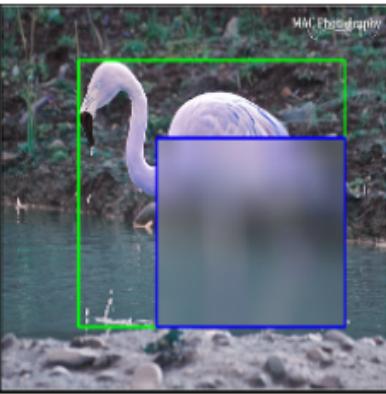
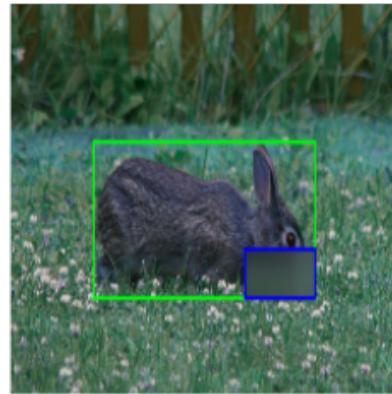


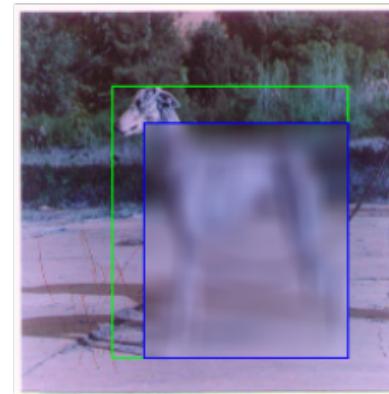
id: 848, bird (id: 26)



id: 15, rabbit (id: 141)



id: 225, dog (id: 58)



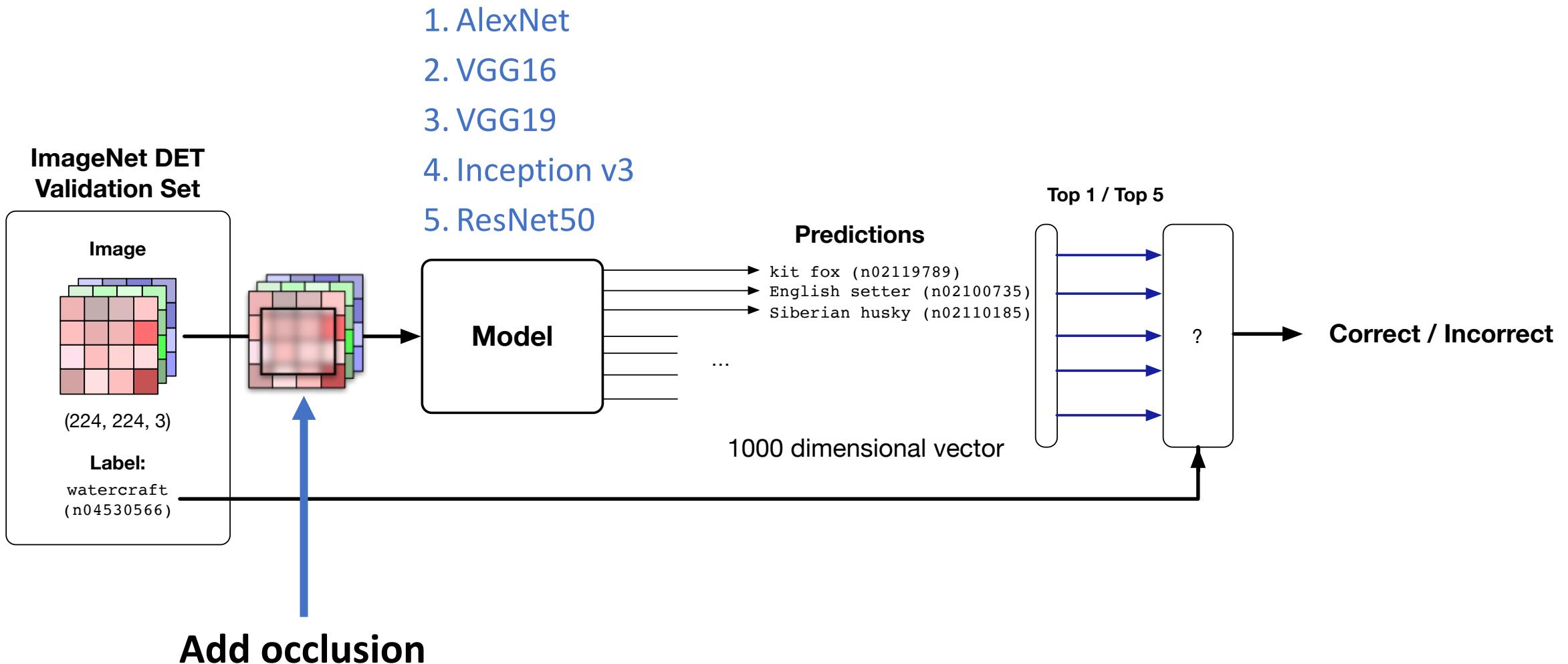
Performance Analysis of Deep Neural Networks on Objects with Occlusion

6.861 Final Project

Enrique Fernandez

(████████@mit.edu)

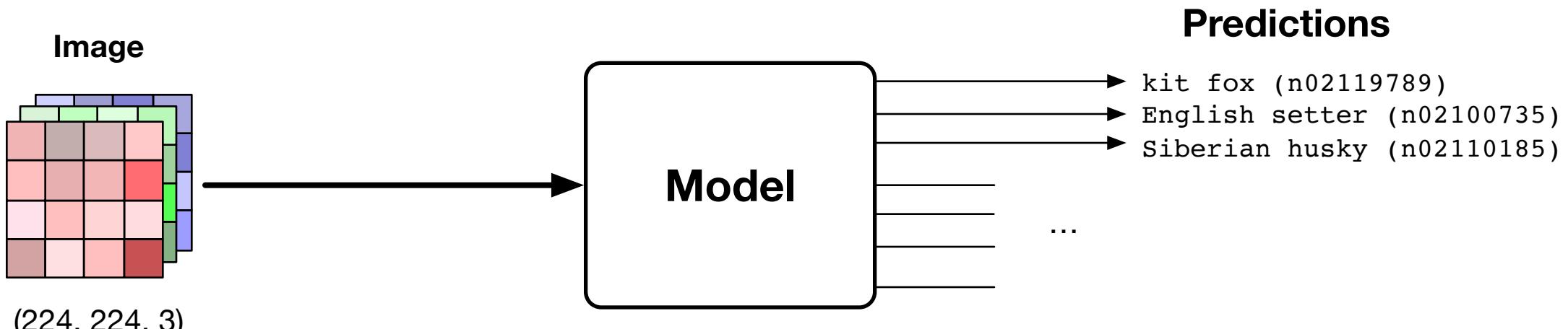
Method



Models

Pre-trained models on ImageNet data.

1. AlexNet Krizhevsky, Sutskever, and Hinton (2012)
2. VGG16 Simonyan, Zisserman (2014)
3. VGG19
4. Inception v3 Szegedy, Vanhoucke, Ioffe, Shlens, Wojna (2015)
5. ResNet50 He, Zhang, Ren, Sun (2015)



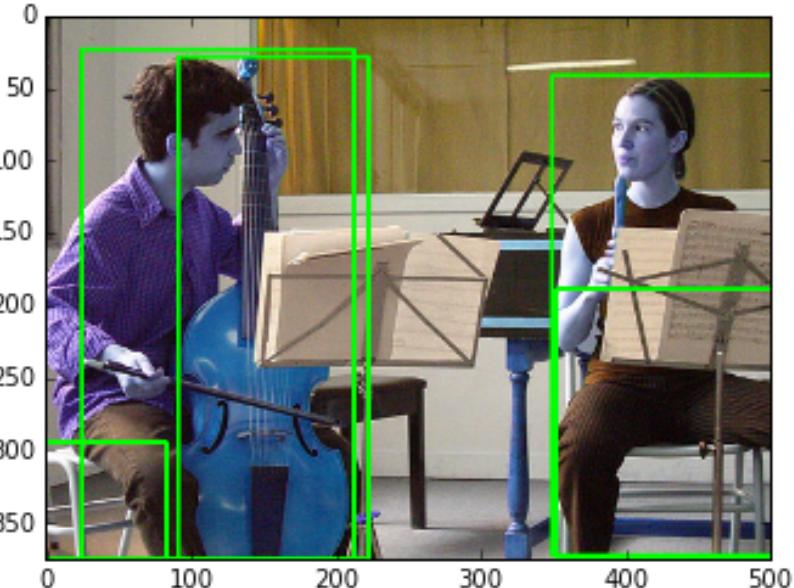
The Data

- Large Scale Visual Recognition Challenge (ILSVRC) – ImageNet
 - Classification-Location dataset (**CLS-LOC**)
 - 1000 object categories
 - Available models trained with this data
 - Object Detection Dataset (**DET**)
 - target object < 50% image
 - more general images
 - Validation Set
 - 20121 images
 - 200 categories

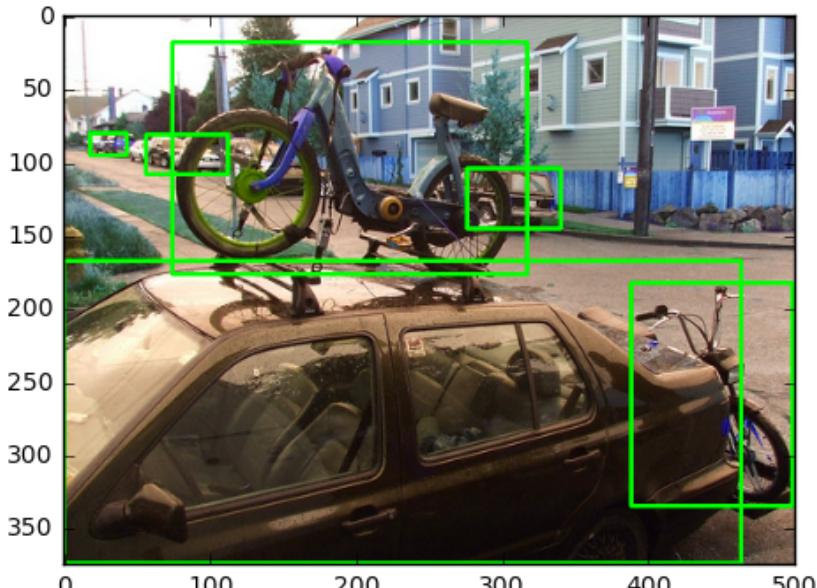
Dataset used in experiments

Problem: Models output 1000 classes, labeled data has 200 classes

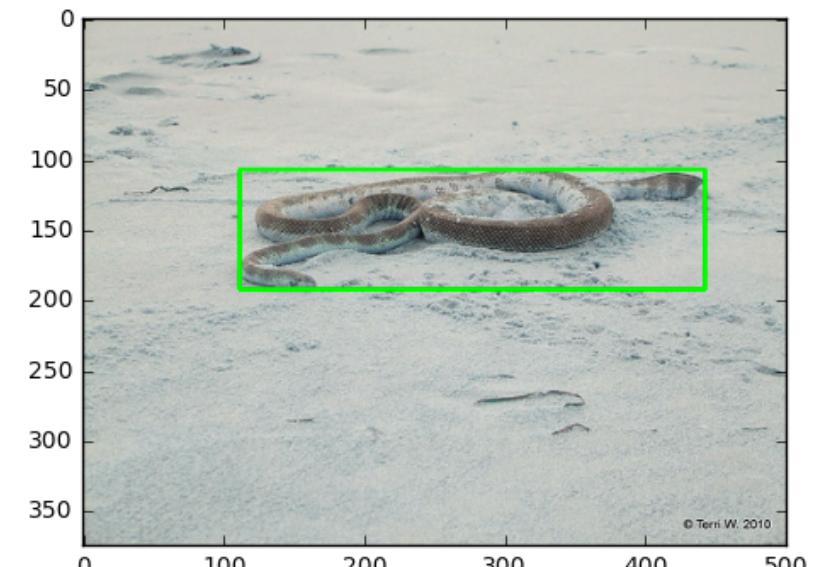
The ILSVRC DET dataset (200 categories)



Object 0: n00007846, person
Object 1: n02992211, cello
Object 2: n04536866, violin
Object 3: n03001627, chair
Object 4: n03001627, chair



