

10 Visualization of High/Low Accuracy Classes Predicted by Self-Classifier

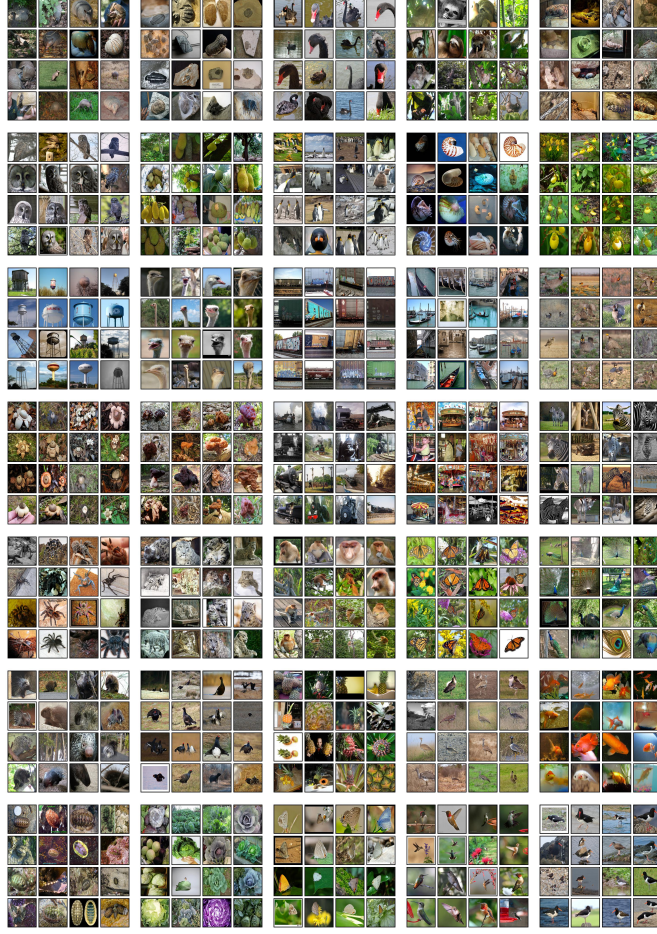


Fig. 2: *High* accuracy classes predicted by *Self-Classifier* on ImageNet validation set (unseen during training). Classes are sorted by accuracy, and images are sampled **randomly** from each predicted class. Note that the predicted classes capture a large variety of different backgrounds and viewpoints. This provides further evidence that *Self-Classifier* learns semantically meaningful classes without any labels.

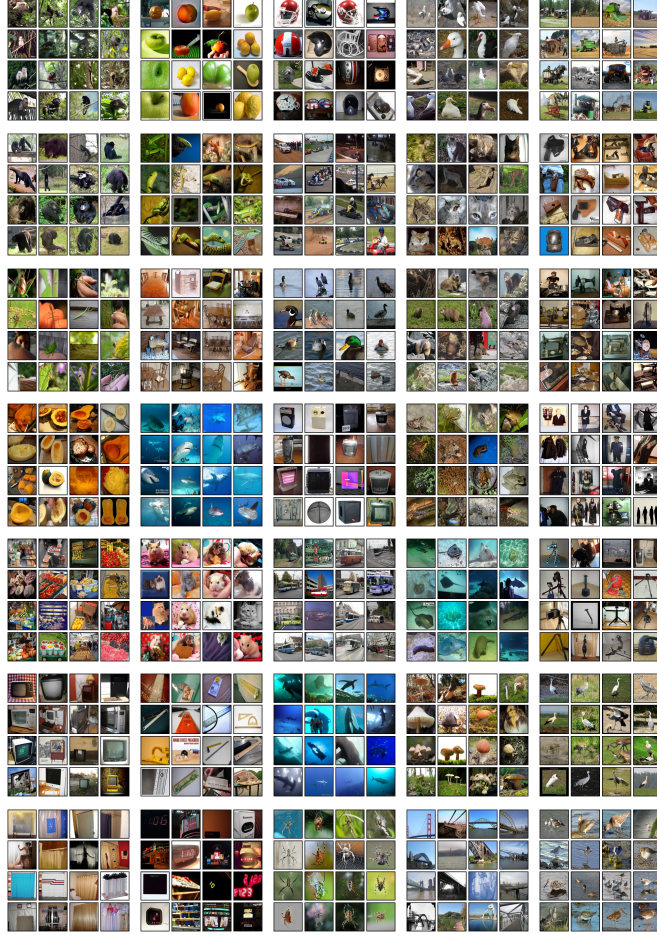


Fig. 3: **Low accuracy classes predicted by *Self-Classifier* on ImageNet validation set (unseen during training)**. Images are sampled **randomly** from each predicted class. We see that even for low accuracy classes, unsupervised semantic grouping is reasonably good. A lot of the misclassified samples (with regards to ground truth) is due to subclasses from the same superclass that are clustered together (please see Tab. 2 for empirical results). For example, different types of birds, monkeys, fruits, spyders, sea animals, helmets, screens (TV vs computer screen), etc. In practice, such clustering is good, yet is not aligned with ImageNet ground truth and thus the accuracy of such clusters is low.

11 Theoretical Analysis

In this section, we show mathematically how *Self-Classifier* avoids trivial solutions by design, i.e., a collapsing solution is simply not in the set of optimal solutions of our proposed loss function (4). Furthermore, and more importantly, we show that by setting $p(y)$ manually, the required optimal solution can be defined by the user.

