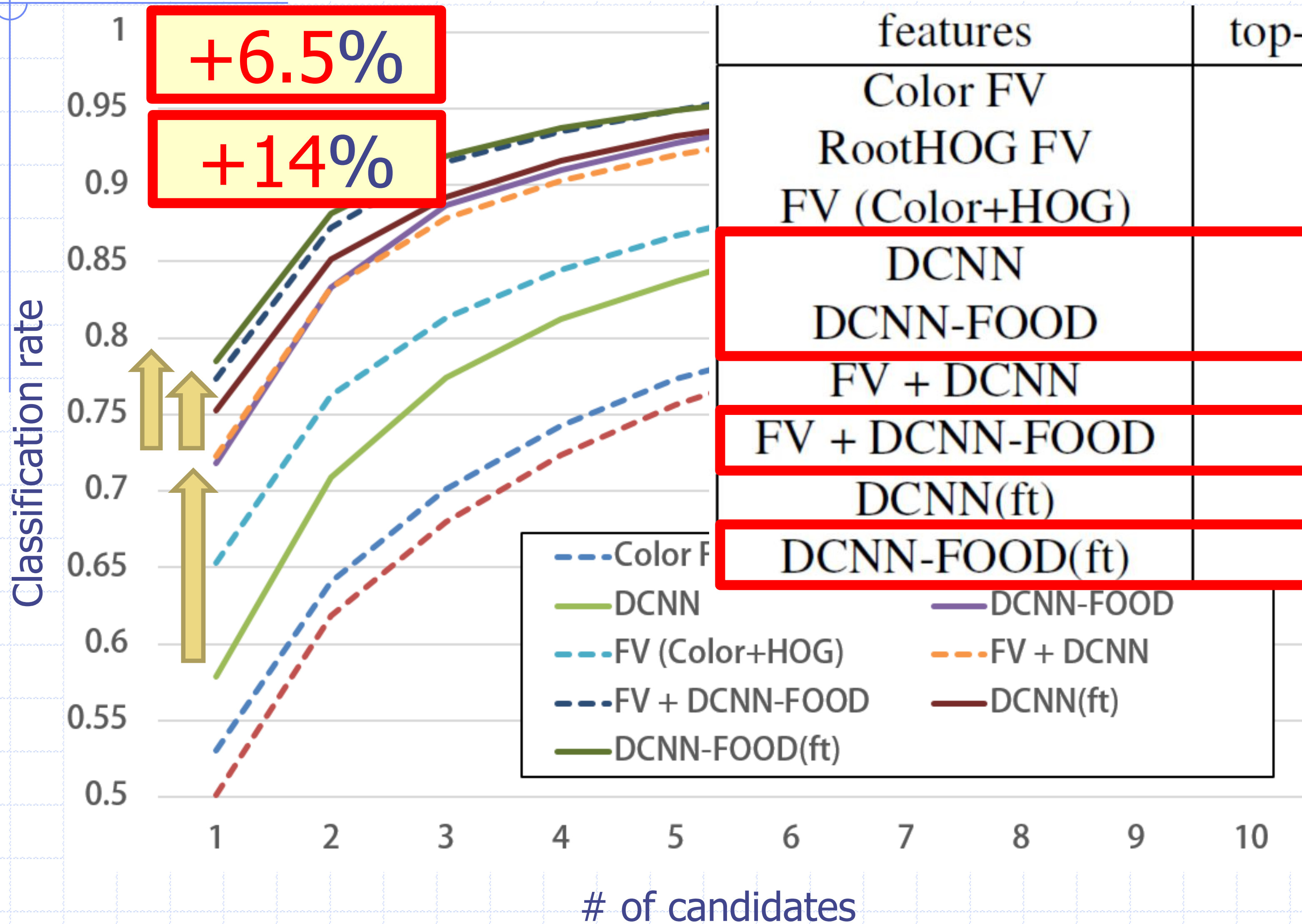
- Takoyaki

- Ramen

Baseline features & classifiers

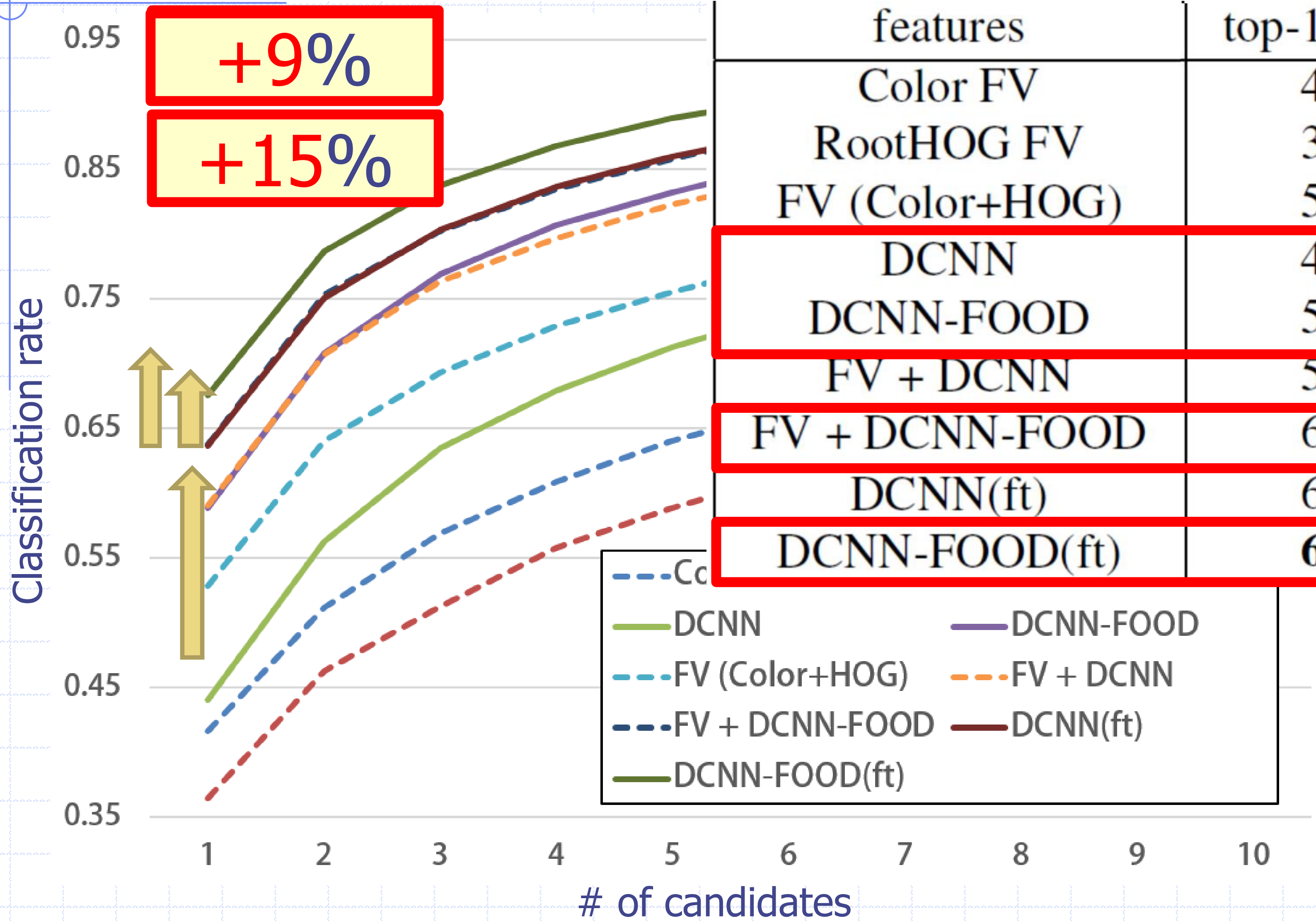
- Conventional baseline features
  - Root HOG patch and Color patch
  - Fisher Vector (FV)
  - SPM level2 (1x1+3x1+2x2)
  - 32768-dim RootHOG-FV
  - 24576-dim Color-FV
- Classifiers
  - 1-vs-rest multiclass linear SVM
- Evaluation: 5fold cross-validation

Results: UEC-FOOD100



features	top-1 rate
Color FV	53.04
RootHOG FV	50.14
FV (Color+HOG)	65.32
DCNN	57.87
DCNN-FOOD	71.80
FV + DCNN	72.26
FV + DCNN-FOOD	77.35
DCNN(ft)	75.25
DCNN-FOOD(ft)	**78.48**

Results: UEC-FOOD256



features	top-1 rate
Color FV	41.60
RootHOG FV	36.46
FV (Color+HOG)	52.85
DCNN	43.98
DCNN-FOOD	58.81
FV + DCNN	59.06
FV + DCNN-FOOD	63.77
DCNN(ft)	63.64
DCNN-FOOD(ft)	**67.57**

Results on ETH-Food101

Table 2. Classification rate on ETH Food-101 dataset [1].

RF-based [1]	DCNN [1]	DCNN(ft)	FOOD-DCNN(ft)
50.76	56.40	68.44	70.41

- Fine-tuned DCNN with ImageNet+food1000 pretraining achived the best results.

Summary

- Pre-training with ImageNet + Food1000 is effective.
- Fine-tuning can improve performance over Pre-training DCNN + FV.
- Fine-tuning the DCNN which was pre-trained with ImageNet1000 + Food1000 is the best.

Comments:

- For further improvements
  - Using deeper network (VGG16 or GoogLeNet) instead of Alexnet
  - Fusing DCNN-FOOD (ft) with FV
- Both are not examined yet.
  - (Because the second author graduated…)

Apply DCNN-FOOD(ft) to Twitter Real-time Food Photo Mining

Keiji Yanai and Yoshiyuki Kawano: Twitter Food Image Mining and Analysis for One Hundred Kinds of Foods , Pacifit-Rim Conference on Multimedia (PCM), (2014).