Object 0: n02958343, car
Object 1: n02958343, car
Object 2: n02958343, car
Object 3: n02834778, bicycle
Object 4: n02834778, bicycle
Object 5: n02958343, car



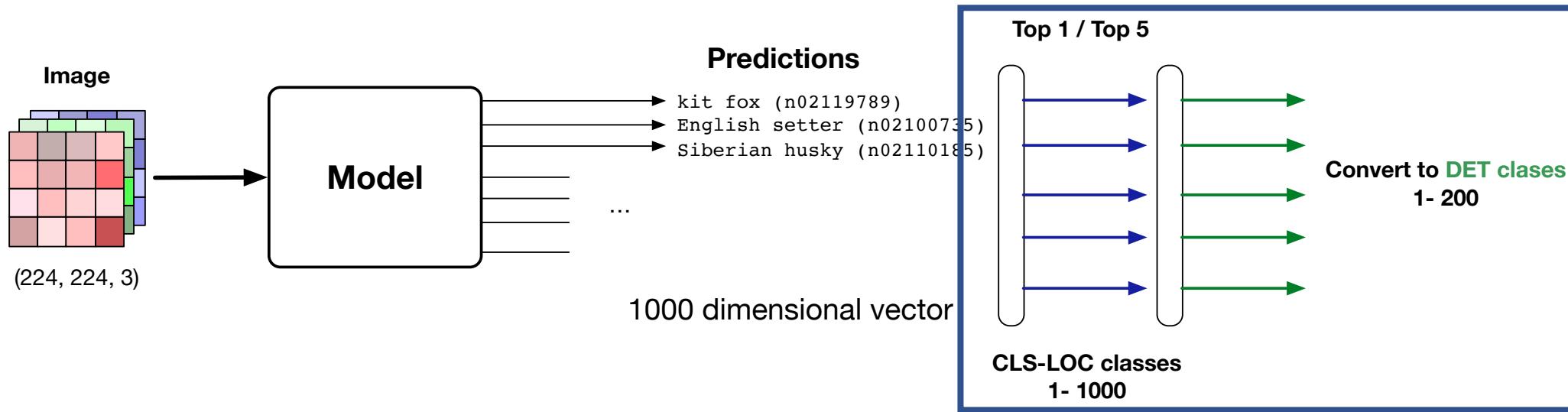
Object 0: n01726692, snake

Complete Database: 20121

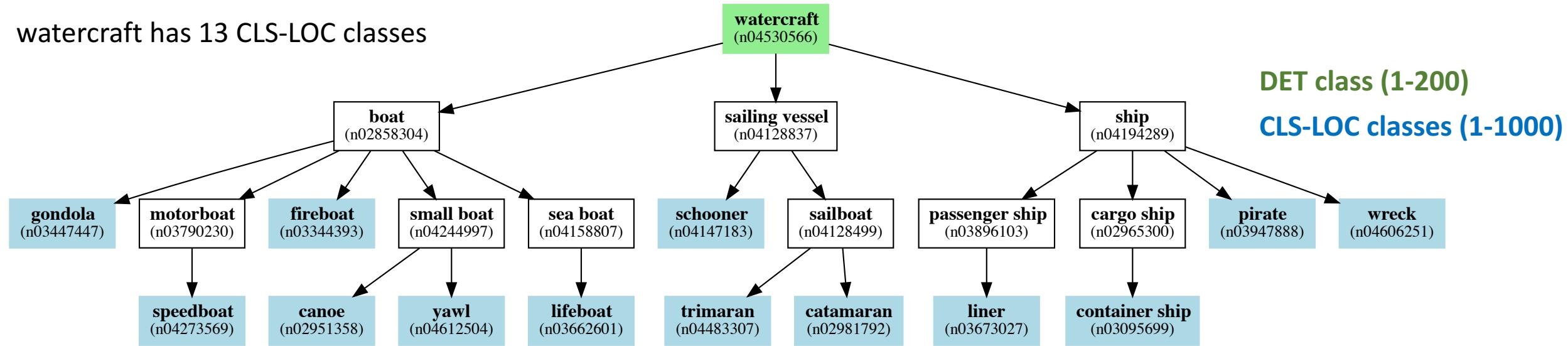
Single Object Database: 7706

Problem: Models output 1000 classes (CLS-LOC), labeled data has 200 classes

Conversion CLS-LOC -> DET

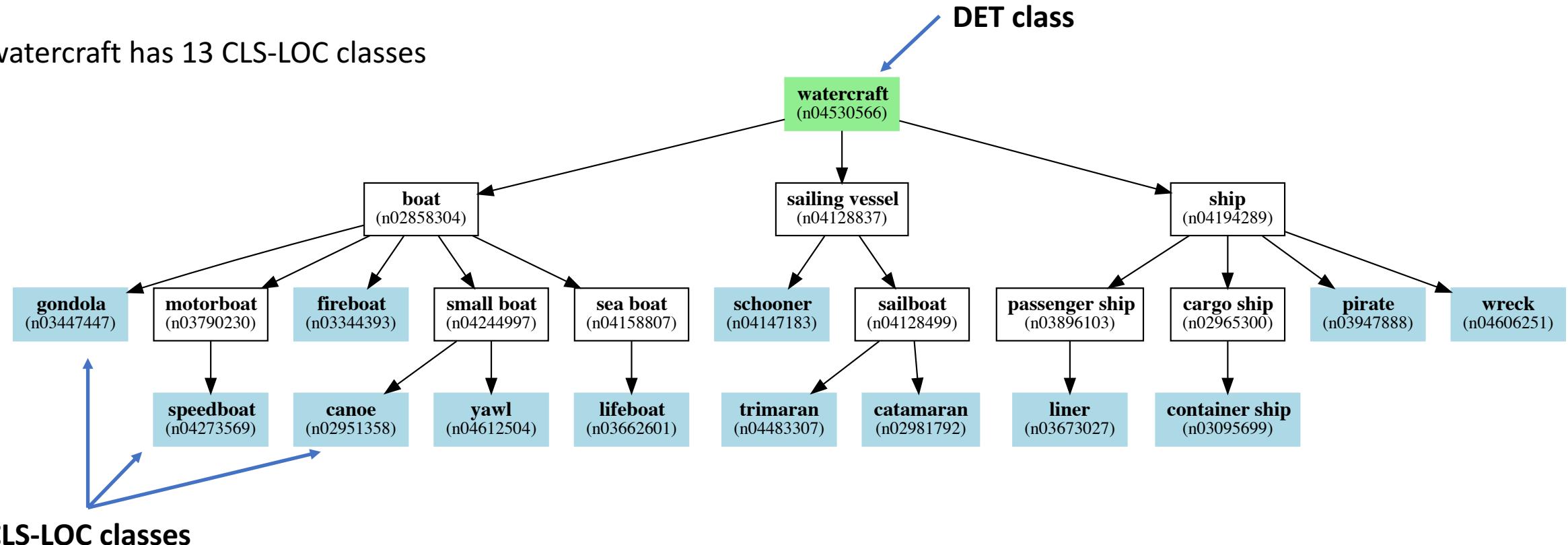


watercraft has 13 CLS-LOC classes



Conversion CLS-LOC (1000) -> DET (200)

watercraft has 13 CLS-LOC classes



Dog

116 classes



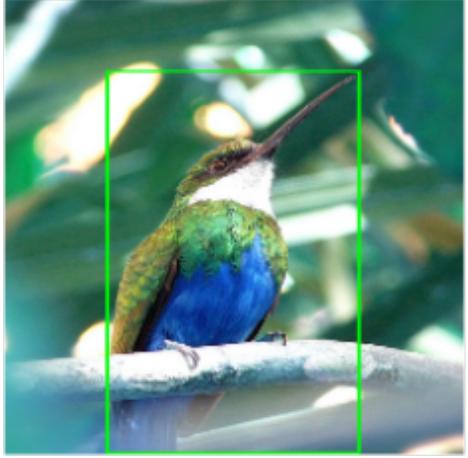
Conversion affects the random chance of each
of the 1-200 DET classes

Occlusions: Gaussian Blur

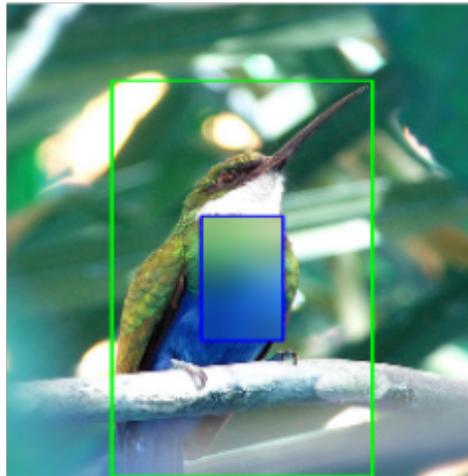
- Occlusion Location:
 - Center
 - Corners
 - Random
- Occlusion amount **0 %, 10%, 20%, 50%, 75% and 100%**

Center Occlusion

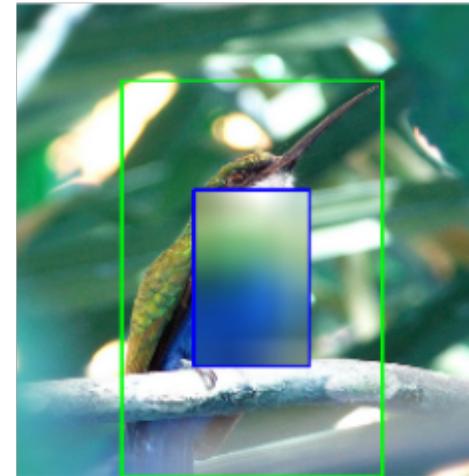
id: 2561, bird (id: 26)



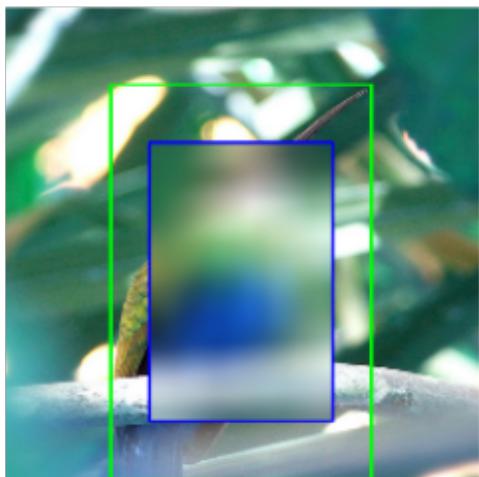
10 %



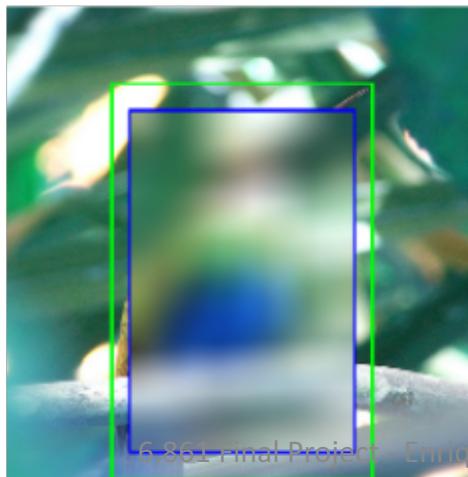
20 %



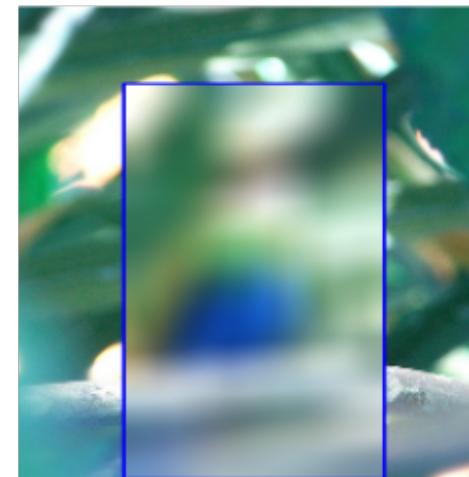
50 %



75 %



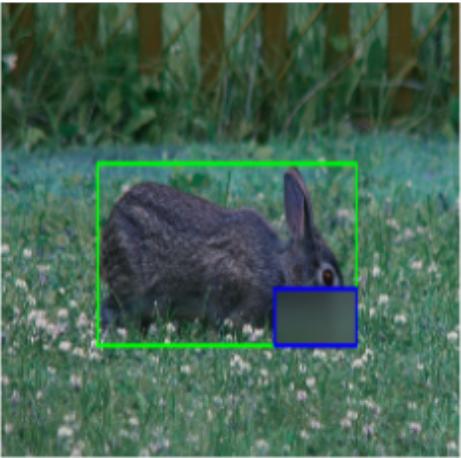
100 %



Corner Occlusion

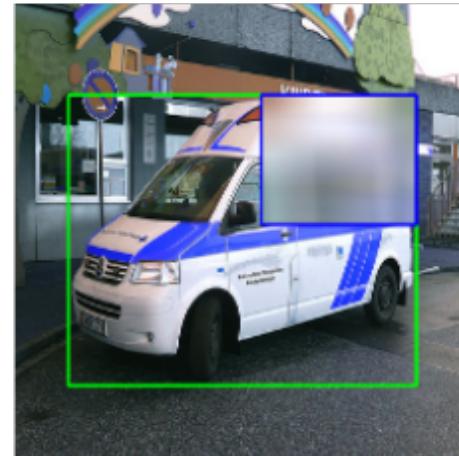
10 %

id: 15, rabbit (id: 141)



