

ANIMAL DETECTION FOR PHOTOGRAPHIC CENSUSING



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November 10th, 2021

PhD Defense Outline

Introduction

Animal Detection Pipeline

Review of the 5-component detection pipeline

Additional detection components

Overview of Photographic Censusing

Required components & automated Lincoln-Petersen Index

Grevy's Zebra Census Dataset (GZCD)

Census Annotation

Census Annotation (CA) & Census Annotation Regions (CA-R)

User study on human reviews & simulations on human interaction

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Results from GGR-16, GGR-18

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Contributions & future work



Species of Zebra in Kenya

IUCN Red List
Near Threatened



Plains Zebra
(*Equus quagga*)

IUCN Red List
Endangered (2-3k left)



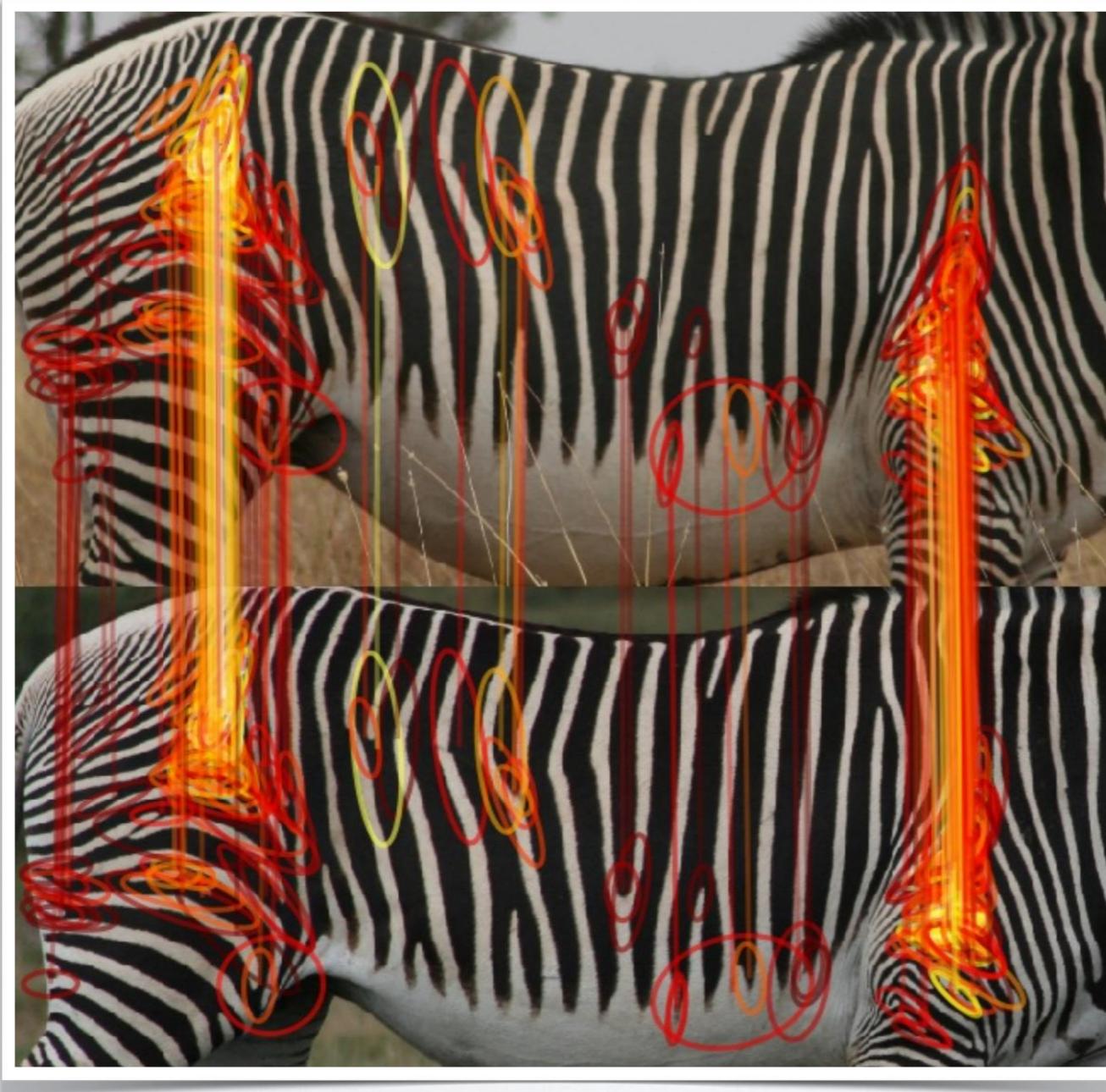
Grévy's Zebra
(*Equus grevyi*)

INTRODUCTION

Motivation



Motivation



Work by Dr. Jonathan Crall

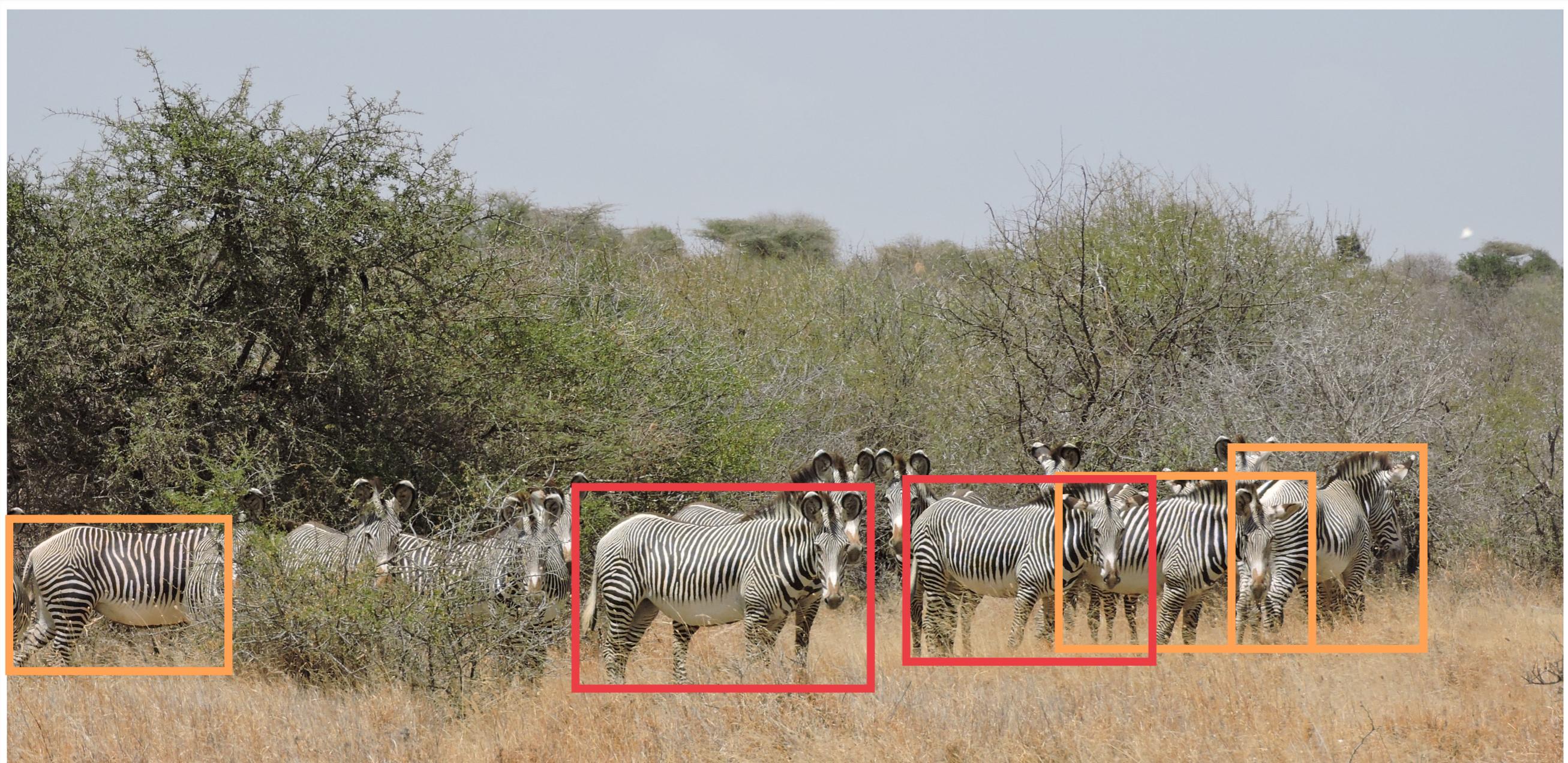
INTRODUCTION



Motivation



Motivation



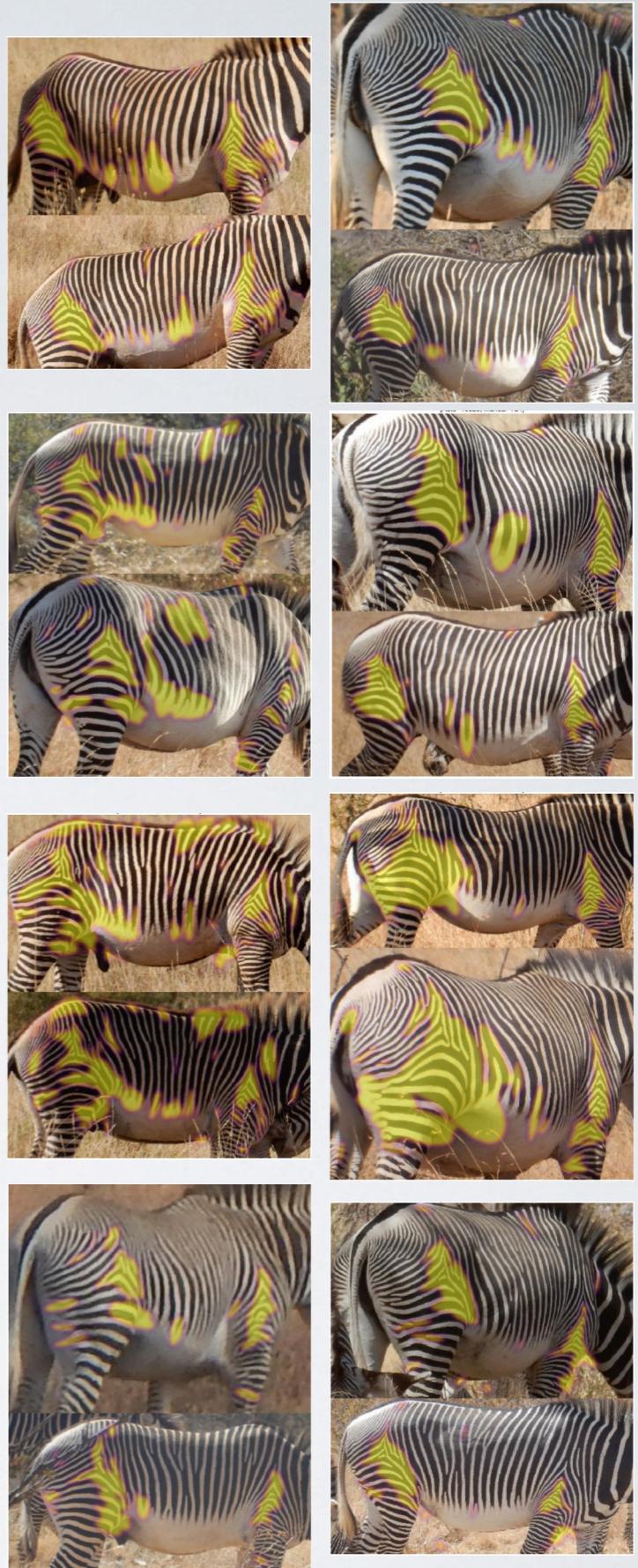


Motivation

Some automated ID algorithms will only match specific parts of an animal.

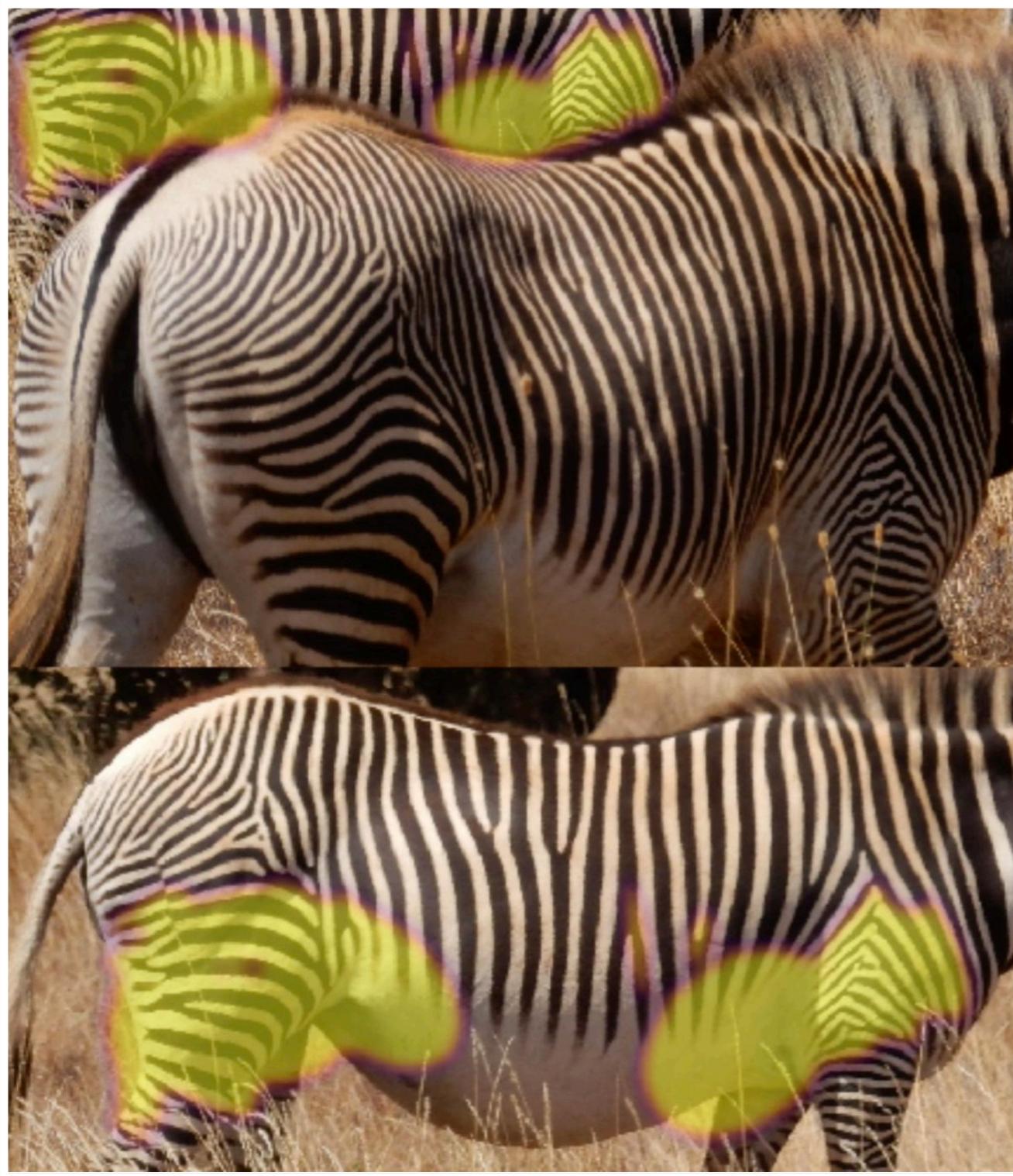
We can:

- improve accuracy
- reduce human involvement, and
- speed up human decision-making when automated animal detection can find these areas.



