# Predicting Visual Memory:

## Behavioral, Neuroscience and Computational Accounts

**Aude Oliva**

**Computer Science and Artificial Intelligence Lab**

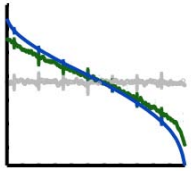
**Massachusetts Institute of Technology**


# Can we predict which images are memorable ?

# Memorability

## A metric of the utility of information

### Understand human memory




Source: Isola, Phillip, Jianxiong Xiao, Devi Parikh, Antonio Torralba, and Aude Oliva. "What makes a photograph memorable?." IEEE transactions on pattern analysis and machine intelligence 36, no. 7 (2014): 1469-1482.

### Diagnose memory problems



### Design mnemonic aids




### Data Visualization



### Mobile applications



### Retrieve better images from search



### Logos Slogans - words-



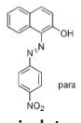

### Social Networking




### Computer Graphics - *cognitive* saliency



### Education -Individual differences



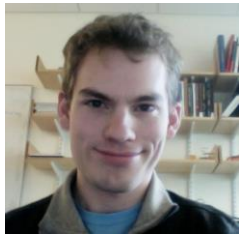



### Face Memorability



### Summarize Bigdata – images, videos

# Visual Memory Experiments



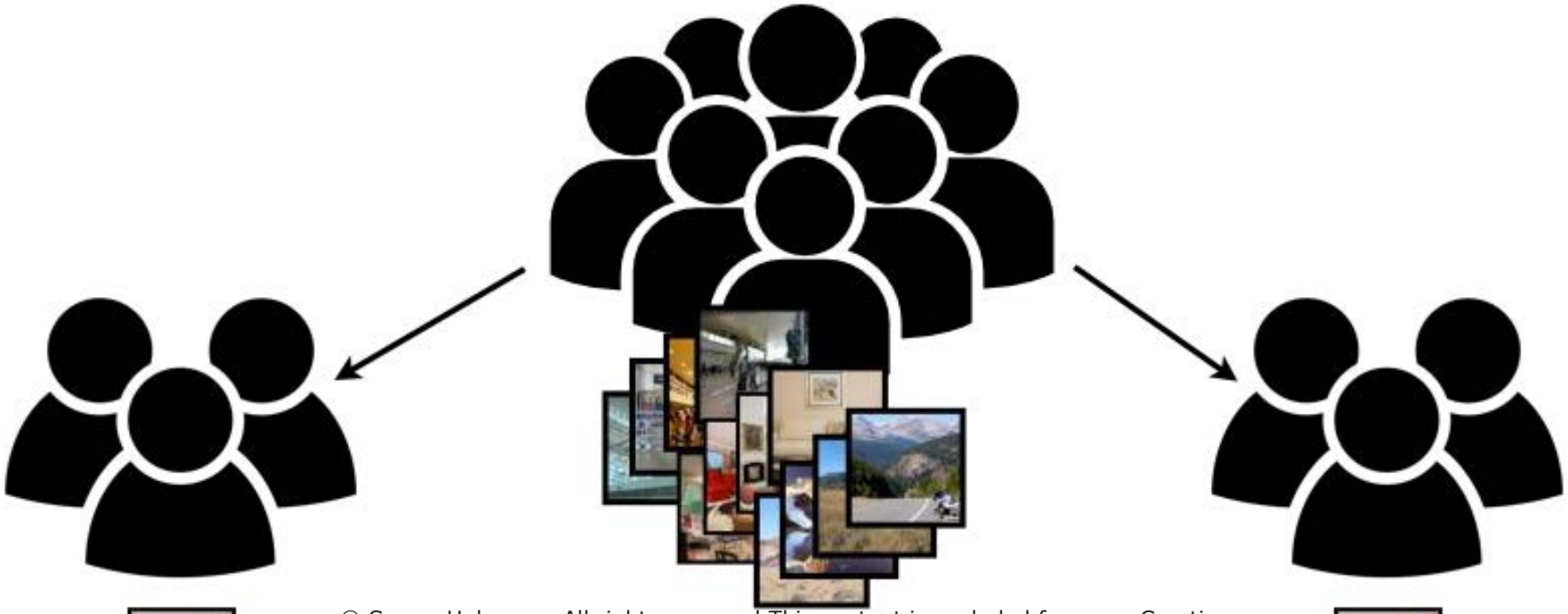
**Phillip Isola**

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

# Large difference in image memorability & high consistency between observers' groups

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

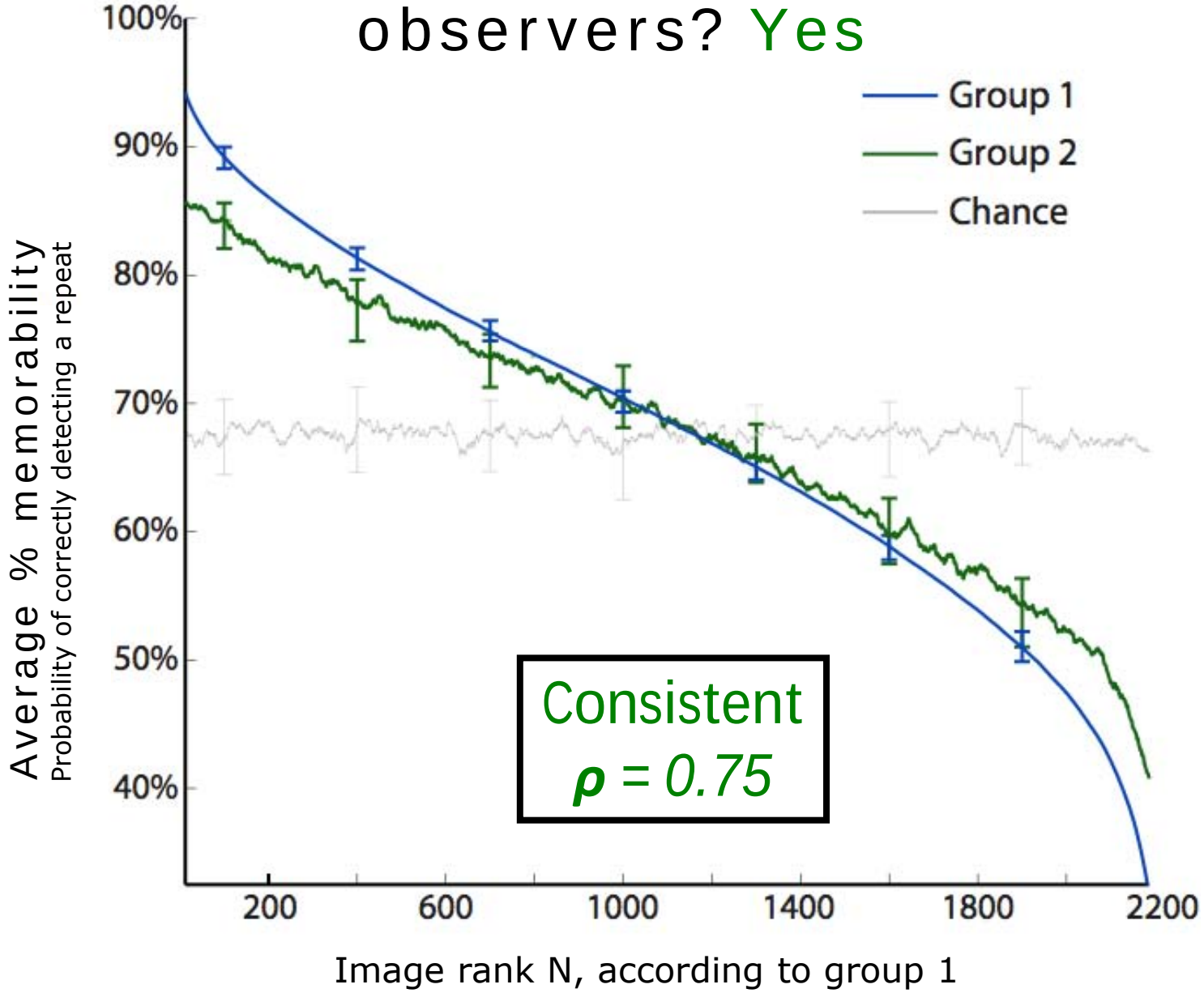
Isola et al (2011). *IEEE CVPR*





**0.75**

# Is memorability consistent across different observers? Yes




chance level rank calculated by randomly ordering the images on the x-axis

~ 80 scores per image

# Subjective judgments do not predict image memorability

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

# Image memorability is distinct from image aesthetic

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

# Is memorability stable across time? Yes

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

# When do memorability differences arise?

**At stage of encoding**: This suggests some images (features) are encoded in less sufficient detail than others

Figure removed due to copyright restrictions. Please see the video.
Source: Isola, Phillip, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "What makes an image memorable?" In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on, pp. 145-152. IEEE, 2011.

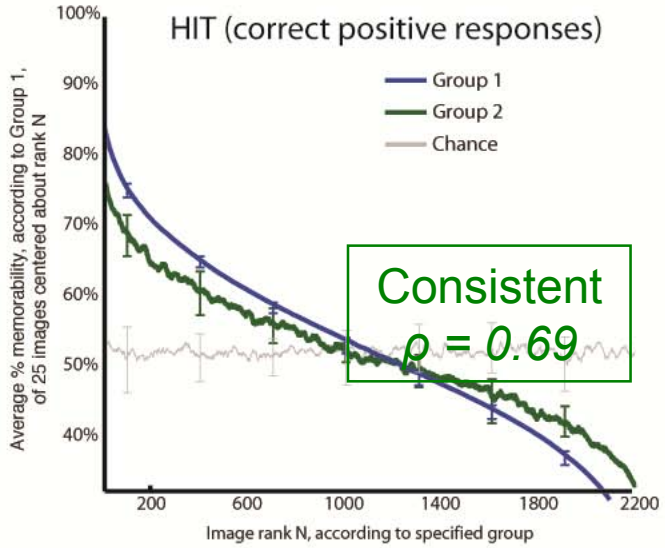
**Wilma Bainbridge**

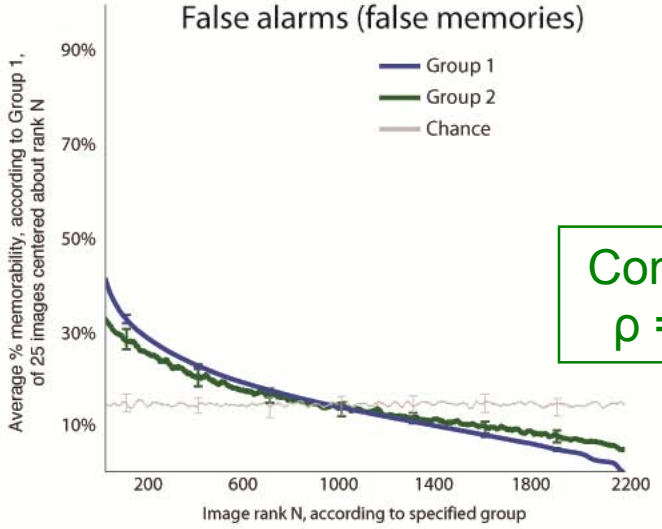
Courtesy of The American Psychological Association. Used with permission.
Source: Bainbridge, Wilma A., Phillip Isola, and Aude Oliva."The intrinsic memorability of face photographs." Journal of Experimental Psychology: General 142, no. 4 (2013): 1323.

**Face dataset 10K: faces selection follows the distribution of the US census. Available on the web**

Bainbridge, Isola, Oliva, (2013). J. Exp. Psychology: General.

# Large difference in face memorability & high consistency between observers' groups



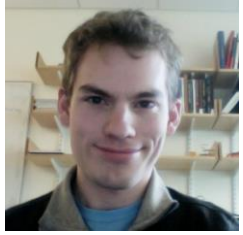





Source: Bainbridge, Wilma A., Phillip Isola, and Aude Oliva. "The intrinsic memorability of face photographs." Journal of Experimental Psychology: General 142, no. 4 (2013): 1323.

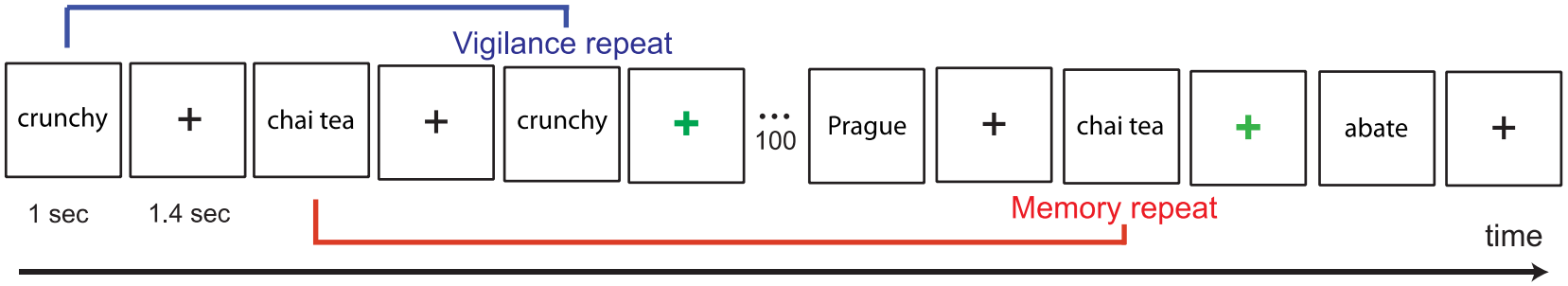
# Words Memorability

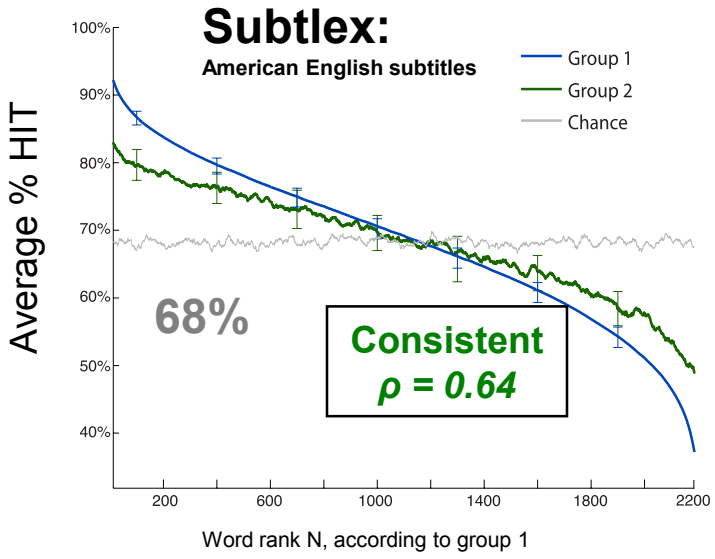

Kyle Mahowald

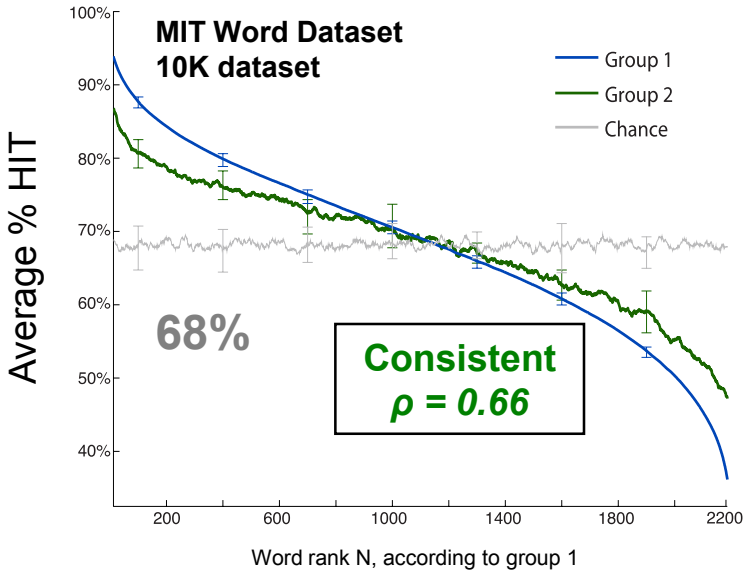

Phillip Isola


Ted Gibson


Ev Fedorenko

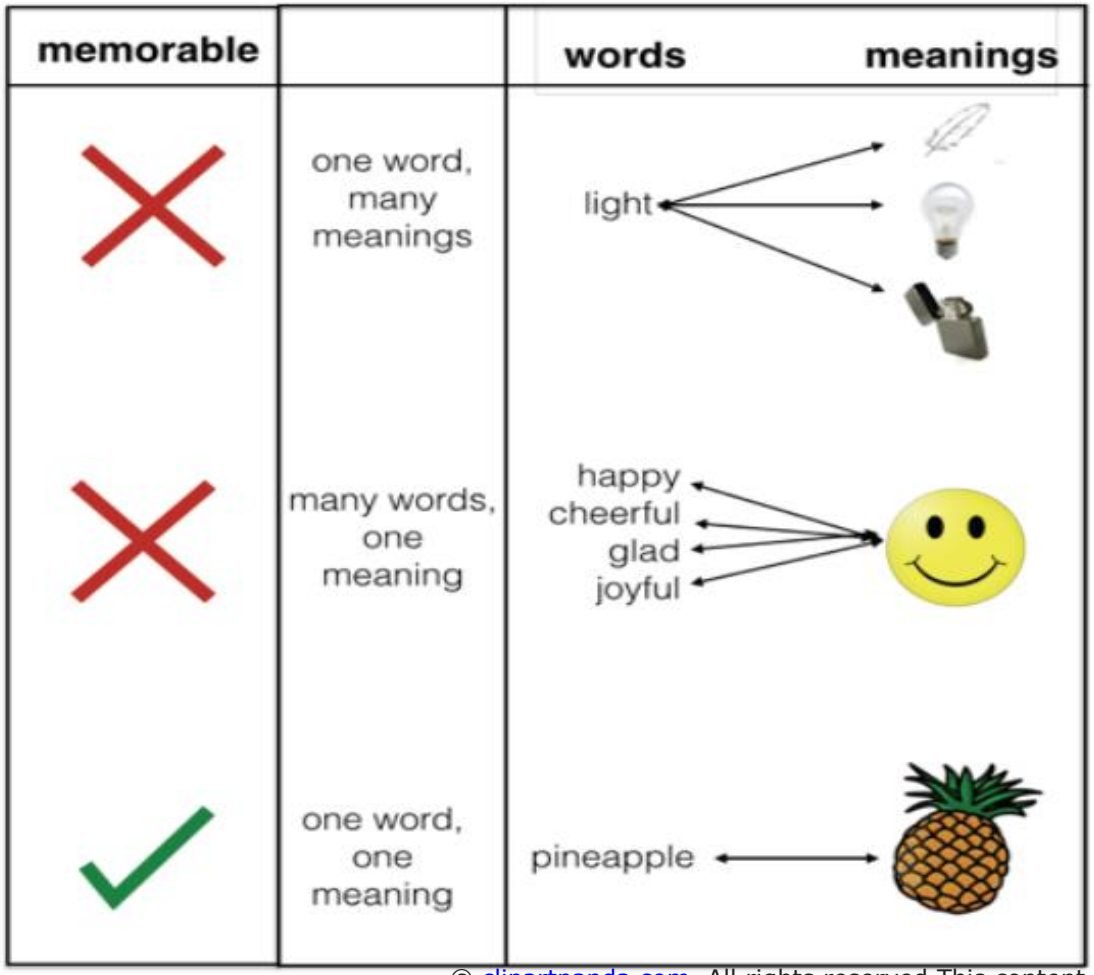



Mahowald, Isola, Fedorenko, Oliva, Gibson (submitted, 2015).