Yoshiyuki Kawano and Keiji Yanai, **FoodCam: A Real-time Food Recognition System on a Smartphone**, Multimedia Tools and Applications (2014). (in press) (http://dx.doi.org/10.1007/s11042-014-2000-8)

Twitter Real-time Food Photo Mining System (mm.cs.uec.ac.jp/tw/)

- What kinds of foods are being eaten in Japan ?

Objective

- Twitter Photo Mining for Food Photos
  - As a case study of Twitter Photo Mining on specific kinds of photos
    - Food is one of frequent topics of Twitter Photos.
  - Real-time Photo Collection from the stream

- To collect more food photos for training
  - Twitter is a good source of food photos.
  - Unlike "FoodLog", we have no users who upload their food photos regularly. Twitter is alternative.

Preparation

- Add “non-food” category to the best classifier（FOOD-DCNN (ft)）.
- Prepare 10000 non-food samples gathered from Twitter by 100 food names
- Fine-tuning with 101 category.

- Food/non-food classification: 98.86%

Approach for food photo mining

- [old] Three-step food photo selection

Keyword-based selection → Food/non-food classification → 100-foods classification

Image-based analysis

[new] Two-step food photo selection

Keyword-based selection → 101-foods classification

Experiments

- Collect photo tweets via Twitter Streaming API
  - From 2011/5 to 2013/8
  - About one billion tweets
- Search for the tweets including any of 100-food names (in Japanese)
  - 1.7 million ⇐ Apply food image classifier
  - 0.03 image/classification w/GPU (4 hours by 4 GPU machines)

Twitter food photo ranking

rank	foods	#photos









Ramen noodle is the most popular food in Japan.
I have solved “ramen vs curry” problem !!!