INTRODUCTION

Examples of Photobombs



Traditional vs Proposed Censusing

Traditional	Proposed
<i>invasive</i> ear notches, tags, radio collars, tranquil.	<i>passive</i> <u>appearance-based</u> by computer vision
<i>expensive</i> costs time/money, special equipment	<i>inexpensive</i> uses volunteers, no special hardware
<i>error-prone</i> human interaction, double-counting	<i>evidence-based</i> machine learning, data-driven
<i>one-time analysis</i> difficult to repeat, cannot audit	<i>recurring</i> resightings over time, ecological trends
Infeasible for large populations	Ideal for large populations



Motivation

- How can we effectively census an entire animal population while being minimally invasive?

Problem Statement

- Accurately produce a population estimate of an endangered species through photographs
- Reduce human interactions with automated decision-making for detection and ID curation

Solution

- A detection pipeline, CA, CA-R, and LCA curation algorithm can produce an accurate estimate with significantly less human effort

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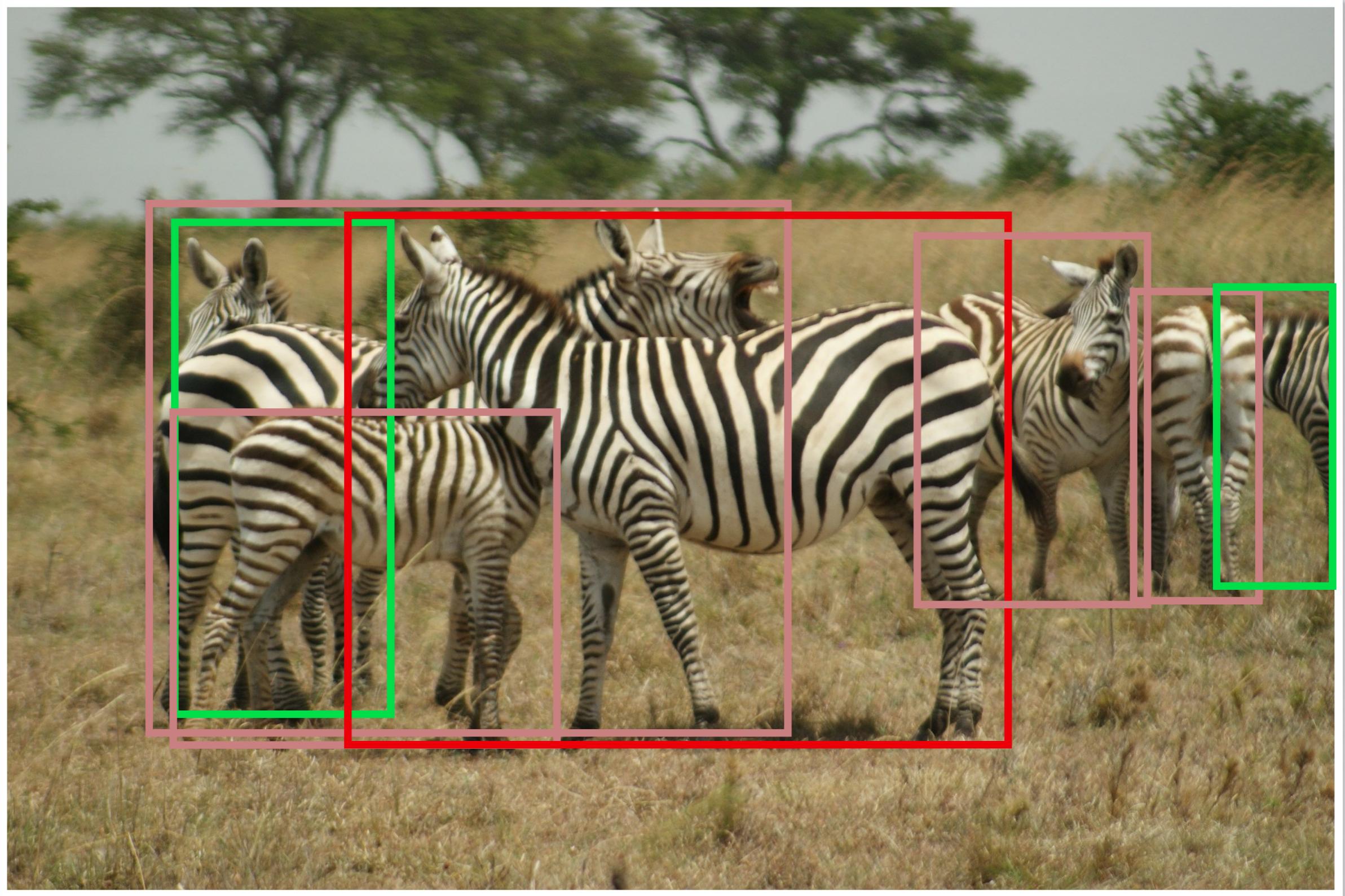
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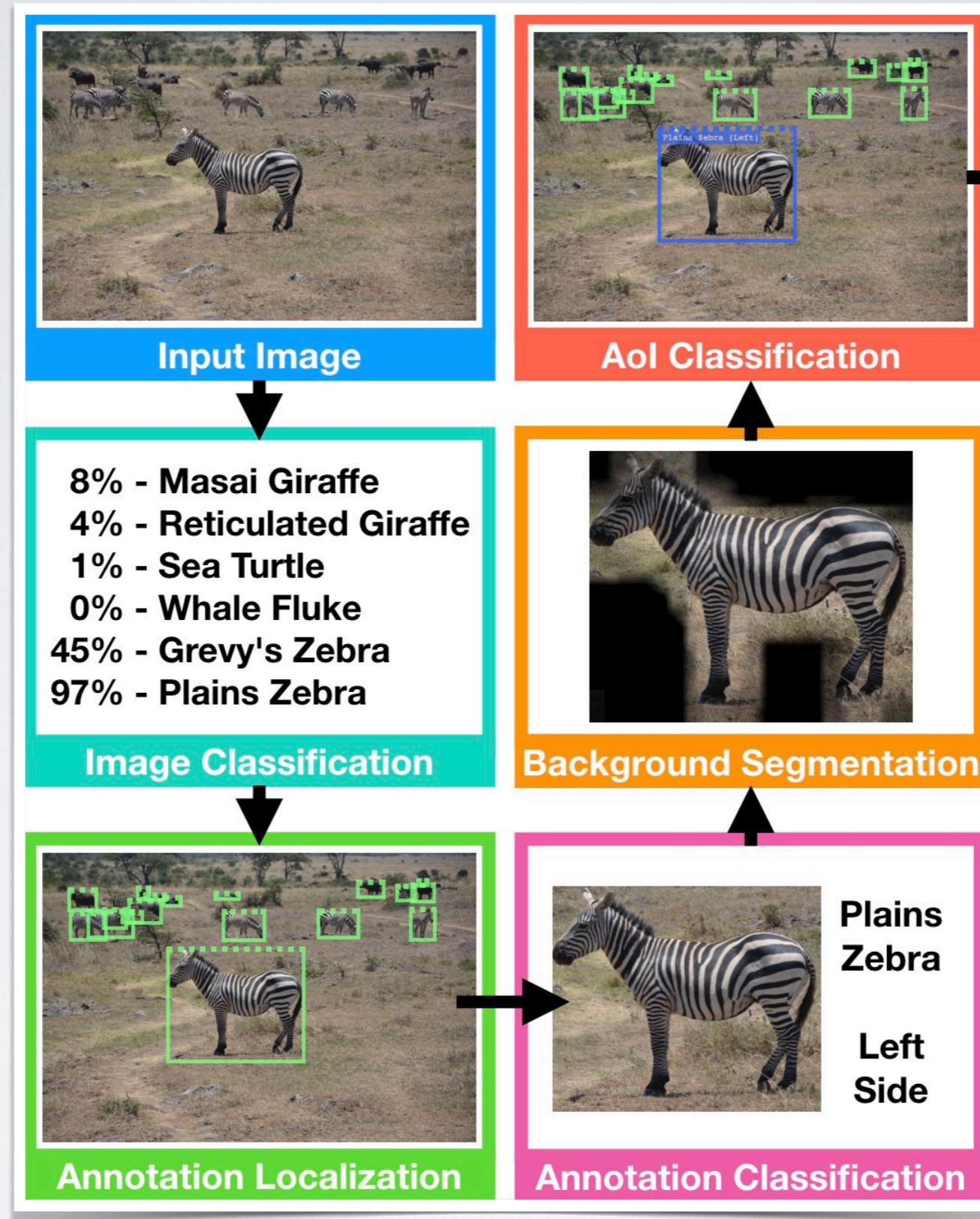
Example Detections for Plains Zebras