Theorem 3 (Non-Zero Posterior Probability). *Let B be a batch of N samples with two views per sample, $(x_1, x_2) \in B$. Let $p(y)$ and $p(x)$ be the class and sample distributions, respectively, where $y \in [C]$. Let (5) be the loss function. Then, each class $y \in [C]$ will have at least one sample $y \in [C]$ with non-zero posterior probability $p(x|y) > 0$ assigned into it, and each sample $x \in [N]$ will have at least one class $y \in [C]$ with $p(x|y) > 0$.*

Proof. Consider the non-negative denominators $\sum_{y \in [C]} p(x_2|y)$ and $\sum_{x_1 \in [B]} p(y|x_1)$ of the first and the second term of (4), respectively. To avoid unbounded loss, both denominators must be strictly positive. Thus, for every $x_2 \in [N]$ there is $y \in [C]$ such as $p(x_2|y) > 0$, and for every $y \in [C]$ there is $x_1 \in [N]$ such that $p(y|x_1) > 0$. Using the symmetrized objective loss function (5) allows dropping the subscripts $_1$ and $_2$ of x .

Theorem 4 (Optimal Solution With Uniform Prior). *Let B be a batch of N samples with two views per sample, $(x_1, x_2) \in B$. Let $p(y)$ and $p(x)$ be the class and sample distribution, respectively, where $y \in [C]$. Then, the uniform probabilities $p(y) = \frac{1}{C}$ and $p(x) = \frac{1}{N}$ constitute a global minimizer of the loss (4).*

Proof. The first term $\frac{p(x_2|y)}{\sum_{\bar{y}} p(x_2|\bar{y})}$ summed over y in (4) is normalized such that the probabilities assigned to each $x_2 \in [N]$ sum to one. Additionally, setting $p(y) = \frac{1}{C}$ and $p(x) = \frac{1}{N}$ renders the argument $\frac{N}{C} \frac{p(y|x_1)}{\sum_{\bar{x}_1} p(y|\bar{x}_1)}$ of the logarithm in the second term in (4) normalized such that the probabilities assigned to each $y \in [C]$ sum to $\frac{N}{C}$. Thus, an optimal zero loss solution is one in which $\forall y \in [C]$, exactly $\frac{N}{C}$ samples are assigned a probability of one, and $\forall x \in [N]$, exactly 1 class is assigned probability of one, which concludes the proof.

12 Unsupervised Classification Accuracy & Training Loss Vs. Number of Epochs

In Fig. 4 we plot the unsupervised classification accuracy and training loss vs. the number of training epochs of *Self-Classifier*. This figure further illustrates the fact that the training objective of *Self-Classifier* is aligned with semantically meaningful classification of unseen data (ImageNet validation set) despite being trained strictly with unlabeled data.

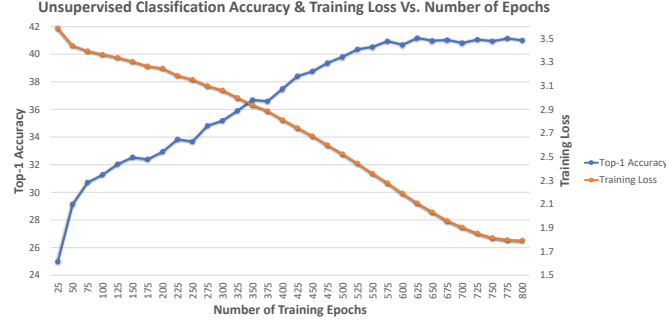


Fig. 4: Unsupervised classification accuracy & training loss vs. number of training epochs.

13 Superclasses Datasets

In Tab. 2 we report results for different numbers of ImageNet superclasses (10, 29, 128, 466 and 591) resulting from cutting the default (WordNet) ImageNet hierarchy on different levels - levels 2 to 6, respectively. More specifically:

1. Level 2 contains 10 superclasses - *furnishing; structure, place; fungus; conveyance, transport; plant, flora, plant life; apparel, toiletries; animal, animate being, beast, brute, creature, fauna; food, nutrient; paraphernalia; person.*
2. Level 3 contains 29 superclasses - *echinoderm; bird; wheeled vehicle; furniture, piece of furniture, article of furniture; soft furnishings, accessories; produce, green goods, green groceries, garden truck; mollusk, mollusc, shellfish; vascular plant, tracheophyte; man-made structure, construction; instrument; accessory, accoutrement, accouterment; geological formation, formation; appliance; mammal, mammalian; amphibian; garment; fungus; craft; reptile, reptilian; arthropod; cooked food, prepared food; fish; sled, sledge, sleigh; beverage, drink, drinkable, potable; person; toiletry, toilet articles; equipment; worm; coelenterate, cnidarian.*
3. Level 4 contains 128 superclasses - *dummy8; dummy6; seat; gastropod, uni-valve; building, edifice; spacecraft, ballistic capsule, space vehicle; medical instrument; motor vehicle, automotive vehicle; alcohol, alcoholic drink, alcoholic beverage, intoxicant, inebriant; train, railroad train; rodent, gnawer; lagomorph, gnawing mammal; bag; dummy53; dummy79; dummy0; anthozoan, actinozoan; piece of cloth, piece of material; dummy68; tool; screen; barrier; chiton, coat-of-mail shell, sea cradle, polyplacophore; baked goods; insect; neckwear; arachnid, arachnoid; person, individual, someone, somebody, mortal, soul; landing, landing place; bandage, patch; bony fish; area; gallinaceous bird, gallinacean; dummy77; dummy69; handwear, hand wear; dummy67; mountain, mount; coffee, java; bedclothes, bed clothing, bedding; dummy73; dummy14; facial accessories; dummy1; primate; sports equipment;*