Precision of the top 5 foods

Food	raw	FV-based		DCNN
ramen	275,652 **72.0%**	80,021 **99.7%**		132,095 **99.5%**
curry	224,685 **75.0%**	59,264 **99.3%**		68,091 **100.0%**
sushi	86,509 **69.0%**	25,898 **92.7%**		224,908 **99.8%**
tsukemen	33,165 **88.7%**	22,158 **99.0%**		22,004 **100.0%**
omelet	34,125 **90.0%**	17,520 **99.0%**		20,039 **99.9%**

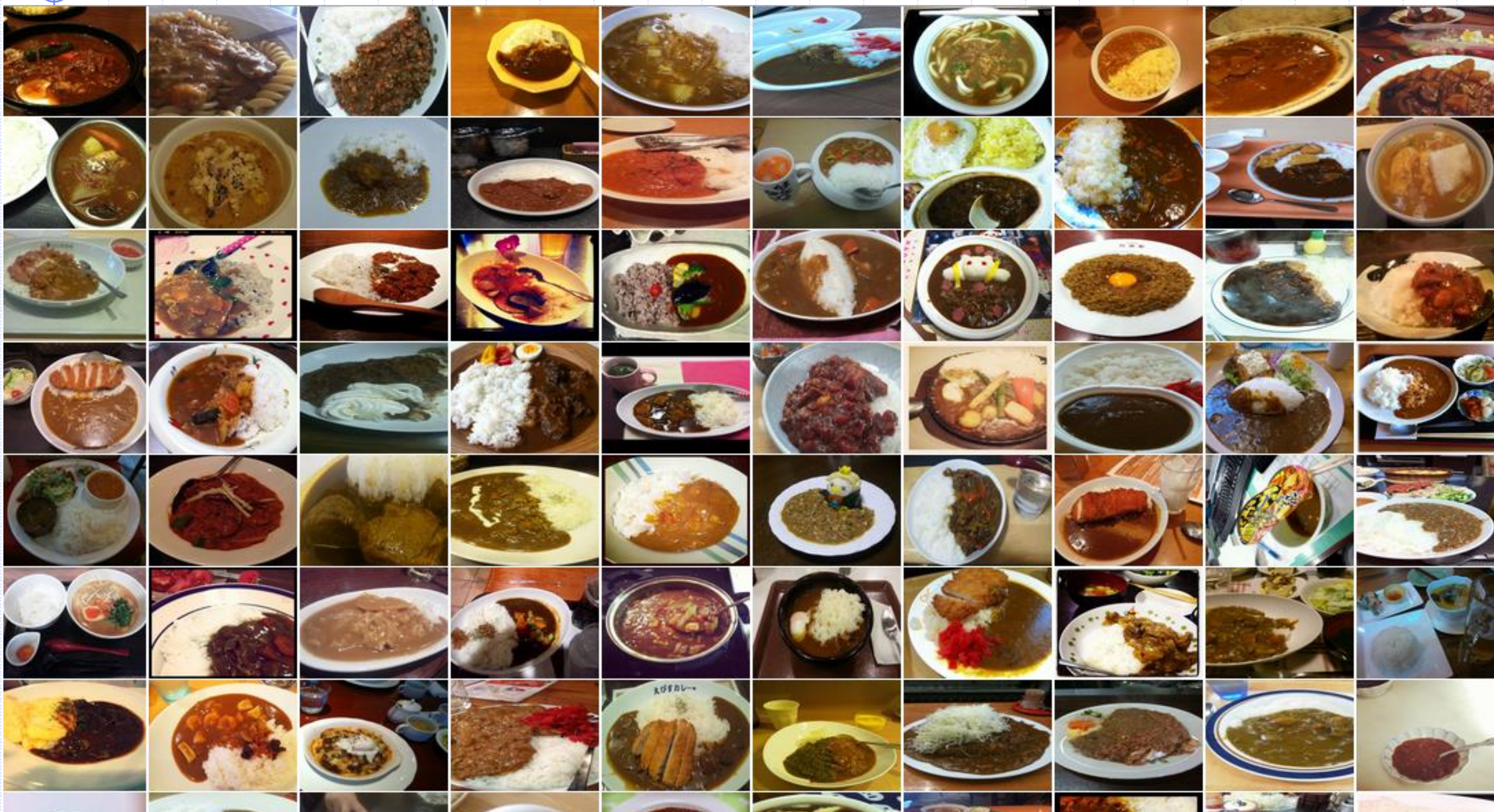
Only keyword search (Ramen noodle) (72.0%)

After applying 100-class food classifier (final) (99.5%)

Only keyword search (curry) (75.0%)