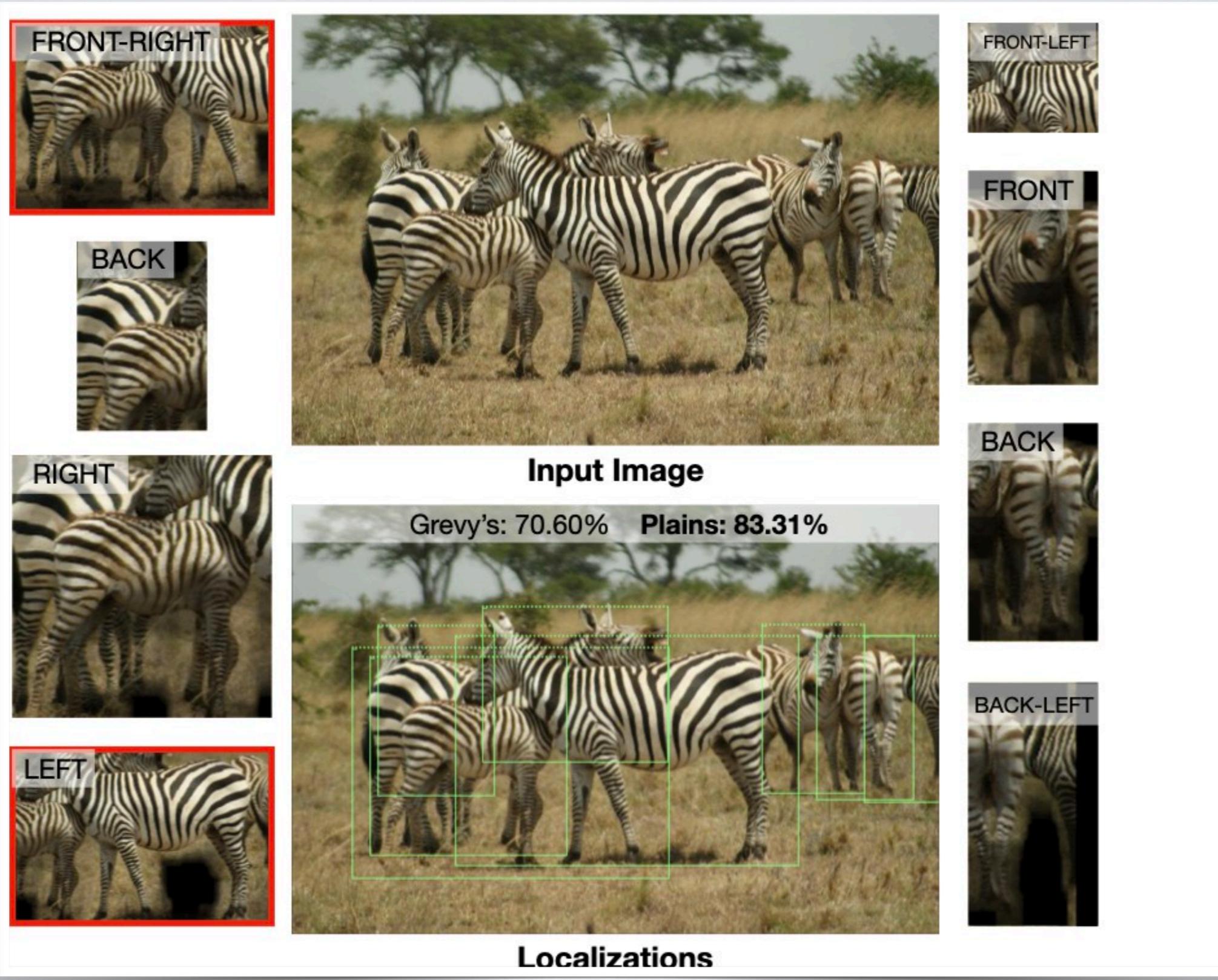
Example Detections for Plains Zebras



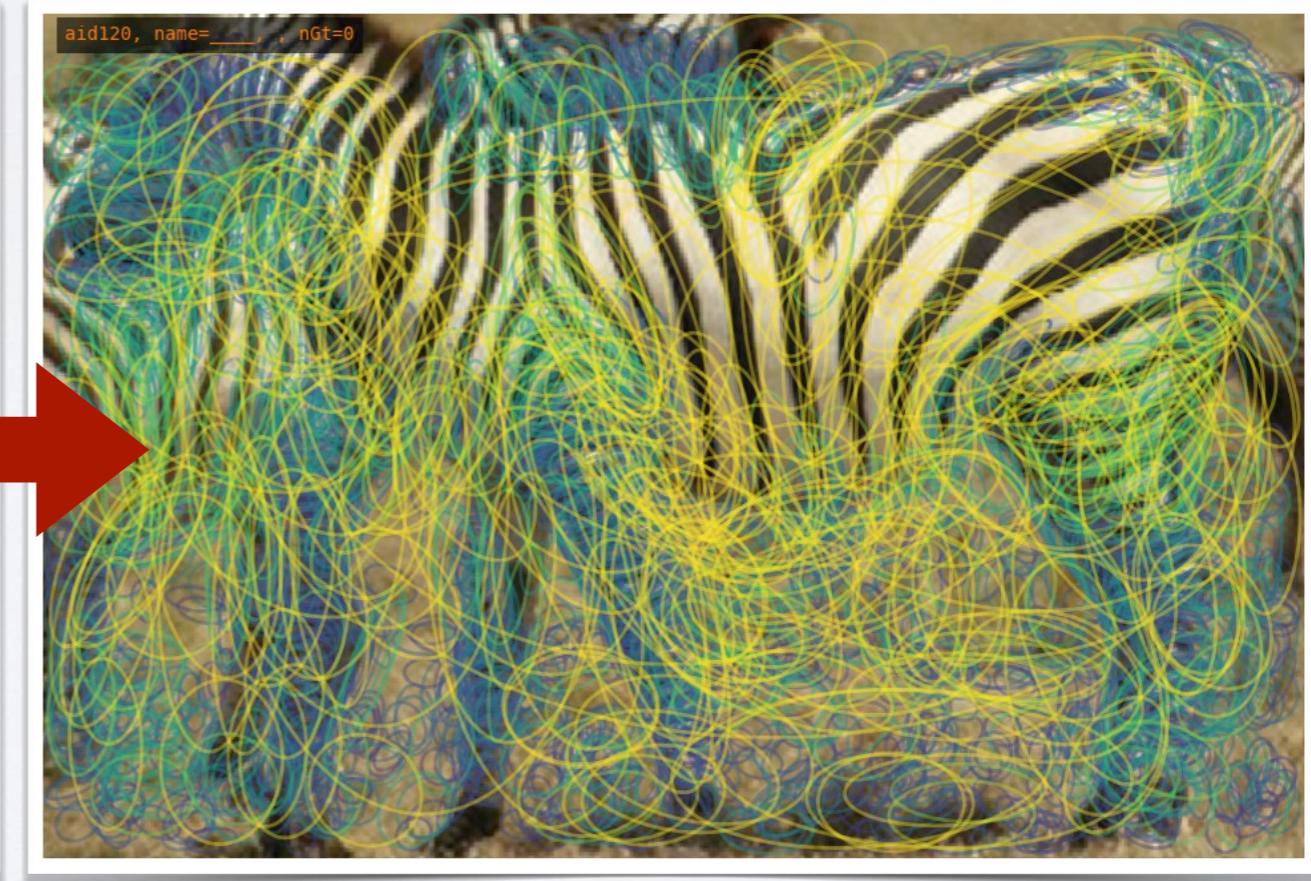
Detection Pipeline Overview



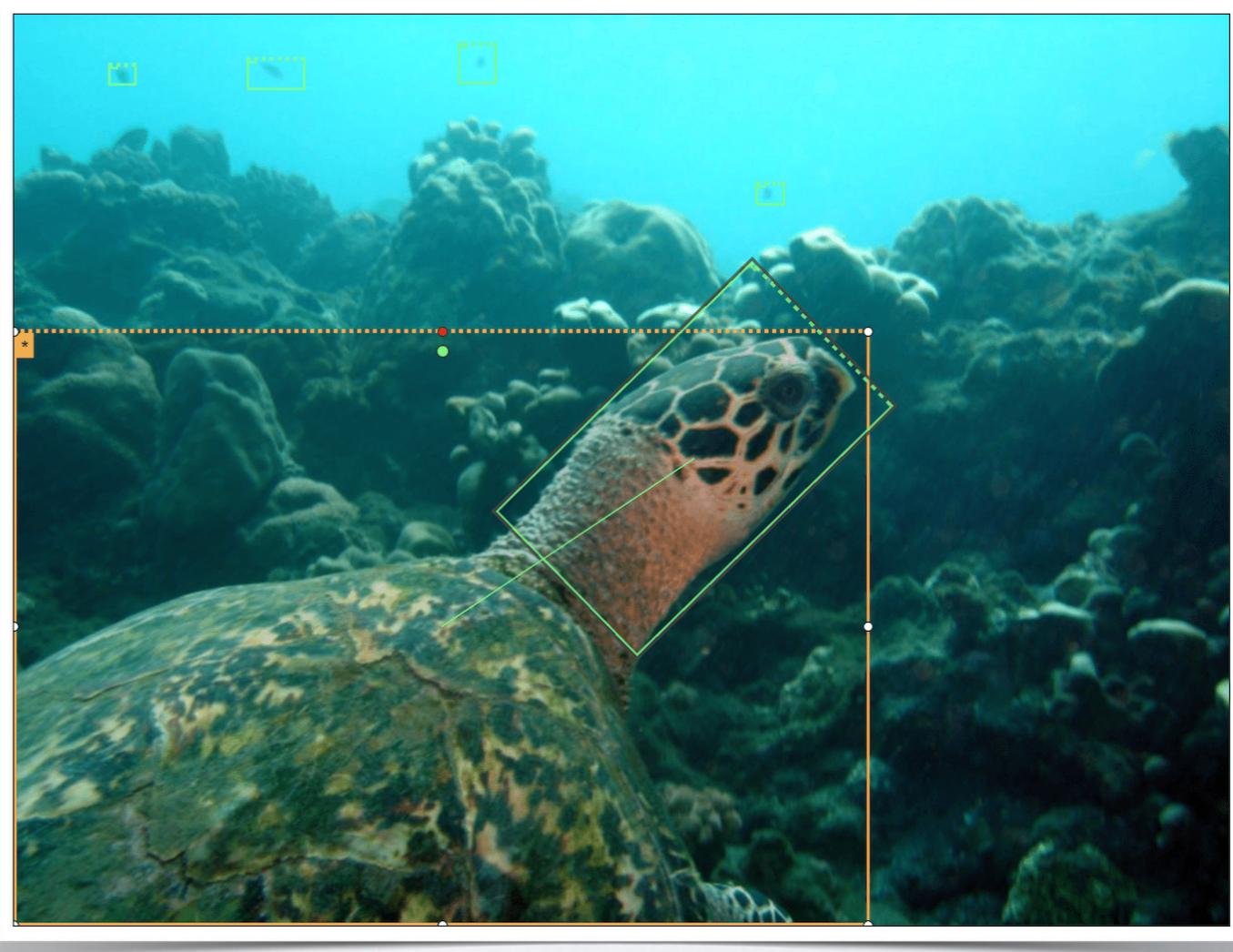
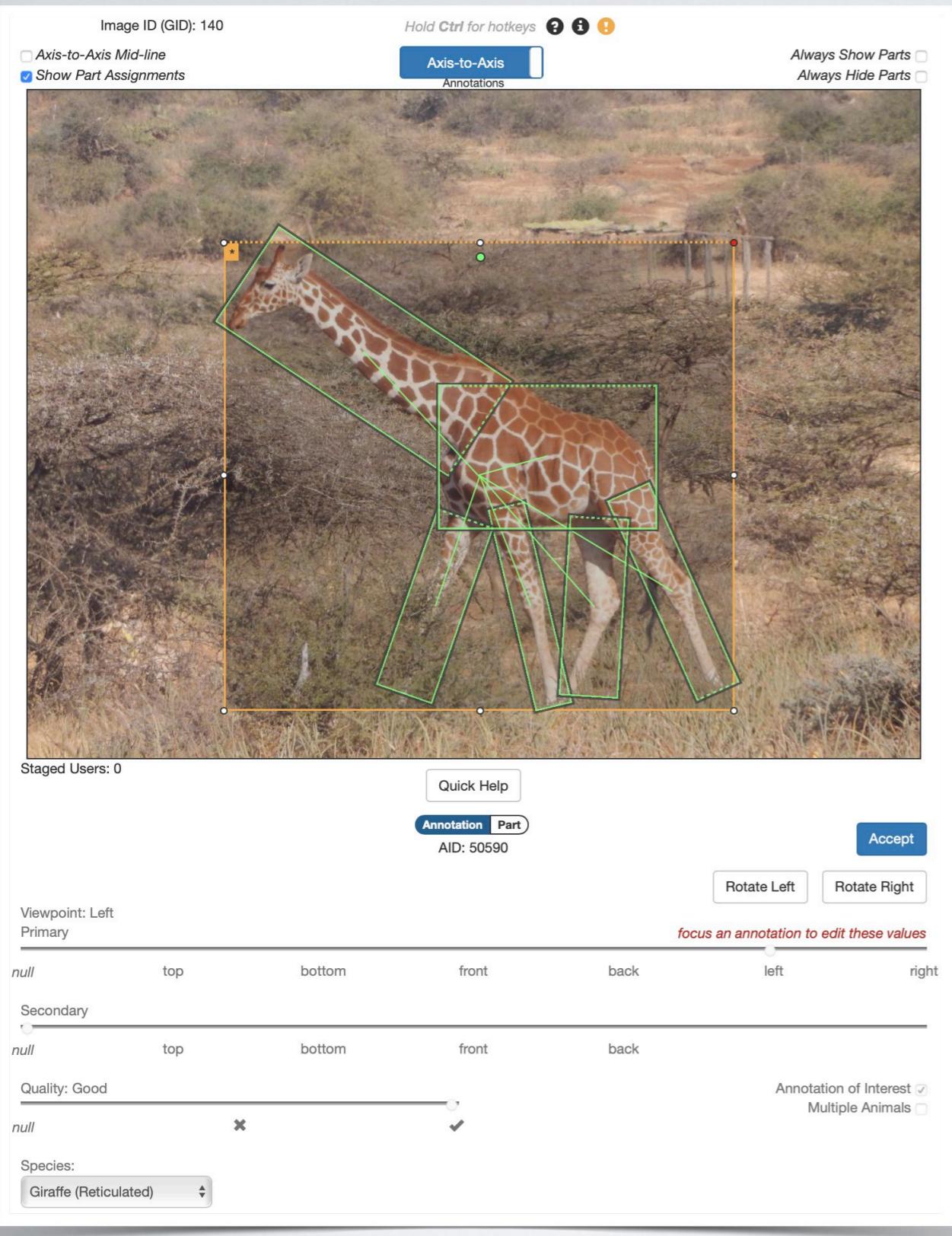
Detection Pipeline Example



Detection Pipeline Example



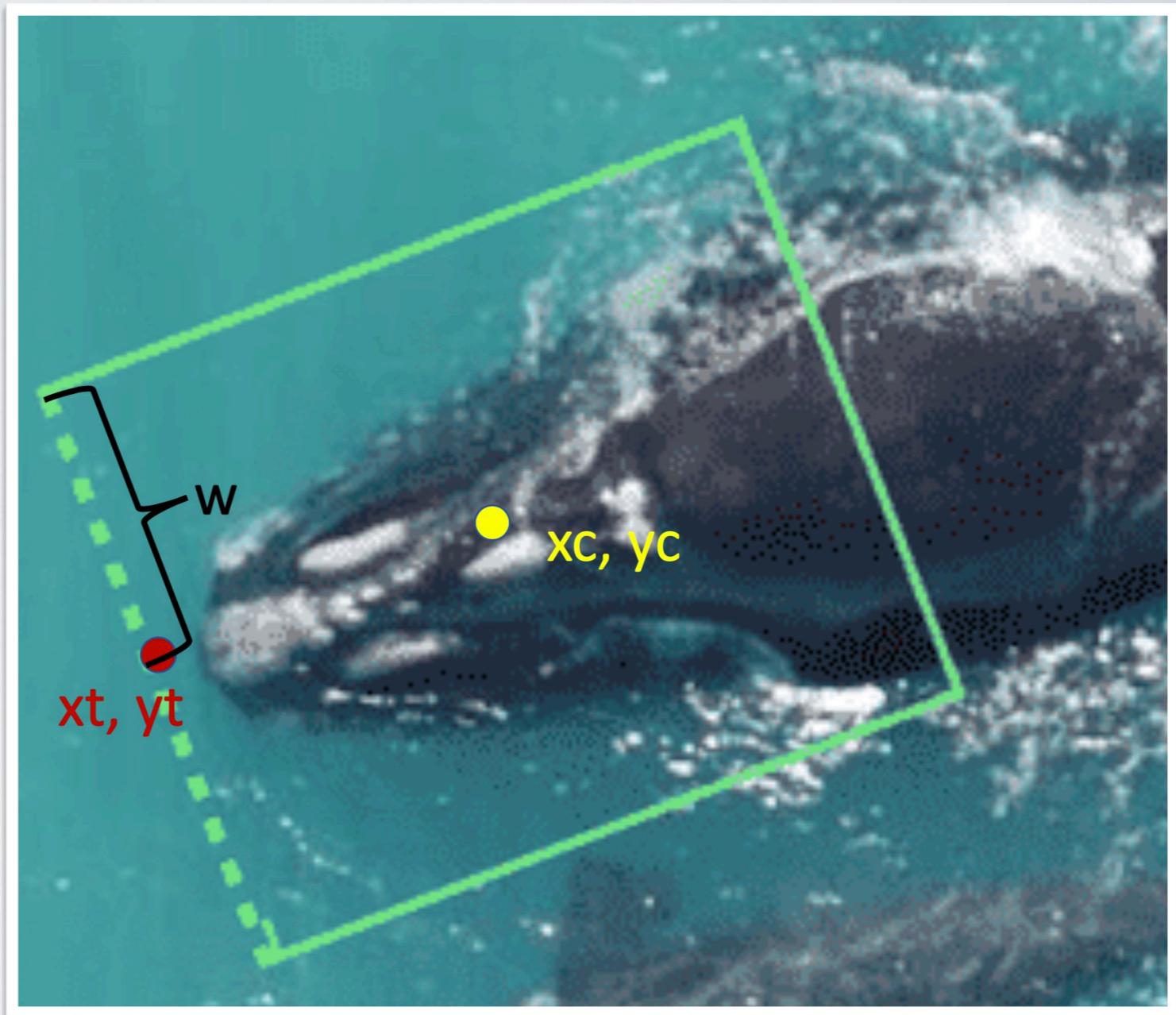
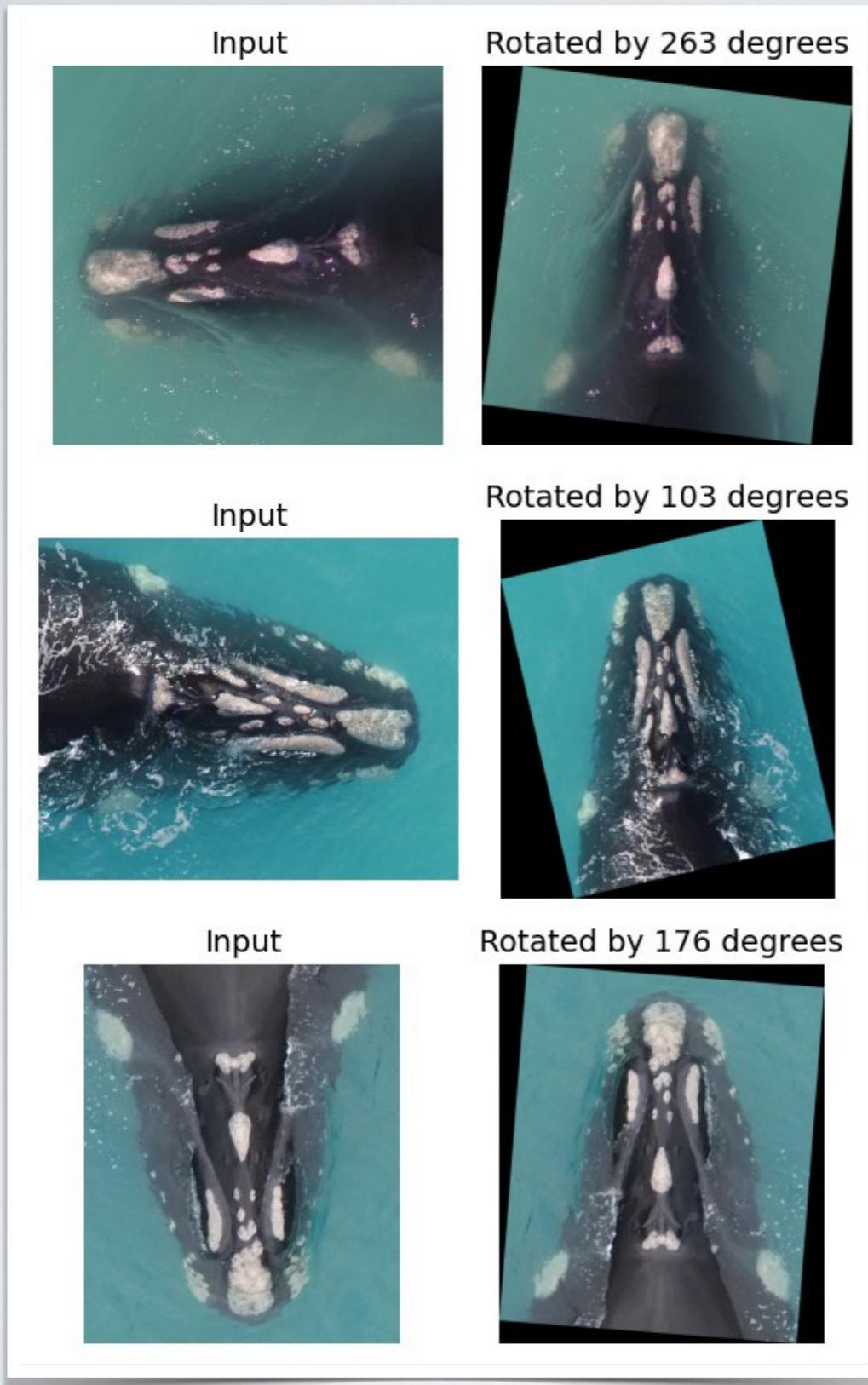
Additional Component - Part/Body Assignment