# Memorable vs. Forgettable words






Forgettable words

**Excellent**
**Blast**
**Irrational**
**Massive**

Memorable words

**Fabulous**
**Vogue**
**Grotesque**
**Avalanche**

Information-theoretic norm (number of synonyms, number of meanings) predict word memorability

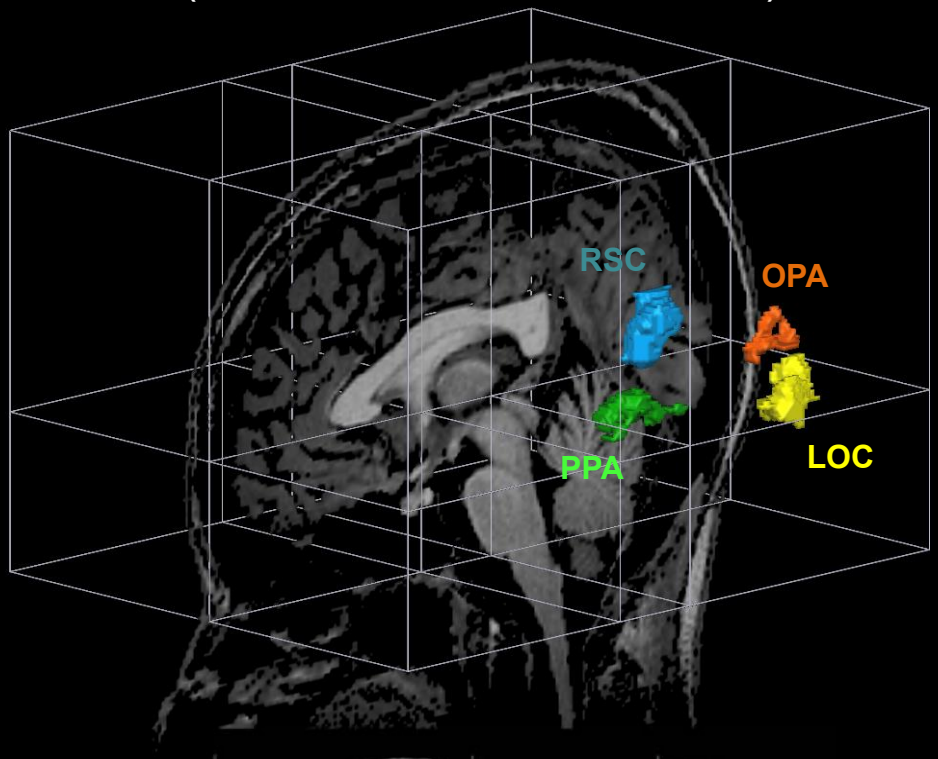
See Konkle, et al (2011), JEP:General

Mahowald, Isola, Fedorenko, Oliva, Gibson (submitted, 2015).

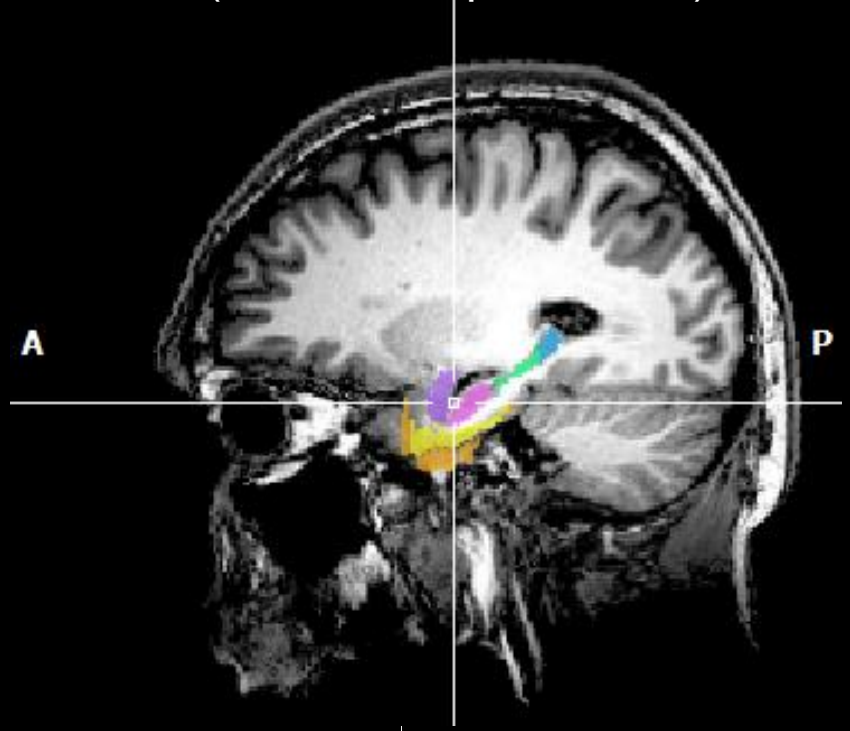
# Neural framework of memorability

Wilma Bainbridge

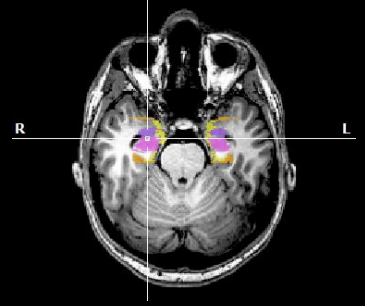
**Perception**
(ventral/dorsal visual cortex)



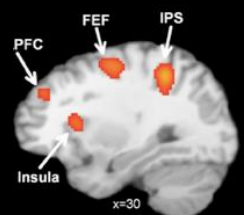

**Memory**
(Medial Temporal Lobe)



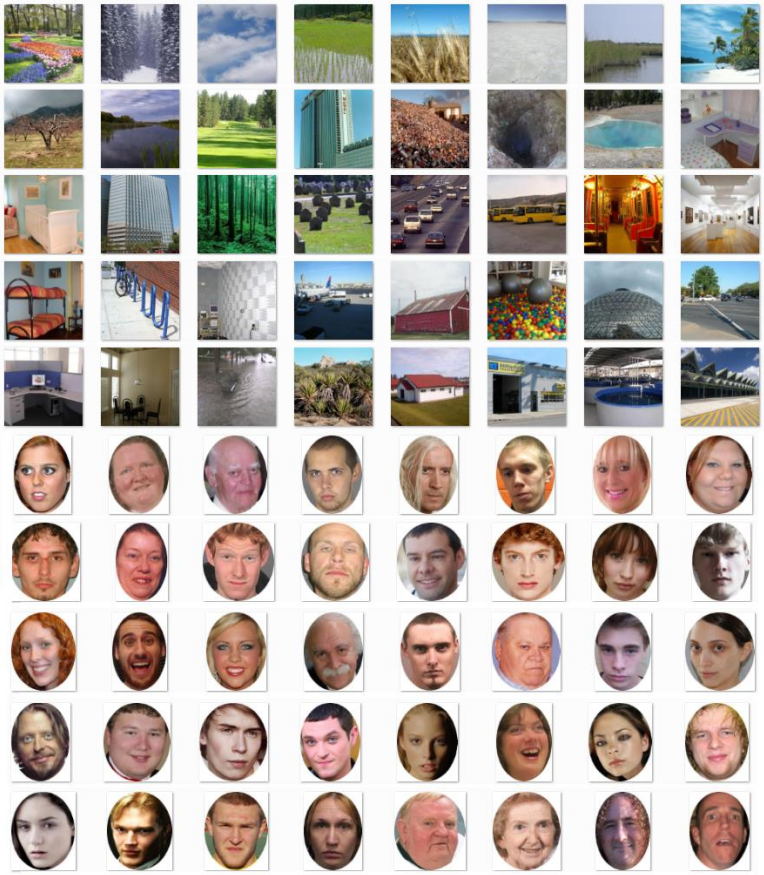

Early visual areas




Attention network

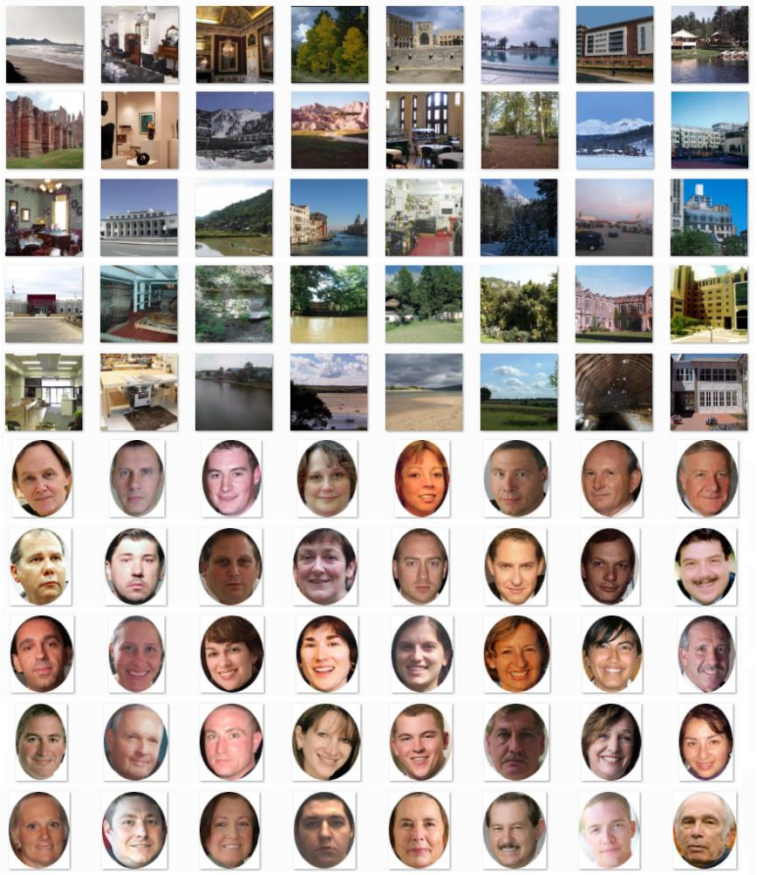


Novel



Memorable

Novel



Forgettable

# *Equalized* Memorable & Forgettable Groups

Interestingness
Aesthetic

180 memorable scenes
90 indoor, 90 outdoor (38 landscapes)
HIT : **0.97** (above 25% of HR) - FA: 0.10
Color (RGB, Lab), spectral frequency

180 forgettable scenes
90 indoor, 90 outdoor (38 landscapes)
**HIT** : **0.69** (below 25% of HR) - FA: 0.10
Color (RGB, Lab), spectral frequency

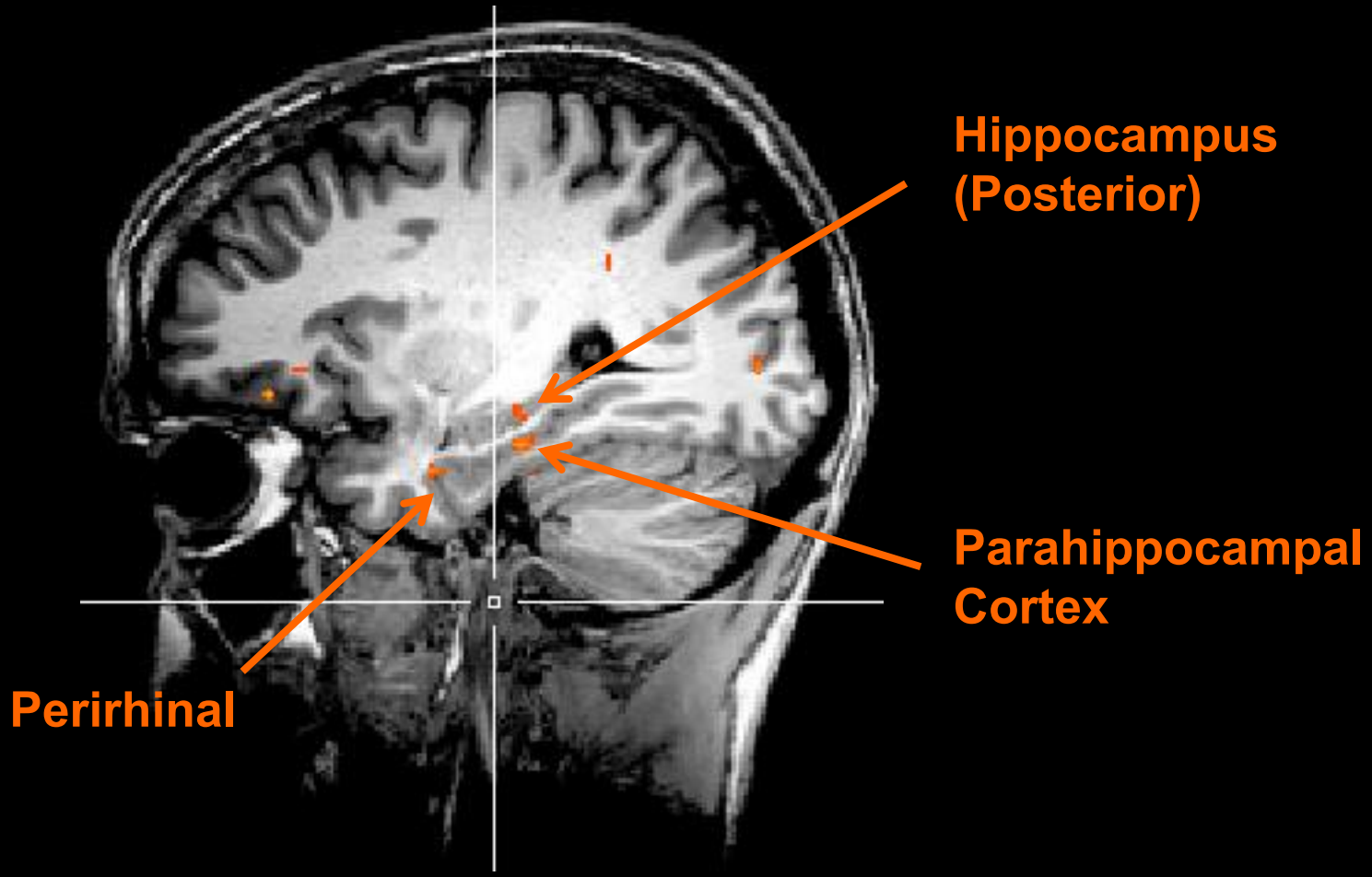
Attractiveness
Emotion
Kindness
Friendliness
Happiness
Introversion
Confidence

180 memorable faces
90 women, 90 men
**HIT** : **0.72** (above 25% of HR) - FA: 0.11
Race, age, type of emotion, spectral frequency

180 forgettable faces
90 women, 90 men
**HIT** : **0.32** (below 25% of HR) - FA: 0.11
Race, age, type of emotion, spectral frequency