aircraft; dryer, drier; proboscidean, proboscidian; kitchen utensil; centipede; wall unit; vegetable, veggie, veg; headdress, headgear; basidiomycete, basidiomycetous fungi; monotreme, egg-laying mammal; scientific instrument; aquatic mammal; crustacean; archosaur, archosaurian, archosaurian reptile; musical instrument, instrument; tracked vehicle; ascomycete; ungulate, hoofed mammal; chelonian, chelonian reptile; electronic equipment; dummy51; dummy71; dummy11; footwear, legwear; dummy39; dessert, sweet, afters; dummy56; cuculiform bird; fruit; door; carnivore; piciform bird; crocodilian reptile, crocodilian; dummy78; cosmetic; garment; aquatic bird; table; floor cover, floor covering; cartilaginous fish, chondrichthian; sled, sledge, sleigh; coraciiform bird; dummy10; serpentes; rig; vessel, watercraft; cycles; condiment; dummy13; flower; cephalopod, cephalopod mollusk; ratite, ratite bird, flightless bird; reef; spring, fountain, outflow, outpouring, natural spring; apodiform bird; dish; marsupial, pouched mammal; dummy15; tableware; bird of prey, raptor, raptorial bird; measuring instrument, measuring system, measuring device; lamp; passerine, passeriform bird; shore; photographic equipment; home appliance, household appliance; edentate; trilobite; dummy50; bedroom furniture; tank, storage tank; dummy12; armor; dummy7; saurian; weapon, arm, weapon system; dummy72; dummy57; cart; bar; dummy74; padding, cushioning.

where, dummy8 is European fire salamander, *Salamandra salamandra*; eft; common newt, *Triturus vulgaris*; spotted salamander, *Ambystoma maculatum*; axolotl, mud puppy, *Ambystoma mexicanum*. dummy6 is African grey, African gray, *Psittacus erithacus*; sulphur-crested cockatoo, *Kakatoe galerita*, *Cacatua galerita*; lorikeet; macaw. dummy52 is plastic bag; purse; backpack, back pack, knapsack, packsack, rucksack, haversack; mailbag, postbag. dummy53 is buckle. dummy79 is chest. dummy0 is cock. dummy68 is cliff, drop, drop-off. dummy77 is brass, memorial tablet, plaque; triumphal arch; megalith, megalithic structure. dummy69 is promontory, headland, head, foreland. dummy67 is fountain. dummy73 is viaduct; suspension bridge; steel arch bridge. dummy14 is flatworm, platyhelminth. dummy34 is mask; sunglasses, dark glasses, shades; gasmask, respirator, gas helmet; ski mask. dummy1 is hen. dummy19 is gyromitra. dummy51 is crutch. dummy71 is valley, vale. dummy11 is starfish, sea star. dummy39 is scabbard; holster. dummy56 is shower curtain; theater curtain, theatre curtain. dummy78 is totem pole; pedestal, plinth, footstall; obelisk. dummy10 is jellyfish. dummy9 is ringneck snake, ring-necked snake, ring snake; king snake, kingsnake; thunder snake, worm snake, *Carphophis amoenus*; green mamba; boa constrictor, *Constrictor constrictor*; vine snake; garter snake, grass snake; horned viper, cerastes, sand viper, horned asp, *Cerastes cornutus*; diamondback, diamondback rattlesnake, *Crotalus adamanteus*; hognose snake, puff adder, sand viper; sidewinder, horned rattlesnake, *Crotalus cerastes*; Indian cobra, *Naja naja*; sea snake; water snake; green snake, grass snake; night snake, *Hypsiglena torquata*; rock python, rock snake, *Python sebae*. dummy30 is mountain bike, all-terrain bike, off-roader; unicycle, monocycle; tricycle, trike, velocipede; bicycle-built-for-two, tandem bicycle, tandem. dummy13 is sea urchin. dummy15 is nematode, nematode worm,

roundworm. dummy50 is handkerchief, hankie, hanky, hankey. dummy12 is sea cucumber, holothurian. dummy35 is chain mail, ring mail, mail, chain armor, chain armour, ring armor, ring armour; breastplate, aegis, egis; cuirass; bulletproof vest. dummy7 is tree frog, tree-frog; bullfrog, *Rana catesbeiana*; tailed frog, bell toad, ribbed toad, tailed toad, *Ascaphus trui*. dummy72 is traffic light, traffic signal, stoplight; scoreboard; street sign. dummy57 is umbrella. dummy74 is maze, labyrinth.