Assigning detected parts to parent annotations allows for ID info. to be associated between an animal's identifiable area (head) and its body.

Joint work with Drew Blount

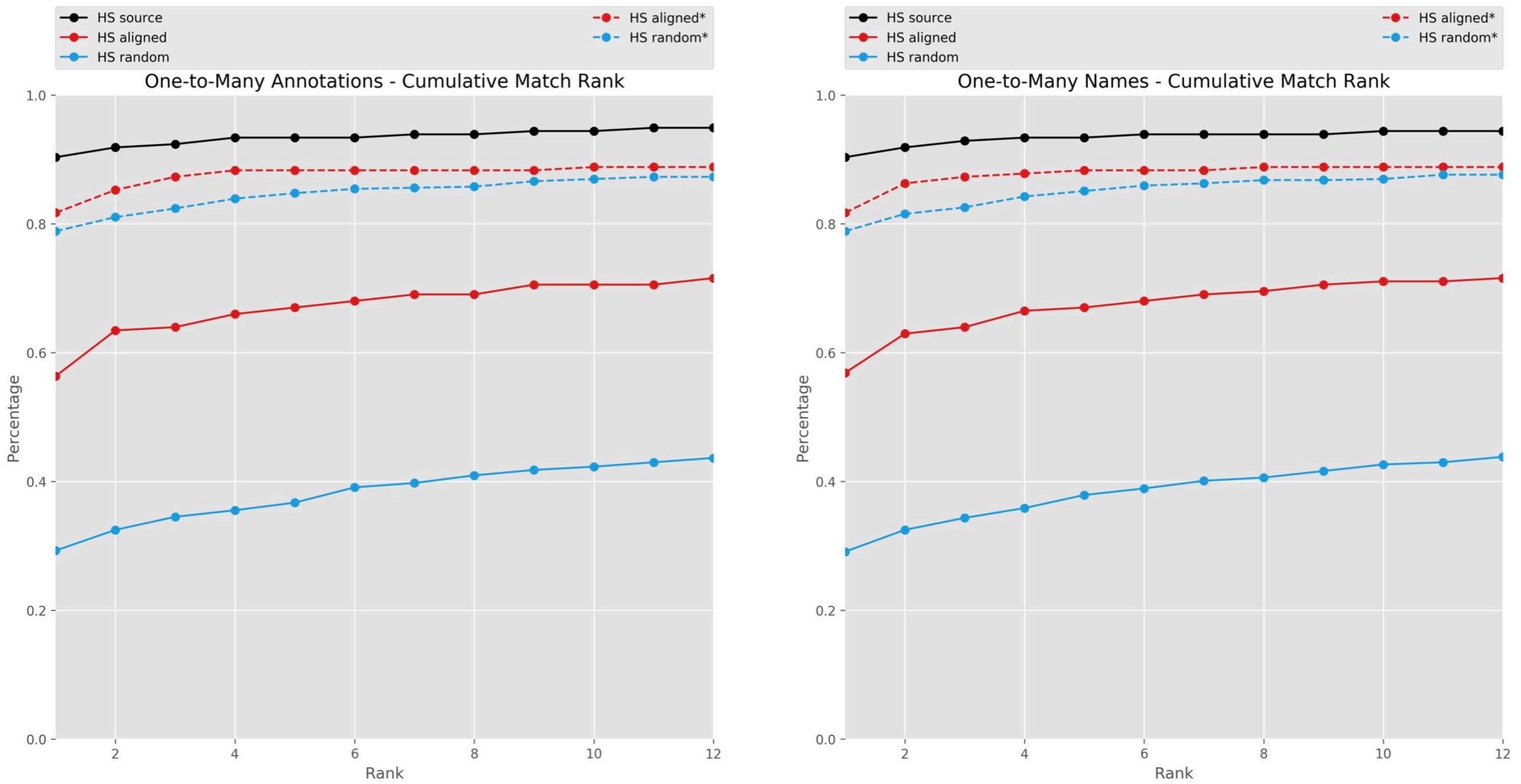
Additional Component - Bounding Box Rotation



Predict a rotation value and adjust the bounding box to fit snugly

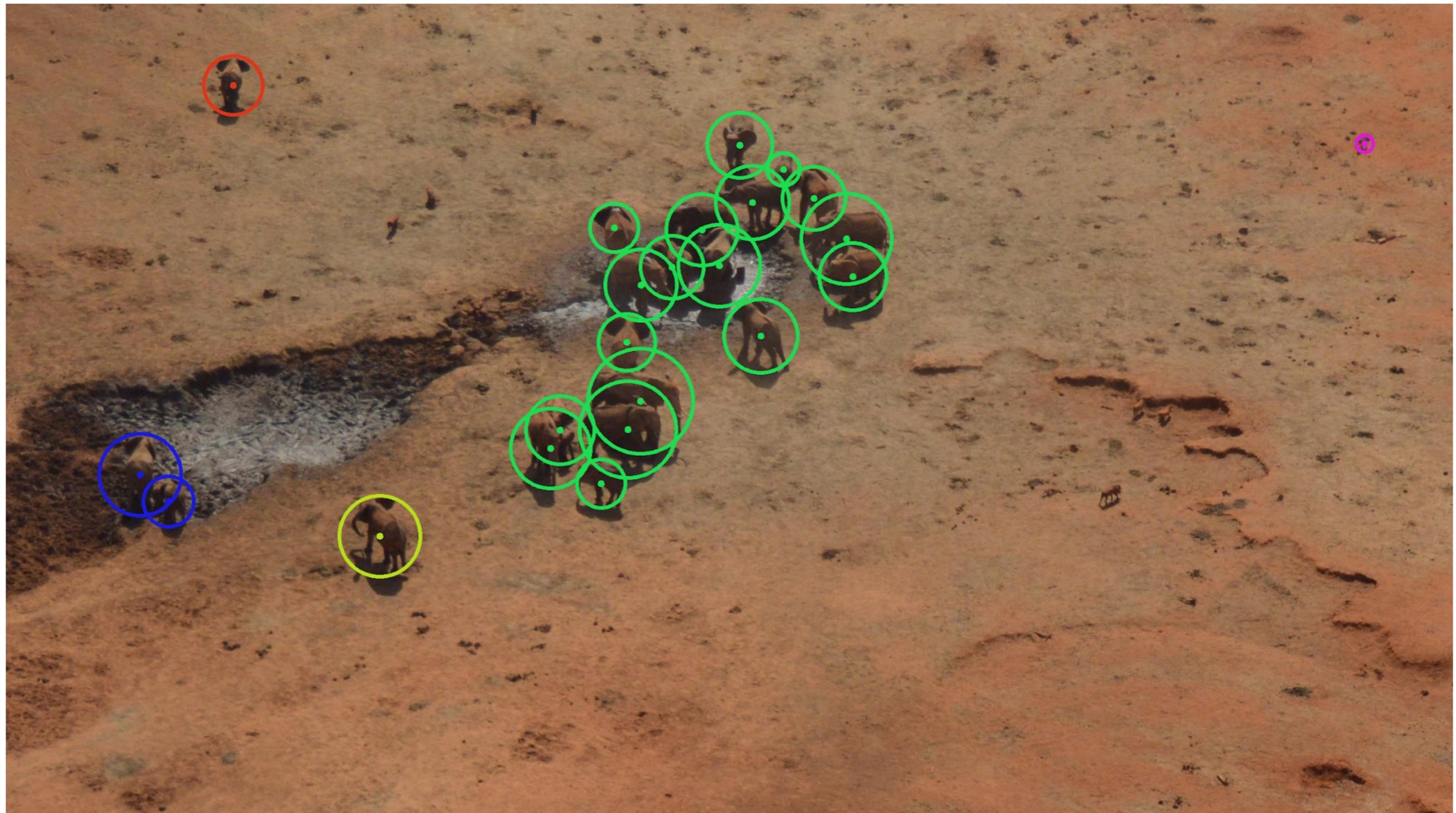
Joint work with Olga Moskvyak

Rotated Annotations Improve ID Performance



HotSpotter's ID recall performance drastically improves with rotation

Additional Component - Overhead Detection



Cut image up into smaller tiles and run the pipeline on smaller chunks

Completed Work

- Detection Pipeline with 5 components
 - Whole-Image Classifier (WIC)
 - Annotation Localization
 - Annotation Classification
 - Coarse Background Segmentation
 - Annotation of Interest (AoI)
- Three additional detection components*
- New animal detection datasets
 - WILD - 6 species, each with 1,000 images
 - DETECT - 2 species of zebra, each with 2,500

[1] J. Parham and C. Stewart, “Detecting Plains and Grevy’s Zebras in the Real World,” in *2016 IEEE Winter Conf. Applicat. of Comput. Vis. Workshops*, Lake Placid, NY, USA, Mar. 2016, pp. 1–9.

[2] J. Parham et al., “An Animal Detection Pipeline for Identification,” in *2018 IEEE Winter Conf. Applicat. of Comput. Vis.*, Lake Tahoe, CA, USA, Mar. 2018, pp. 1–9.