Final results（curry）（100%）

Final results（omelet）（99.9%）



Misclassified photos

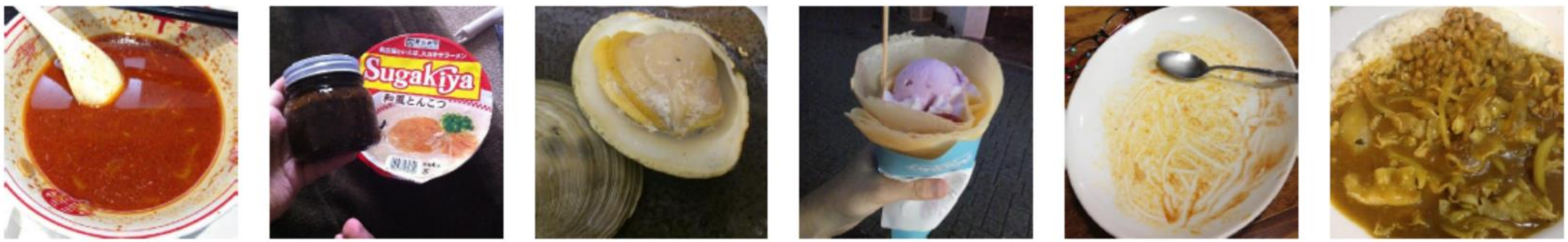
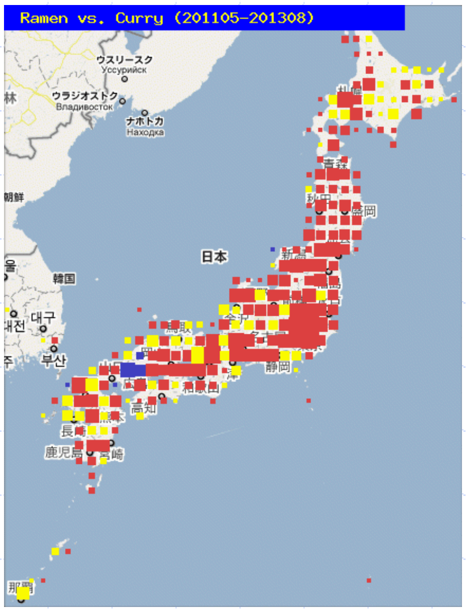
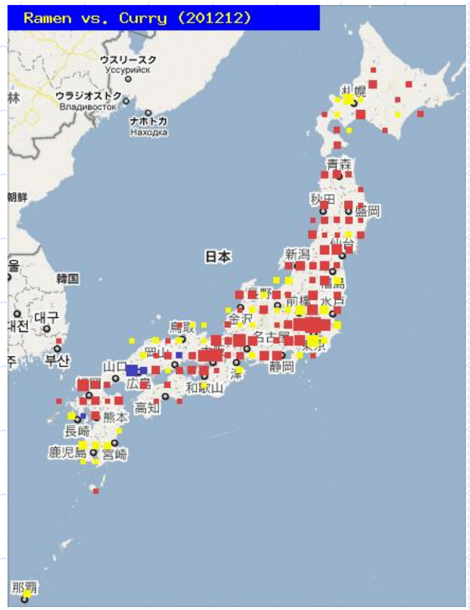


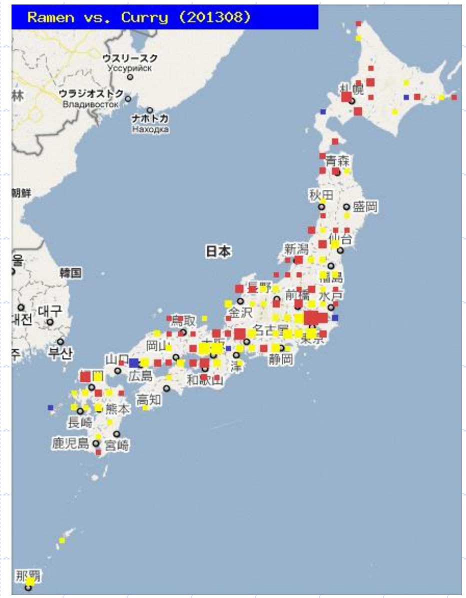
Fig. 6. Examples of misclassified Twitter food photos. Eaten ramen bowl (recognized as “ramen”), unopened instant ramen (ramen), a clam (sushi), ice cream (sushi), an eaten plate (omelet) and curry without cutlet (cutlet curry).

Geographical-Temporal analysis on ramen vs curry

12.6% of the obtained food photos have geotag.







Whole year | Dec. (winter) | Aug. (summer)

Ramen is popular.

Curry gets more popular than ramen in many areas.

Ramen Curry

Utilization of large number of food photos: Omerice analysis

- Omerice-style classification
  - Classification rate: 84.184%

letters drawing texture source plain

認識結果：
各1000枚で学習．1500枚を分類

分類先⇒	文字	絵	模様	ソース	プレーン
文字	85.6	10.0	3.1	1.1	0.1
絵	9.9	84.2	3.5	1.9	0.5
模様	3.1	5.7	80.7	8.8	1.6
ソース	1.2	1.9	6.9	86.5	3.5
プレーン	0.0	2.9	0.0	15.8	81.3

Real-time Food Collection

- Monitor the Twitter stream
  - Photo Tweet
  - Text including any of 100 food names
    - 13 candidate photo tweets / minute on avg.
    - Download: 2～3sec. , recognition: ～1sec.
    - Single machine is enough！
- Recognize 20,000 photos and find 5,000 food photos from the TW stream everyday in our lab

Demo visualization system

- Map each food photo on an online map with online clustering [Yanai ICMR2012]
  - Geotagged Tweets
  - Non-geotagged Tweets for which GeoNLP can assign locations based on text msg.

- Overlay a food photo on the Streetview
  - Finding “ramen noodle shop” game !