4. Level 5 contains 466 superclasses - jellyfish; owl, bird of Minerva, bird of night, hooter; coral fungus; screwdriver; rotisserie; sharpener; dummy45; flatworm, platyhelminth; car, railcar, railway car, railroad car; timepiece, timekeeper, horologe; bottle; chest of drawers, chest, bureau, dresser; eel; towel; fan; sandbar, sand bar; tripod; orchid, orchidaceous plant; squirrel; sturgeon; plate rack; hip, rose hip, rosehip; cicada, cicala; balloon; otter; plate; seashore, coast, seacoast, sea-coast; phasianid; rabbit, coney, cony; warthog; opener; plow, plough; bun, roll; dip; compass; lemur; rug, carpet, carpeting; waffle iron; alp; gymnastic apparatus, exerciser; wild dog; pudding, pud; junco, snowbird; harvestman, daddy longlegs, *Phalangium opilio*; column, pillar; horse cart, horse-cart; earthstar; mug; bookcase; leafhopper; lesser panda, red panda, panda, bear cat, cat bear, *Ailurus fulgens*; window shade; punch; mercantile establishment, retail store, sales outlet, outlet; banister, banister, balustrade, balusters, handrail; espresso; cheetah, chetah, *Acinonyx jubatus*; clog, geta, patten, sabot; acorn; platypus, duckbill, duck-billed platypus, duck-billed platypus, *Ornithorhynchus anatinus*; mink; remote control, remote; percussion instrument, percussive instrument; hyena, *hyaena*; duck; dam, dike, dyke; parrot; wine, vino; alligator, gator; abacus; spatula; spectacles, specs, eyeglasses, glasses; curtain, drape, drapery, mantle, pall; memorial, monument; snipe; sock; buckeye, horse chestnut, conker; monitor; glove; sheath; mosquito net; brambling, *Fringilla montifringilla*; beaver; snorkel; armadillo; crayfish, crawfish, crawdad, crawdaddy; strawberry; space heater; cricket; custard apple; computer keyboard, keypad; telephone, phone, telephone set; black-footed ferret, ferret, *Mustela nigripes*; robin, American robin, *Turdus migratorius*; titmouse, tit; amphibian, amphibious vehicle; tape player; bobsled, bobsleigh, bob; toaster; penguin; cuckoo; magpie; bed; hamster; coral; cannon; mat; snail; home theater, home theatre; wind instrument, wind; goldfish, *Carassius auratus*; undergarment, unmentionable; patio, terrace; tank, army tank, armored combat vehicle, armoured combat vehicle; snowmobile; pin; oystercatcher, oyster catcher; mongoose; scarf; gyromitra; isopod; swan; adhesive bandage; firearm, piece, small-arm; water ouzel, dipper; bell cote, bell cot; boot; dummy46; snake, serpent, ophidian; albatross, mollymawk; damselfly; marmot; weasel; coffee maker; submarine, pigboat, sub, U-boat; saltshaker, salt shaker; cap; beetle; slug; lock; whale; wild boar, boar, *Sus scrofa*; ray; makeup, make-up, war paint; limpkin, *Aramus pictus*; geyser; measuring cup; lizard; jug; photocopier; radio, wireless; buckle; plunger, plumber's helper; hairpiece, false hair, postiche; potato, white potato, Irish potato, murphy, spud, tater; lion, king of beasts, *Panthera leo*; sloth, tree sloth; passenger train; shoe; dummy49; shovel; salmon;

stork; helmet; bustard; daisy; wardrobe, closet, press; desk; puffer, pufferfish, blowfish, globefish; cooker; tights, leotards; hen; mouse, computer mouse; dwelling, home, domicile, abode, habitation, dwelling house; reservoir; binoculars, field glasses, opera glasses; echidna, spiny anteater, anteater; jacamar; bag; entertainment center; fly; bow; skunk, polecat, wood pussy; domestic cat, house cat, *Felis domesticus*, *Felis catus*; dogsled, dog sled, dog sleigh; stew; cattle, cows, kine, oxen, *Bos taurus*; lighter, light, igniter, ignitor; dock, dockage, docking facility; tiger, *Panthera tigris*; porcupine, hedgehog; cream, ointment, emollient; chain saw, chainsaw; crab; lynx, catamount; knife; necktie, tie; monkey; broccoli; bib; stove; missile; sewing machine; car, auto, automobile, machine, motorcar; screw; grasshopper, hopper; chair; hare; display, video display; crane; lobster; audio system, sound system; bus, autobus, coach, charabanc, double-decker, jitney, motorbus, motorcoach, omnibus, passenger vehicle; outbuilding; jackfruit, jak, jack; lens cap, lens cover; apple; projectile, missile; coral reef; chest; meerkat, mierkat; spoon; crutch; mushroom; squash; coat; sheep; cliff, drop, drop-off; pot; television, television system; jaguar, panther, *Panthera onca*, *Felis onca*; scale, weighing machine; llama; acarine; sea slug, nudibranch; valley, vale; oxcart; bee eater; body armor, body armour, suit of armor, suit of armour, coat of mail, cataphract; rapeseed; window screen; lawn mower, mower; cucumber, cuke; fox; butterfly; racket, racquet; cassette player; grouse; hand blower, blow dryer, blow drier, hair dryer, hair drier; giant panda, panda, panda bear, coon bear, *Ailuropoda melanoleuca*; power drill; volcano; seal; pomegranate; refrigerator, icebox; toucan; horse, *Equus caballus*; salamander; damselfish, demoiselle; sea urchin; stinkhorn, carrion fungus; sweater, jumper; sandpiper; stocking; dummy⁴⁷; shoji; spoonbill; hummingbird; frozen dessert; stage; pizza, pizza pie; sea cow, sirenian mammal, sirenian; microscope; kangaroo; goldfinch, *Carduelis carduelis*; cougar, puma, catamount, mountain lion, painter, panther, *Felis concolor*; mantis, mantid; reel; fire screen, fireguard; iron, smoothing iron; jewelry, jewellery; bee; nail; heron; gar, garfish, garpike, billfish, *Lepisosteus osseus*; pelican; maze, labyrinth; projector; cracker; torch; phalanger, opossum, possum; sandwich; boat; fig; cauliflower; vulture; quilt, comforter, comfort, puff; cushion; factory, mill, manufacturing plant, manufactory; ear, spike, capitulum; CD player; pool table, billiard table, snooker table; barometer; ape; butterfly fish; modem; skirt; fountain; soup; sliding door; hippopotamus, hippo, river horse, *Hippopotamus amphibius*; indigo bunting, indigo finch, indigo bird, *Passerina cyanea*; groom, bridegroom; antelope; pepper; microwave, microwave oven; bowl; cabbage, chou; shirt; eagle, bird of Jove; wombat; paintbrush; Old World buffalo, buffalo; goose; stethoscope; microphone, mike; lacewing, lacewing fly; burrito; guinea pig, *Cavia cobaya*; elephant; washer, automatic washer, washing machine; scorpion; airship, dirigible; hair spray; handkerchief, hankie, hanky, hankey; spider; scuba diver; sofa, couch, lounge; dragonfly, darning needle, devil's darning needle, sewing needle, snake feeder, snake doctor, mosquito hawk, skeeter hawk; breakwater, groin, groyne, mole, bulwark, seawall, jetty; jinrikisha, ricksha, rick-