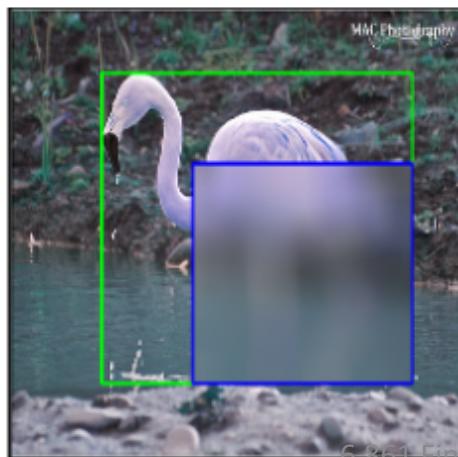
20 %

id: 4215, car (id: 37)



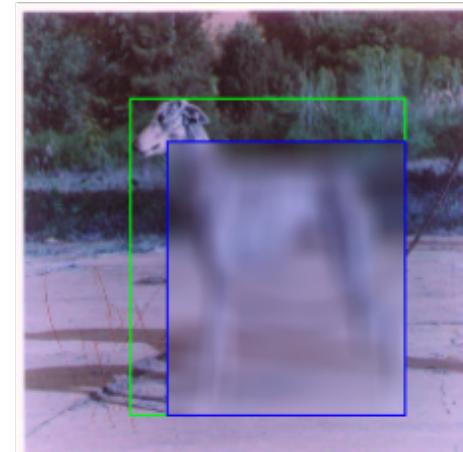
50 %

id: 848, bird (id: 26)



75 %

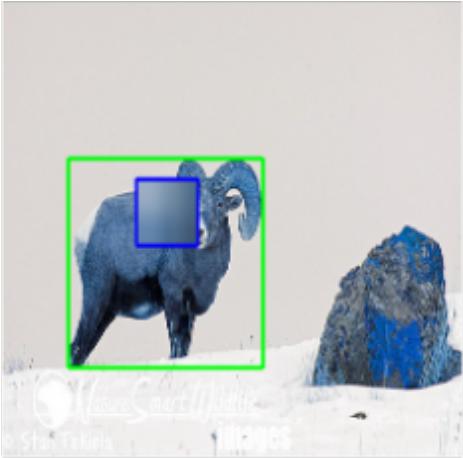
id: 225, dog (id: 58)



Random Occlusion

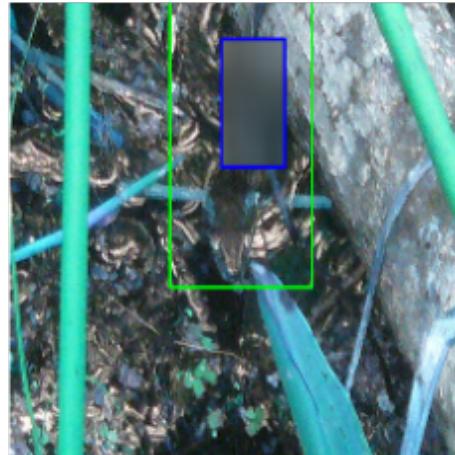
10 %

id: 597, sheep (id: 155)



20 %

id: 14, snake (id: 159)



50 %

id: 3121, monkey (id: 113)



75 %

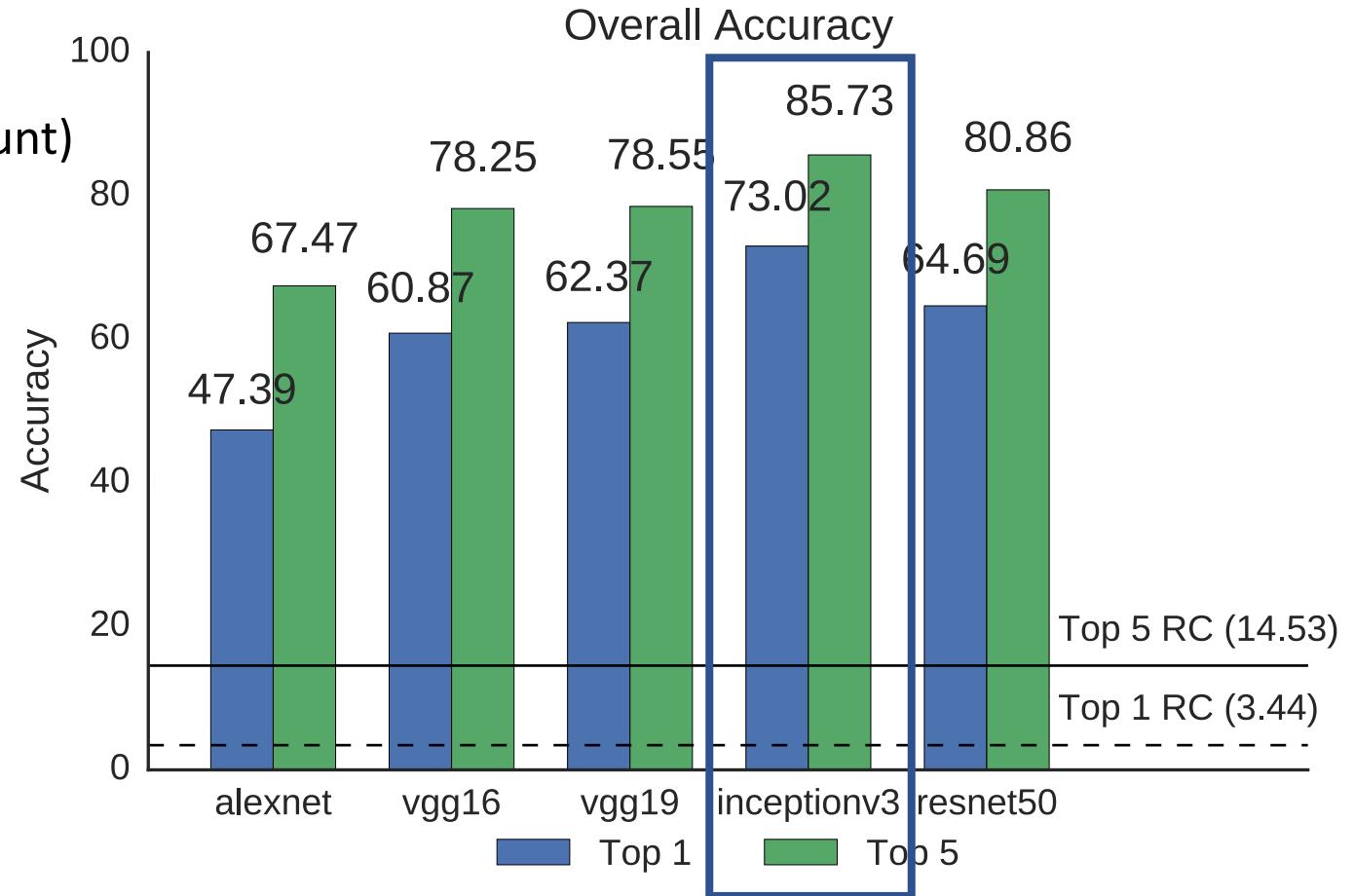
id: 1191, dog (id: 58)



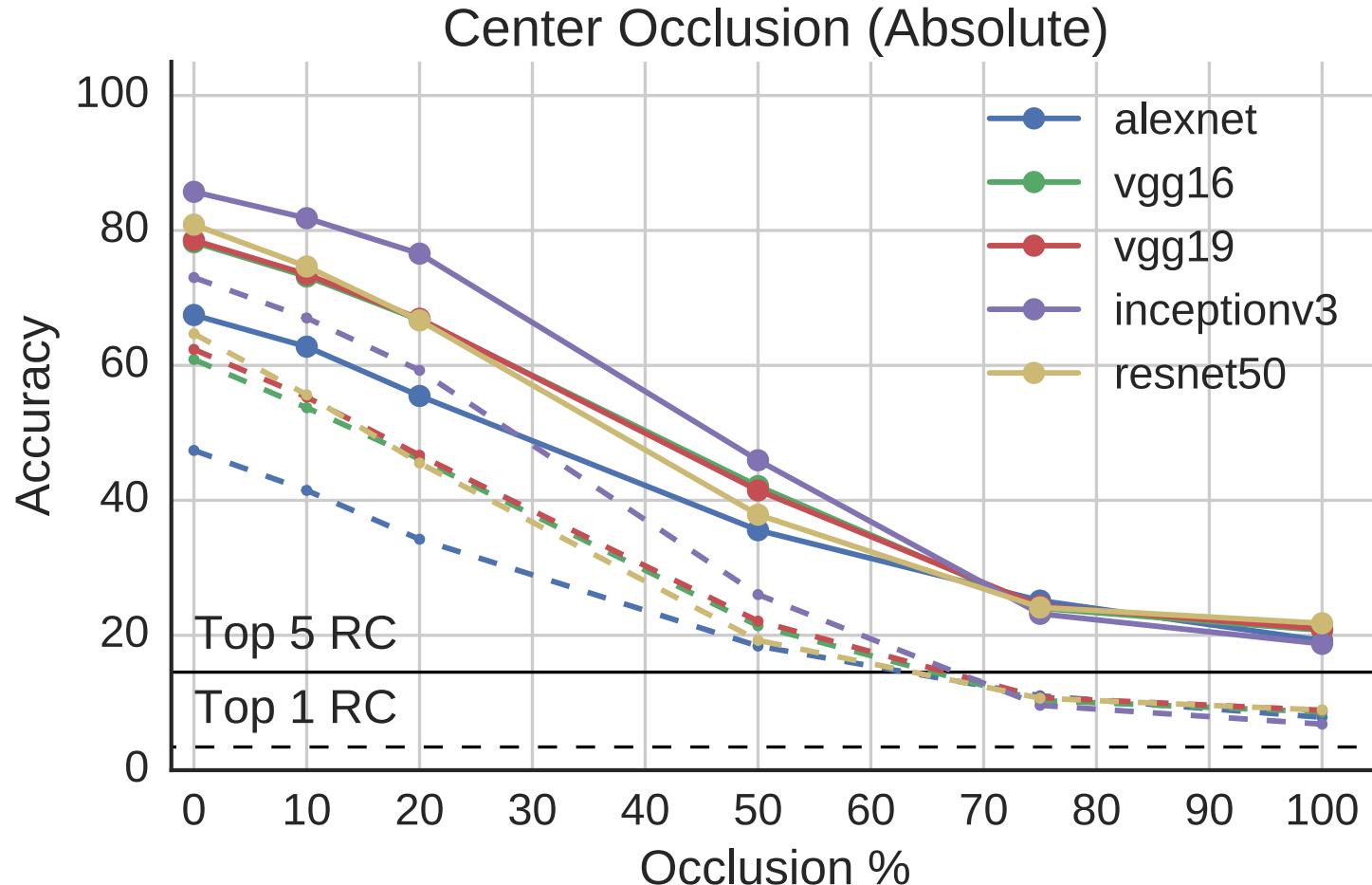
Results

- 5 models
- 14 datasets (occlusion location and amount)
- 7706 images per dataset
- 539,420 images analyzed
 - A few hours on a GPU