# Multi-variate Pattern Analysis

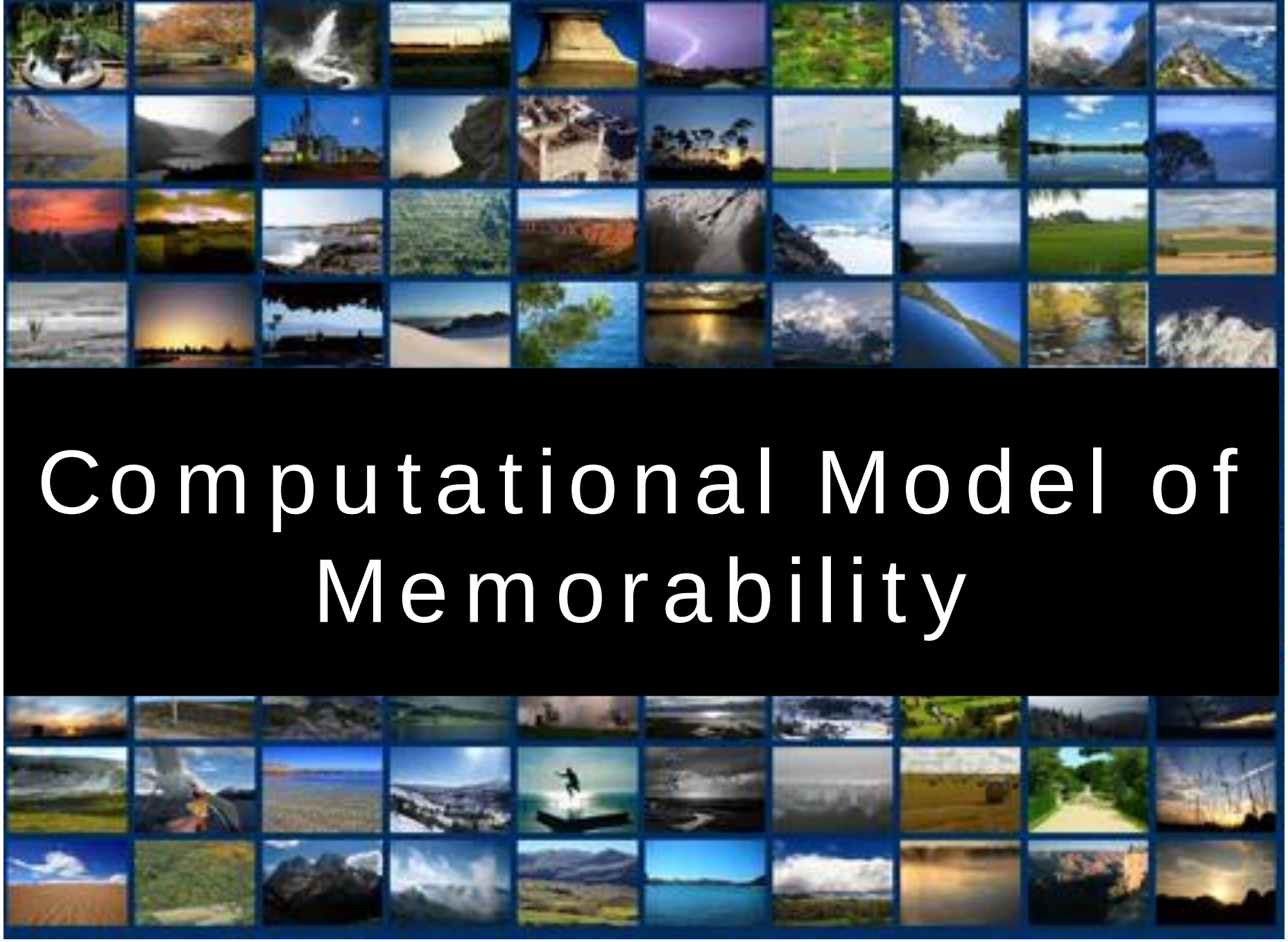
## Memorable vs. Forgettable




A role for the hippocampus in **higher-order statistical perception**

MVPA Searchlight preliminary results (3x3x3 cubic voxel grid)

**Bainbridge, Dilks, Oliva (in preparation)**



# Computational Model of Memorability

# Large scale visual memorability

60,000 photographs with memorability scores

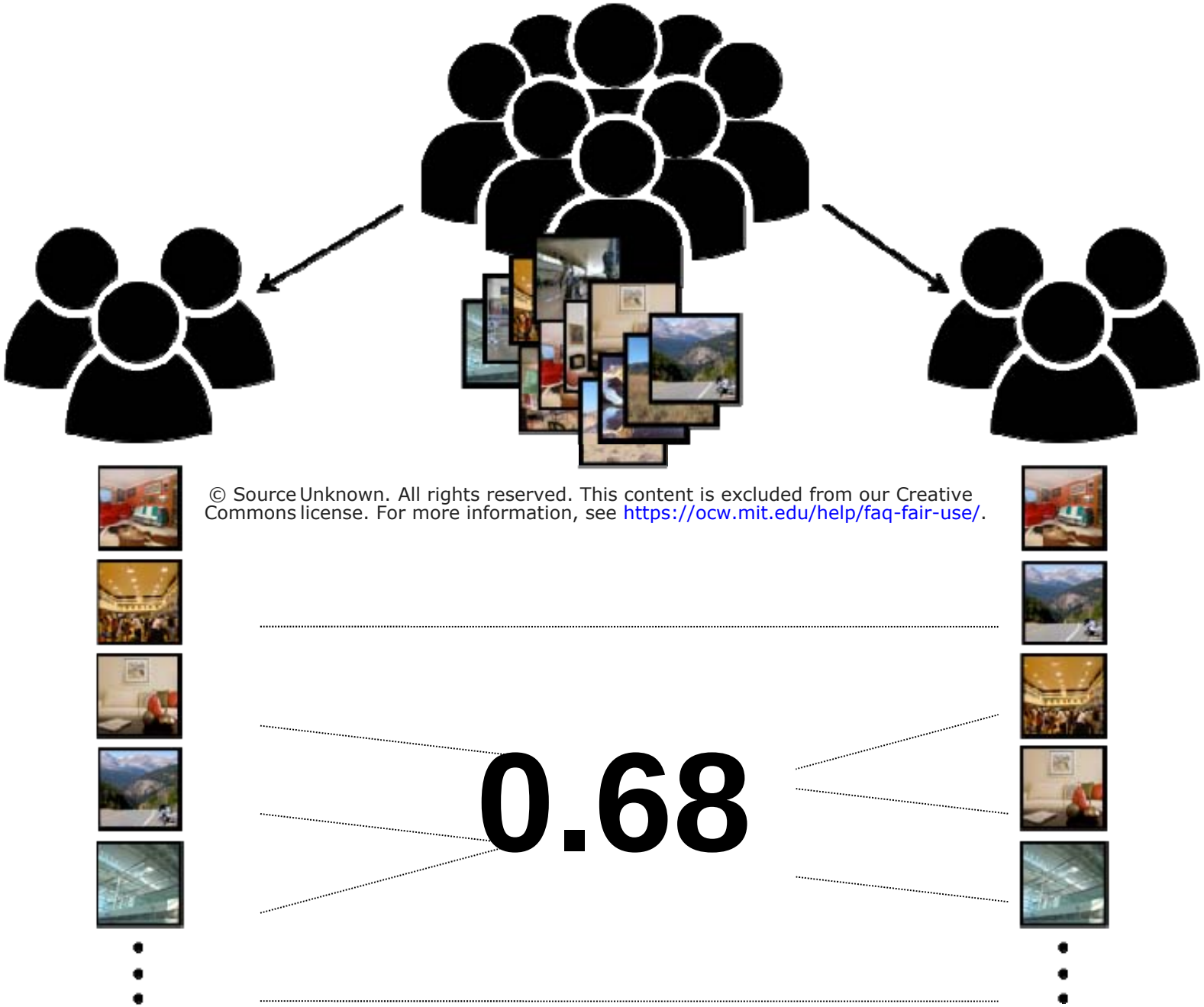
**Aditya Khosla**

Figure removed due to copyright restrictions.
Source: Khosla, Aditya, Akhil S. Raju, Antonio Torralba, and Aude Oliva."Understanding and predicting image memorability at a large scale." In *Proceedings of the IEEE International Conference on Computer Vision*, pp. 2390-2398. 2015.

Most memorable

Less memorable

http://memorability.csail.mit.edu/



## Most memorable

## Less memorable

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Source: Khosla, Aditya, Akhil S. Raju, Antonio Torralba, and Aude Oliva."Understanding and predicting image memorability at a large scale." In P*roceedings of the IEEE International Conference on Computer Vision*, pp. 2390-2398. 2015.

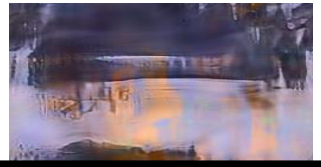
**60,000 images**

- **Focus**
- **Enclosed Setting**
- **Dynamics**
- **Unusual**

- **No single focus**
- **Distant view**
- **Static**
- **Common**

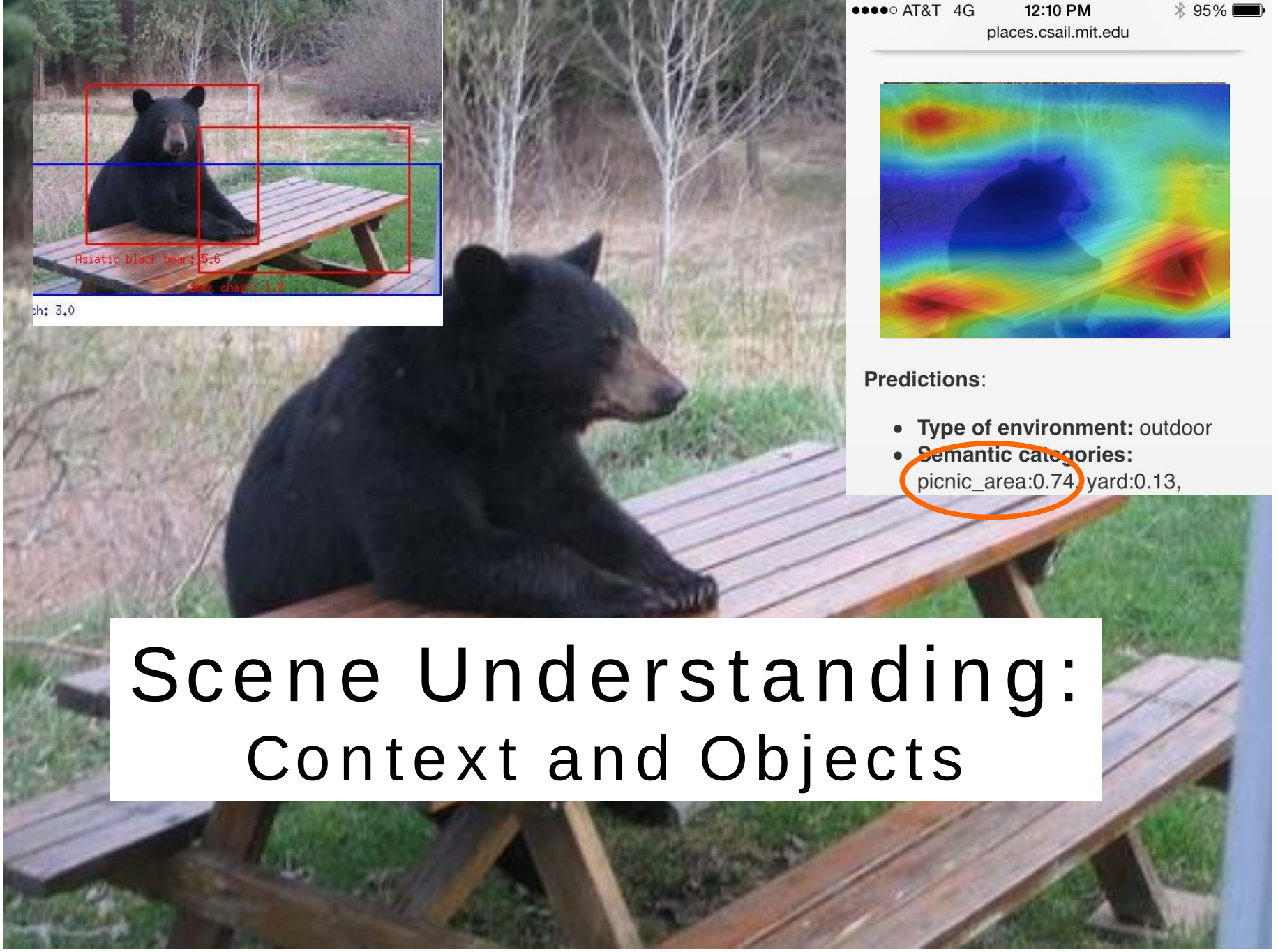







# You need to recognize to remember






# Scene Understanding:
## Context and Objects

# The evolution of scene and object centered databases

COIL-20

Caltech 101

MNIST (1998)

IMAGENET (2009)

2 year old kid

$10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$ # images

Caltech-4 (2003)

PASCAL (2005)