shaw; locomotive, engine, locomotive engine, railway locomotive; toilet seat; roof; knee pad; dishrag, dishcloth; keyboard instrument; hat, chapeau, lid; apron; streetcar, tram, tramcar, trolley, trolley car; tricycle, trike, velocipede; shark; table lamp; banana; jay; clip; ski; baby bed, baby's bed; ball; barracouta, snoek; weight, free weight, exercising weight; fence, fencing; nematode, nematode worm, roundworm; lampshade, lamp shade; unicycle, monocycle; hermit crab; camel; frog, toad, toad frog, anuran, batrachian, salientian; sauce; promontory, headland, head, foreland; bridge, span; motorcycle, bike; ballplayer, baseball player; artichoke, globe artichoke; nightwear, sleepwear, nightclothes; orange; airplane, aeroplane, plane; place of worship, house of prayer, house of God, house of worship; polecat, fitch, foulmart, fountmart, *Mustela putorius*; potpie; sea cucumber, holothurian; oscilloscope, scope, cathode-ray oscilloscope, CRO; camera, photographic camera; bear; house finch, linnet, *Carpodacus mexicanus*; starfish, sea star; dining table, board; wild sheep; badger; mushroom; pen; carpenter's kit, tool kit; scorpaenid, scorpaenid fish; digital computer; zebra; pineapple, ananas; drilling platform, offshore rig; truck, motortruck; signboard, sign; cock; bison; vacuum, vacuum cleaner; nightingale, *Luscinia megarhynchos*; hornbill; military uniform; cabinet; perfume, essence; chambered nautilus, pearly nautilus, nautilus; lakeside, lakeshore; cardoon; snow leopard, ounce, *Panthera uncia*; meat loaf, meatloaf; dress, frock; wolf; dishwasher, dish washer, dishwashing machine; brace; tray; tower; eraser; ostrich, *Struthio camelus*; theater, theatre, house; glass, drinking glass; warplane, military plane; sea anemone, anemone; hog, pig, grunter, squealer, *Sus scrofa*; ant, emmet, pismire; bicycle, bike, wheel, cycle; crocodile; lemon; leopard, *Panthera pardus*; meter; dinosaur; suit, suit of clothes; hammer; goat, caprine animal; trouser, pant; cockroach, roach; half track; loaf of bread, loaf; conch; gallinule, marsh hen, water hen, swamphen; dog, domestic dog, *Canis familiaris*; turtle; gate; corn; flamingo; face mask; hawk; ladle; pan, cooking pan; cocktail shaker; umbrella; rail; space shuttle; printer; stringed instrument; syringe; swimsuit, swimwear, bathing suit, swimming costume, bathing costume; measuring stick, measure, measuring rod; handcart, pushcart, cart, go-cart; ship; plover; joystick; walking stick, walkingstick, stick insect; tench, *Tinca tinca*; telescope, scope. where, dummy45 is library. dummy46 is planetarium. dummy49 is restaurant, eating house, eating place, eatery. dummy47 is prison, prison house. dummy20 is hen-of-the-woods, hen of the woods, *Polyporus frondosus*, *Gri-fola frondosa*; agaric; bolete.

5. Level 6 contains 591 superclasses - German shepherd, German shepherd dog, German police dog, alsatian; hen-of-the-woods, hen of the woods, *Polyporus frondosus*, *Gri-fola frondosa*; Maltese dog, Maltese terrier, Maltese; pirate, pirate ship; cellular telephone, cellular phone, cellphone, cell, mobile phone; red fox, *Vulpes vulpes*; Dandie Dinmont, Dandie Dinmont terrier; sweet pepper; suspension bridge; spotted salamander, *Ambystoma maculatum*; kuvasz; coho, coho, coho salmon, blue jack, silver salmon, *Oncorhynchus kisutch*; violin, fiddle; gown; lory; schooner; organ, pipe organ; Saluki, gazelle hound; hot pot, hotpot; Border collie; briard; Windsor tie;