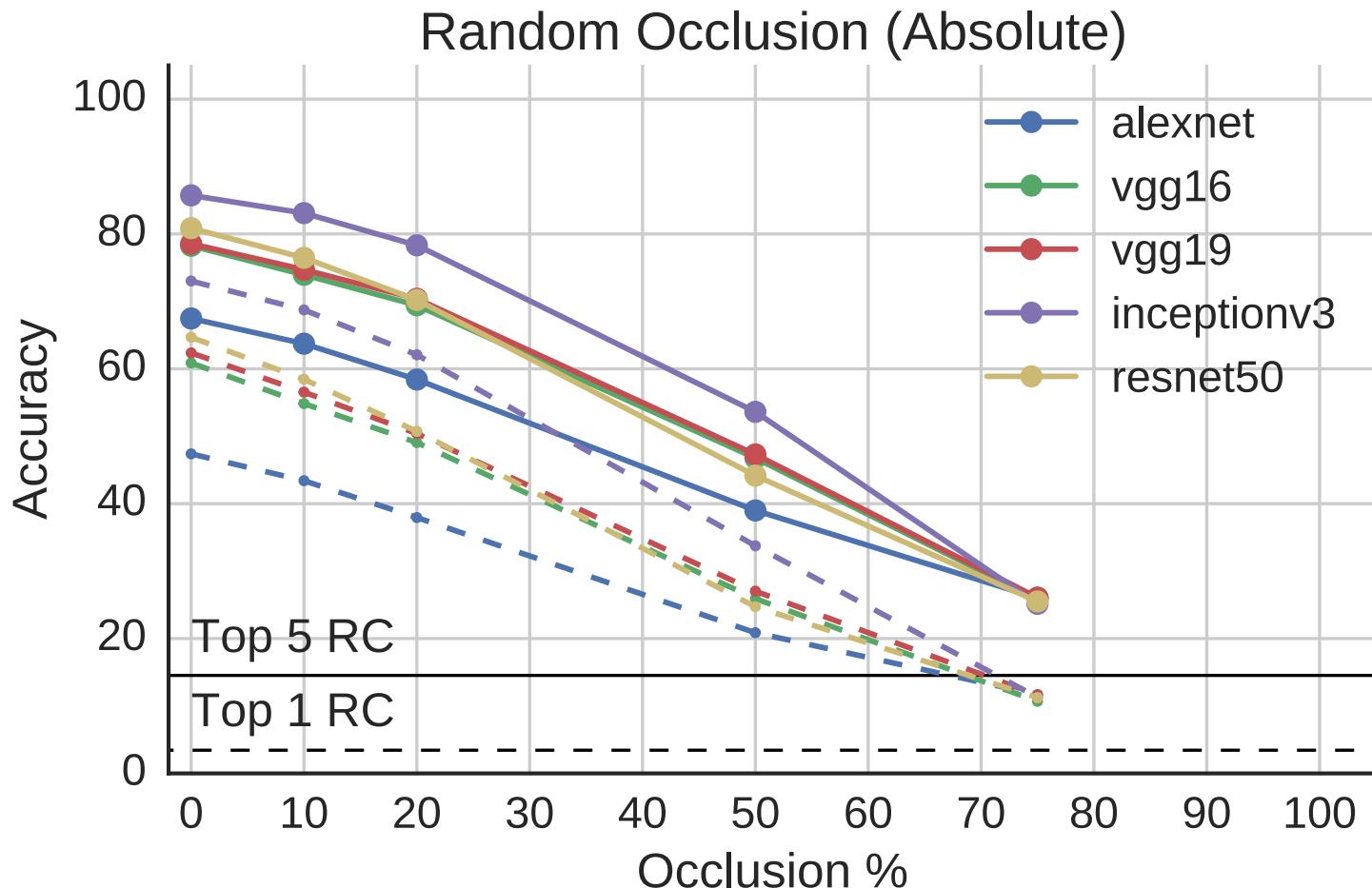
Baseline (no occlusions)



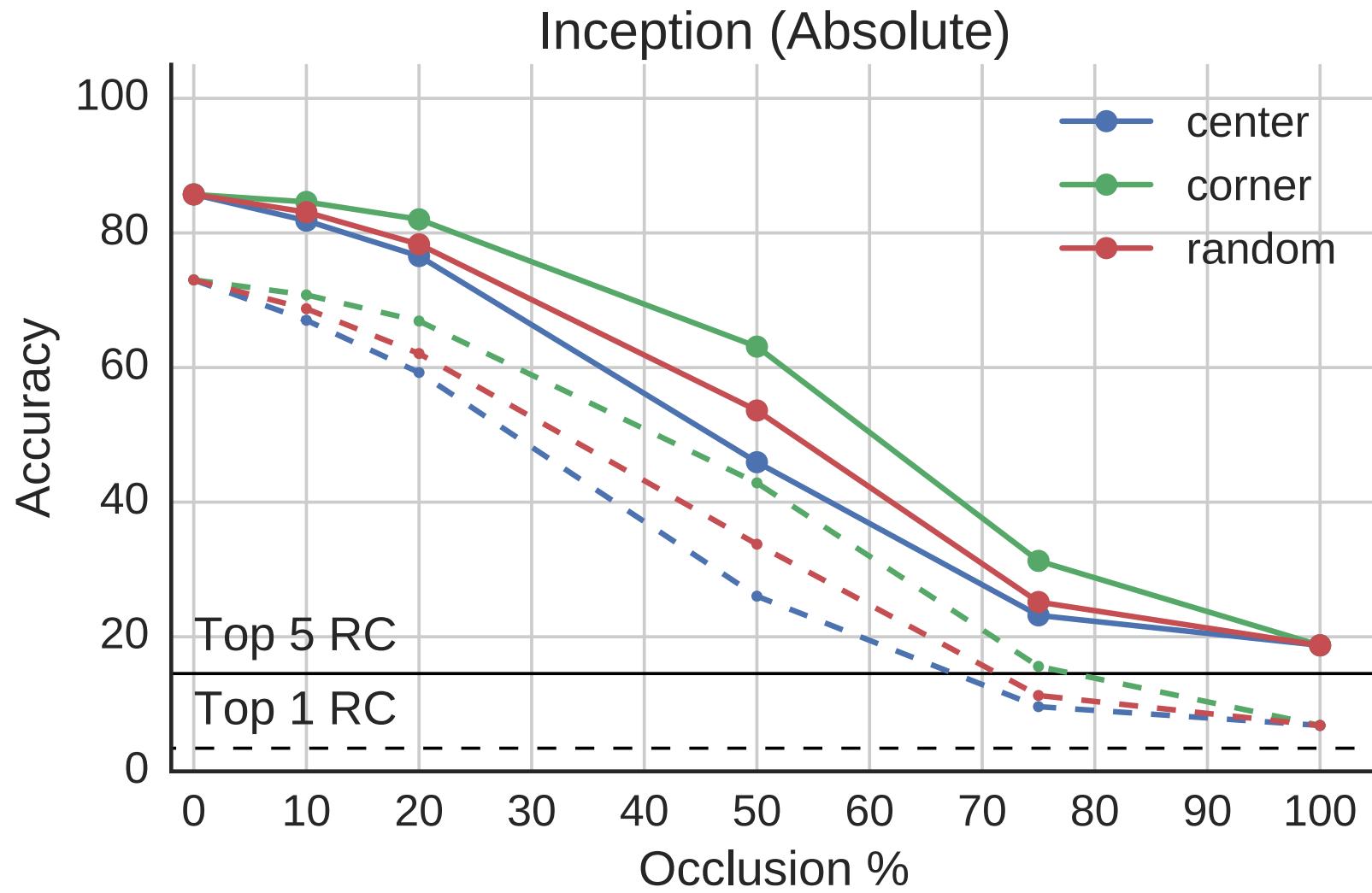
Center Occlusion



Random Occlusions

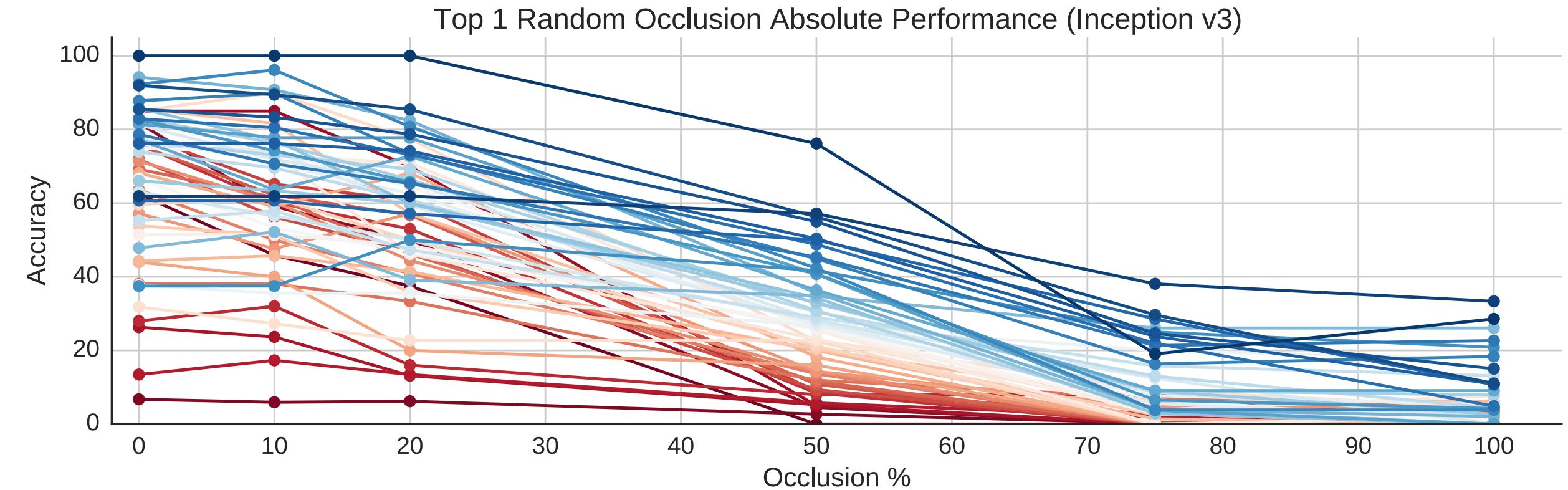


Inception v3



Category Breakdown

Performance Across Categories – Inception v3



Performance Across Categories – Inception v3

No occlusions

| | name | RC_5 | # | Top 1 | Top 5 |
|----|-------------|--------|------|-------|-------|
| 1 | golf ball | 0.005 | 21 | 1 | 1 |
| 2 | dog | 0.461 | 1365 | 0.94 | 0.98 |
| 3 | skunk | 0.005 | 26 | 0.92 | 0.96 |
| 4 | butterfly | 0.03 | 199 | 0.92 | 0.96 |
| 5 | whale | 0.01 | 49 | 0.88 | 0.94 |
| 6 | airplane | 0.005 | 35 | 0.86 | 0.97 |
| 7 | swine | 0.015 | 49 | 0.86 | 0.94 |
| 8 | bird | 0.235 | 1629 | 0.86 | 0.95 |
| 9 | giant panda | 0.005 | 20 | 0.85 | 0.95 |
| 10 | koala bear | 0.005 | 40 | 0.85 | 0.93 |
| .. | | | | | |
| 49 | tape player | 0.005 | 42 | 0.38 | 0.95 |
| 50 | train | 0.005 | 45 | 0.38 | 0.47 |
| 51 | mushroom | 0.005 | 24 | 0.38 | 1 |
| 52 | wine bottle | 0.005 | 22 | 0.32 | 0.86 |
| 53 | purse | 0.005 | 25 | 0.28 | 0.76 |
| 54 | bowl | 0.01 | 38 | 0.26 | 0.5 |
| 55 | cup or mug | 0.005 | 52 | 0.13 | 0.52 |
| 56 | lamp | 0.005 | 34 | 0.12 | 0.29 |
| 57 | person | 0.015 | 371 | 0.07 | 0.11 |
| 58 | table | 0.005 | 64 | 0 | 0.05 |