http:/mm.cs.uec.ac.jp/tw/

Twitter Food Image Bots

- Bot who recognize food photos and return results
  - @foodimg_bot

- Bot who re-tweets food photo tweets automatically

DeepFoodCam

Release soon at http://foodcam.mobi/

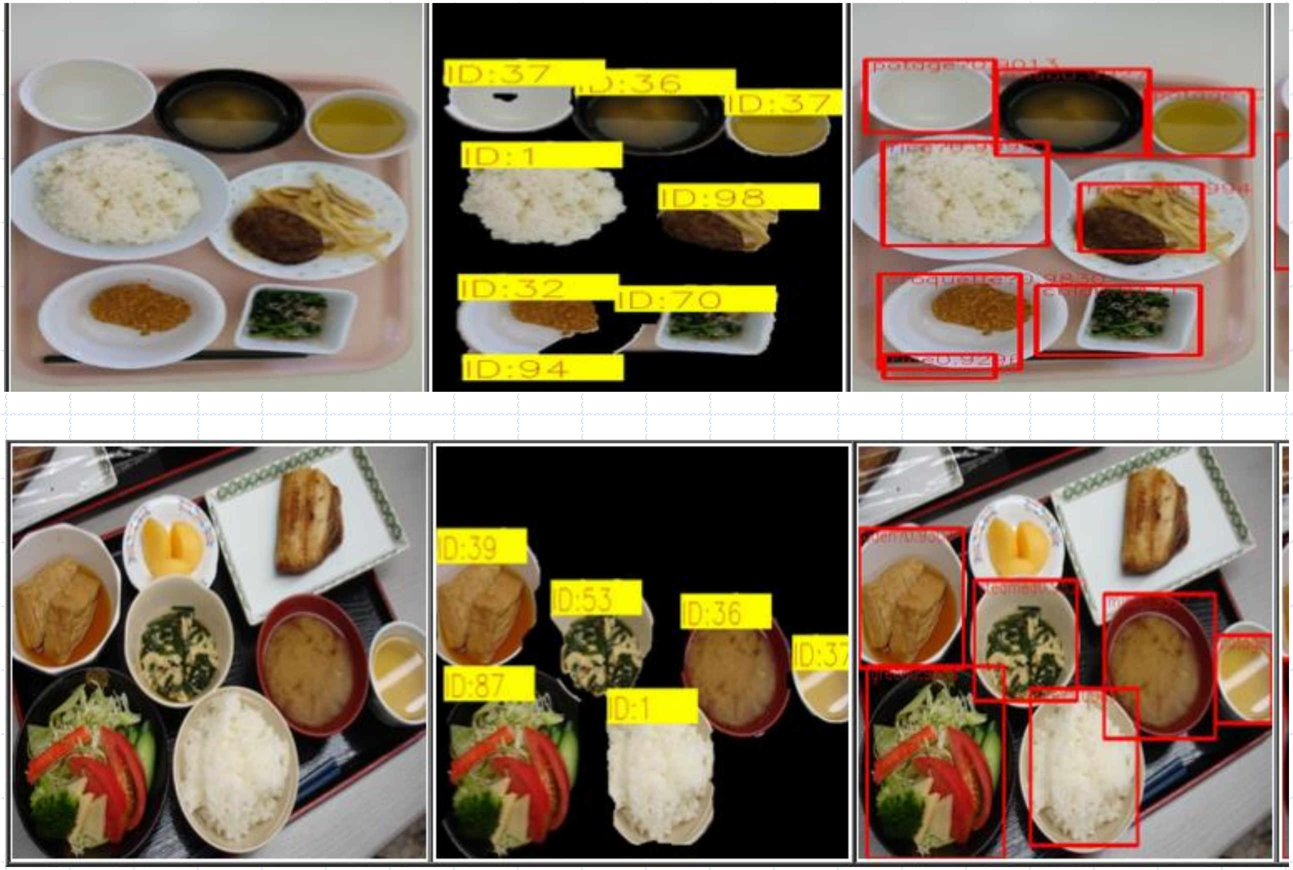
- DCNN-based food rec. app
  - Network-in-network (NIN) instead of AlexNet
  - PQ-based weight compression (7MB ⇔ 256MB)

Conclusions

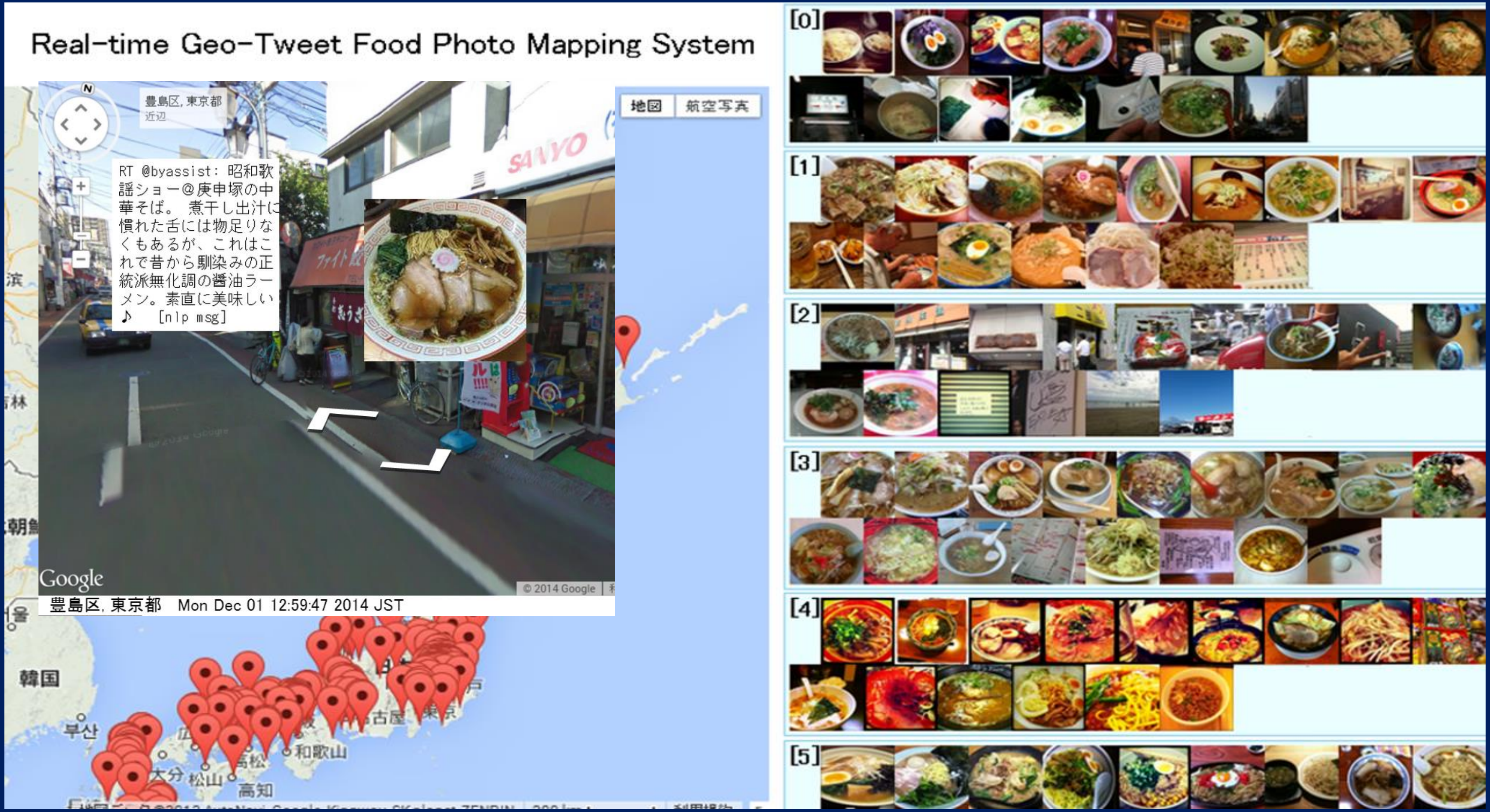
- Food recognition with DCNN features
  - Pre-trained DCNN with ImageNet2000 categories
  - Fine-tuned the pre-trained DCNN with UEC-FOOD
- Achieved the best performance so far
  - UEC FOOD-100: 78.48%
  - UEC FOOD-256: 94.85%
- We showed the effectiveness for the application, Twitter food photo mining