* New work since candidacy, joint effort with Drew Blount and Olga Moskvyak



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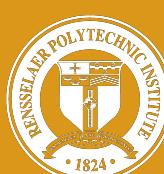
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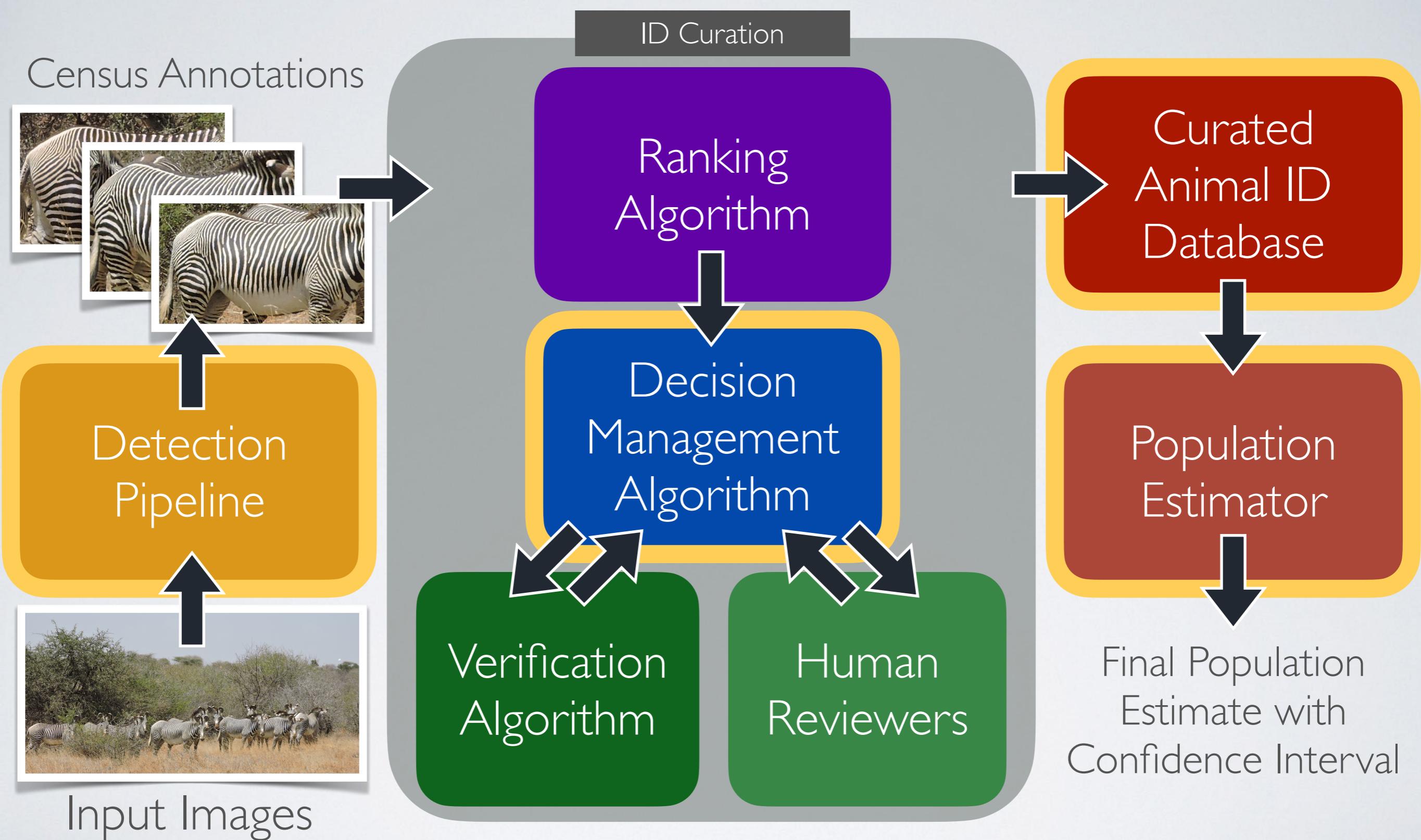
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System for Animal Photographic Censusing



Algorithms for Animal Photographic Censusing

Detection Pipeline

CA **CA-R**

Ranking Algorithm

HotSpotter **PIEv2**

Decision Management Algorithm

Graph ID **LCA**

Verification Algorithm

VAMP **PIEv2**

Population Estimator

Auto. Lincoln-Petersen



Grevy's Zebra Census Dataset (GZCD)

Rally	Day	Date	Images
GGR 2016	Day 1	January 30 th , 2016	1,209
GGR 2016	Day 2	January 31 st , 2016	1,695
GGR 2018	Day 1	January 28 th , 2018	1,331
GGR 2018	Day 2	January 29 th , 2018	1,229
TOTAL			5,464

5,281 Grevy's zebra annotations for 554 names
24,129 automated and 43,048 human pair decisions
Each annotation participated in 25.7 decisions on average ($\sigma=34.3$)

CA + CA-R + HotSpotter + PIEv2 + VAMP + Graph ID + LCA



Completed Work Since PhD Candidacy

Proposed Work	Ph.D. Contributions
Evaluation Dataset Gather a new evaluation dataset for testing Canonical Annotations	Grevy's Zebra Census Dataset Dataset of “clean” and “dirty” detections from Meru County GGR-16 and GGR-18
Incidental Matching Detection Develop newer AOL implementation for more accurate photobombs, scenery match detection, plus mother-foals	Auto. Lincoln-Petersen Index Incidental matching is mitigated by Census Annotations and LCA ID curation, added new terms to estimator for ML errors
Canonical Annotation Finalize Canonical Annotations and HotSpots, compare to AOL, results for reducing human effort during census	“Census” Annotation Completed evaluation of Census Annotations (CA) and CA Regions with a user study and simulations with LCA
Culminating Experiment Complete analysis of GGR-16 compared to GGR-18 with new specialized detection pipeline components	Culminating Experiment Completed audit of the GGR-18 with Census Annotations, Census Annotation Regions, LCA, and Auto. L-P Index



Completed Work

- Photographic Censusing System
 - Detection Pipeline
 - Ranking Algorithm
 - Decision Management Algorithm
 - Verification Algorithm
 - Human-in-the-Loop Reviewer
 - Population Estimator
- Integrated LCA and 1st comparison with Graph ID
- Grevy's Zebra Census Dataset (GZCD)
 - 5,281 Grevy's annotations for 554 names
 - Over 24,000 auto. and 43,000 human decisions
 - Curated with feature-based and DL methods



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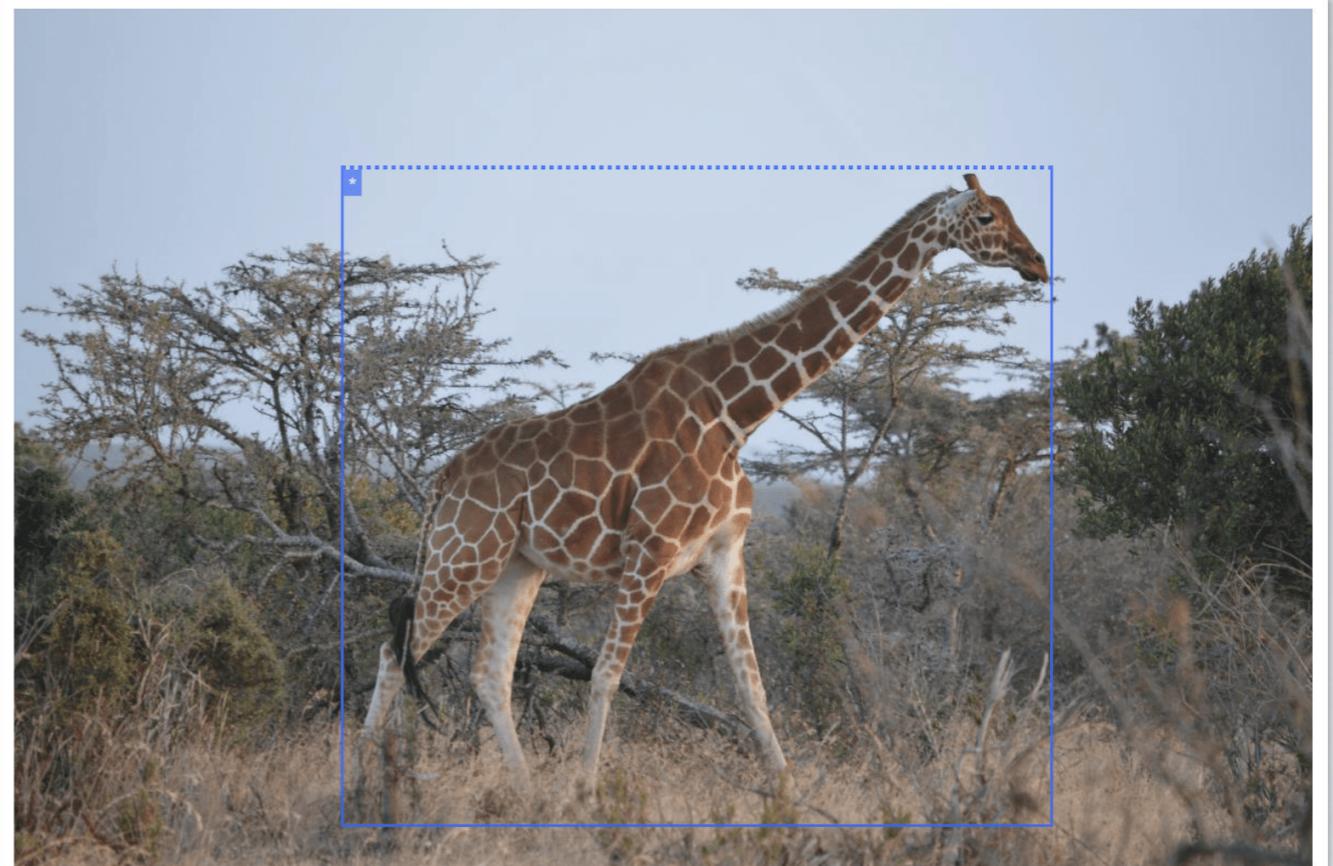
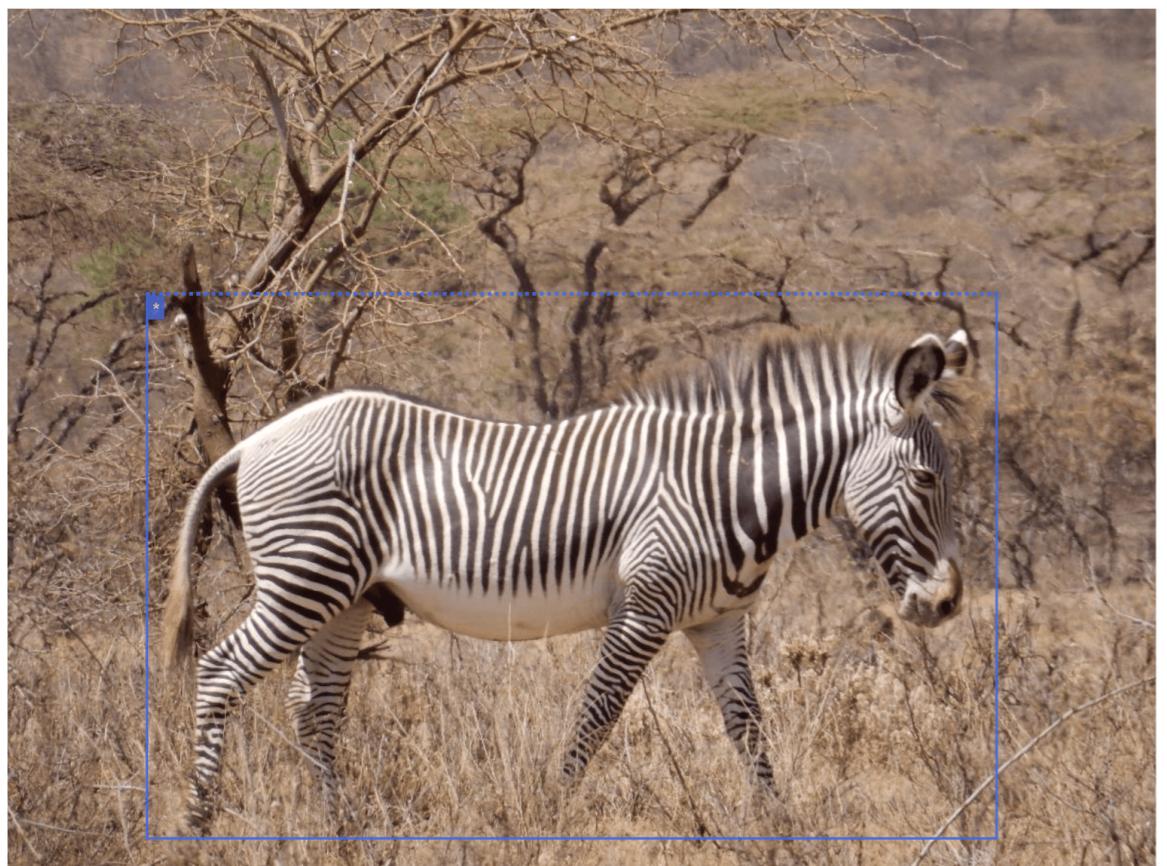
Culminating experiment on GGR-18

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Ideal Animal Sightings of Zebra and Giraffe



Animals are clearly illuminated, well posed, not occluded or truncated and are of the correct viewpoint for identification