50% Random Occlusion

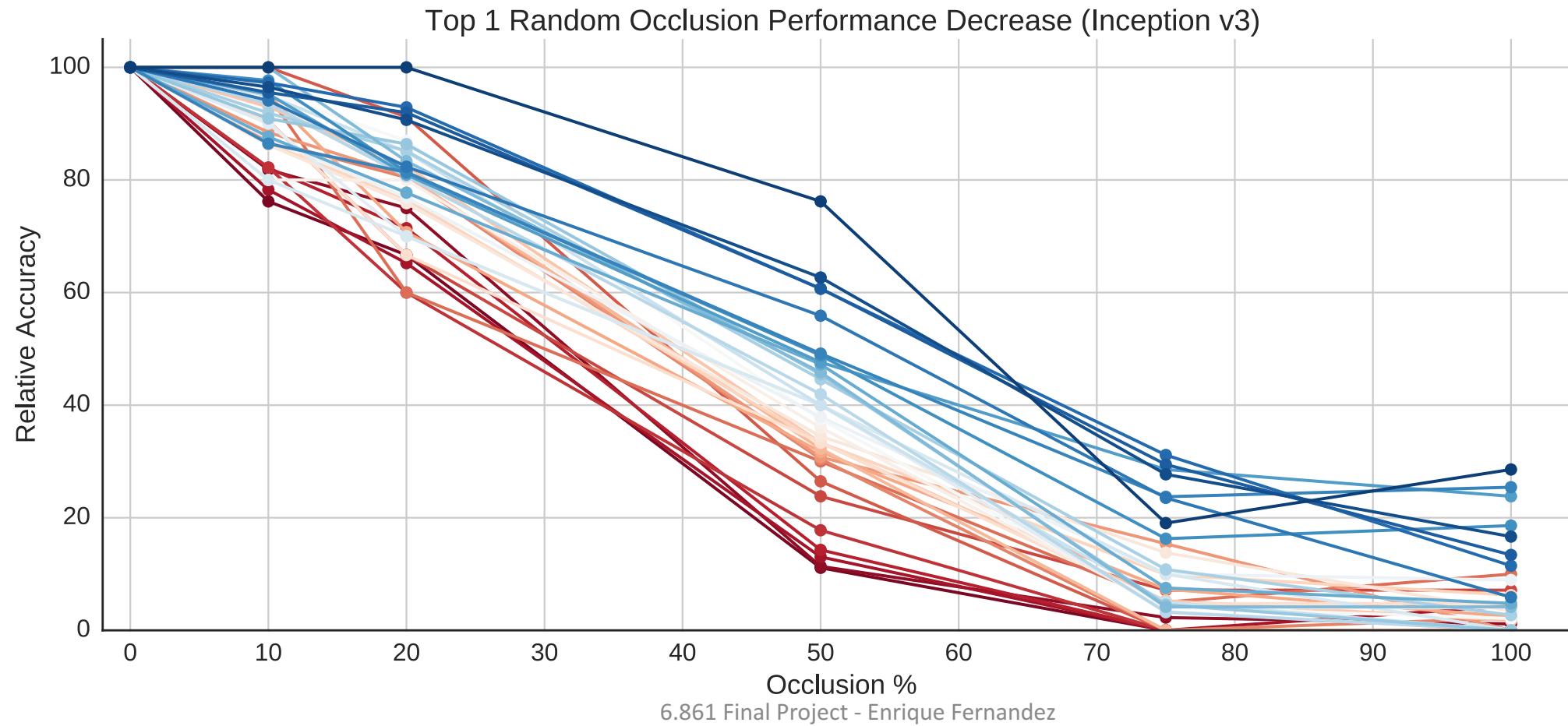
| | name | RC_5 | # | Top 1 | Top 5 |
|----|----------------|--------|------|-------|-------|
| 1 | golf ball | 0.005 | 21 | 0.76 | 0.95 |
| 2 | nail | 0.005 | 21 | 0.57 | 0.71 |
| 3 | butterfly | 0.03 | 199 | 0.56 | 0.78 |
| 4 | bird | 0.235 | 1629 | 0.55 | 0.77 |
| 5 | watercraft | 0.063 | 147 | 0.5 | 0.85 |
| 6 | soap dispenser | 0.005 | 28 | 0.5 | 0.75 |
| 7 | ray | 0.01 | 41 | 0.49 | 0.71 |
| 8 | bear | 0.02 | 75 | 0.45 | 0.61 |
| 9 | whale | 0.01 | 49 | 0.45 | 0.71 |
| 10 | skunk | 0.005 | 26 | 0.42 | 0.58 |
| .. | | | | | |
| 49 | turtle | 0.025 | 112 | 0.09 | 0.27 |
| 50 | frog | 0.015 | 83 | 0.08 | 0.31 |
| 51 | purse | 0.005 | 25 | 0.08 | 0.32 |
| 52 | cup or mug | 0.005 | 52 | 0.06 | 0.29 |
| 53 | bowl | 0.01 | 38 | 0.05 | 0.24 |
| 54 | giant panda | 0.005 | 20 | 0.05 | 0.3 |
| 55 | isopod | 0.005 | 22 | 0.05 | 0.14 |
| 56 | person | 0.015 | 371 | 0.03 | 0.07 |
| 57 | centipede | 0.005 | 24 | 0 | 0.12 |
| 58 | table | 0.005 | 64 | 0 | 0.08 |

100% Occlusion

| | name | RC_5 | # | Top 1 | Top 5 |
|----|-------------|--------|------|-------|-------|
| 1 | nail | 0.005 | 21 | 0.33 | 0.52 |
| 2 | golf ball | 0.005 | 21 | 0.29 | 0.52 |
| 3 | flower pot | 0.005 | 23 | 0.26 | 0.52 |
| 4 | bear | 0.02 | 75 | 0.23 | 0.37 |
| 5 | mushroom | 0.005 | 24 | 0.21 | 0.33 |
| 6 | whale | 0.01 | 49 | 0.18 | 0.39 |
| 7 | train | 0.005 | 45 | 0.18 | 0.33 |
| 8 | bird | 0.235 | 1629 | 0.15 | 0.37 |
| 9 | bee | 0.005 | 38 | 0.13 | 0.66 |
| 10 | butterfly | 0.03 | 199 | 0.11 | 0.37 |
| .. | | | | | |
| 49 | lamp | 0.005 | 34 | 0 | 0.09 |
| 50 | otter | 0.005 | 30 | 0 | 0.1 |
| 51 | porcupine | 0.005 | 32 | 0 | 0.03 |
| 52 | purse | 0.005 | 25 | 0 | 0 |
| 53 | rabbit | 0.01 | 70 | 0 | 0.11 |
| 54 | sheep | 0.005 | 25 | 0 | 0 |
| 55 | snail | 0.005 | 37 | 0 | 0 |
| 56 | squirrel | 0.005 | 35 | 0 | 0.11 |
| 57 | table | 0.005 | 64 | 0 | 0.02 |
| 58 | tennis ball | 0.005 | 26 | 0 | 0.04 |

Most/Least Resilient Categories

Performance decrease with respect to performance without occlusions



Most/Least Resilient Categories

**Relative performance
with respect to No Occlusions**

50% Random Occlusion

| | name | RC_5 | # | Top 1 | Top 5 |
|----|--------------|--------|------|-------|-------|
| 1 | golf ball | 0.005 | 21 | 0.76 | 0.95 |
| 2 | bird | 0.235 | 1393 | 0.63 | 0.8 |
| 3 | watercraft | 0.063 | 112 | 0.61 | 0.87 |
| 4 | butterfly | 0.03 | 183 | 0.61 | 0.81 |
| 5 | ray | 0.01 | 34 | 0.56 | 0.74 |
| 6 | bear | 0.02 | 59 | 0.49 | 0.62 |
| 7 | whale | 0.01 | 43 | 0.49 | 0.74 |
| 8 | bee | 0.005 | 21 | 0.48 | 0.91 |
| 9 | snake | 0.082 | 292 | 0.47 | 0.59 |
| 10 | skunk | 0.005 | 24 | 0.46 | 0.6 |
| .. | | | | | |
| 26 | porcupine | 0.005 | 26 | 0.31 | 0.53 |
| 27 | antelope | 0.015 | 46 | 0.3 | 0.55 |
| 28 | chime | 0.005 | 20 | 0.3 | 0.65 |
| 29 | koala bear | 0.005 | 34 | 0.26 | 0.49 |
| 30 | swine | 0.015 | 42 | 0.24 | 0.43 |
| 31 | domestic cat | 0.025 | 45 | 0.18 | 0.28 |
| 32 | snail | 0.005 | 28 | 0.14 | 0.31 |
| 33 | scorpion | 0.005 | 23 | 0.13 | 0.1 |
| 34 | turtle | 0.025 | 88 | 0.11 | 0.3 |
| 35 | frog | 0.015 | 63 | 0.11 | 0.35 |

Summary

- **Conclusions**
 - Performance advantage of best models vanishes when occlusion increases
 - Simpler classes are more resilient to occlusion
 - Circular, rectangular or elongated shapes
 - Classes that appear in distinctive environments are easier to classify
 - Bees or butterflies – easier (flowers, grass, etc)
 - Domestic cats – hard, as they appear in non-distinctive environments
- **Ideas for future work**
 - Try with circular occlusion – smoother edges
 - Try with salt and pepper noise
 - Analyze activation of layers under the presence of occlusion
 - Incorporate occlusion to training sets

Thanks!

<https://github.com/enriquefernandez/OcclusionProject>

Random chance

Probability of imagen of class j being randomly guessed among the top best k categories, given that there are n_j classes of j in the CLS-LOC classes (1000 classes).

$$\psi_j(k) = \frac{\sum_{i=1}^k \binom{n_{c_j}}{i} \binom{N-n_{c_j}}{k-i}}{\binom{N}{k}}$$

Overall random chance

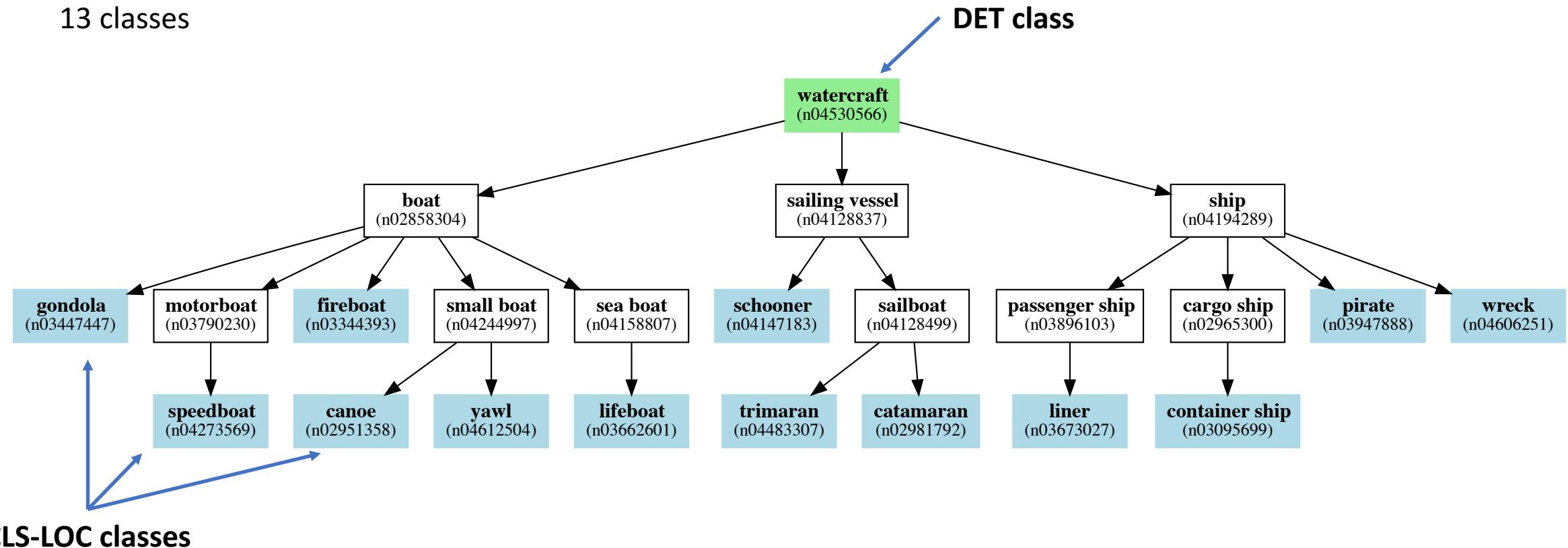
$$\Psi_k = \frac{\sum_j m_j \psi_j(k)}{\sum_j m_j}$$