Future works

- CNN-based food region segmentation



Thank you for your attention !



1	ramen noodle	80021
2	curry	59264
3	sushi	25898
4	dipping noodle	22158
5	omelet with fried rice	17520
6	pizza	16921
7	jiaozi	16014
8	Japanese-style pancake	15234
9	steamed rice	14264
10	sashimi	13927
11	hambarg steak	11583
12	beef stake	9503
13	takoyaki	9004
14	fried rice	8383
15	fried noodle	7905
16	oden	7453
17	toast	6350
18	cutlet curry	6339
19	tempura	5905
20	rice ball	5462
21	gratin	5223
22	croquette	4837
23	stew	4797
24	sashimi bowl	4730
25	chicken-'n'-egg on rice	4513
26	tempura bowl	4464
27	beef bowl	4285
28	spicy chili-flavored tofu	4081
29	yakitori	3829
30	hamburger	3662
31	chilled noodle	3473
32	sukiyaki	3408
33	miso soup	3295

34	fish-shaped pancake with bean jam	3281
35	pork cutlet on rice	3188
36	omelet with grilled minced meat	2592
37	bibimbap	2368
38	spaghetti	2171
39	lightly roasted fish	2162
40	seasoned beef with potatoes	2129
41	natto	2094
42	spaghetti with meat source	1994
43	steamed egg hotchpotch	1843
44	egg sunny-side up	1635
45	croissant	1579
46	udon noodle	1500
47	simmered pork	1443
48	mixed sushi	1371
49	pork miso soup	1229
50	ginger-fried pork	1158
51	potato salad	1150
52	egg omelet	1146
53	eels on rice	1071
54	egg roll	1058
55	sweet and sour pork	1049
56	fried shrimp	1049
57	sauteed vegetables	1040
58	shrimp with chill source	1003
59	cabbage roll	965
60	mixed rice	901
61	pilaf	891
62	soba noodle	880
63	potage	816
64	hot dog	795
65	chicken rice	736
66	wiener sausage	577

67	dried fish	563
68	steamed meat dumpling	561
69	french fries	561
70	beef ramen noodle	555
71	sandwiches	551
72	cold tofu	517
73	boiled chicken and vegetables	352
74	sirloin cutlet	331
75	nanbanzuke	323
76	fried chicken	314
77	stir-fried beef and peppers	312
78	roll bread	288
79	roast chicken	263
80	macaroni salad	239
81	boiled fish	228
82	kinpira-style sauteed burdock	225
83	tempura udon	213
84	raisins bread	205
85	goya chanpuru	198
86	green salad	145
87	chinese soup	141
88	Japanese tofu and vegetable chowder	137
89	salmon meuniere	96
90	grilled pacific saury	84
91	chip butty	76
92	fried fish	72
93	begitable tempura	71
94	tensin noodle	69
95	ganmodoki	34
96	grilled salmon	25
97	sauteed spinach	12
98	teriyaki grilled fish	3
99	grilled eggplant	2
100	pizza toast	0

2.1 group and some food categories

noodles	udon nooles, dipping noodles, ramen
yellow color	omlet, potage, steamed egg hotchpotch
soup	miso soup, pork miso soup, japanese tofu and vegetable chowder
fried	takoyaki, japanese-stype pancake, fried noodle
deep fried	croquette, sirloin cutlet, fried chicken
salad	green salad, sauteed vegetables, vegetable tempra
bread	sandwiches, raisin bread, roll bread
seafood	sashimi, sashimi bowl, sushi
rice	rice, pilaf, fried rice
fish	grilled salmon, grilled pacific saury, dried fish
boiled and seasoned	sesoned beef with potatoes simmered ganmodoki sesoned beef with potatoes
sauteed	sauteed vegetables, goya chanpuru, kinpira-style sauteed burdock
sauce	stew, curry, stir-fried shrimp in chili sauce