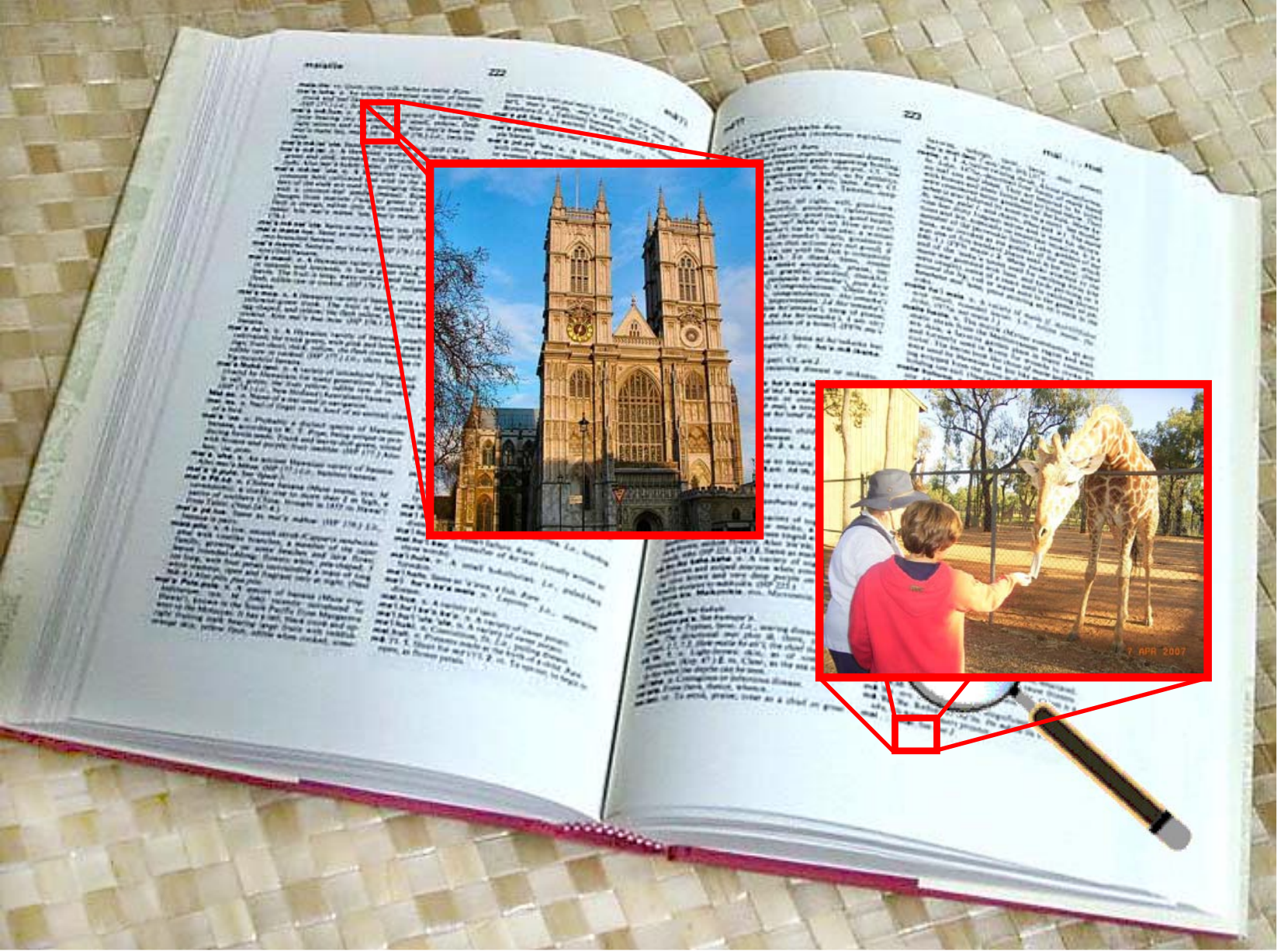
**15 scenes database (2006)**

**8 scenes database (2001)**

**SUN database (2010)**

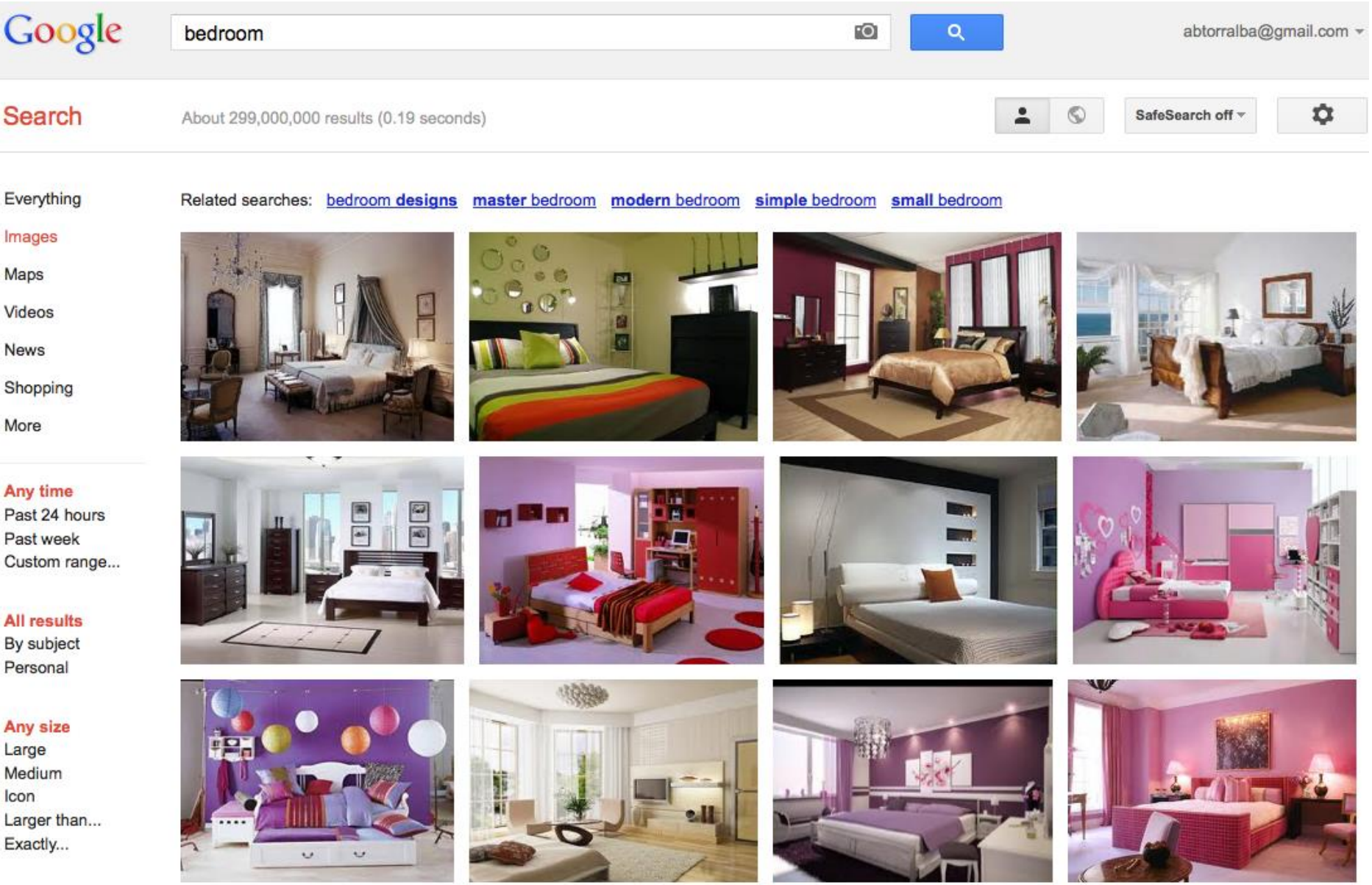
places

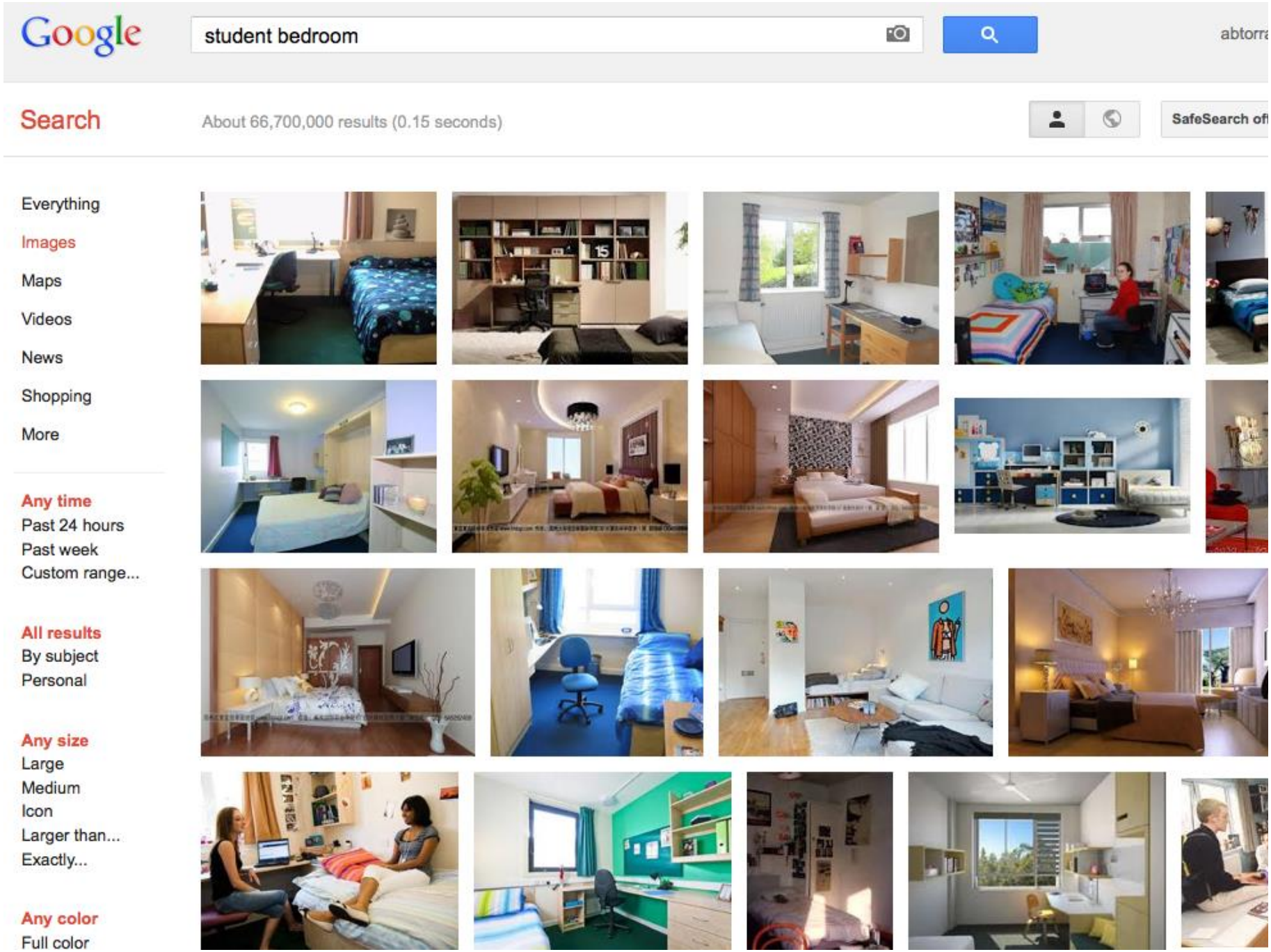
$10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$ # images




Source: Xiao, Jianxiong, James Hays, Krista A. Ehinger, Aude Oliva, and Antonio Torralba."Sun database: Large-scale scene recognition from abbey to zoo." In Computer vision and pattern recognition (CVPR), 2010 IEEE conference on, pp. 3485-3492. IEEE, 2010.

**Xiao et al (2010), CVPR, Ehinger et al (2011)**

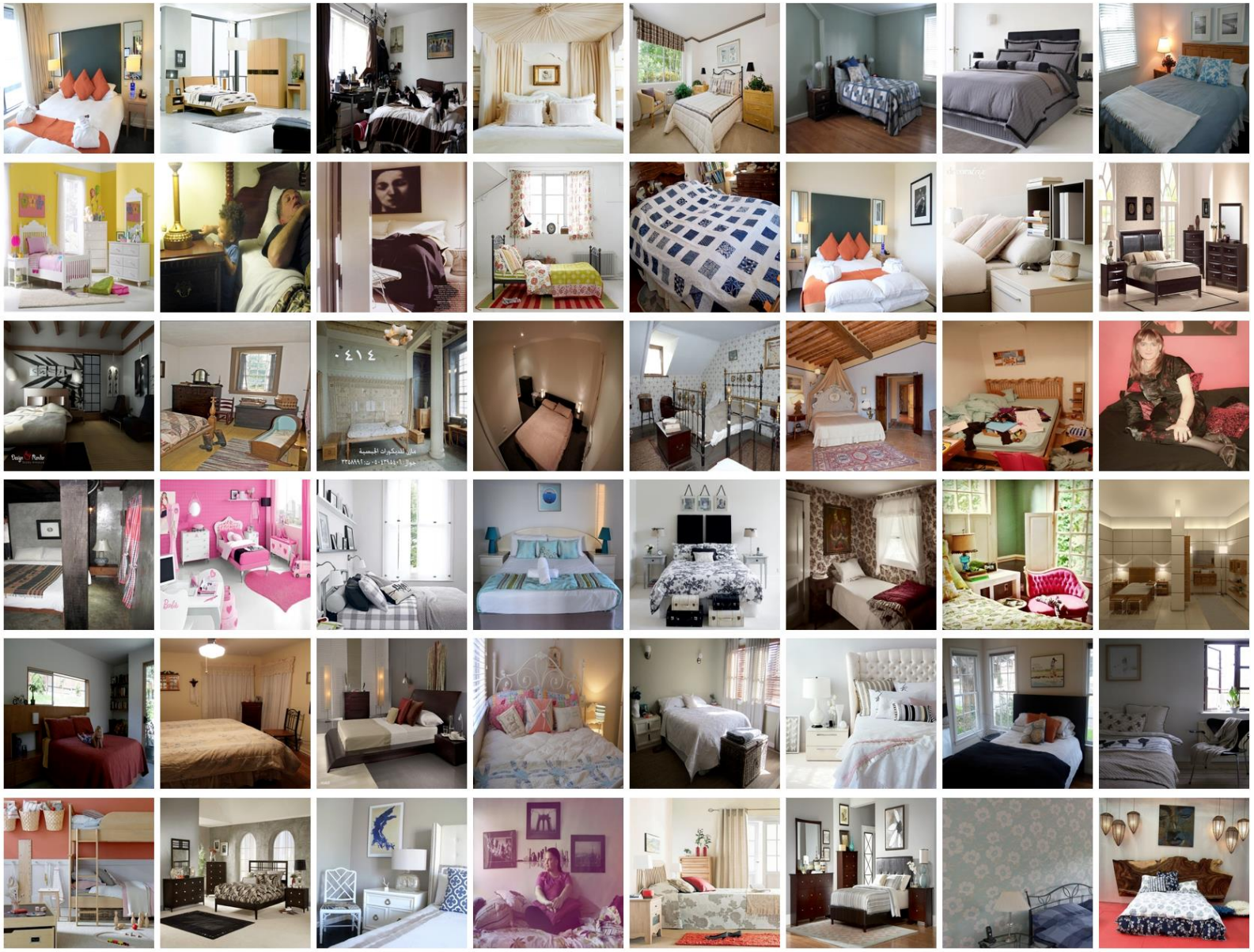




# Improving diversity

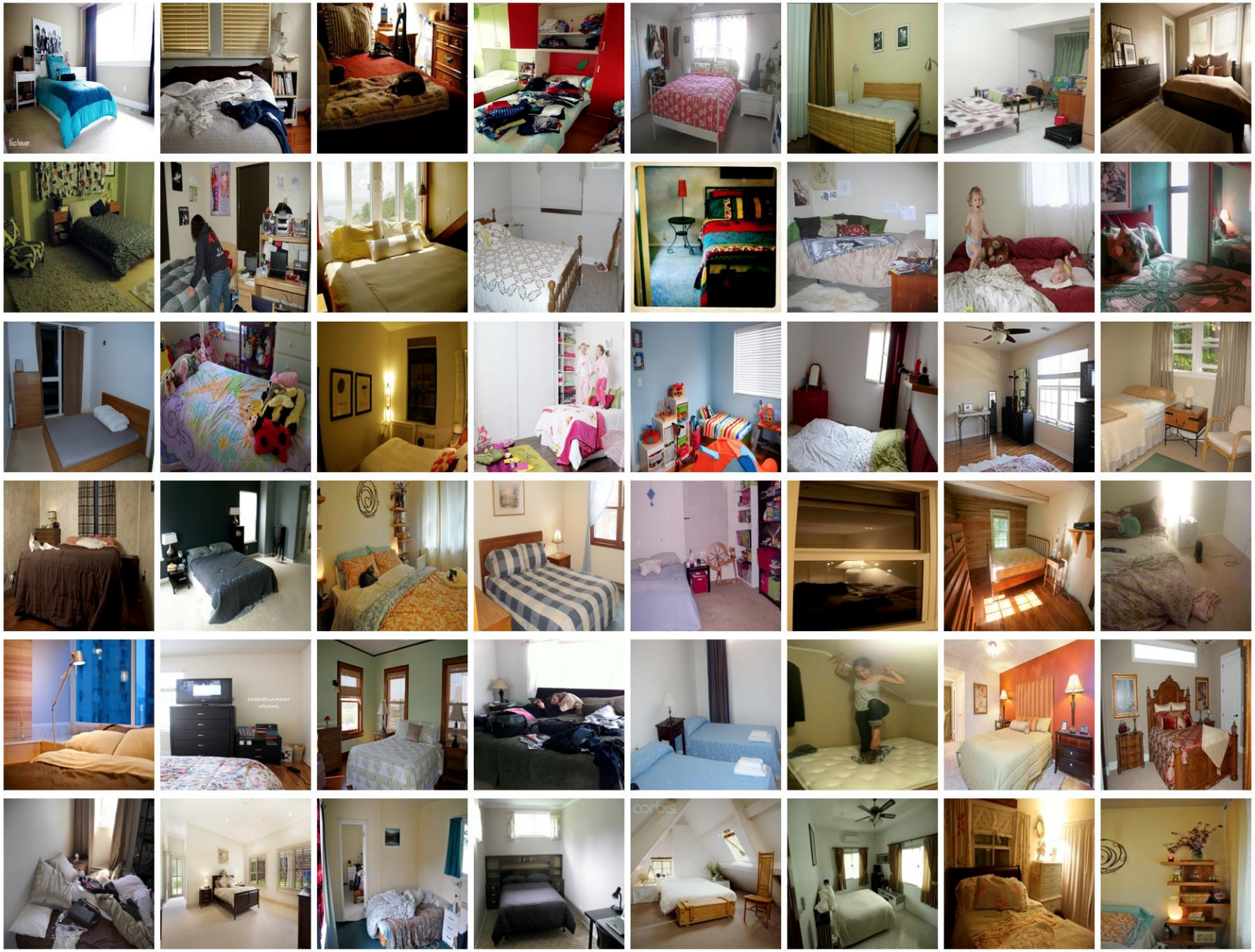
abandoned, acceptable, accessible, additional, adjacent, advertised, affordable, air-conditioned, alternative, american, amusing, ancient, antique, appealing, appropriate, architectural, asian, astonishing, astounding, attractive, austere, authentic, available, average, awesome, beautiful, beguiling, beloved, best, better, better-known, big, bigger, biggest, bizarre, black, black-and-white, bland, boring, breezy, brick-built, bright, brighter, brightest, brilliant, broken, busiest, business-like, bustling, busy, central, centralized, certain, changed, changing, charming, cheap, cheaper, cheapest, cheerful, cheerless, cheery, cherished, chilling, chilly, civilized, classic, classical, clean, cleaner, clear, clearer, clinical, closer, closest, closing, cloudy, coastal, cold, coldest, colourful, comfortable, comforting, comfortless, comfy, common, comparable, comparative, competitive, complementary, complete, complex, complicated, concealed, conceivable, confined, considerable, contemporary, cool, coolest, cosmopolitan, cost-effective, cosy, cozy, cream-white, creative, crowded, cultivated, cultural, current, damp, dangerous, dark, darkened, darker, darkest, decorative, delightful, designated, designed, desirable, desired, desolate, desolated, different, difficult, dilapidated, dim, dimly-lit, dingy, dirty, disadvantageous, disorderly, do-it-yourself, domestic, double, double-fronted, double-length, downtown, drab, dreadful, driest, dry, dual, dull, duller, dullest, dusty, early, economic, economical, elegant, embarrassing, empty, enormous, especial, european, everyday, exciting, exemplary, exotic, exterior, external, extraordinary, extravagant, familiar, famous, fancy, fantastic, far-away, fascinating, fashionable, fashioned, favourable, fictional, fictitious, filmed, filthy, fine, foggy, foreign, formal, fractured, friendly, frightening, frightful, frosty, frozen, frustrating, full, funny, furnished, fuzzy, gaudy, ghastly, ghostly, glamorous, glassy, glazed, glittering, gloomy, glorious, glossy, godlike, gold-plated, good, gorgeous, graceful, gracious, grand, gray, great, greatest, green, greener, grey, grisly, gruesome, habitable, habitual, handy, happy, harmonious, harrowing, harsh, hazardous, healthful, healthy, heart-breaking, heart-rending, heavy, hideous, hiding, higgledy-piggledy, high, hilarious, historic, historical, holiest, home, horizontal, hospitable, hostile, hot, huge, humid, idyllic, illegal, imaginary, immaculate, immense, imminent, immortal, impassable, impassioned, impersonal, important, impossible, impressive, improbable, improper, inauspicious, inconceivable, inconvenient, incredible, independent, individual, indoor, industrial, ineffable, inexpensive, informal, inhabited, inhospitable, initial, innovatory, innumerable, insecure, insignificant, inspiring, integrated, intentional, interesting, intermediate, internal, international, intimidating, intriguing, inviting, irrational, irregular, isolated, joint, joyful, key, known, large, large-scale, largest, less-favored, lesser, licensed, lifeless, light, limited, little, little-frequented, little-known, lively, living, local, lofty, logical, lone, long, long-awaited, long-forgotten, long-inhabited, long-netting, long-stays, long-term, lost, lousy, lovely, low, low-ceilinged, low-cost, low-energy, lower, lucky, luxury, magical, magnificent, main, majestic, major, marginal, marine, marvellous, massive, masterful, maximum, mean, meaningless, mechanised, medieval, mediocre, medium-sized, melancholy, memorable, messy, middle, middle-order, mighty, miniature, minor, miserable, missing, misty, mixed, modern, moist, mouldy, mountainous, moving, muddy, multi-functional, multiple, mundane, murky, musty, muted, mysterious, mysterious-looking, mystic, mystical, mythic, naff, named, nameless, narrow, national, native, natural, naturalistic, nearby, neat, necessary, neglected, neighboring, new, nice, night-time, nineteenth-century, noisy, nondescript, normal, northern, notable, notorious, numerous, odd, odorous, official, old, only, open, open-air, operatic, orderly, ordinary, organic, original, ornamental, out-of-homes, out-of-the-way, outdoor, outlying, outside, outstanding, over-crowded, overgrown, overwhelming, paid, painful, painted, palatial, pastoral, peaceful, peculiar, perfect, periodic, peripheral, permanent, permitted, personal, petty, pictorial, picturesque, pitiful, placid, plain, planted, pleasant, pleasing, poisonous, poor, popular, populated, populous, positive, possible, post-war, posterior, postmodern, potential, powerful, practical, pre-arranged, pre-eminent, precise, predictable, present, present-day, preserved, pretty, previous, pricey, primal, prior, private, privileged, probable, professional, profitable, promising, proven, public, pure, queer, quiet, rainy, rare, real, realistic, reasonable, rebuilt, recent, recognized, recommended, reconstructed, recreated, recurring, red, red-brick, redundant, refused, regional, regular, related, relative, relaxing, relevant, reliable, religious, remaining, remarkable, remote, rented, representative, reputable, required, reserved, residential, respectable, respected, restful, restless, restricted, retail, rich, ridiculous, right, rigid, river-crossing, rocky, romantic, rural, sacred, sad, safe, salubrious, satisfying, scary, scattered, scenic, scientific, secondary, secret, secured, selected, senior, separated, serious, sexy, shiny, shocking, shoddy, short-term, significant, silent, silly, similar, simple, single, sizable, slack, small, smelly, smoke-free, smoking, snowy, sobering, soft, solid, sombre, soothing, sophisticated, sorrowful, sound-filled, southern, spare, spatial, special, specialized, spectacular, sporting, stable, standard, static, steady, stifling, strange, stressful, striking, stunning, stupendous, stupid, stylish, successful, sufficient, sunny, super, superb, superior, surrealistic, suspicious, symbolic, teenage, terrible, terrific, theoretical, thrilling, thriving, tidier, tight, tiny, tough, tragic, unattractive, unbelievable, uncertain, unchanging, uncharted, uncivilized, uncomfortable, unconventional, underground, underwater, undisturbed, uneven, unexpected, unfamiliar, unforgettable, unfriendly, unhappy, unhealthy, unimportant, unknown, unnatural, unnecessary, unparalleled, unpleasant, unsafe, unseemly, unsuitable, unusual, upmarket, urban, vague, valuable, varied, various, vertical, very, vibrant, virtual, visual, vital, vivid, voluntary, vulgar, vulnerable, wacky, waiting, warm, wealthy, weeping, weird, weird-looking, well-assured, well-defended, well-designed, well-hidden, well-insulated, well-known, well-lit, well-loved, well-ordered, well-organized, well-secured, well-sheltered, well-used, wet, white, whole, wicked, wide, widespread, wild, windy, wintering, wonderful, wondrous, wooded, wordless, working, worldly, worldwide, worst, worthwhile, worthy, wretched, wrong, young, yucky,