Top 1 Random Chance: 3.44 %

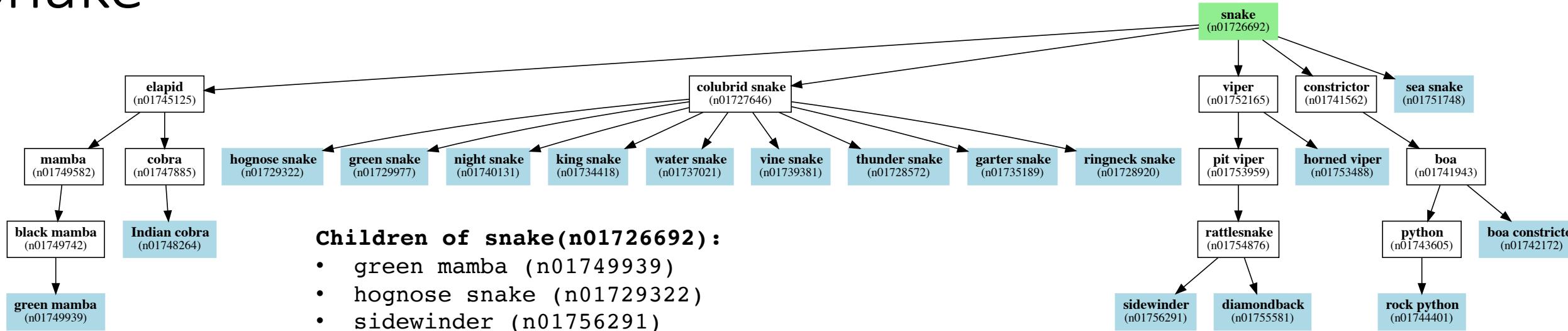
Top 5 Random Chance: 14.53 %

Watercraft

13 classes



Snake

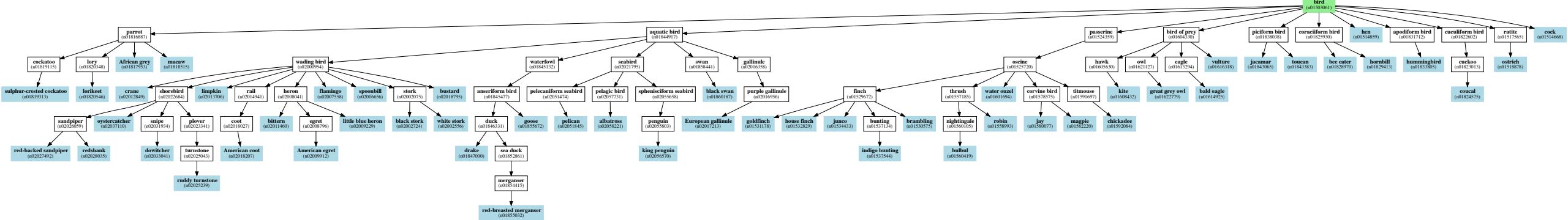


Children of snake(n01726692):

- green mamba (n01749939)
- hognose snake (n01729322)
- sidewinder (n01756291)
- rock python (n01744401)
- green snake (n01729977)
- night snake (n01740131)
- diamondback (n01755581)
- king snake (n01734418)
- sea snake (n01751748)
- horned viper (n01753488)
- water snake (n01737021)
- vine snake (n01739381)
- thunder snake (n01728572)
- garter snake (n01735189)
- ringneck snake (n01728920)
- boa constrictor (n01742172)
- Indian cobra (n01748264)

Bird

52 classes

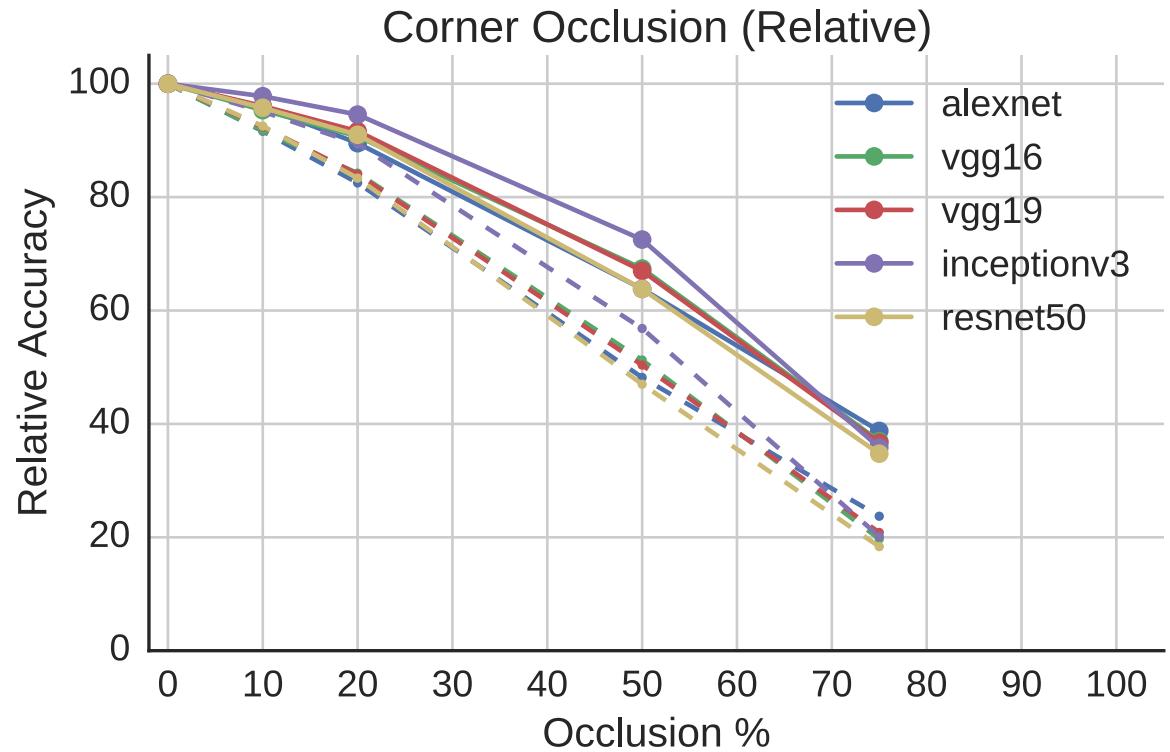
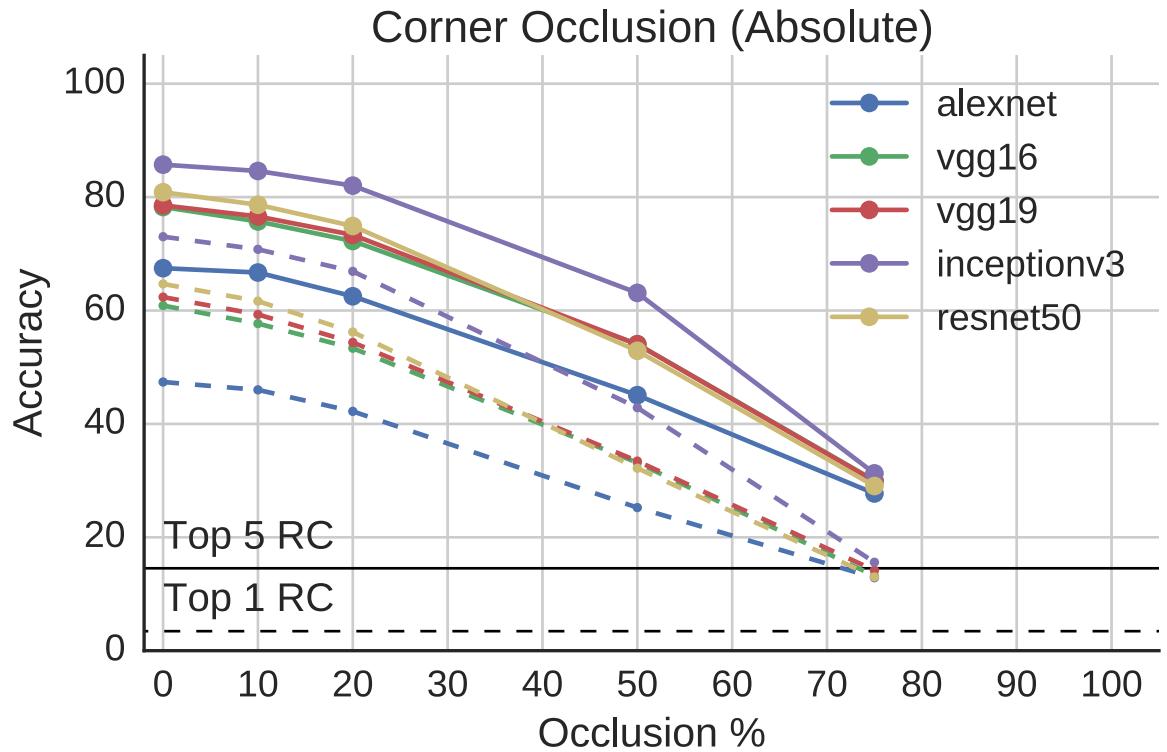


Top 20 CLS-LOC categories

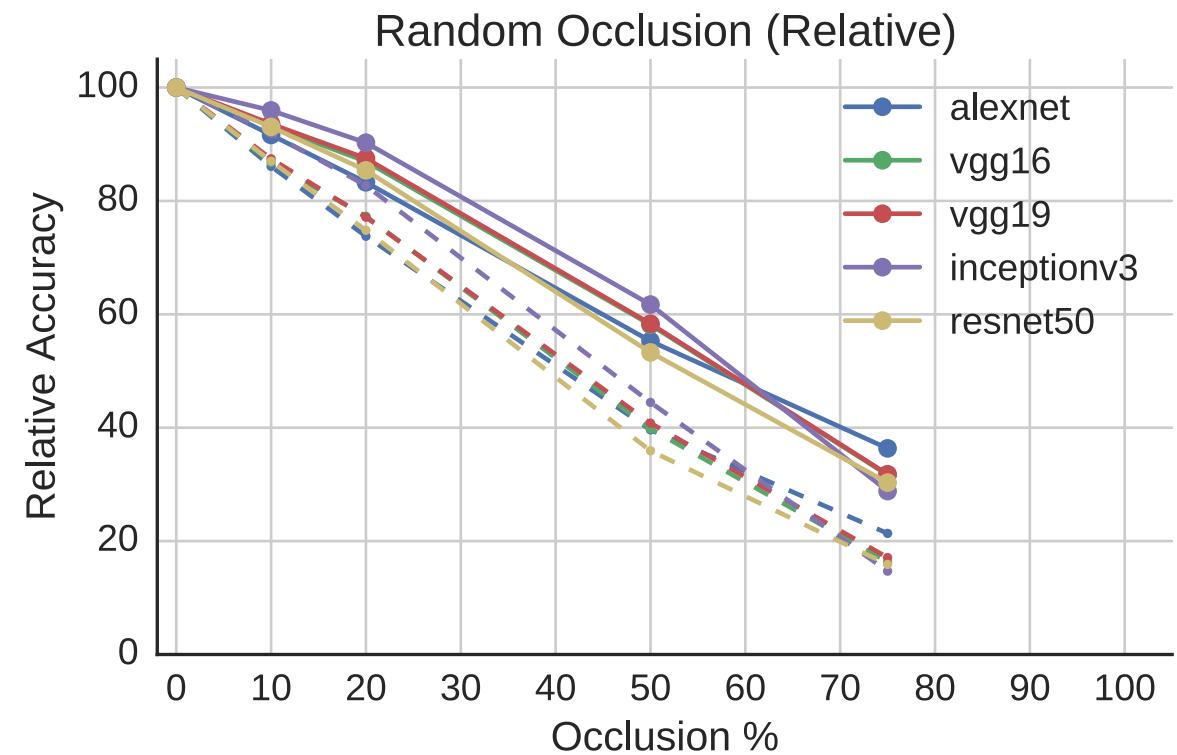
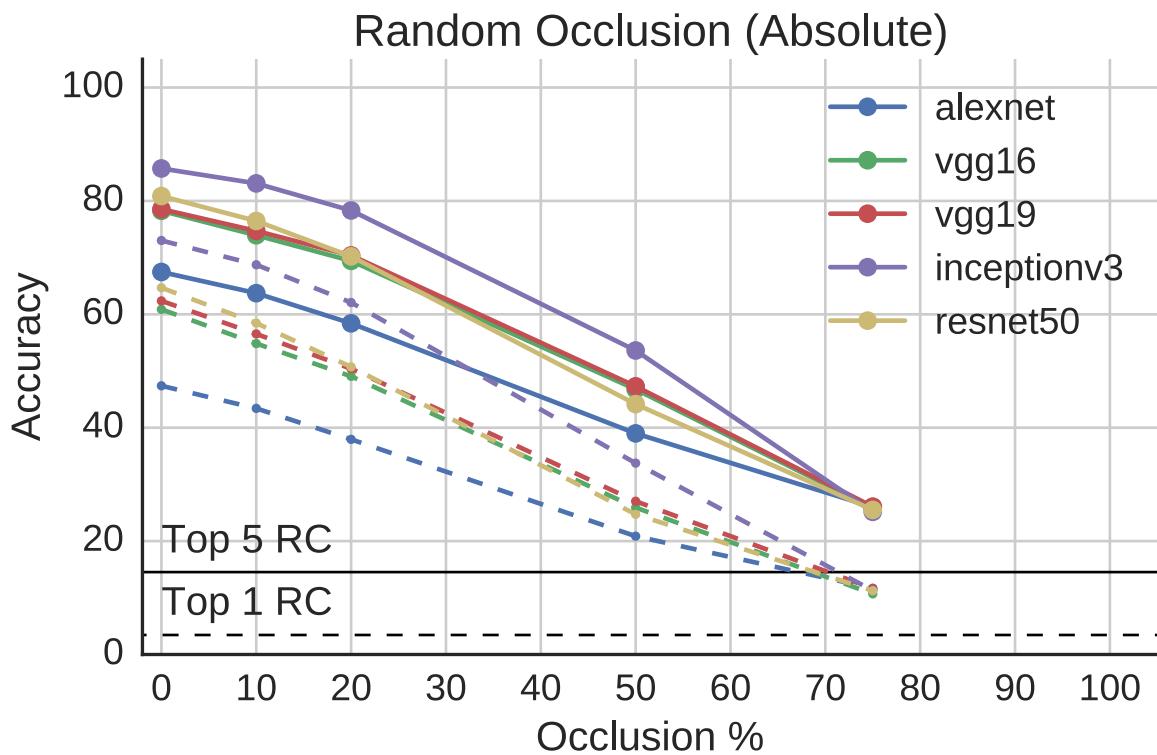
| Class | nc |
|--------------------------|-----|
| dog (n02084071) | 116 |
| bird (n01503061) | 52 |
| snake (n01726692) | 17 |
| watercraft (n04530566) | 13 |
| monkey (n02484322) | 13 |
| lizard (n01674464) | 11 |
| car (n02958343) | 10 |
| butterfly (n02274259) | 6 |
| domestic cat (n02121808) | 5 |
| turtle (n01662784) | 5 |
| chair (n03001627) | 4 |
| bear (n02131653) | 4 |
| fox (n02118333) | 4 |
| swine (n02395003) | 3 |
| baby bed (n02766320) | 3 |