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noodles	udon nooles, dipping noodles, ramen
yellow color	omlet, potage, steamed egg hotchpotch
[illegible]	[illegible]
	ed salmon, grilled pacific saury, [illegible]
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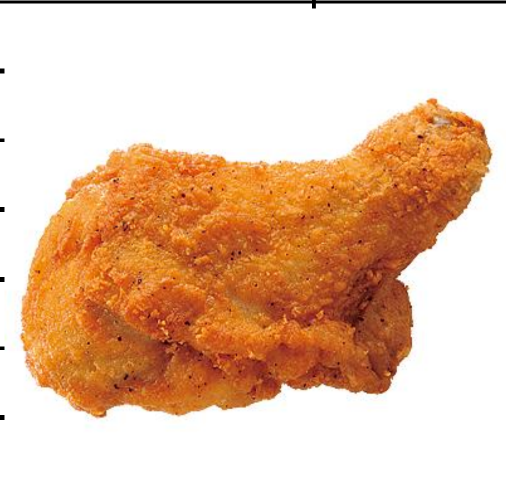

fish	grilled salmon, grilled pacific saury, dried fish
boiled and seasoned	sesoned beef with potatoes simmered ganmodoki sesoned beef with potatoes
sauteed	sauteed vegetables, goya chanpuru, kinpira-style sauteed burdock
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[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
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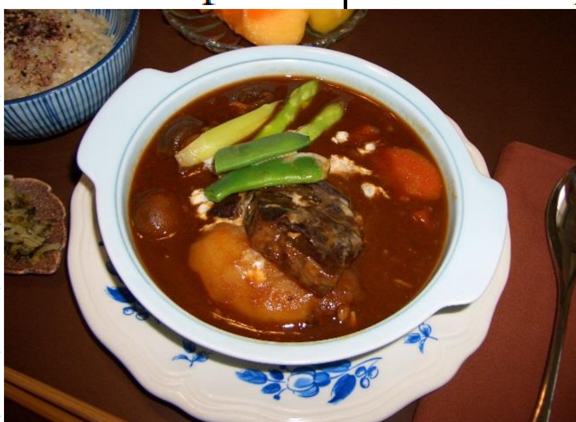

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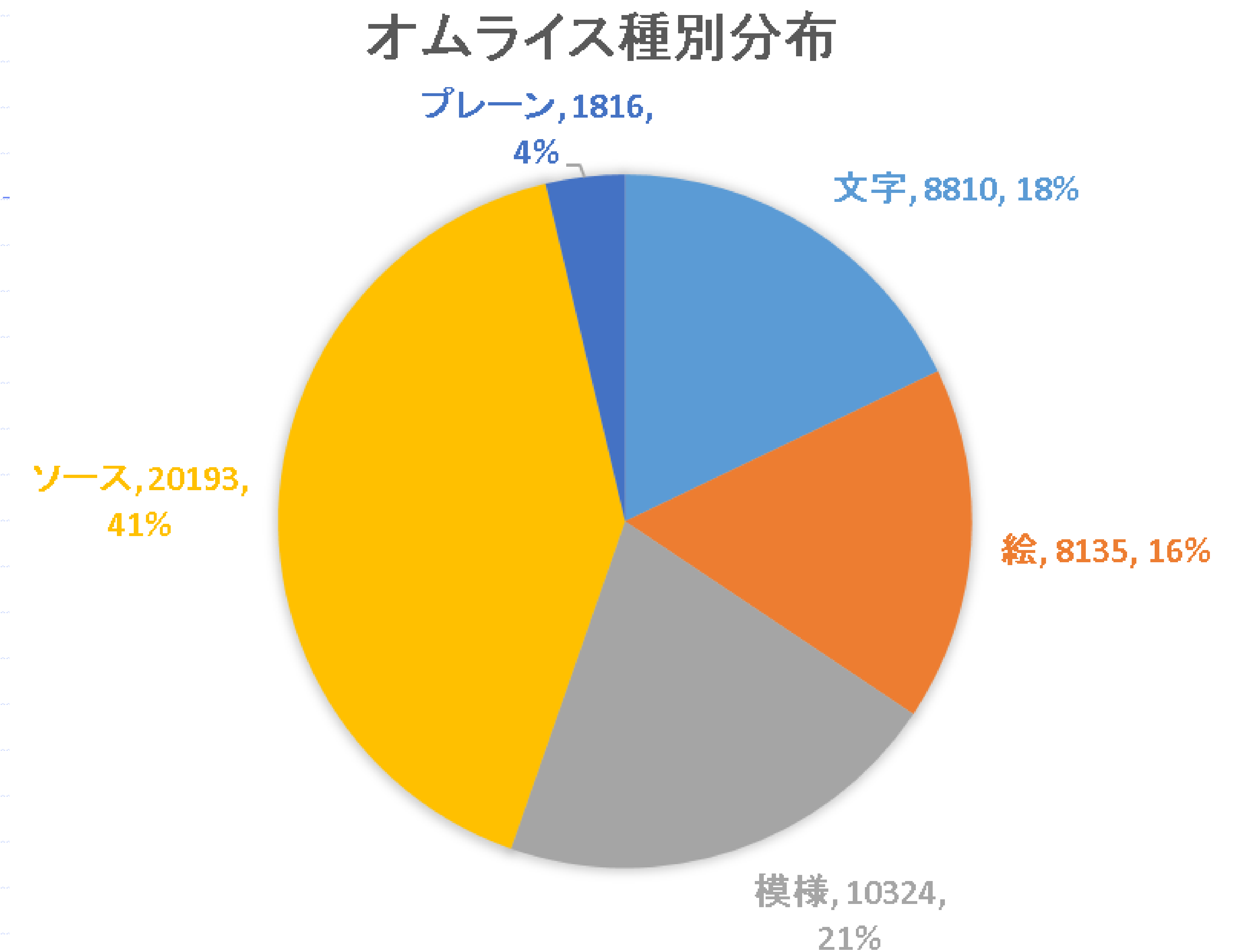
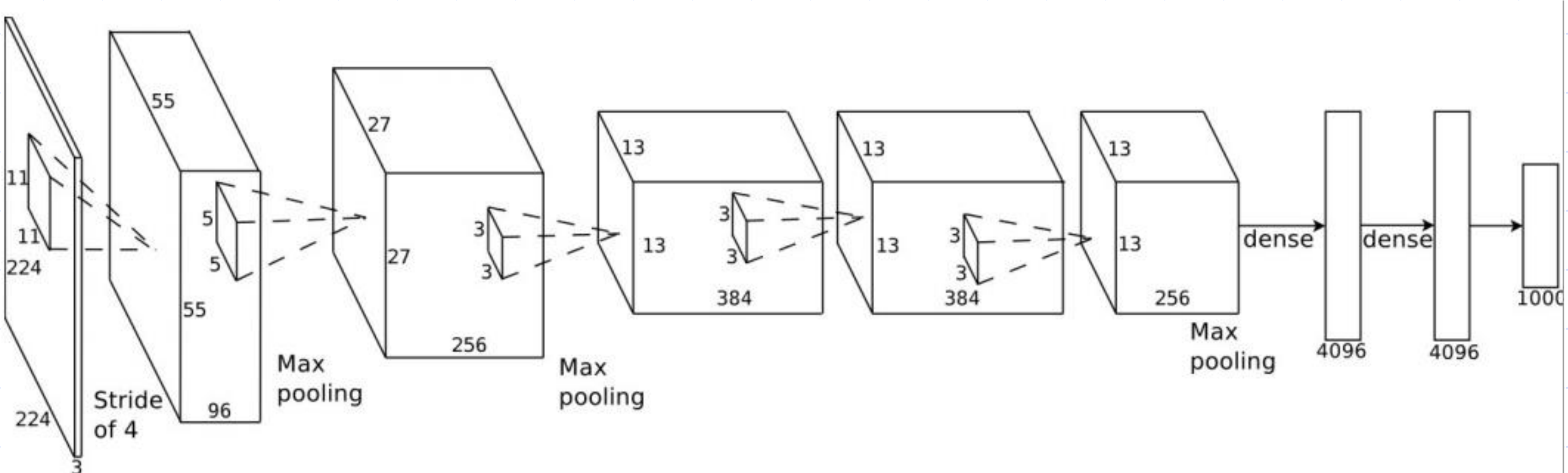
【復習】