# simple bedroom:476



# colourful bedroom:209

**cleaner bedroom:205**

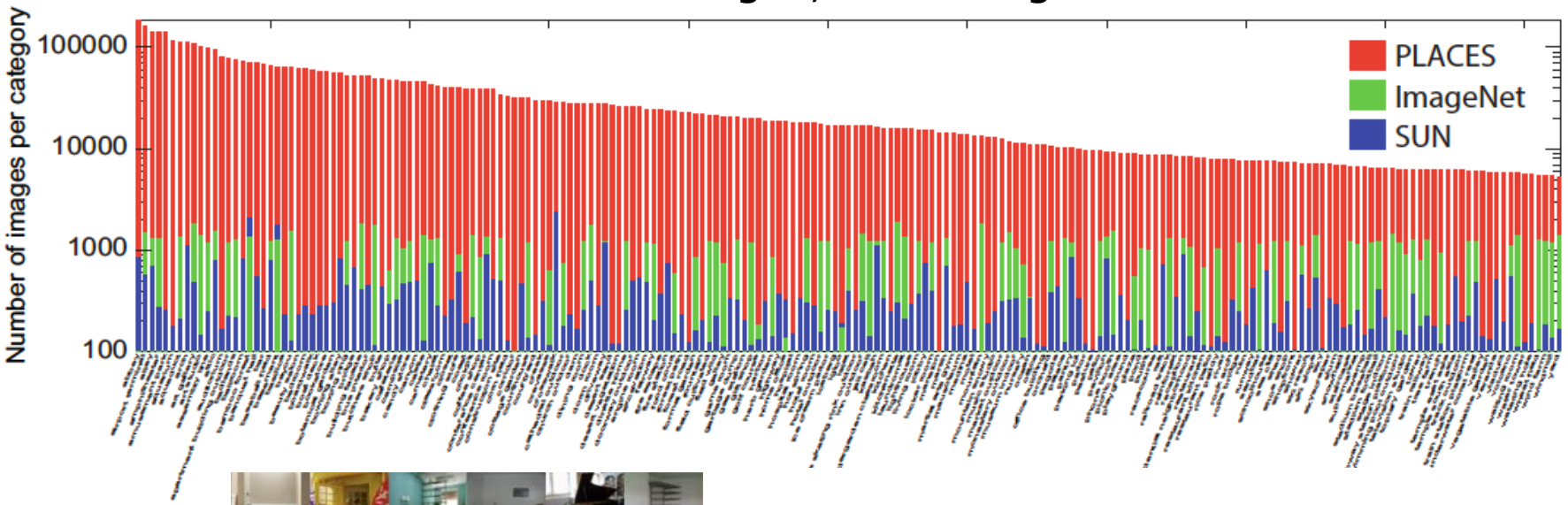


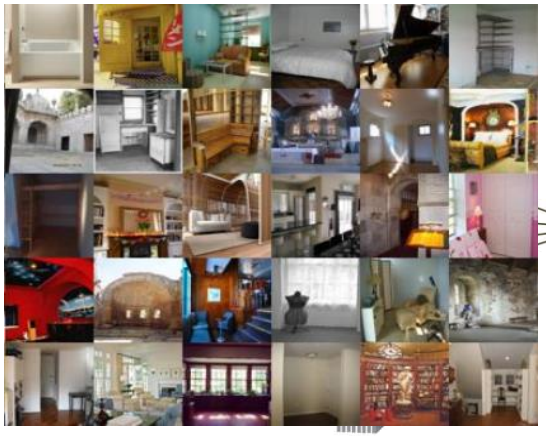
# messy bedroom:808

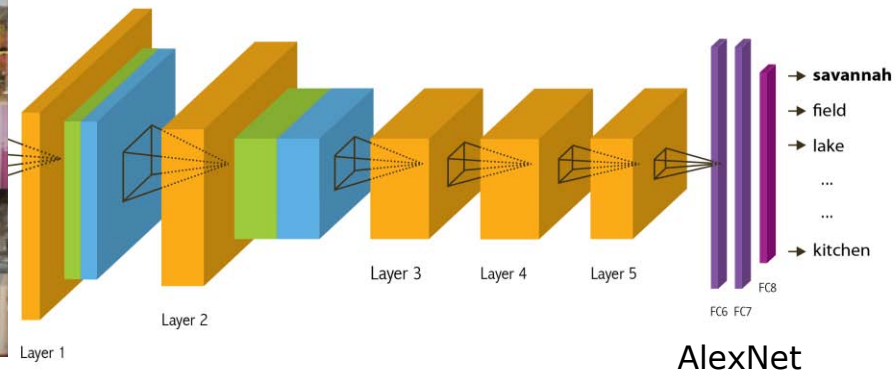
# places

**Bolei Zhou** **Aditya Khosla** **Agata Lapedriza** **Antonio Torralba**

10 million images, 460 categories






AlexNet

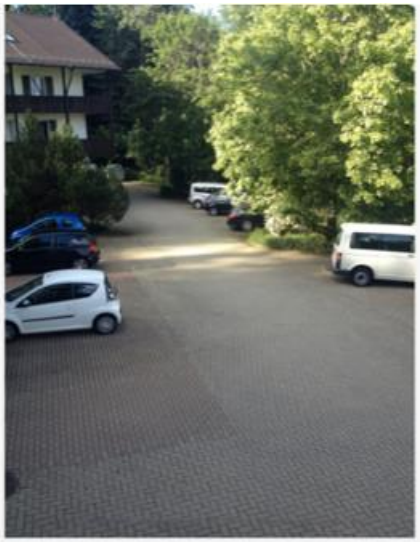
Courtesy of Zhou, Bolei, Agata Lapedriza, Jianxiong Xiao, Antonio Torralba, and Aude Oliva. "Learning deep features for scene recognition using places database." In Advances in neural information processing systems, pp. 487-495. 2014.

places.csail.mit.edu

# Web demo: places.csail.mit.edu

Predictions:

- **Type of environment:** indoor
- **Semantic categories:** restaurant:0.27, coffee_shop:0.23, cafeteria:0.21, food_court:0.12, restaurant_patio:0.09



Predictions:

- **Type of environment:** outdoor
- **Semantic categories:** parking_lot:0.46, driveway:0.44,

Predictions:

- **Type of environment:** indoor
- **Semantic categories:** conference_room:0.29, dining_room:0.27, banquet_hall:0.08, classroom:0.06,

Predictions:

- **Type of environment:** outdoor
- **Semantic categories:** patio:0.38, restaurant_patio:0.35, restaurant:0.06,

# Web demo: places.csail.mit.edu

Take/Choose a photo

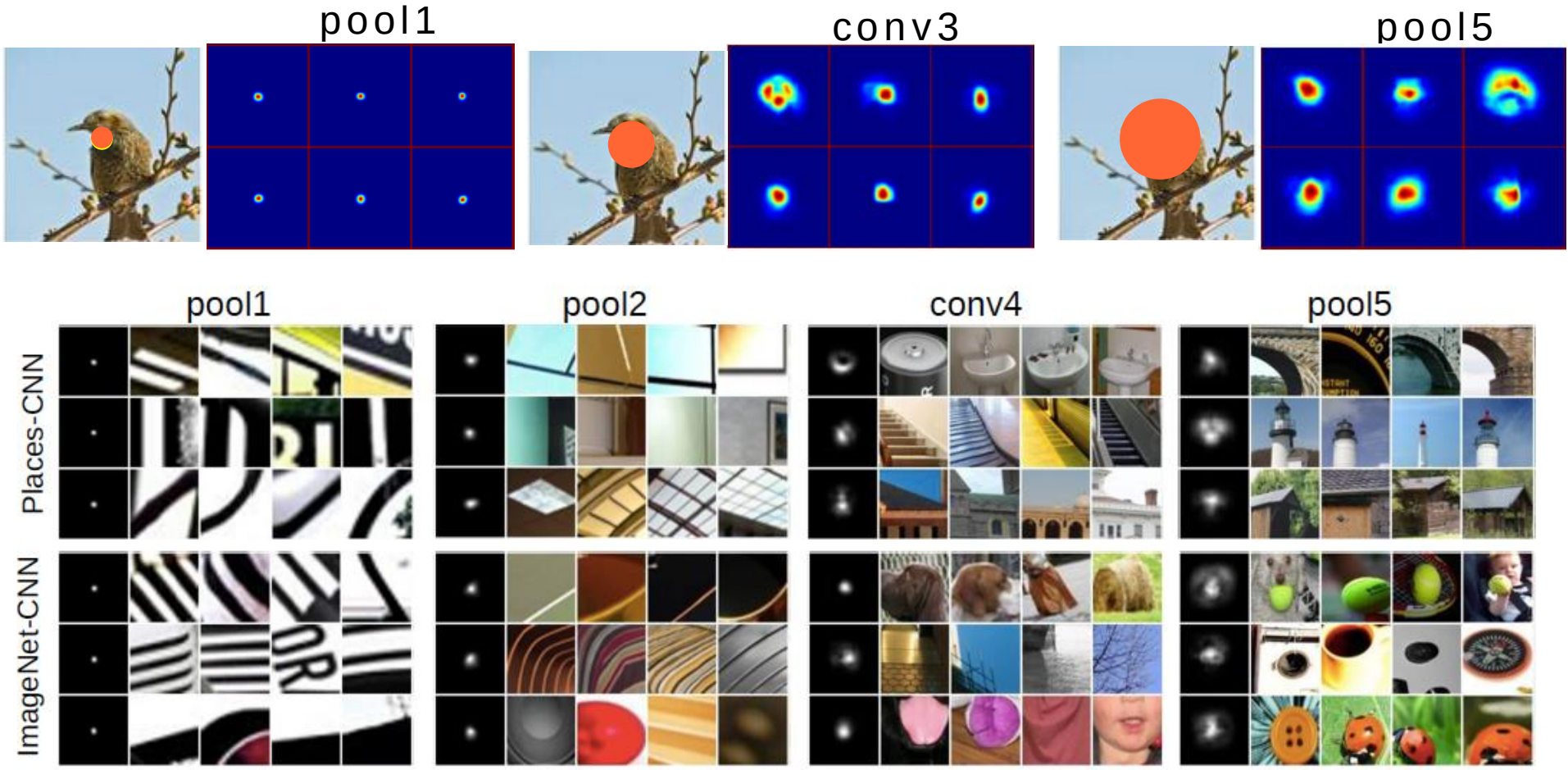
**Predictions**:

- **Type of environment:** outdoor
- **Semantic categories:** harbor:0.50, dock:0.11, boat_deck:0.06,
- **SUN scene attributes:** naturallight, openarea, man-made, sailingboating, far-awayhorizon, transportingthingsorpeople, clouds, swimming, metal, stillwater

**Predictions**:

- **Type of environment:** indoor
- **Semantic categories:** restaurant:0.16, cafeteria:0.15, coffee_shop:0.14, food_court:0.12, bar:0.09
- **SUN scene attributes:** enclosedarea, nohorizon, electricindoorlighting, man-made, wood(notpartofatree), socializing, eating, working, glossy, congregating