Affects the random chance of each of the 1-200 DET classes

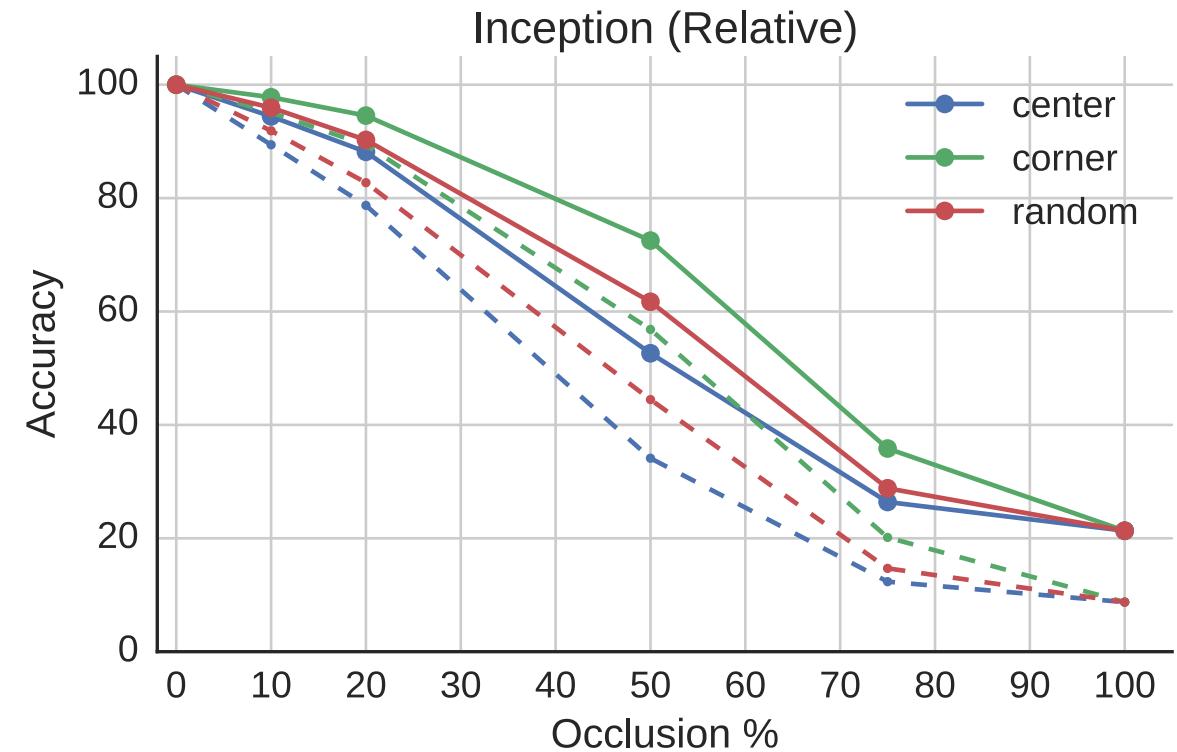
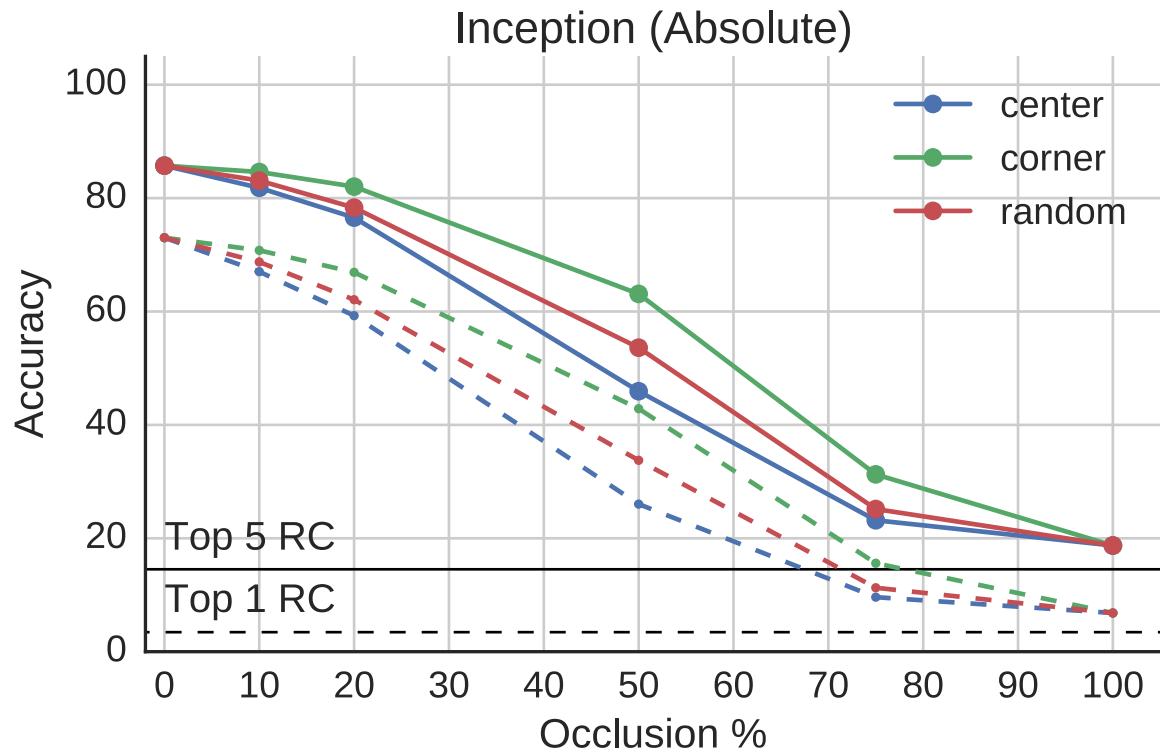
Corner Occlusions



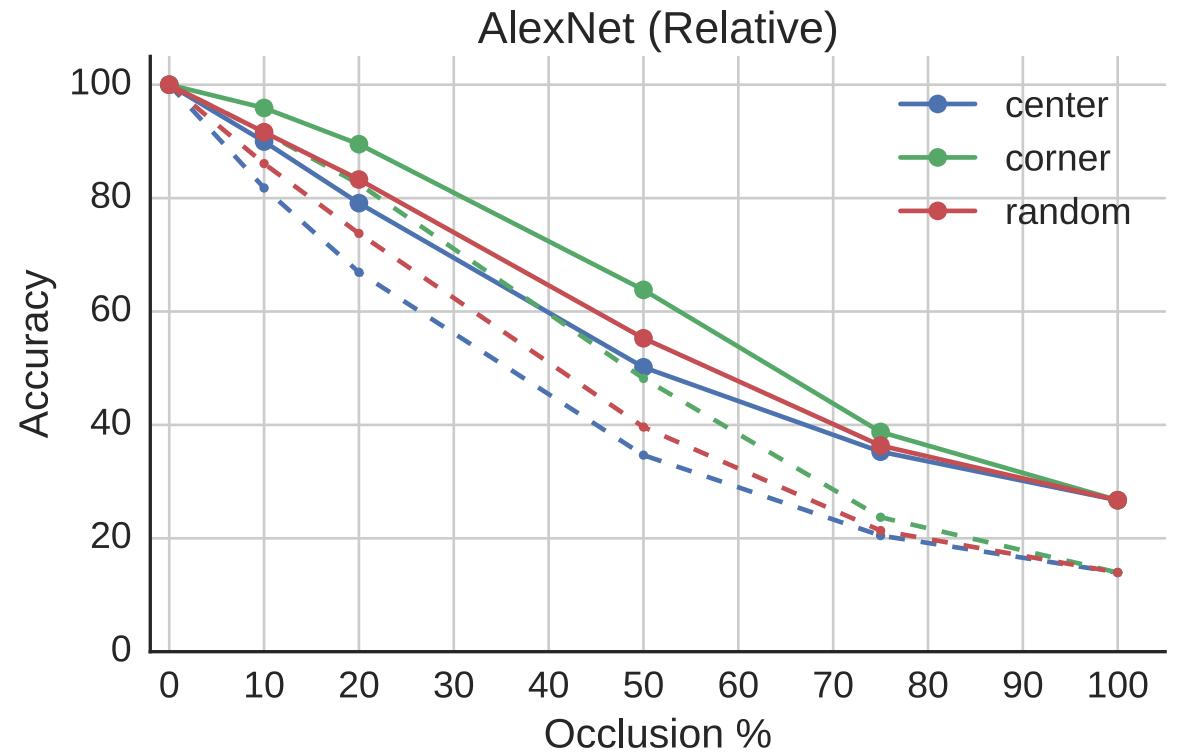
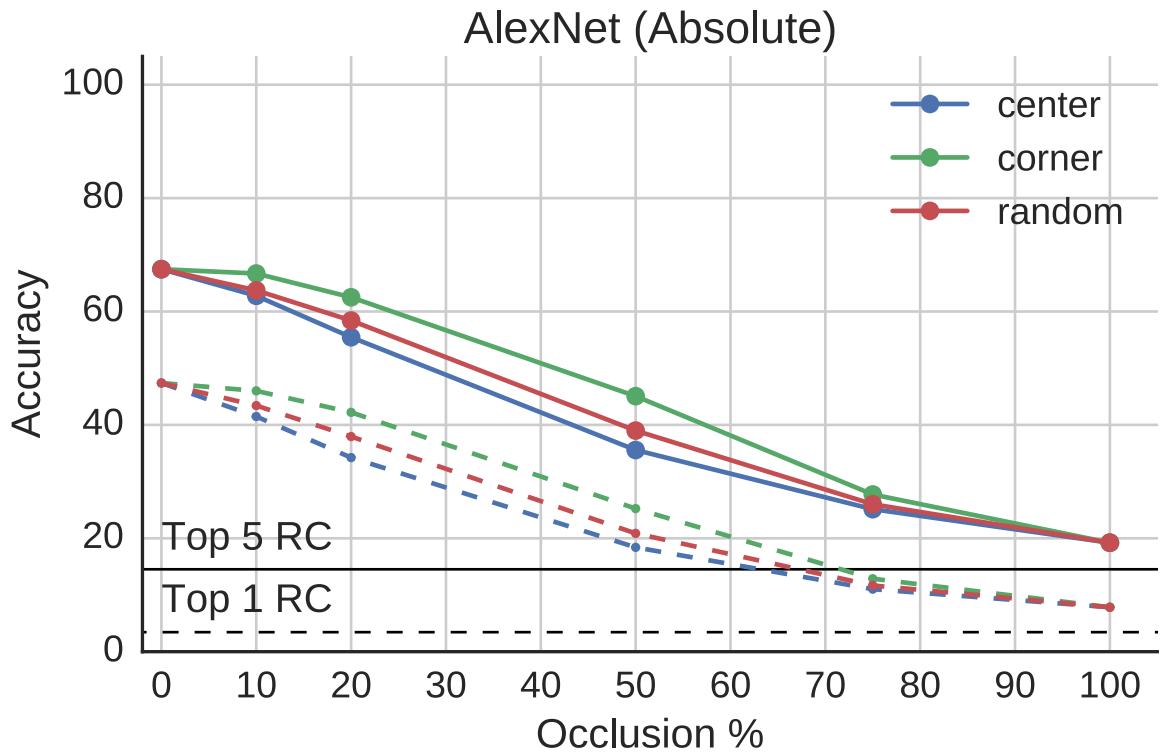
Random Occlusions