kite; Norwich terrier; mask; china cabinet, china closet; water jug; tractor; bonnet, poke bonnet; vault; boxer; Bernese mountain dog; tarantula; Tibetan terrier, chrysanthemum dog; marmoset; ice cream, icecream; eggnog; cloak; king crab, Alaska crab, Alaskan king crab, Alaska king crab, Paralithodes camtschatica; python; rail fence; accordion, piano accordion, squeeze box; birdhouse; Samoyed, Samoyede; caldron, cauldron; winter squash; night snake, *Hypsiglena torquata*; fox squirrel, eastern fox squirrel, *Sciurus niger*; agaric; head cabbage; thunder snake, worm snake, *Carphophis amoenus*; Arabian camel, dromedary, *Camelus dromedarius*; padlock; stingray; Australian terrier; dalmatian, coach dog, carriage dog; shower curtain; spiny lobster, langouste, rock lobster, crawfish, crayfish, sea crawfish; minibike, motorbike; lipstick, lip rouge; fox terrier; Egyptian cat; egret; cornet, horn, trumpet, trump; tow truck, tow car, wrecker; ski mask; espresso maker; Rottweiler; pickelhaube; vizsla, Hungarian pointer; basenji; kit fox, *Vulpes macrotis*; frying pan, frypan, skillet; whiskey jug; automatic firearm, automatic gun, automatic weapon; weevil; safety pin; cardigan; coyote, prairie wolf, brush wolf, *Canis latrans*; Shih-Tzu; siamang, *Hylobates syndactylus*, *Symphalangus syndactylus*; redshank, *Tringa totanus*; Eskimo dog, husky; West Highland white terrier; dugong, *Dugong dugon*; timer; harmonica, mouth organ, harp, mouth harp; malamute, malemute, Alaskan malamute; laptop, laptop computer; red wolf, maned wolf, *Canis rufus*, *Canis niger*; bulbul; mamba; chiffonier, commode; shoe shop, shoe-shop, shoe store; axolotl, mud puppy, *Ambystoma mexicanum*; mosque; black and gold garden spider, *Argiope aurantia*; snowplow, snowplough; red wine; bulletproof vest; hognose snake, puff adder, sand viper; recreational vehicle, RV, R.V.; bagel, beigel; Ibizan hound, Ibizan Podenco; street sign; ballpoint, ballpoint pen, ballpen, Biro; lumbermill, sawmill; king snake, kingsnake; kelpie; rifle; cup; picket fence, paling; golf ball; bakery, bakeshop, bakehouse; trolleybus, trolley coach, trackless trolley; Gordon setter; indri, indris, *Indri indri*, *Indri brevicaudatus*; tailed frog, bell toad, ribbed toad, tailed toad, *Ascaphus trui*; lotion; fountain pen; black-and-tan coonhound; cobra; cowboy hat, ten-gallon hat; ringneck snake, ring-necked snake, ring snake; wreck; loudspeaker, speaker, speaker unit, loudspeaker system, speaker system; partridge; dial telephone, dial phone; electric fan, blower; bloodhound, sleuthhound; wallaby, brush kangaroo; iguanid, iguanid lizard; sailboat, sailing boat; dome; Greater Swiss Mountain dog; airliner; cab, hack, taxi, taxicab; macaque; sandal; sulphur butterfly, sulfur butterfly; spaghetti sauce, pasta sauce; bathing cap, swimming cap; gibbon, *Hylobates lar*; African elephant, *Loxodonta africana*; soup bowl; miniature pinscher; bittern; pullover, slipover; mobile home, manufactured home; purple gallinule; Band Aid; Italian greyhound; cockatoo; poncho; Doberman, Doberman pinscher; prairie chicken, prairie grouse, prairie fowl; hammerhead, hammerhead shark; capuchin, ringtail, *Cebus capucinus*; purse; lifeboat; poodle, poodle dog; French horn, horn; shower cap; grey whale, gray whale, devilfish, *Eschrichtius gibbosus*, *Eschrichtius robustus*; sloth bear, *Melursus ursinus*, *Ursus ursinus*; tabby, tabby cat; African hunting dog, hyena dog, Cape

hunting dog, *Lycaon pictus*; drum, membranophone, tympan; church, church building; pencil sharpener; long-horned beetle, longicorn, longicorn beetle; canoe; Persian cat; folding chair; green snake, grass snake; prison, prison house; rock crab, *Cancer irroratus*; ocarina, sweet potato; gecko; box turtle, box tortoise; timber wolf, grey wolf, gray wolf, *Canis lupus*; overskirt; screen, CRT screen; wirehair, wirehaired terrier, wire-haired terrier; wig; English foxhound; tree frog, tree-frog; thatch, thatched roof; ibex, *Capra ibex*; pajama, pyjama, pj's, jammies; harp; pistol, handgun, side arm, shooting iron; Lhasa, Lhasa apso; brass, memorial tablet, plaque; Weimaraner; wooden spoon; tiger cat; terrapin; fire engine, fire truck; library; fireboat; bolo tie, bolo, bola tie, bola; lady's slipper, lady-slipper, ladies' slipper, slipper orchid; electric ray, crampfish, numbfish, torpedo; Norfolk terrier; vestment; pipe; coffee mug; racer, race car, racing car; scarabaeid beetle, scarabaeid, scarabaeid; red-bone; totem pole; miniskirt, mini; Boston bull, Boston terrier; swimming trunks, bathing trunks; barber chair; file, file cabinet, filing cabinet; grocery store, grocery, food market, market; limousine, limo; punching bag, punch bag, punching ball, punchball; face powder; balance beam, beam; warship, war vessel, combat ship; scoreboard; guacamole; hand-held computer, hand-held microcomputer; four-poster; neck brace; dowitcher; sports car, sport car; komondor; pay-phone, pay-station; wok; barrow, garden cart, lawn cart, wheelbarrow; fur coat; anguid lizard; Pekinese, Pekingese, Peke; grey fox, gray fox, *Urocyon cinereoargenteus*; little blue heron, *Egretta caerulea*; rugby ball; anemone fish; eating apple, dessert apple; maillot; Labrador retriever; raincoat, waterproof; Brittany spaniel; pickup, pickup truck; tick; vine snake; bikini, two-piece; langur; odometer, hodometer, mileometer, milometer; croquet ball; running shoe; convertible, sofa bed; theater curtain, theatre curtain; pug, pug-dog; pop bottle, soda bottle; breastplate, aegis, egis; kimono; white stork, *Ciconia ciconia*; ladybug, ladybeetle, lady beetle, ladybird, ladybird beetle; palace; koala, koala bear, kangaroo bear, native bear, *Phascogaleos cinereus*; true frog, ranid; Irish setter, red setter; schipperke; chameleon, chamaeleon; triumphal arch; tiger beetle; garden spider, *Aranea diademata*; Rhodesian ridgeback; great grey owl, great gray owl, *Strix nebulosa*; Crock Pot; golfcart, golf cart; maraca; soccer ball; colobus, colobus monkey; bath towel; bow tie, bow-tie, bowtie; steam locomotive; summer squash; water bottle; bicycle-built-for-two, tandem bicycle, tandem; Afghan hound, Afghan; ptarmigan; toy terrier; yurt; European fire salamander, *Salamandra atra*; water tower; red-backed sandpiper, dunlin, *Erolia alpina*; restaurant, eating house, eating place, eatery; stole; ping-pong ball; minivan; academic gown, academic robe, judge's robe; steel drum; gorilla, *Gorilla gorilla*; cello, violoncello; wood rabbit, cottontail, cottontail rabbit; rock beauty, *Holocanthus tricolor*; black grouse; toyshop; garter snake, grass snake; trailer truck, tractor trailer, trucking rig, rig, articulated lorry, semi; rubber eraser, rubber, pencil eraser; hamburger, beefburger, burger; black widow, *Latrodectus mactans*; goblet; quill, quill pen; school bus; sax, saxophone; hair slide; ram, tup; steel arch bridge; magnetic compass; Walker hound, Walker fox-