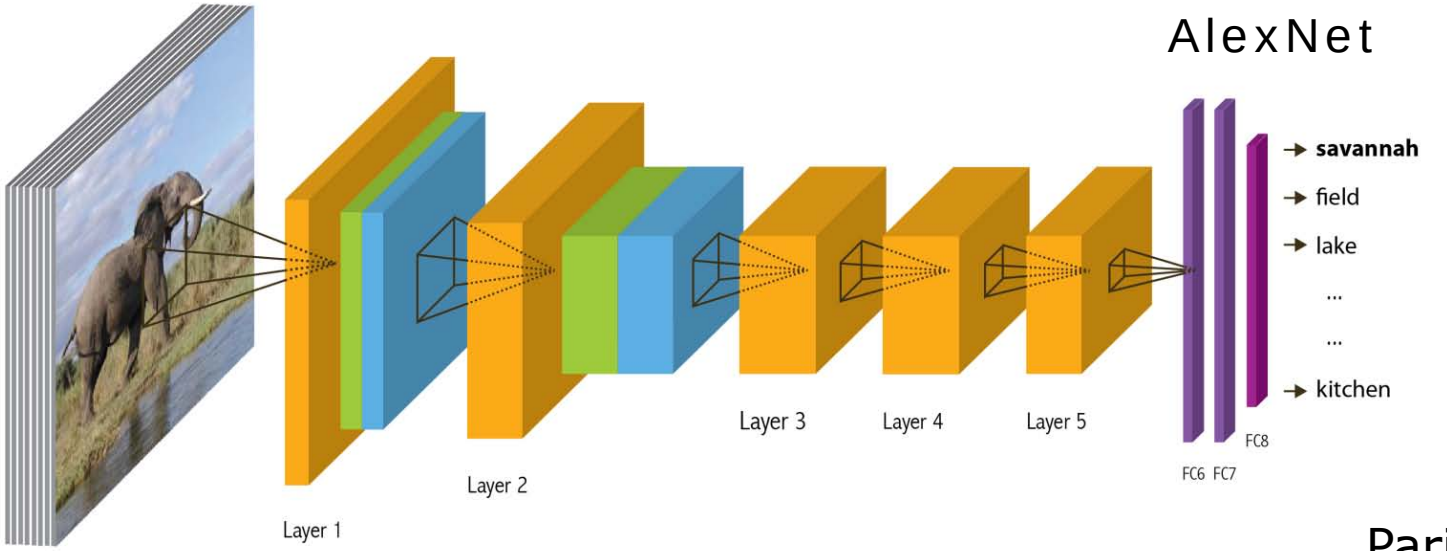
# Estimating the Receptive Fields

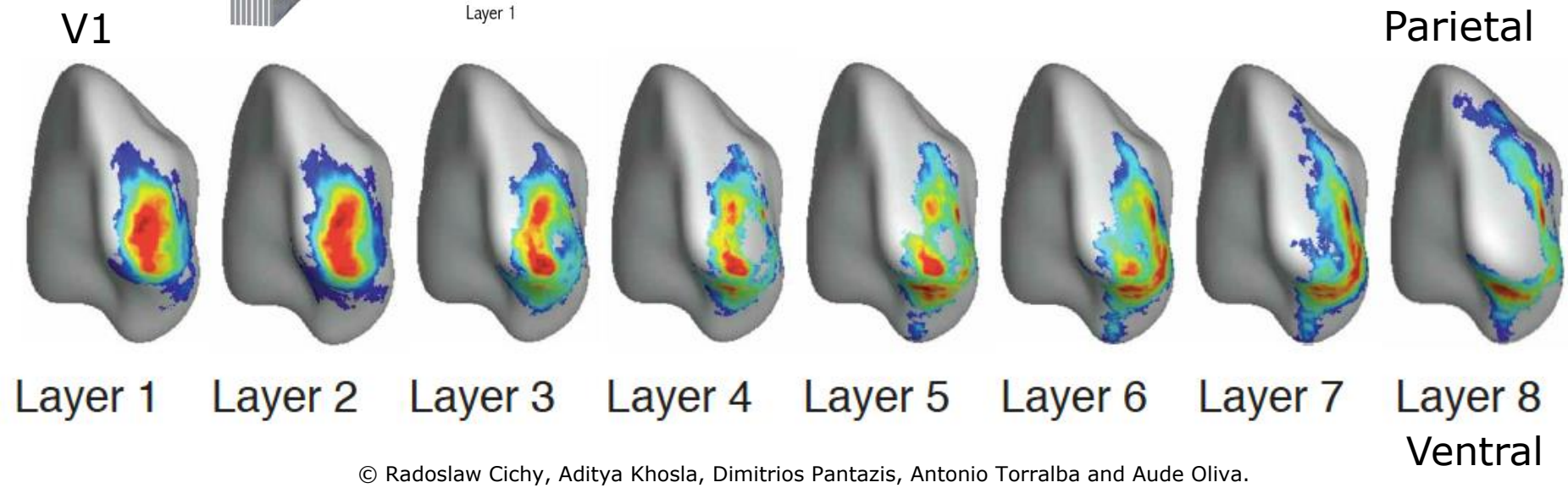



Courtesy of Bolei Zhou, Aditya Khosla, Agata Lapedriza, Aude Oliva and Antonio Torralba. Used with permission.

Zhou, Khosla, Lapedriza, Oliva, Torralba (2015), ICLR

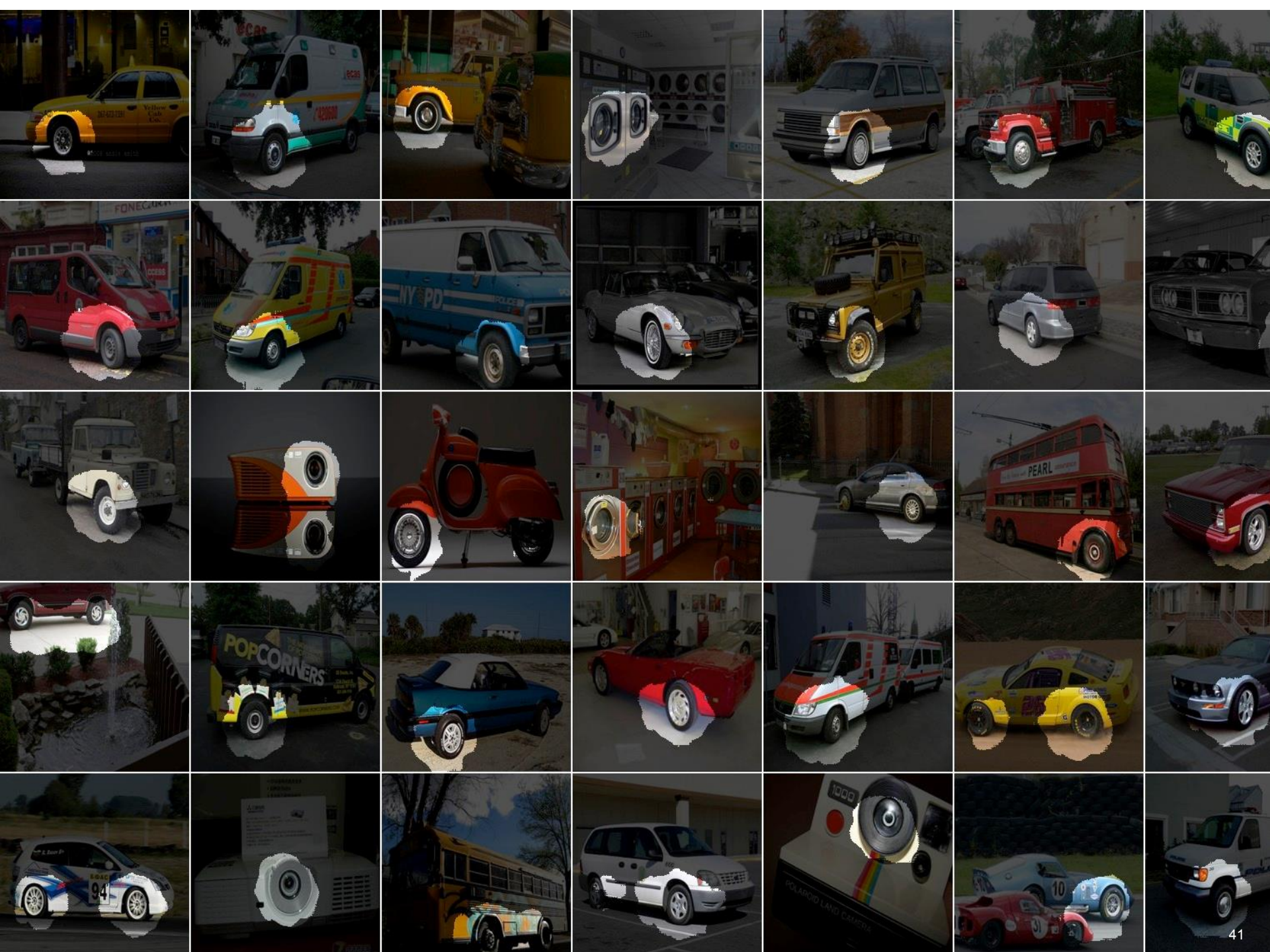
# Spatial maps of correlations between human brain and model layers

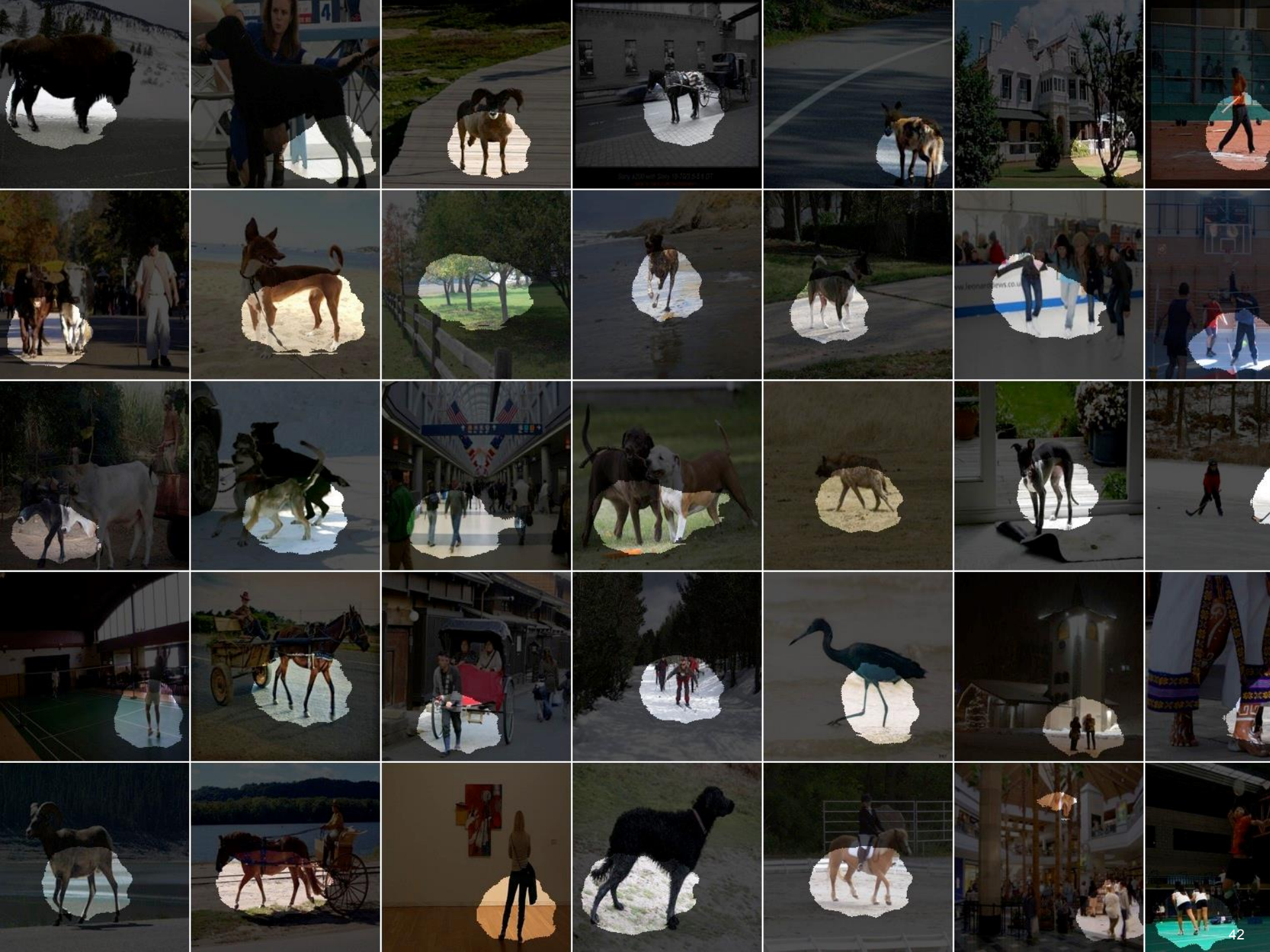


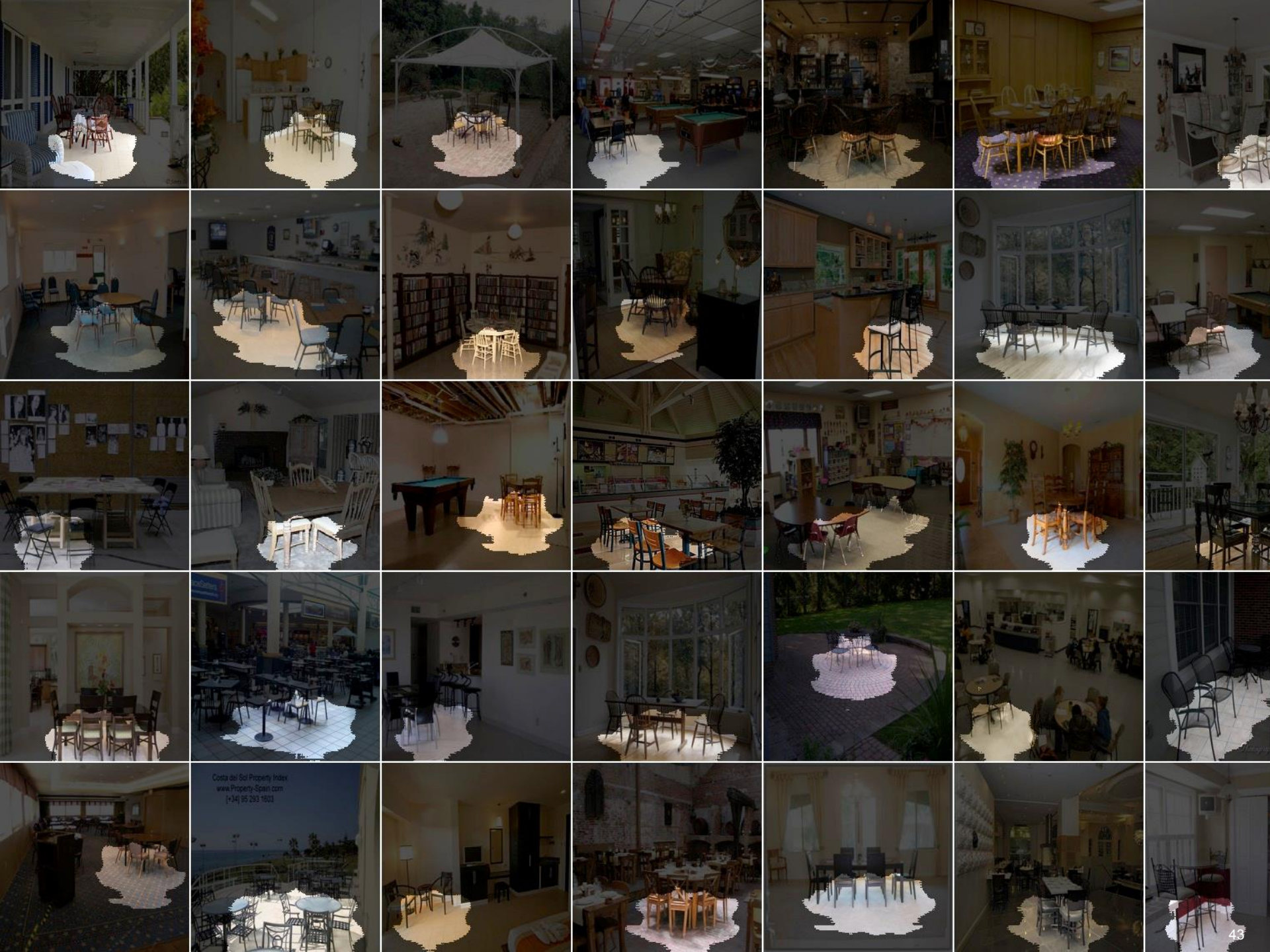






Cichy, Khosla, Pantazis, Torralba, Oliva (submitted)