Inception v3



AlexNet



| | name | # | RC1 | RC5 | inceptionv3 | resnet50 | vgg19 | vgg16 | alexnet |
|----|----------------------------|------|-------|-------|-------------|-------------|-------------|-------------|-------------|
| 1 | bird (id: 26) | 1629 | 0.052 | 0.235 | 1393 (0.86) | 1275 (0.78) | 1283 (0.79) | 1257 (0.77) | 1159 (0.71) |
| 2 | dog (id: 58) | 1365 | 0.116 | 0.461 | 1286 (0.94) | 1230 (0.90) | 1198 (0.88) | 1198 (0.88) | 906 (0.66) |
| 3 | person (id: 124) | 371 | 0.003 | 0.015 | 25 (0.07) | 26 (0.07) | 15 (0.04) | 12 (0.03) | 21 (0.06) |
| 4 | snake (id: 159) | 353 | 0.017 | 0.082 | 292 (0.83) | 237 (0.67) | 249 (0.71) | 228 (0.65) | 184 (0.52) |
| 5 | lizard (id: 105) | 246 | 0.011 | 0.054 | 192 (0.78) | 169 (0.69) | 179 (0.73) | 167 (0.68) | 79 (0.32) |
| 6 | monkey (id: 113) | 229 | 0.013 | 0.063 | 190 (0.83) | 147 (0.64) | 144 (0.63) | 145 (0.63) | 110 (0.48) |
| 7 | butterfly (id: 34) | 199 | 0.006 | 0.03 | 183 (0.92) | 174 (0.87) | 165 (0.83) | 159 (0.80) | 150 (0.75) |
| 8 | watercraft (id: 197) | 147 | 0.013 | 0.063 | 112 (0.76) | 105 (0.71) | 99 (0.67) | 105 (0.71) | 68 (0.46) |
| 9 | car (id: 37) | 112 | 0.01 | 0.049 | 74 (0.66) | 71 (0.63) | 66 (0.59) | 64 (0.57) | 26 (0.23) |
| 10 | turtle (id: 188) | 112 | 0.005 | 0.025 | 88 (0.79) | 68 (0.61) | 62 (0.55) | 59 (0.53) | 44 (0.39) |
| 11 | frog (id: 72) | 83 | 0.003 | 0.015 | 63 (0.76) | 55 (0.66) | 49 (0.59) | 39 (0.47) | 36 (0.43) |
| 12 | fox (id: 70) | 76 | 0.004 | 0.02 | 57 (0.75) | 49 (0.64) | 47 (0.62) | 46 (0.61) | 23 (0.30) |
| 13 | bear (id: 20) | 75 | 0.004 | 0.02 | 59 (0.79) | 49 (0.65) | 38 (0.51) | 42 (0.56) | 15 (0.20) |
| 14 | rabbit (id: 141) | 70 | 0.002 | 0.01 | 31 (0.44) | 19 (0.27) | 30 (0.43) | 29 (0.41) | 16 (0.23) |
| 15 | table (id: 177) | 64 | 0.001 | 0.005 | 0 (0.00) | 0 (0.00) | 0 (0.00) | 0 (0.00) | 0 (0.00) |
| 16 | domestic cat (id: 59) | 63 | 0.005 | 0.025 | 45 (0.71) | 39 (0.62) | 36 (0.57) | 35 (0.56) | 12 (0.19) |
| 17 | antelope (id: 4) | 55 | 0.003 | 0.015 | 46 (0.84) | 40 (0.73) | 41 (0.75) | 40 (0.73) | 34 (0.62) |
| 18 | dragonfly (id: 60) | 54 | 0.001 | 0.005 | 41 (0.76) | 45 (0.83) | 33 (0.61) | 34 (0.63) | 29 (0.54) |
| 19 | cup or mug (id: 54) | 52 | 0.001 | 0.005 | 7 (0.13) | 10 (0.19) | 12 (0.23) | 11 (0.21) | 1 (0.02) |
| 20 | ladybug (id: 99) | 52 | 0.001 | 0.005 | 31 (0.60) | 20 (0.38) | 22 (0.42) | 18 (0.35) | 25 (0.48) |
| 21 | swine (id: 175) | 49 | 0.003 | 0.015 | 42 (0.86) | 36 (0.73) | 34 (0.69) | 32 (0.65) | 6 (0.12) |
| 22 | whale (id: 198) | 49 | 0.002 | 0.01 | 43 (0.88) | 32 (0.65) | 30 (0.61) | 30 (0.61) | 40 (0.82) |
| 23 | chair (id: 43) | 46 | 0.004 | 0.02 | 29 (0.63) | 23 (0.50) | 18 (0.39) | 18 (0.39) | 15 (0.33) |
| 24 | train (id: 185) | 45 | 0.001 | 0.005 | 17 (0.38) | 15 (0.33) | 16 (0.36) | 13 (0.29) | 13 (0.29) |
| 25 | tape player (id: 178) | 42 | 0.001 | 0.005 | 16 (0.38) | 8 (0.19) | 10 (0.24) | 10 (0.24) | 10 (0.24) |
| 26 | ray (id: 143) | 41 | 0.002 | 0.01 | 34 (0.83) | 23 (0.56) | 19 (0.46) | 20 (0.49) | 16 (0.39) |
| 27 | koala bear (id: 97) | 40 | 0.001 | 0.005 | 34 (0.85) | 34 (0.85) | 31 (0.78) | 29 (0.72) | 22 (0.55) |
| 28 | red panda (id: 144) | 39 | 0.001 | 0.005 | 21 (0.54) | 6 (0.15) | 8 (0.21) | 10 (0.26) | 13 (0.33) |
| 29 | bee (id: 21) | 38 | 0.001 | 0.005 | 21 (0.55) | 18 (0.47) | 19 (0.50) | 17 (0.45) | 23 (0.61) |
| 30 | bowl (id: 30) | 38 | 0.002 | 0.01 | 10 (0.26) | 9 (0.24) | 9 (0.24) | 5 (0.13) | 2 (0.05) |
| 31 | snail (id: 158) | 37 | 0.001 | 0.005 | 28 (0.76) | 22 (0.59) | 18 (0.49) | 17 (0.46) | 14 (0.38) |
| 32 | airplane (id: 2) | 35 | 0.001 | 0.005 | 30 (0.86) | 27 (0.77) | 26 (0.74) | 24 (0.69) | 14 (0.40) |
| 33 | squirrel (id: 166) | 35 | 0.001 | 0.005 | 18 (0.51) | 15 (0.43) | 13 (0.37) | 9 (0.26) | 12 (0.34) |
| 34 | lamp (id: 100) | 34 | 0.001 | 0.005 | 4 (0.12) | 6 (0.18) | 4 (0.12) | 4 (0.12) | 5 (0.15) |
| 35 | porcupine (id: 134) | 32 | 0.001 | 0.005 | 26 (0.81) | 23 (0.72) | 21 (0.66) | 23 (0.72) | 14 (0.44) |
| 36 | scorpion (id: 152) | 32 | 0.001 | 0.005 | 23 (0.72) | 21 (0.66) | 18 (0.56) | 18 (0.56) | 15 (0.47) |
| 37 | otter (id: 120) | 30 | 0.001 | 0.005 | 20 (0.67) | 15 (0.50) | 17 (0.57) | 17 (0.57) | 5 (0.17) |
| 38 | soap dispenser (id: 162) | 28 | 0.001 | 0.005 | 17 (0.61) | 15 (0.54) | 12 (0.43) | 13 (0.46) | 6 (0.21) |
| 39 | armadillo (id: 6) | 27 | 0.001 | 0.005 | 22 (0.81) | 20 (0.74) | 19 (0.70) | 18 (0.67) | 14 (0.52) |
| 40 | bus (id: 33) | 26 | 0.003 | 0.015 | 18 (0.69) | 17 (0.65) | 13 (0.50) | 15 (0.58) | 7 (0.27) |
| 41 | chime (id: 44) | 26 | 0.001 | 0.005 | 20 (0.77) | 21 (0.81) | 16 (0.62) | 15 (0.58) | 1 (0.04) |
| 42 | skunk (id: 157) | 26 | 0.001 | 0.005 | 24 (0.92) | 22 (0.85) | 22 (0.85) | 23 (0.88) | 13 (0.50) |
| 43 | tennis ball (id: 179) | 26 | 0.001 | 0.005 | 20 (0.77) | 16 (0.62) | 16 (0.62) | 17 (0.65) | 11 (0.42) |
| 44 | purse (id: 140) | 25 | 0.001 | 0.005 | 7 (0.28) | 7 (0.28) | 6 (0.24) | 6 (0.24) | 2 (0.08) |
| 45 | sheep (id: 155) | 25 | 0.001 | 0.005 | 11 (0.44) | 6 (0.24) | 6 (0.24) | 7 (0.28) | 1 (0.04) |
| 46 | centipede (id: 41) | 24 | 0.001 | 0.005 | 15 (0.62) | 17 (0.71) | 12 (0.50) | 9 (0.38) | 12 (0.50) |
| 47 | mushroom (id: 115) | 24 | 0.001 | 0.005 | 9 (0.38) | 12 (0.50) | 11 (0.46) | 8 (0.33) | 2 (0.08) |
| 48 | digital clock (id: 56) | 23 | 0.001 | 0.005 | 17 (0.74) | 15 (0.65) | 13 (0.57) | 14 (0.61) | 9 (0.39) |
| 49 | flower pot (id: 68) | 23 | 0.001 | 0.005 | 11 (0.48) | 11 (0.48) | 8 (0.35) | 10 (0.43) | 2 (0.09) |
| 50 | ant (id: 3) | 22 | 0.001 | 0.005 | 17 (0.77) | 15 (0.68) | 15 (0.68) | 15 (0.68) | 10 (0.45) |
| 51 | baby bed (id: 9) | 22 | 0.003 | 0.015 | 14 (0.64) | 12 (0.55) | 8 (0.36) | 13 (0.59) | 5 (0.23) |
| 52 | hippopotamus (id: 90) | 22 | 0.001 | 0.005 | 15 (0.68) | 18 (0.82) | 18 (0.82) | 16 (0.73) | 12 (0.55) |
| 53 | isopod (id: 95) | 22 | 0.001 | 0.005 | 18 (0.82) | 14 (0.64) | 11 (0.50) | 12 (0.55) | 2 (0.09) |
| 54 | wine bottle (id: 199) | 22 | 0.001 | 0.005 | 7 (0.32) | 10 (0.45) | 6 (0.27) | 7 (0.32) | 6 (0.27) |
| 55 | golf ball (id: 76) | 21 | 0.001 | 0.005 | 15 (0.60) | 15 (0.60) | 17 (0.81) | 18 (0.86) | 12 (0.57) |
| 56 | nail (id: 116) | 21 | 0.001 | 0.005 | 13 (0.62) | 16 (0.76) | 14 (0.67) | 15 (0.71) | 10 (0.48) |
| 57 | pencil sharpener (id: 122) | 21 | 0.001 | 0.005 | 12 (0.57) | 12 (0.57) | 9 (0.43) | 9 (0.43) | 2 (0.10) |