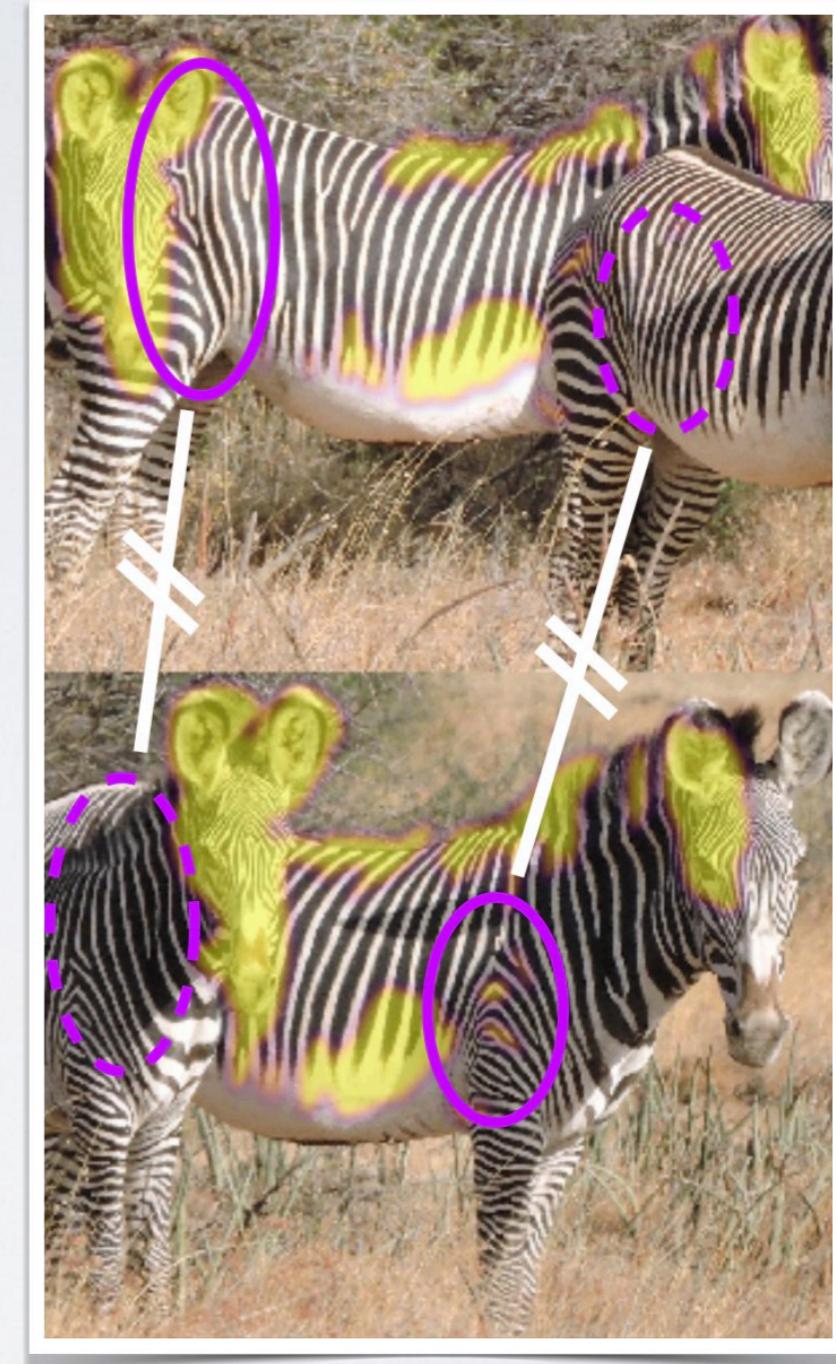
Incidental & Incomparable Matching



Photobomb

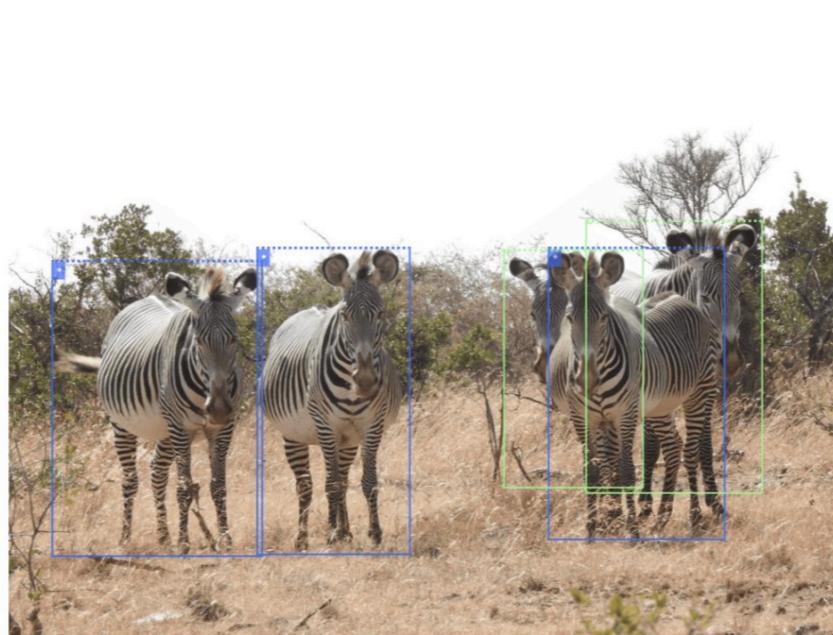
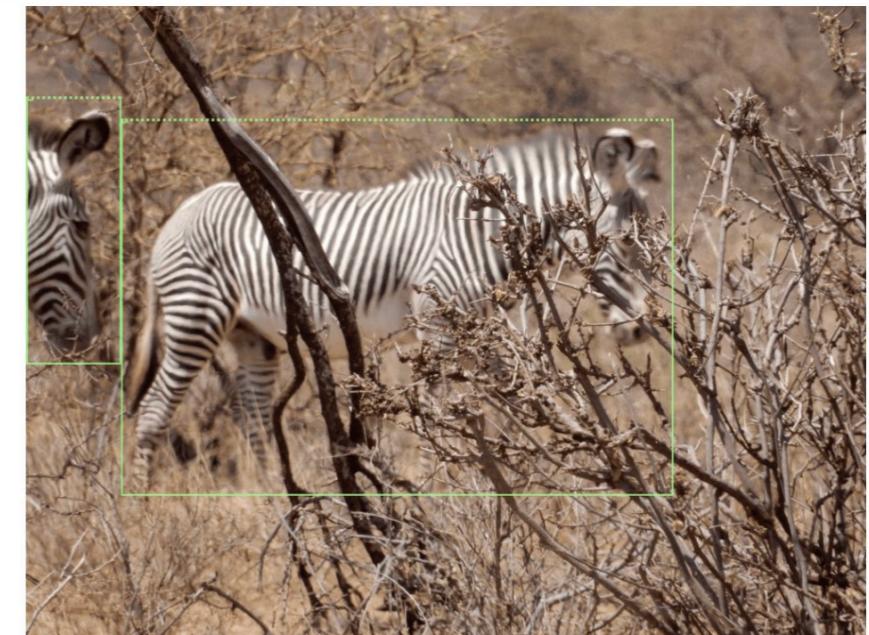
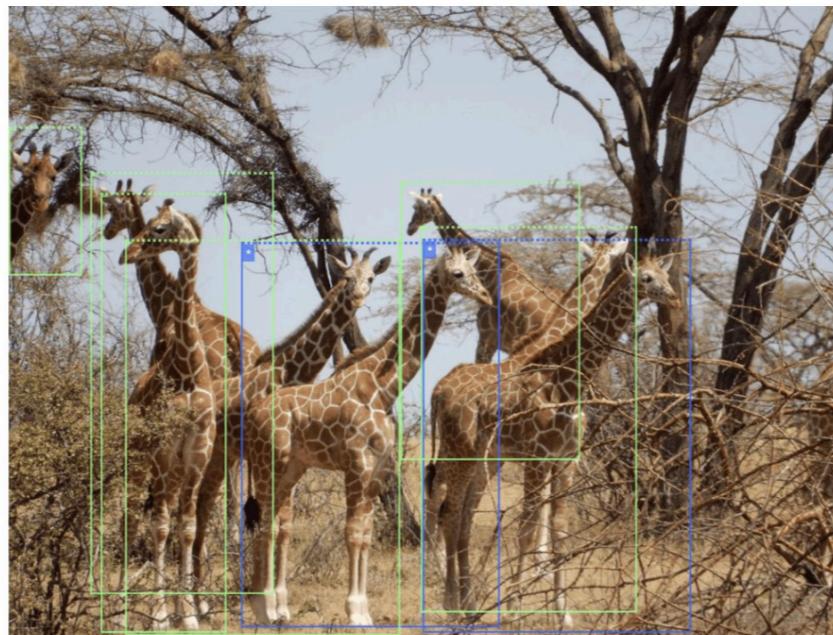
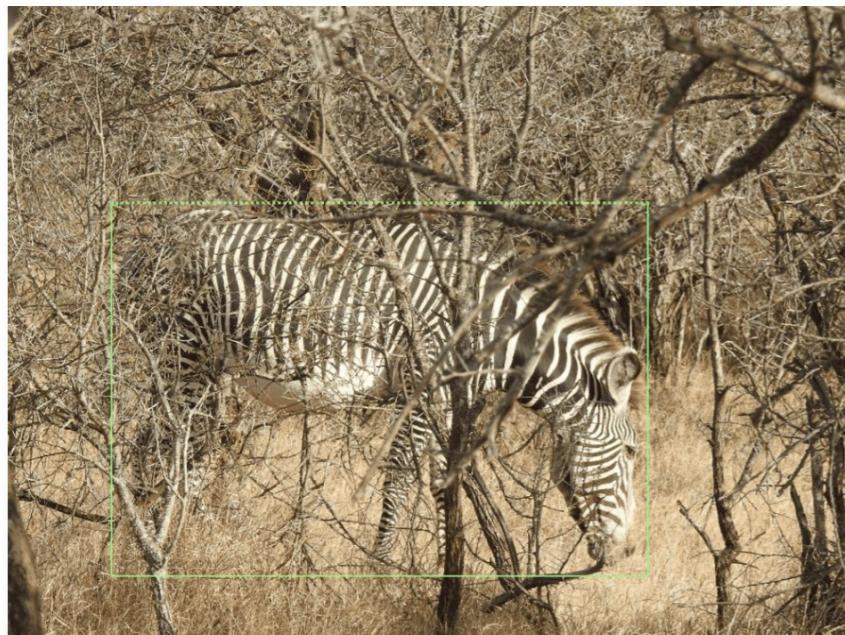


Scenery Match



Incomparable

Not Ideal Animal Sightings of Zebra and Giraffe



These images show animals that are occluded, truncated, blurry, missing relevant species, or are the wrong viewpoint for identification

Census Annotation (CA)

Image 1: 5 Animals with 1 CA

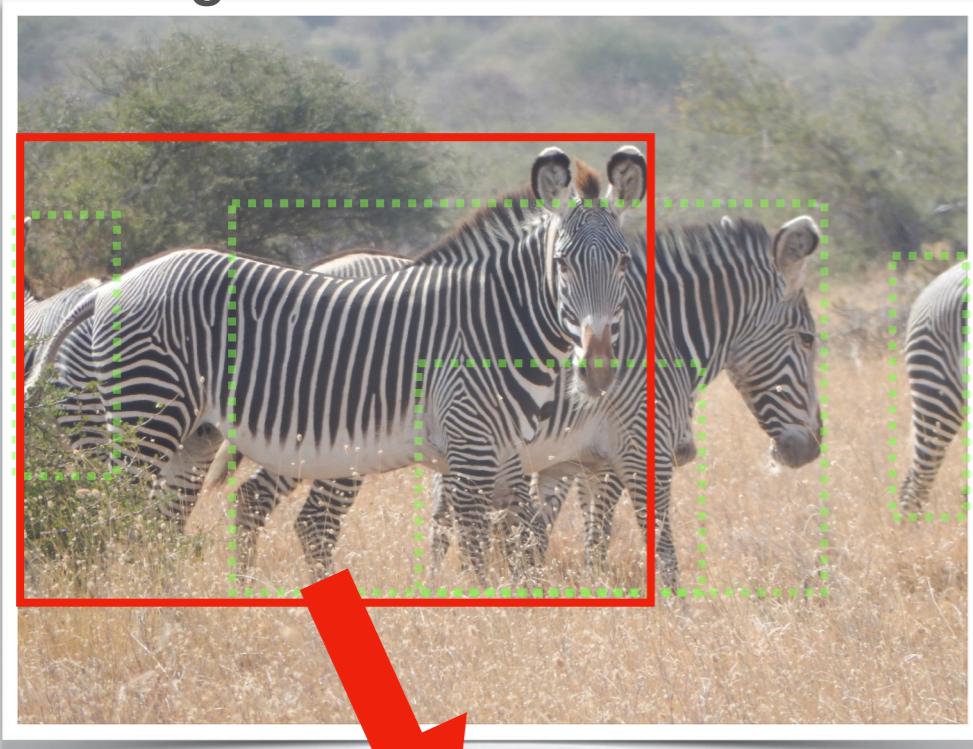
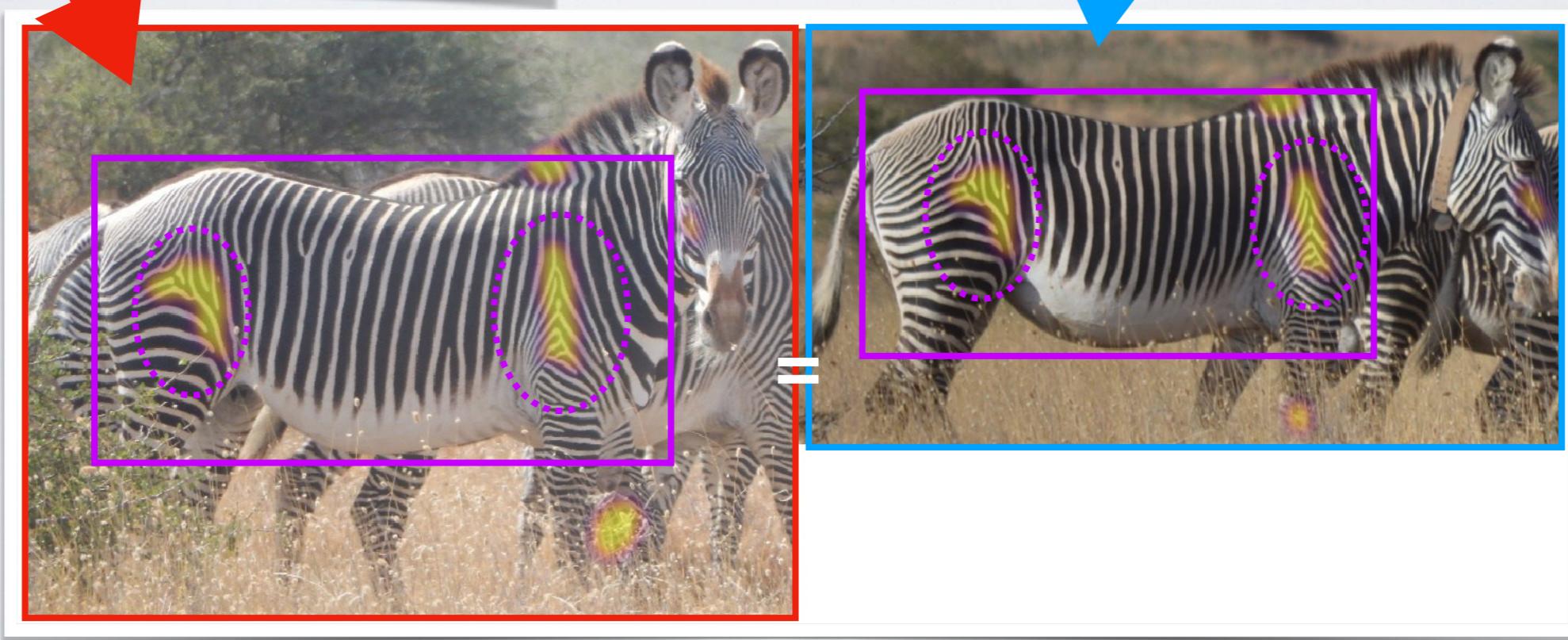
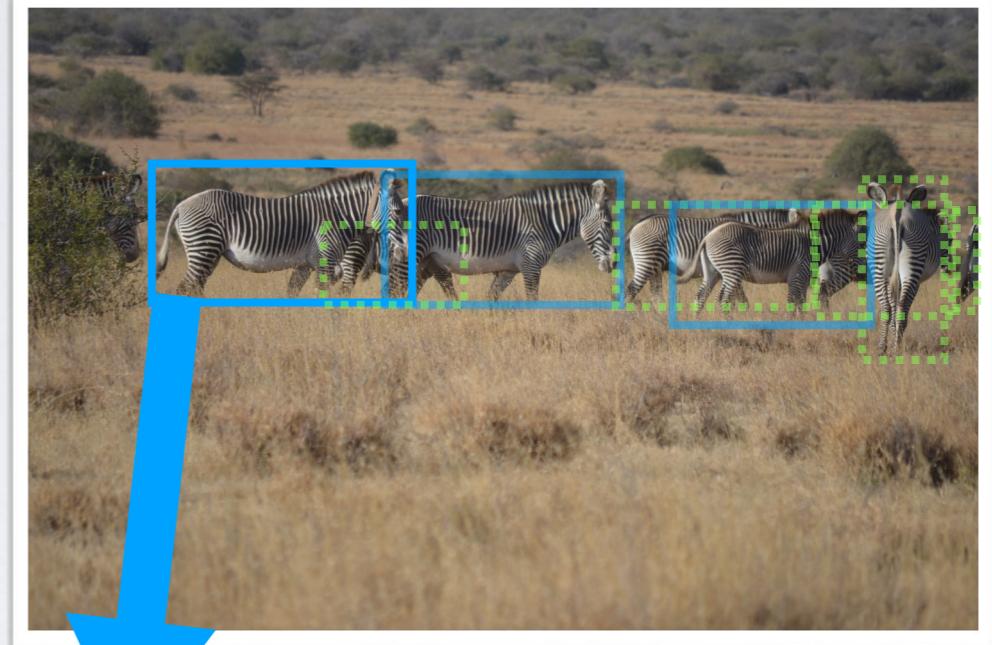
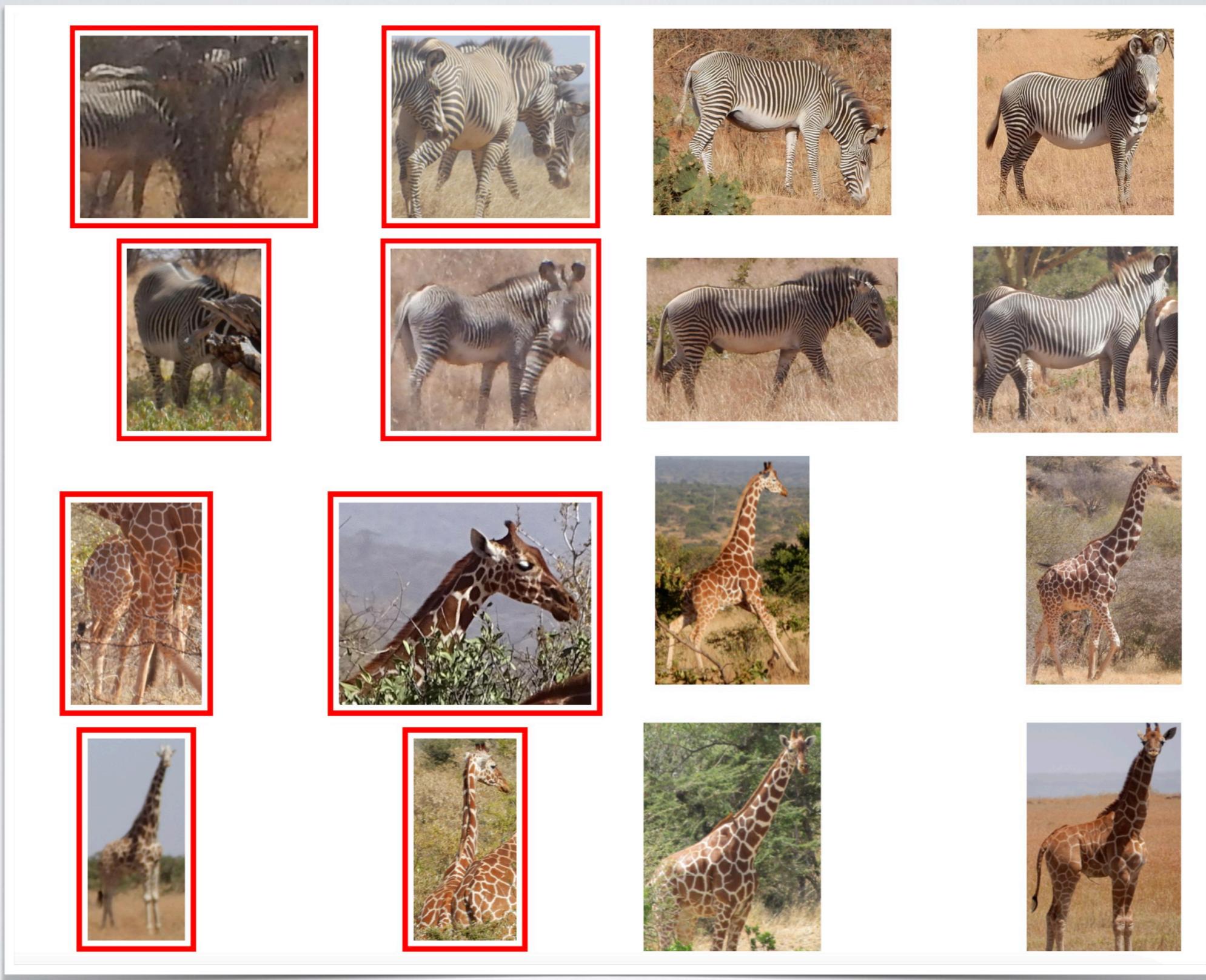