hound; lycaenid, lycaenid butterfly; Irish wolfhound; agamid, agamid lizard; cliff dwelling; impala, *Aepyceros melampus*; EntleBucher; sarong; jersey, T-shirt, tee shirt; fiddler crab; Scotch terrier, Scottish terrier, Scottie; curly-coated retriever; ice bear, polar bear, *Ursus Maritimus*, *Thalarctos maritimus*; sea lion; rule, ruler; crash helmet; medicine chest, medicine cabinet; shopping cart; chocolate sauce, chocolate syrup; gondola; barn; wolf spider, hunting spider; Yorkshire terrier; ruffed grouse, partridge, *Bonasa umbellus*; rocking chair, rocker; freight car; go-kart; Mexican hairless; bolete; obelisk; speedboat; horned viper, cerastes, sand viper, horned asp, *Cerastes cornutus*; barbell; Great Pyrenees; lab coat, laboratory coat; Model T; mashed potato; flat-coated retriever; bullet train, bullet; black stork, *Ciconia nigra*; mitten; greenhouse, nursery, glasshouse; Loafer; sunscreen, sunblock, sun blocker; passenger car, coach, carriage; coot; Sussex spaniel; Dungeness crab, *Cancer magister*; Leonberg; Madagascar cat, ring-tailed lemur, *Lemur catta*; tobacco shop, tobacconist shop, tobacconist; jean, blue jean, denim; parallel bars, bars; scabbard; Angora, Angora rabbit; combination lock; dumbbell; collie; watch, ticker; sundial; hartebeest; prayer rug, prayer mat; American black bear, black bear, *Ursus americanus*, *Euarctos americanus*; football helmet; pierid, pierid butterfly; Norwegian elkhound, elkhound; iPod; king penguin, *Aptenodytes patagonica*; chair of state; guenon, guenon monkey; water spaniel; shrine; traffic light, traffic signal, stoplight; Arctic fox, white fox, *Alopex lagopus*; Siamese cat, Siamese; notebook, notebook computer; toy spaniel; patas, hussar monkey, *Erythrocebus patas*; spider monkey, *Ateles geoffroyi*; cocker spaniel, English cocker spaniel, cocker; barber-shop; chickadee; water buffalo, water ox, Asiatic buffalo, *Bubalus bubalis*; cinema, movie theater, movie theatre, movie house, picture palace; moving van; soft-coated wheaten terrier; forklift; Chihuahua; Pomeranian; corgi, Welsh corgi; ruddy turnstone, *Arenaria interpres*; bassinet; peacock; jeep, landrover; sea snake; lacertid lizard, lacertid; mountain bike, all-terrain bike, off-roader; cairn, cairn terrier; necklace; barn spider, *Araneus cavaticus*; Kerry blue terrier; Polaroid camera, Polaroid Land camera; macaw; bull-terrier, bull terrier; Saint Bernard, St Bernard; desktop computer; sand-glass; can opener, tin opener; mountain sheep; flute, transverse flute; chain mail, ring mail, mail, chain armor, chain armour, ring armor, ring armour; chow, chow chow; tile roof; bull mastiff; Indian elephant, *Elephas maximus*; American alligator, *Alligator mississippiensis*; paper towel; sorrel; howler monkey, howler; Japanese spaniel; cleaver, meat cleaver, chopper; minibus; Great Dane; pedestal, plinth, footstall; silky terrier, Sydney silky; proboscis monkey, *Nasalis larvatus*; Siberian husky; convertible; quail; police van, police wagon, paddy wagon, patrol wagon, wagon, black Maria; merganser, fish duck, sawbill, sheldrake; marimba, xylophone; Airedale, Airedale terrier; abaya; springer spaniel, springer; piano, pianoforte, forte-piano; African grey, African gray, *Psittacus erithacus*; beer bottle; hand glass, simple microscope, magnifying glass; titi, titi monkey; African crocodile, Nile crocodile, *Crocodylus niloticus*; lionfish; gong, tam-tam; mortarboard; griffon, Brussels