NY PD
POLICE
PEARL
POPCORNERS
POLAROID LAND CAMERA

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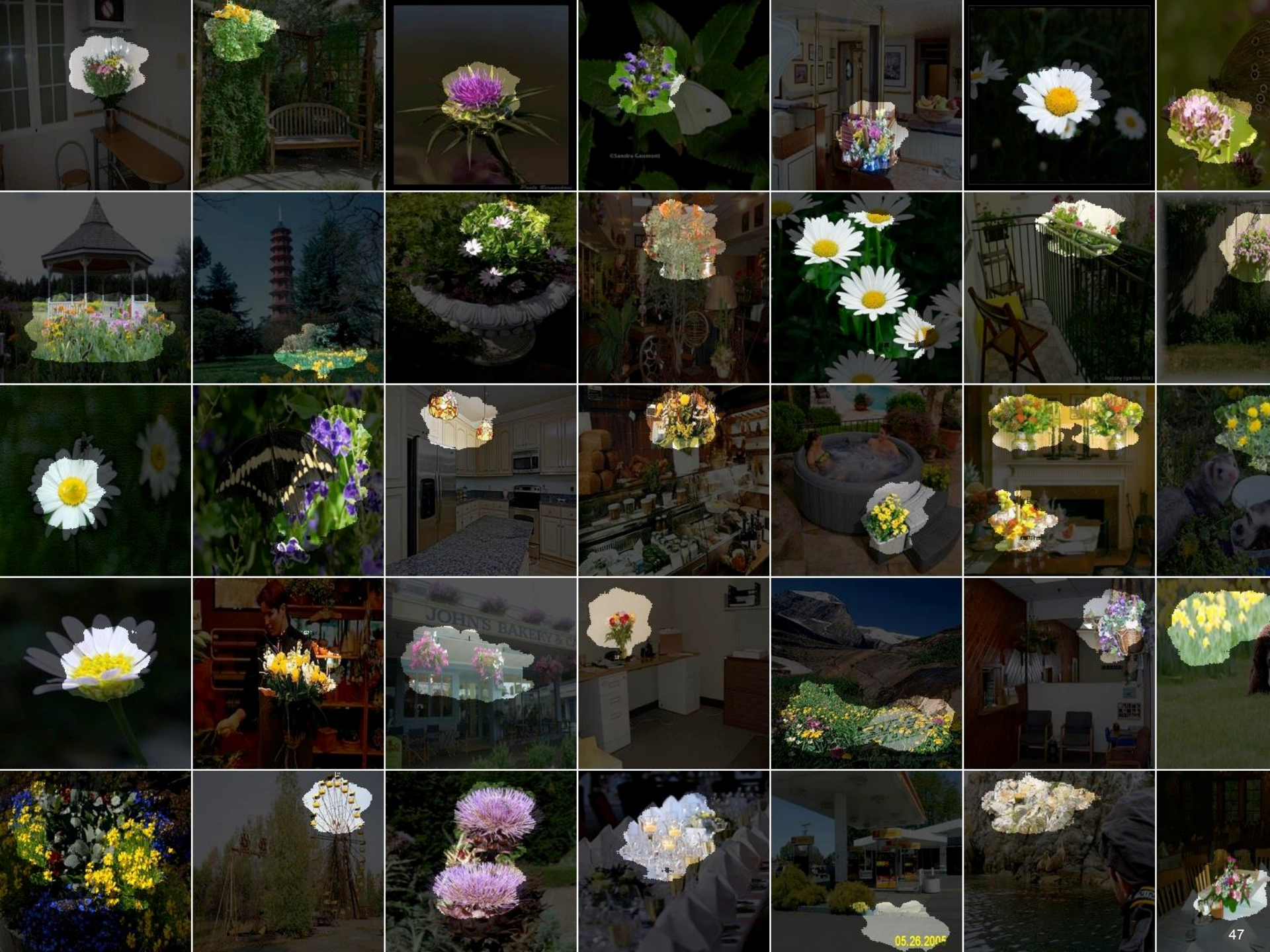
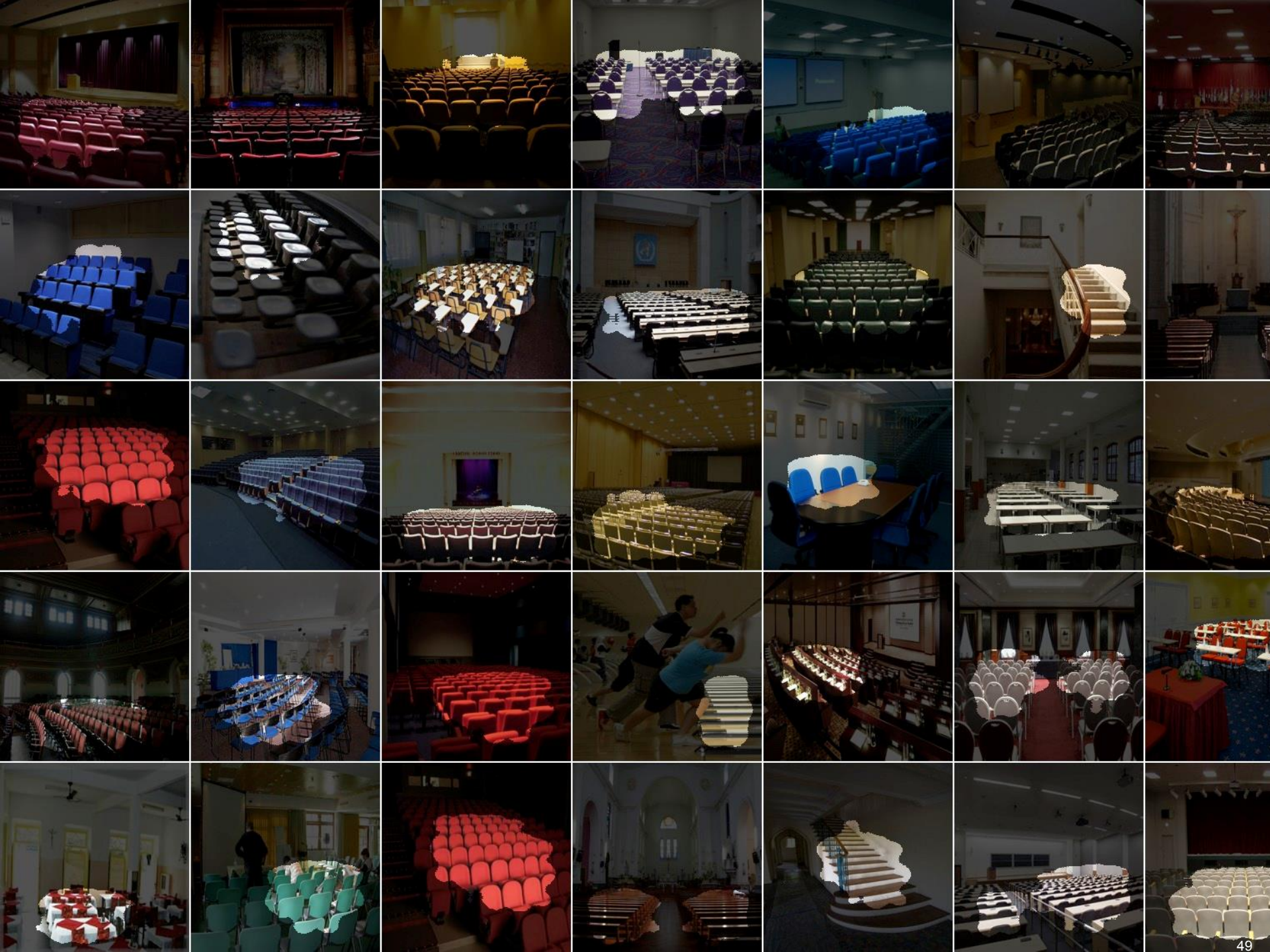
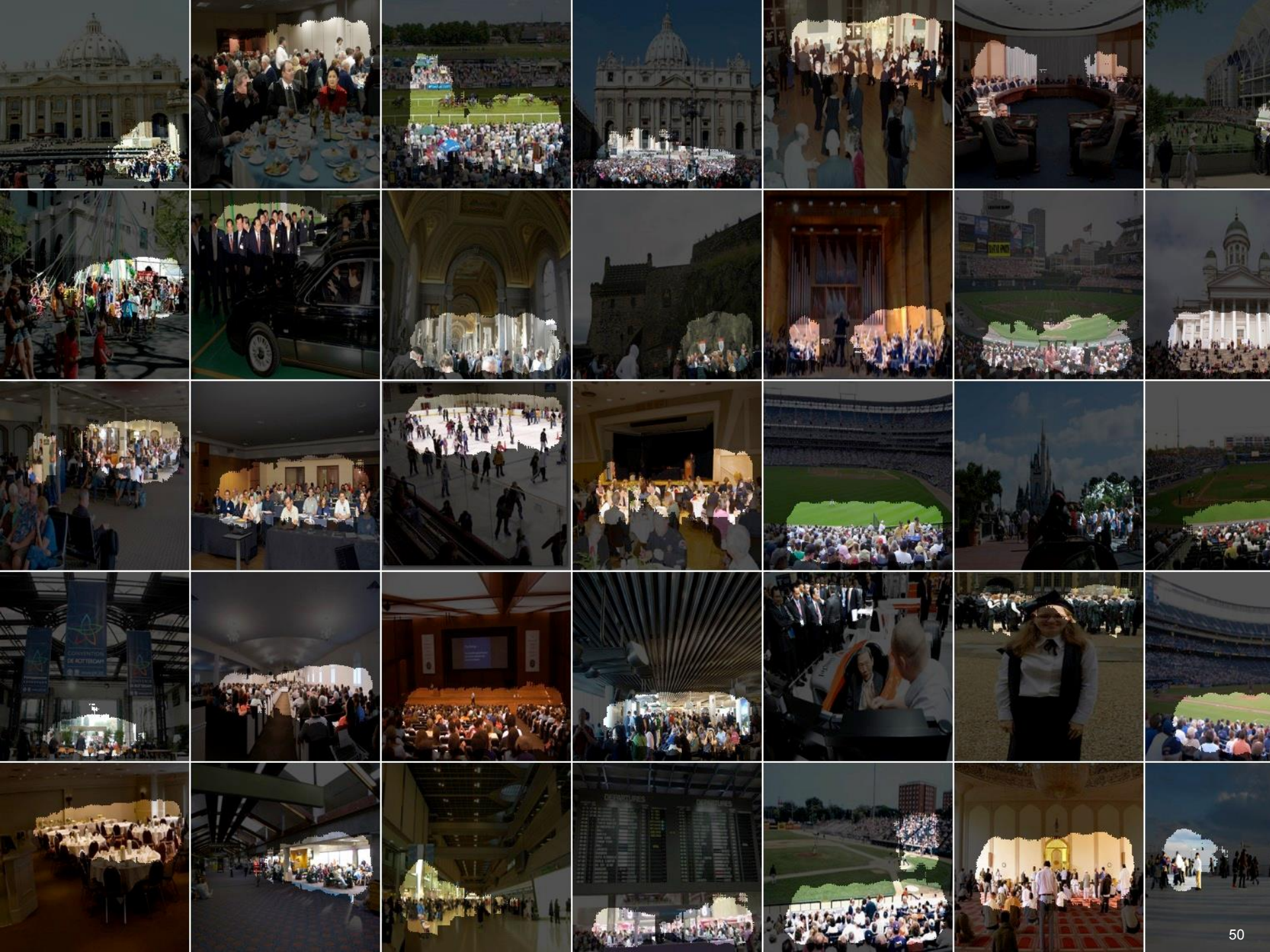
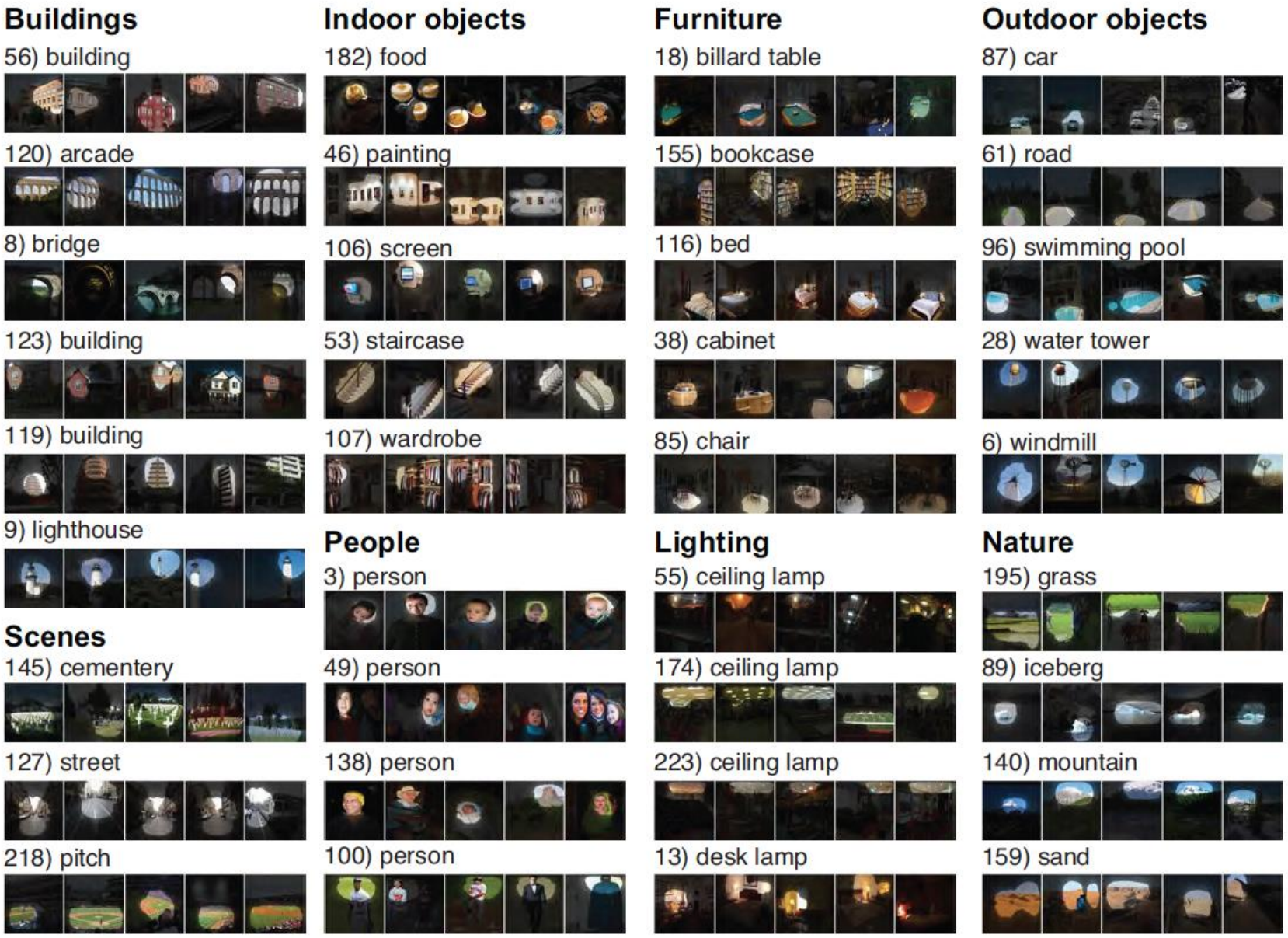

©Sandra Gaumont
JOHN'S BAKERY
05.26.2005





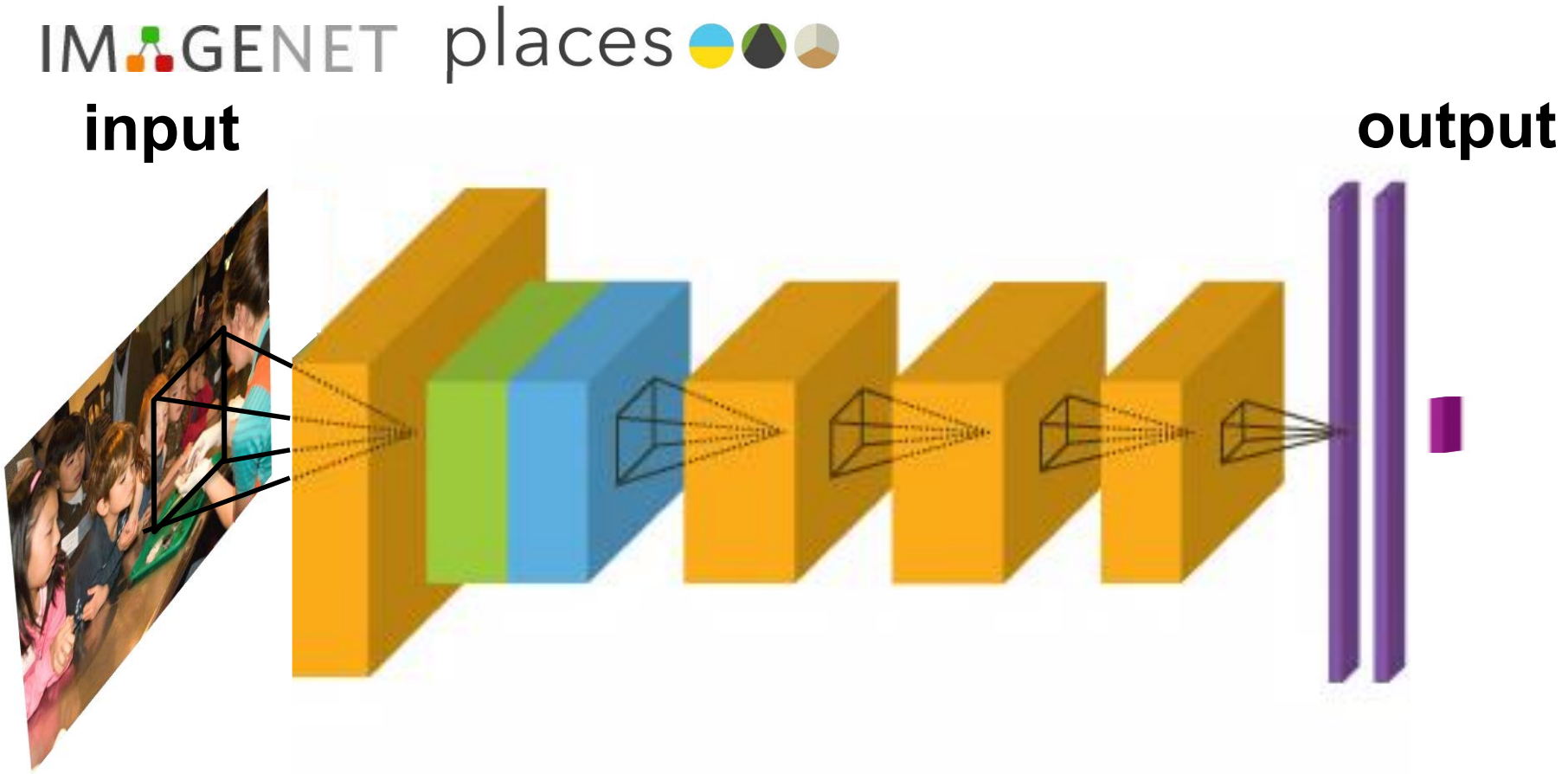
# Object detectors emerge inside the CNN




Courtesy of Bolei Zhou, Aditya Khosla, Agata Lapedriza, Aude Oliva and Antonio Torralba. Used with permission.

