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

Diagnose memory problems

Design mnemonic aids

“heavy”

“lourds”

Retrieve better images from search

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Blackberry. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Google. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Facebook. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

© Source Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.
Visual Memory Experiments

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?"
Large difference in image memorability & high consistency between observers’ groups

Figure removed due to copyright restrictions. Please see the video.
Is memorability consistent across different observers? Yes

Consistent \( \rho = 0.75 \)

Average % memorability: Probability of correctly detecting a repeat

Image rank \( N \), according to group 1

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

\(~ 80 \text{ scores per image} \)
Subjective judgments **do not predict** image memorability

Figure removed due to copyright restrictions. Please see the video.
Image memorability is distinct from image aesthetic

Figure removed due to copyright restrictions. Please see the video.
Is memorability stable across time? Yes

Figure removed due to copyright restrictions. Please see the video.
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.

Large difference in face memorability & high consistency between observers’ groups

Consistent $\rho = 0.69$

Consistent $\rho = 0.72$

© Journal of Experimental Psychology. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.
Words Memorability

**Subtlex:**
American English subtitles

- Group 1
- Group 2
- Chance

**MIT Word Dataset 10K dataset**

- Group 1
- Group 2
- Chance

Consistent

\( \rho = 0.64 \)

Consistent

\( \rho = 0.66 \)

Mahowald, Isola, Fedorenko, Oliva, Gibson (submitted, 2015).
Memorable vs. Forgettable words

<table>
<thead>
<tr>
<th></th>
<th>Memorable</th>
<th>Forgettable</th>
</tr>
</thead>
<tbody>
<tr>
<td>words</td>
<td>one word, one meaning</td>
<td>one word, many meanings</td>
</tr>
<tr>
<td>meanings</td>
<td>pineapple</td>
<td>light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>happy, cheerful, glad, joyful</td>
</tr>
</tbody>
</table>
Neural framework of memorability

Perception
(ventral/dorsal visual cortex)

Memory
(Medial Temporal Lobe)
Whole Brain Contrast

Novel

Memorable

Forgettable
Equalized Memorable & Forgettable Groups

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

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

Bainbridge, Dilks, Oliva (in preparation)
Computational Model of Memorability
Large scale visual memorability
60,000 photographs with memorability scores


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

- Focus
- Enclosed Setting
- Dynamics
- Unusual

Less memorable

- No single focus
- Distant view
- Static
- Common

Figure removed due to copyright restrictions.
You need to recognize to remember
Building first a visual recognition system
Scene Understanding: Context and Objects

Predictions:
- Type of environment: outdoor
- Semantic categories:
  - picnic_area: 0.74
  - yard: 0.13

© Dorothy Hays. All rights reserved. This content is excluded from our Creative Common license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
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


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
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, designated, designing, 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, 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, favoured, fictional, filched, filthy, fine, foggy, foreign, formal, fractured, friendly, frightening, frightful, frozen, frustrating, full, funny, furnished, fuzzy, gaudy, ghastly, ghastly, glamorous, glassy, glazed, glittering, gloomy, glorious, gossy, godlike, gold-plated, good, gorgeous, gracious, grand, gray, great, greatest, green, greener, grey, grimly, gruesome, habitable, habitual, handy, happy, harmonious, harrowing, harsh, hazardous, healthful, healthy, heart-breaking, heart-rending, heavy, hideous, hiding, higgledy-piggledy, high, hilarious, historic, historical, hoisted, 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, ineffective, inexplicable, 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, least-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, major, marginal, marine, marvellous, mass, masterful, maximum, mean, meaningless, mechanised, medieval, mediocr, 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, mythical, 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, popul, 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, unhappy, unhealthy, unimportant, unknown, unnatural, unnecessary, unparalleled, unpleasant, unsafe, unseemly, unsuitable, unusual, upmarket, urban, vague, valuable, varied, varied, 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, wooden, wordless, working, worldly, worldwide, worst, worthwhile, worthy, wretched, wrong, young, yucky,
colourful bedroom:209
cleaner bedroom:205
10 million images, 460 categories


places.csail.mit.edu
Web demo: [places.csail.mit.edu](https://places.csail.mit.edu)
Web demo: places.csail.mit.edu

Predictions:
- **Type of environment:** outdoor
- **Semantic categories:** harbor:0.50, dock:0.11, boat_deck:0.06,
- **SUN scene attributes:** natural light, open area, man-made, sailing, boating, far-away horizon, transporting, things or people, clouds, swimming, metal, still water

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:** enclosed area, no horizon, electric indoor lighting, man-made, wood (not part of a tree), socializing, eating, working, glossy, congregating
Estimating the Receptive Fields

More semantically meaningful


Zhou, Khosla, Lapedriza, Oliva, Torralba (2015), ICLR
Spatial maps of correlations between human brain and model layers

© Radoslaw Cichy, Aditya Khosla, Dimitrios Pantazis, Antonio Torralba and Aude Oliva. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.

Cichy, Khosla, Pantazis, Torralba, Oliva (submitted)
Object detectors emerge inside the CNN

Buildings
- 56) building
- 120) arcade
- 8) bridge
- 123) building
- 9) lighthouse

Scenes
- 145) cemetery
- 127) street
- 218) pitch

Indoor objects
- 182) food
- 46) painting
- 106) screen
- 53) staircase
- 107) wardrobe

People
- 3) person
- 49) person
- 138) person
- 100) person

Furniture
- 18) billiard table
- 155) bookcase
- 116) bed
- 38) cabinet
- 85) chair

Outdoor objects
- 87) car
- 61) road
- 96) swimming pool
- 28) water tower
- 6) windmill

Lighting
- 55) ceiling lamp
- 174) ceiling lamp
- 223) ceiling lamp
- 13) desk lamp

Nature
- 195) grass
- 89) iceberg
- 140) mountain
- 159) sand

MemNet
CNN for Predicting Image Memorability

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

input

output

Scenes and Objects
Training MemNet

Visualizing Neurons RF of Memorability

Figure removed due to copyright restrictions. Please see the video.
Cognitive Saliency: Which regions are memorable?
Modeling Human Memory