griffon, Belgian griffon; Dutch oven; megalith, megalithic structure; newt, triton; Newfoundland, Newfoundland dog; bookshop, bookstore, bookstall; clock; beagle; plastic bag; pillow; orangutan, orang, orangutang, *Pongo pygmaeus*; Border terrier; coucal; sunglasses, dark glasses, shades; white wolf, Arctic wolf, *Canis lupus tundrarum*; danaid, danaid butterfly; passenger ship; feather boa, boa; chime, bell, gong; garbage truck, dustcart; consomme; rattlesnake, rattler; ringlet, ringlet butterfly; teapot; holster; baseball; guitar; bearskin, busby, shako; Irish terrier; reflex camera; water snake; golden retriever; ox; bald eagle, American eagle, *Haliaeetus leucocephalus*; trombone; doormat, welcome mat; bluetick; beacon, lighthouse, beacon light, pharos; trifle; bottle opener; gazelle; killer whale, killer, orca, grampus, sea wolf, *Orcinus orca*; hoopskirt, crinoline; brain coral; borzoi, Russian wolfhound; Scottish deerhound, deerhound; crib, cot; motor scooter, scooter; volleyball; affenpinscher, monkey pinscher, monkey dog; three-toed sloth, ai, *Bradypus tridactylus*; clumber, clumber spaniel; castle; planetarium; cowboy boot; mixing bowl; chimpanzee, chimp, *Pan troglodytes*; whippet; shed; gasmask, respirator, gas helmet; banjo; cradle; confectionery, confectionary, candy store; Old English sheepdog, bobtail; viaduct; yawl; English setter; German short-haired pointer; pretzel; Christmas stocking; radio telescope, radio reflector; sombrero; drake; cuirass; tiger shark, *Galeocerdo cuvieri*; leaf beetle, chrysomelid; ground beetle, carabid beetle; Belgian sheepdog, Belgian shepherd; dhole, *Cuon alpinus*; baboon; beach wagon, station wagon, wagon, estate car, beach waggon, station waggon, waggon; Bouvier des Flandres, Bouviers des Flandres; chainlink fence; basset, basset hound; Appenzeller; butcher shop, meat market; electric locomotive; maillot, tank suit; otterhound, otter hound; mailbag, postbag; ambulance; brown bear, bruin, *Ursus arctos*; Chesapeake Bay retriever; keeshond; true lobster; mastiff; basketball; bulldog, English bulldog; monitor, monitor lizard, varan; coffeepot; oboe, hautboy, hautbois; horizontal bar, high bar; black swan, *Cygnus atratus*; brassiere, bra, bandeau; schnauzer; great white shark, white shark, man-eater, man-eating shark, *Carcharodon carcharias*; wine bottle; sea turtle, marine turtle; nymphalid, nymphalid butterfly, brush-footed butterfly, four-footed butterfly; squirrel monkey, *Saimiri sciureus*; diaper, nappy, napkin; tennis ball; boa constrictor, Constrictor constrictor; ornithischian, ornithischian dinosaur; ice lolly, lolly, lollipop, popsicle; French loaf; monastery; Bedlington terrier; dingo, warrigal, warragal, *Canis dingo*; cargo ship, cargo vessel; backpack, back pack, knapsack, packsack, rucksack, haversack; venomous lizard; bassoon; teiid lizard, teiid; stone wall; bench; mud turtle; hotdog, hot dog, red hot; beer glass; turnstile; Shetland sheepdog, Shetland sheep dog, Shetland.

14 BREEDS dataset

In Tab. 3 we report the results on four ImageNet subpopulation datasets of BREEDS [26] (Entity13, Entity30, Living17, Nonliving26). These datasets are accompanied by class hierarchies re-calibrated by [26] such that classes on same hierarchy level are of the same visual granularity. More specifically,

1. Entity13 contains 13 superclasses - *garment; bird; reptile, reptilian; arthropod; mammal, mammalian; accessory, accoutrement, accouterment; craft; equipment; furniture, piece of furniture, article of furniture; instrument; man-made structure, construction; wheeled vehicle; produce, green goods, green groceries, garden truck.*
2. Entity30 contains 30 superclasses - *serpentes; passerine, passeriform bird; saurian; arachnid, arachnoid; aquatic bird; crustacean; carnivore; insect; ungulate, hoofed mammal; primate; bony fish; barrier; building, edifice; electronic equipment; footwear, legwear; garment; headdress, headgear; home appliance, household appliance; kitchen utensil; measuring instrument, measuring system, measuring device; motor vehicle, automotive vehicle; musical instrument, instrument; neckwear; sports equipment; tableware; tool; vessel, watercraft; dish; vegetable, veggie, veg; fruit.*
3. Living17 contains 17 superclasses - *salamander; turtle; lizard; snake, serpent, ophidian; spider; grouse; parrot; crab; dog, domestic dog, *Canis familiaris*; wolf; fox; domestic cat, house cat, *Felis domesticus*, *Felis catus*; bear; beetle; butterfly; ape; monkey.*
4. Nonliving26 contains 26 superclasses - *bag; ball; boat; body armor, body armour, suit of armor, suit of armour, coat of mail, cataphract; bottle; bus, autobus, coach, charabanc, double-decker, jitney, motorbus, motorcoach, omnibus, passenger vehicle; car, auto, automobile, machine, motorcar; chair; coat; digital computer; dwelling, home, domicile, abode, habitation, dwelling house; fence, fencing; hat, chapeau, lid; keyboard instrument; mercantile establishment, retail store, sales outlet, outlet; outbuilding; percussion instrument, percussive instrument; pot; roof; ship; skirt; stringed instrument; timepiece, timekeeper, horologe; truck, motortruck; wind instrument, wind; squash.*