クラウドソーシング体験課題


オムライス種別分布
プレーン, 1816, 4%
文字, 8810, 18%
絵, 8135, 16%
模様, 10324, 21%
ソース, 20193, 41%

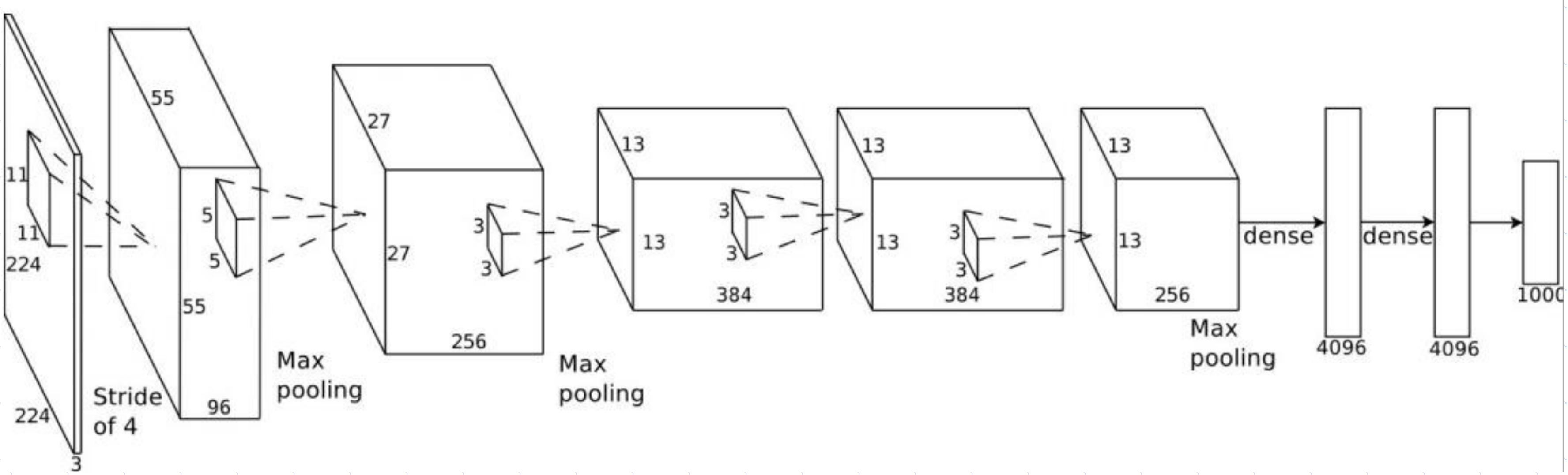
大規模画像認識のための標準ネットワーク構成：Alex Net

- ILSVRC 2012 で，Alex Krizhevskyらが用いたネットワーク構成．
  - Alex Krizhevsky, I.Sutskever, J. Hinton : ImageNet Classification with Deep Convolutional Neural Networks, NIPS 2012.
- 2013, 2014はどのチームもこれをベースに改良，拡張．
  ⇒ 事実上の標準ネットワーク．



Convolutional network

- 前半が畳み込み層 (convolutional layer)，後半が昔と同じ全結合層 (full



Convolutional layer

Full-connection layer