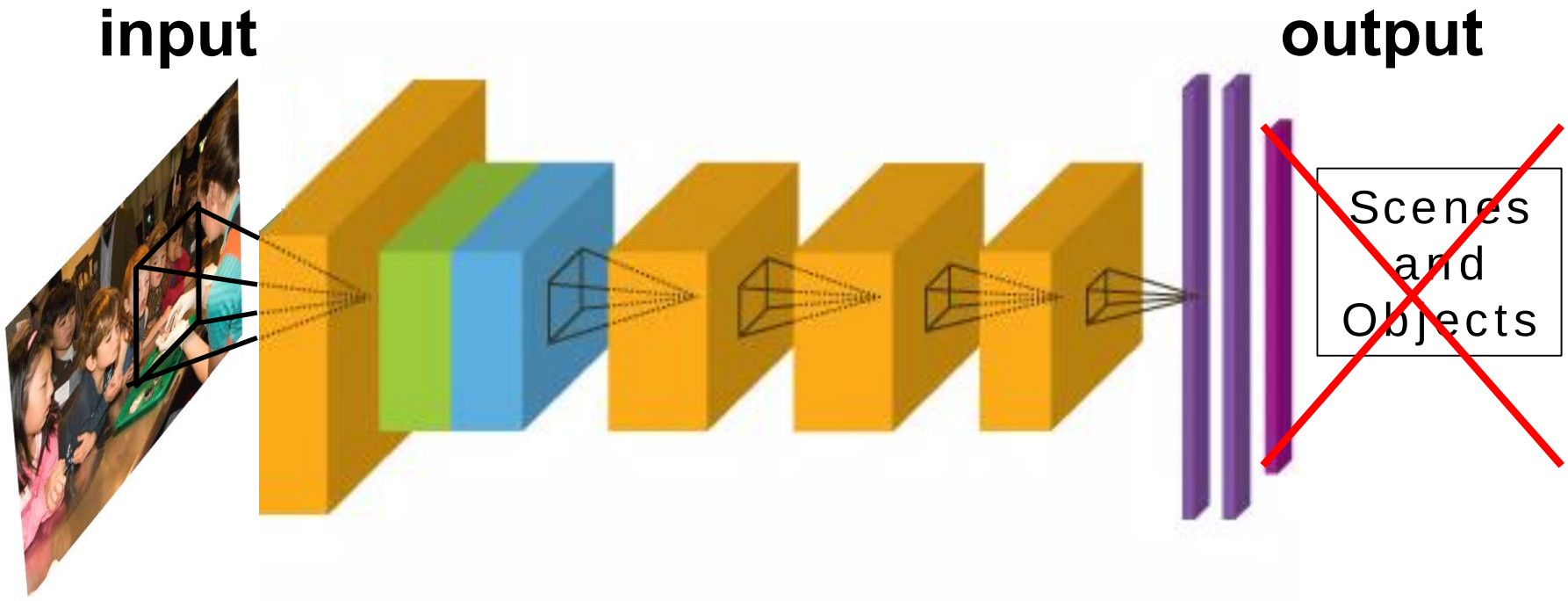
# MemNet

## CNN for Predicting Image Memorability

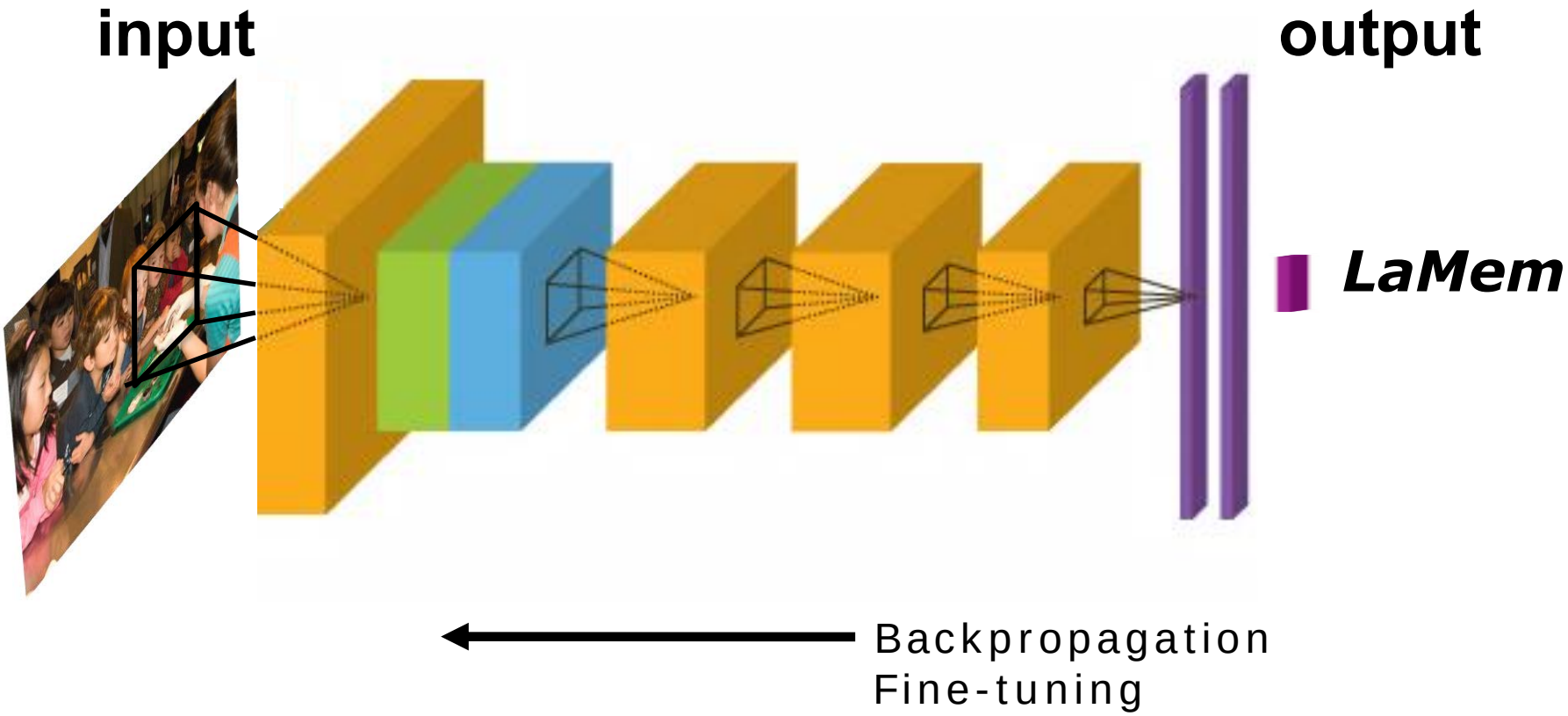



HybridNet from Zhou et al, NIPS 2014 (places.csail.mit.edu)

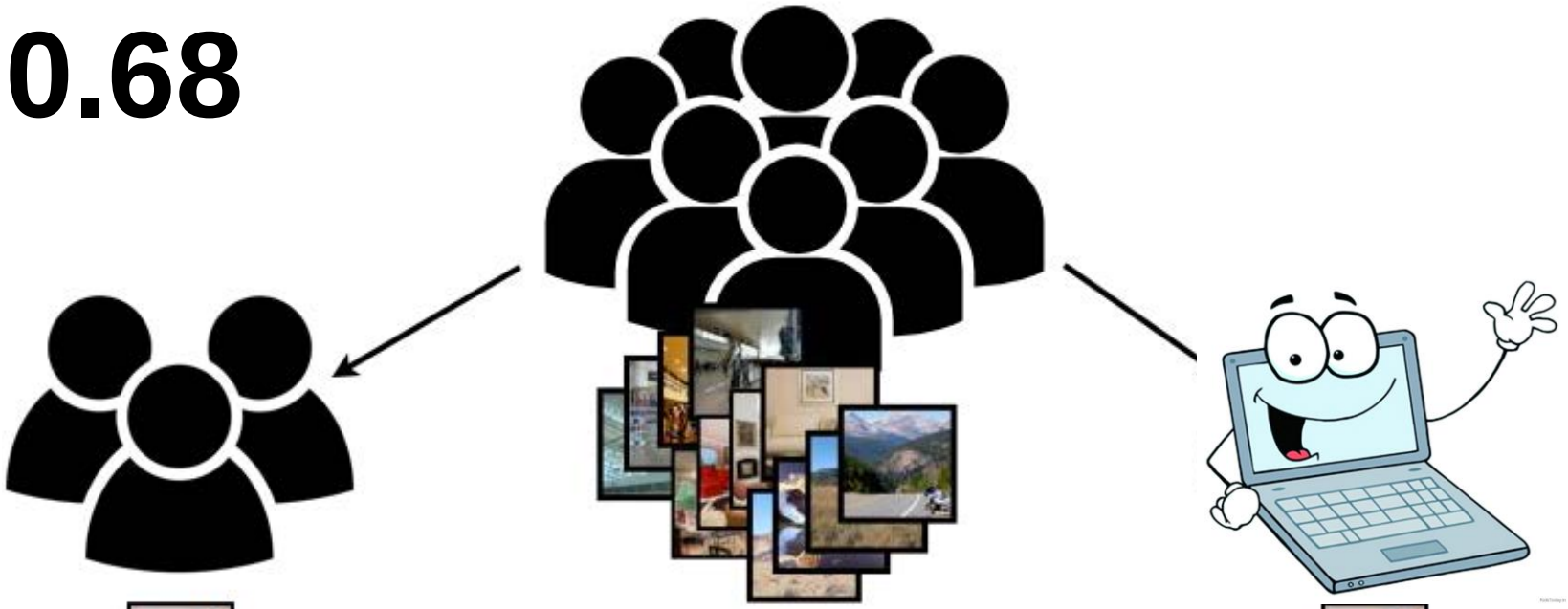
# Training MemNet



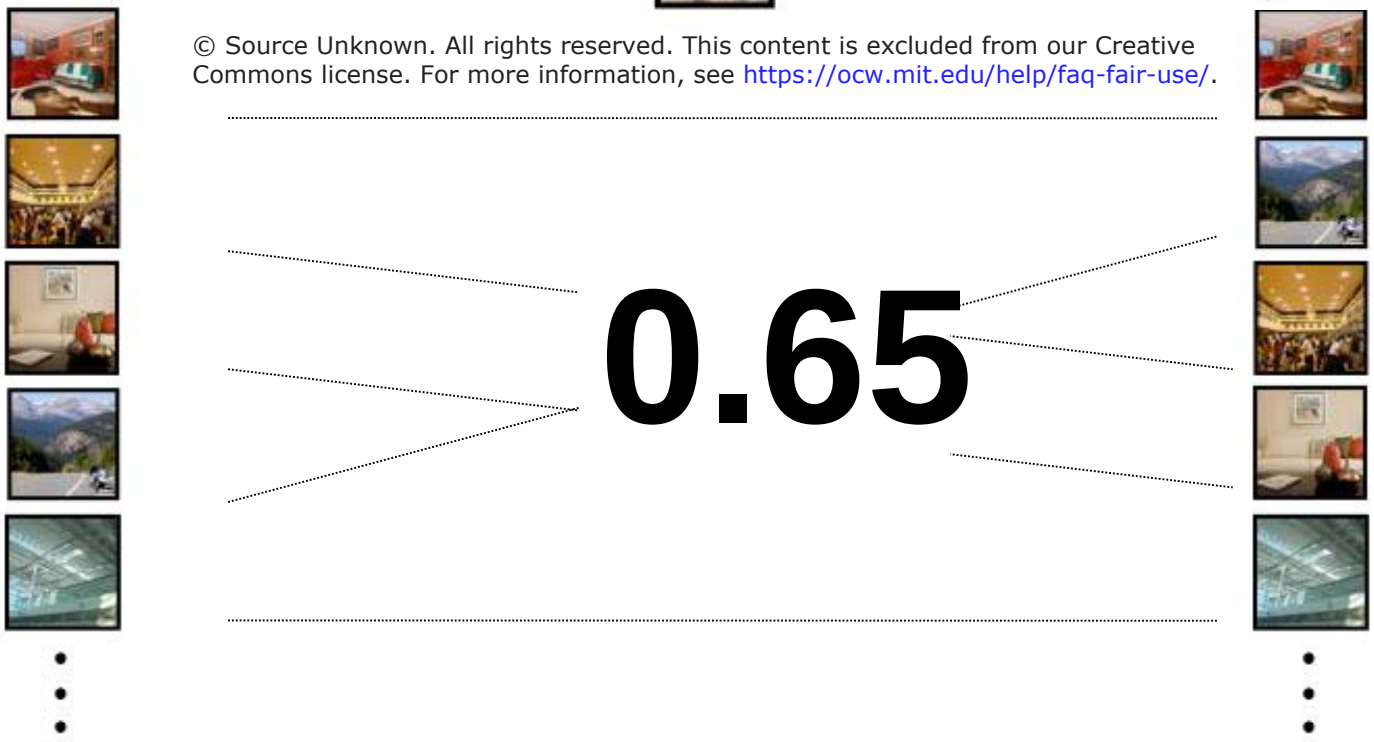
# Training MemNet




Khosla, Raju, Torralba and Oliva (under review). Understanding and Predicting Image Memorability at a Large Scale. http://memorability.csail.mit.edu/.





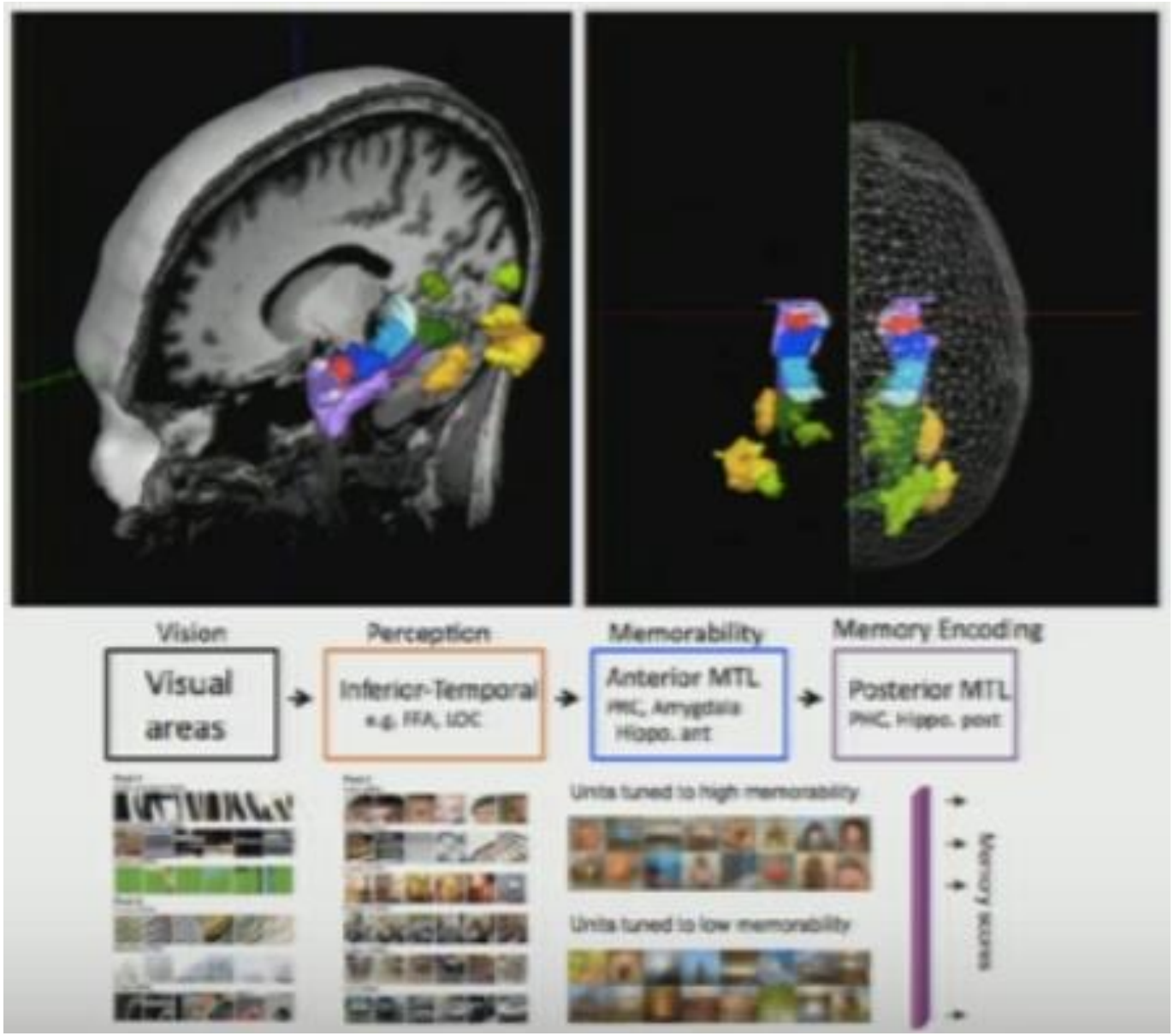



# Visualizing Neurons RF of Memorability

Figure removed due to copyright restrictions. Please see the video.
Source: Khosla, Aditya, Akhil S. Raju, Antonio Torralba, and Aude Oliva."Understanding and predicting image memorability at a large scale." In Proceedings of the IEEE International Conference on Computer Vision, pp. 2390-2398. 2015.

# Cognitive Saliency: Which regions are memorable?

# Modeling Human Memory



# Resource: Brains, Minds and Machines Summer Course

Tomaso Poggio and Gabriel Kreiman