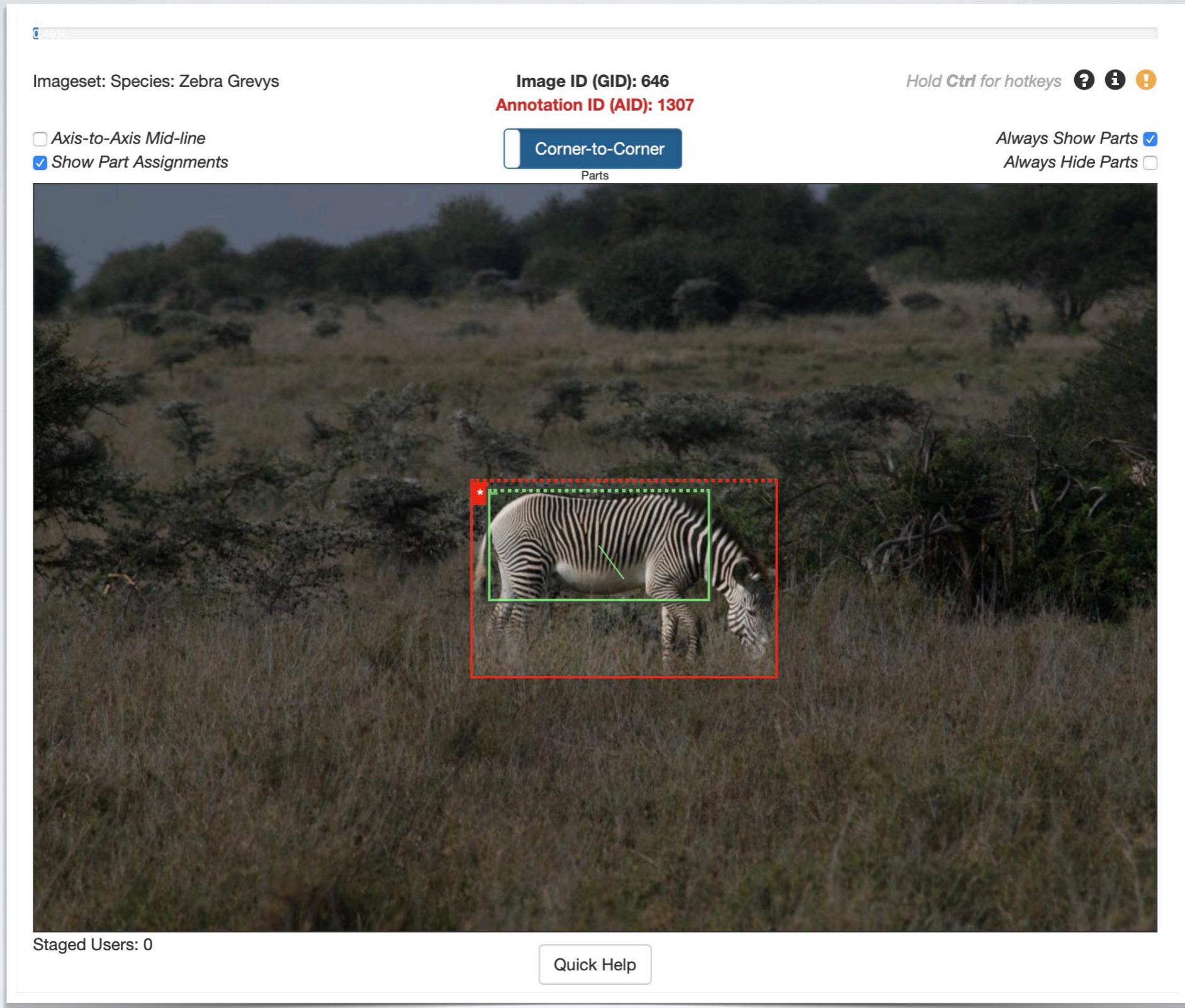
Image 2: 8 Animals with 3 CAs



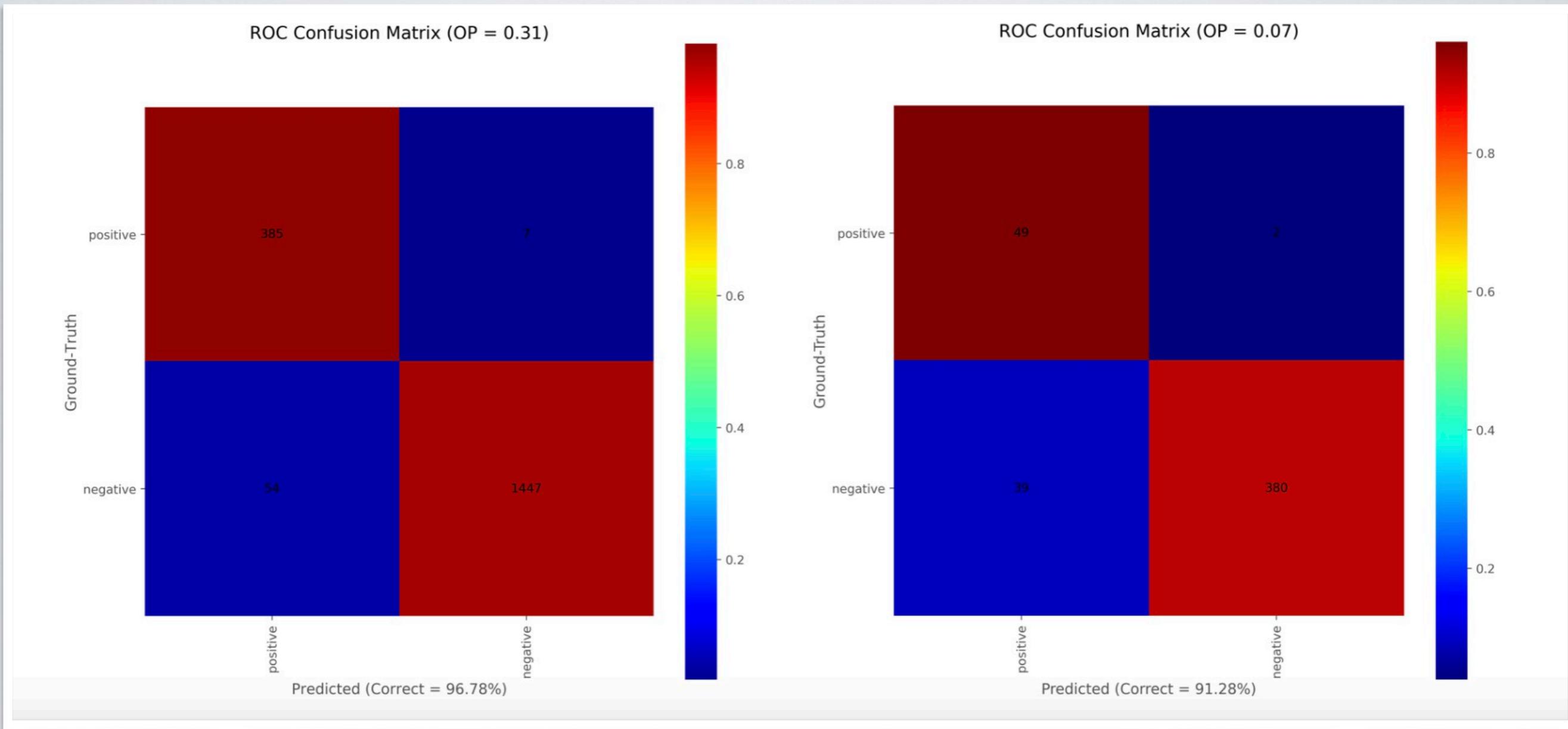
Census Annotation Dataset



Census Annotation Region Web Interface



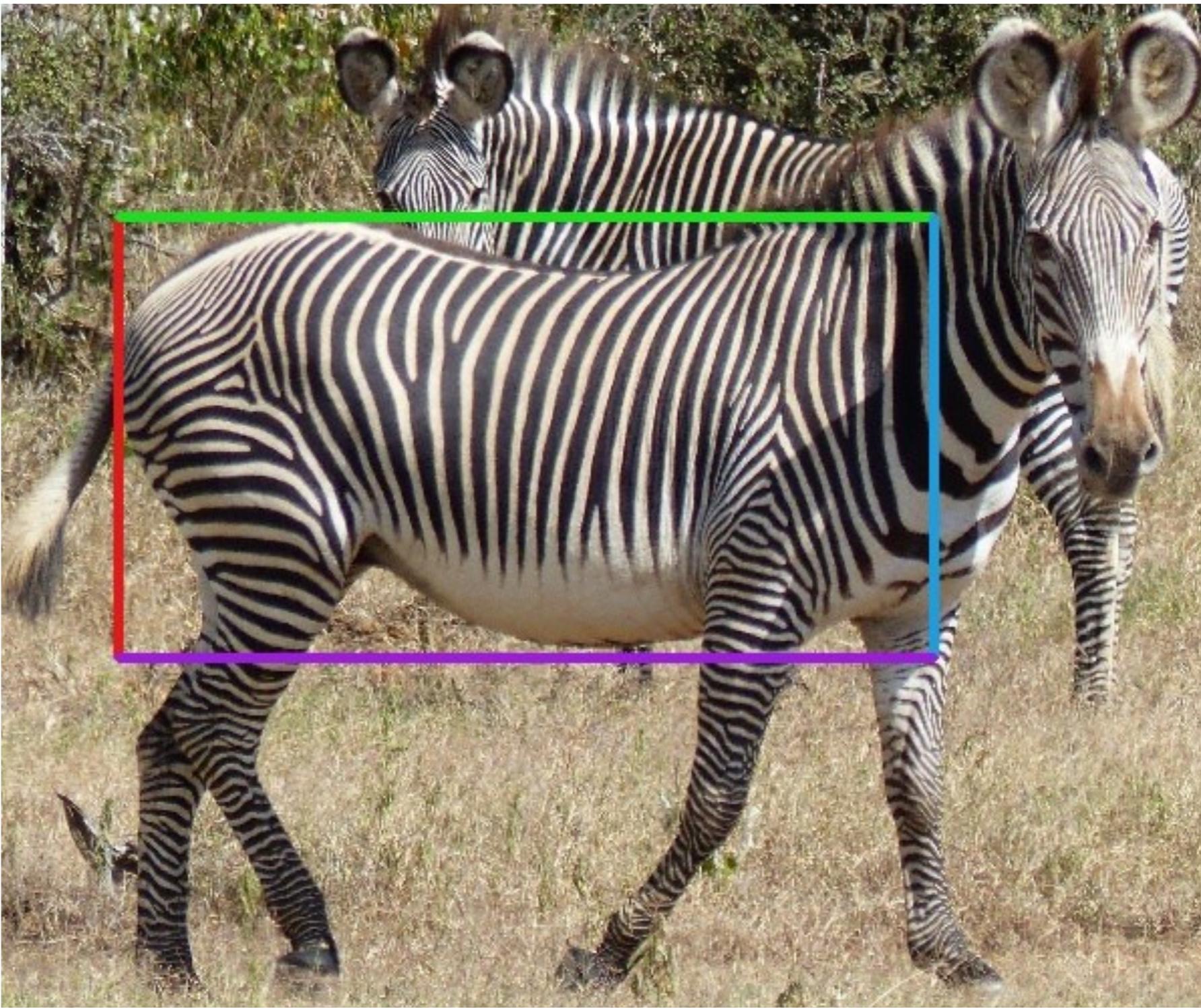
Census Annotation Classifier Confusion Matrix



Grevy's Zebra

Reticulated Giraffe

Census Annotation Region (CA-R)

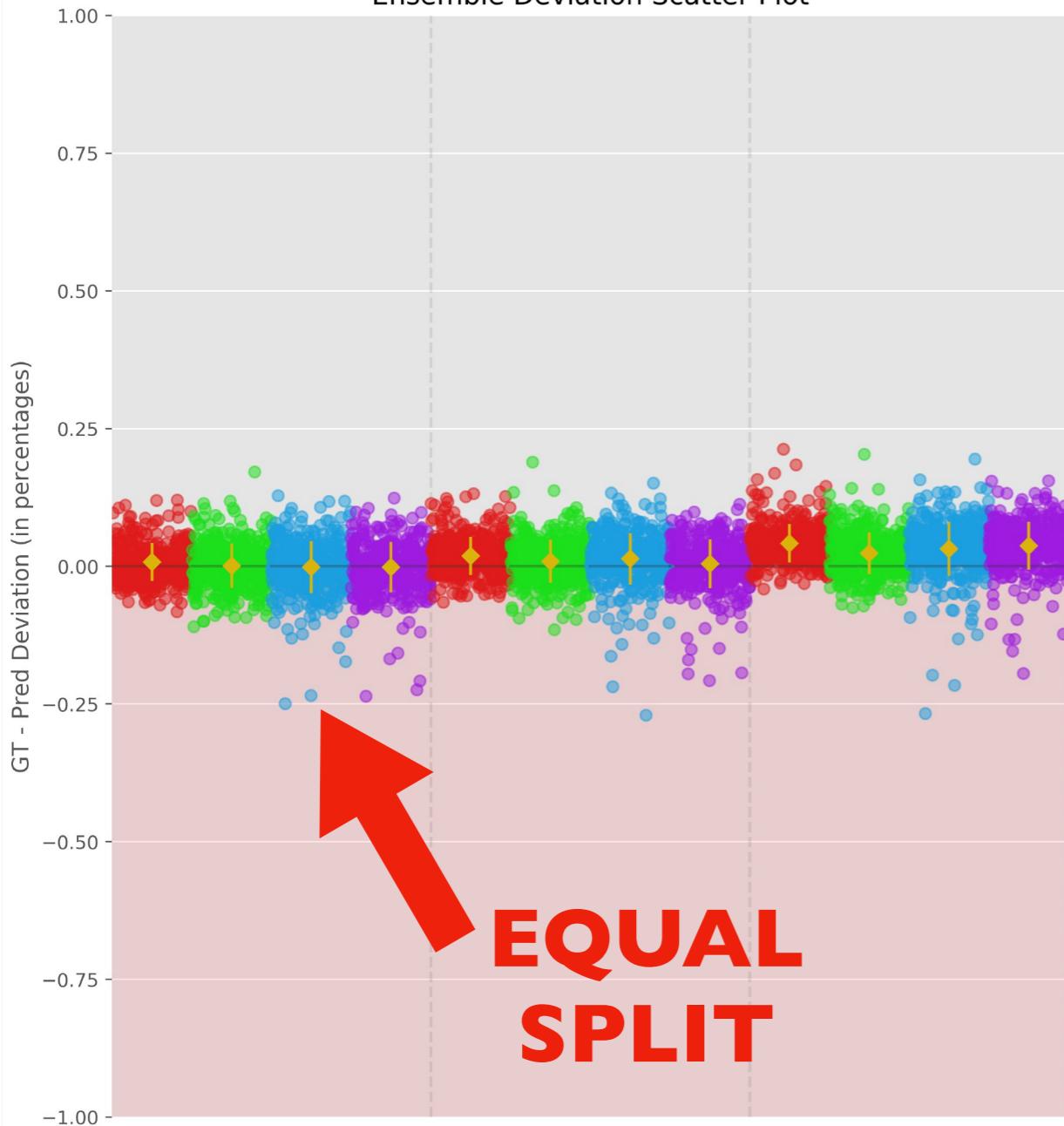


Census Annotation Regions are predicted as 4 offset pixel values

Census Annotation Region Regression Performance

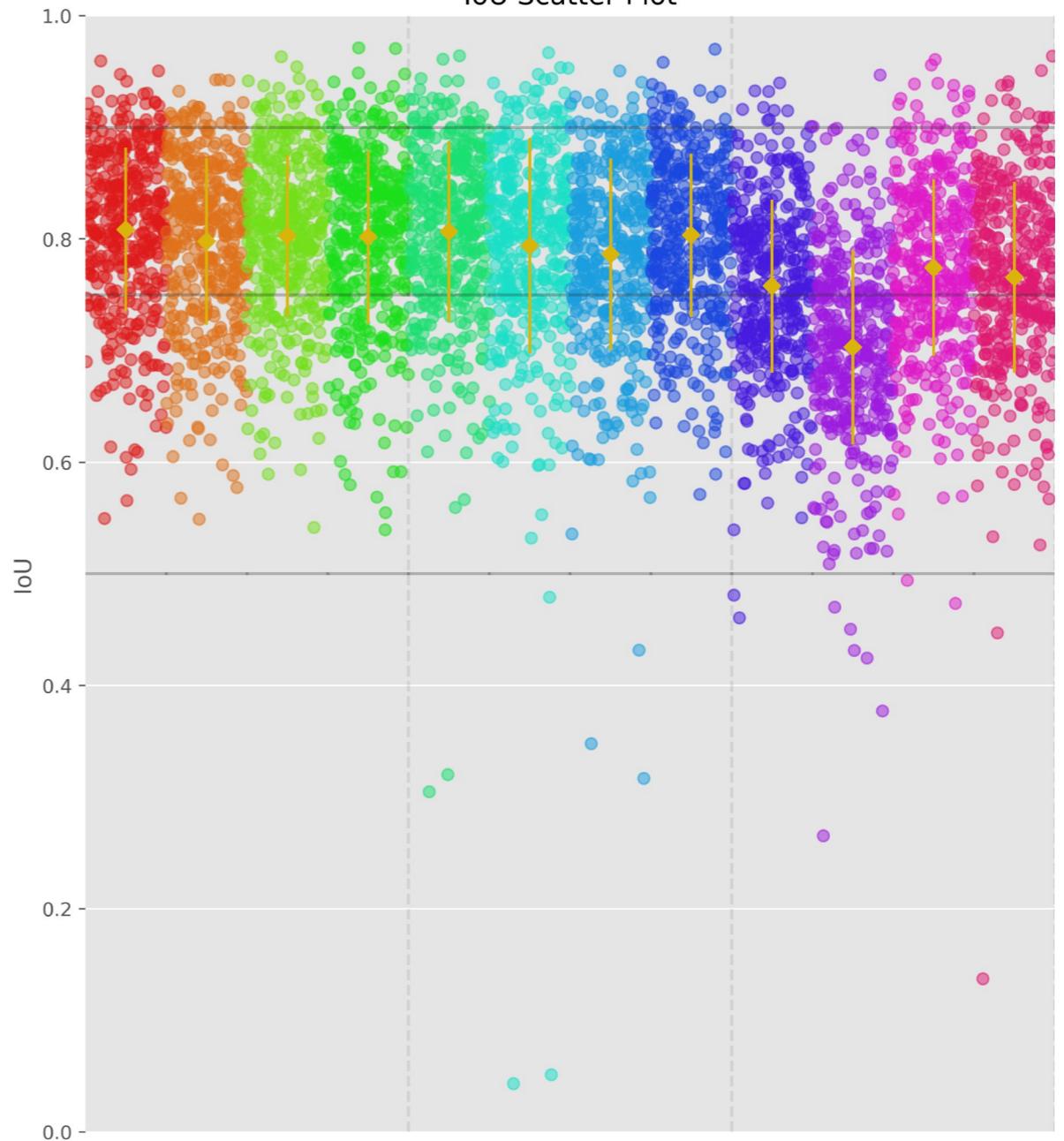
- CA V5-1.0 Ens. x0 (Over: 0.44, 0.01+/-0.03)
- CA V5-1.0 Ens. y0 (Over: 0.48, 0.00+/-0.04)
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- CA V6-2.0 Ens. y1 (Over: 0.42, 0.00+/-0.04)
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- CA V4-4.0 Ens. x1 (Over: 0.18, 0.03+/-0.05)
- CA V4-4.0 Ens. y1 (Over: 0.15, 0.04+/-0.04)

Ensemble Deviation Scatter Plot



- CA V5-1.0 Ens. (Acc: 0.79, 0.81+/-0.07)
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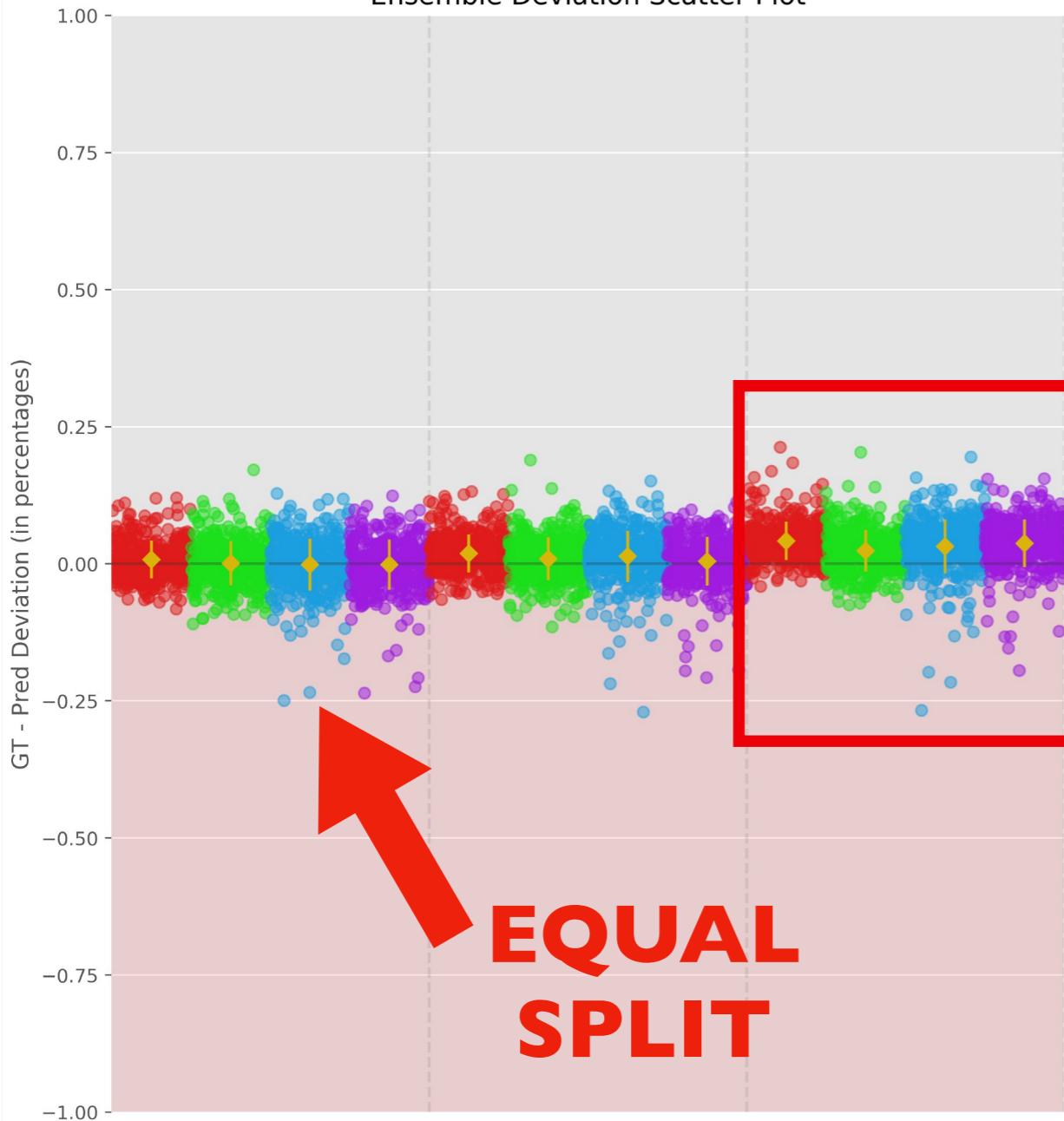
IoU Scatter Plot



Census Annotation Region Regression Performance

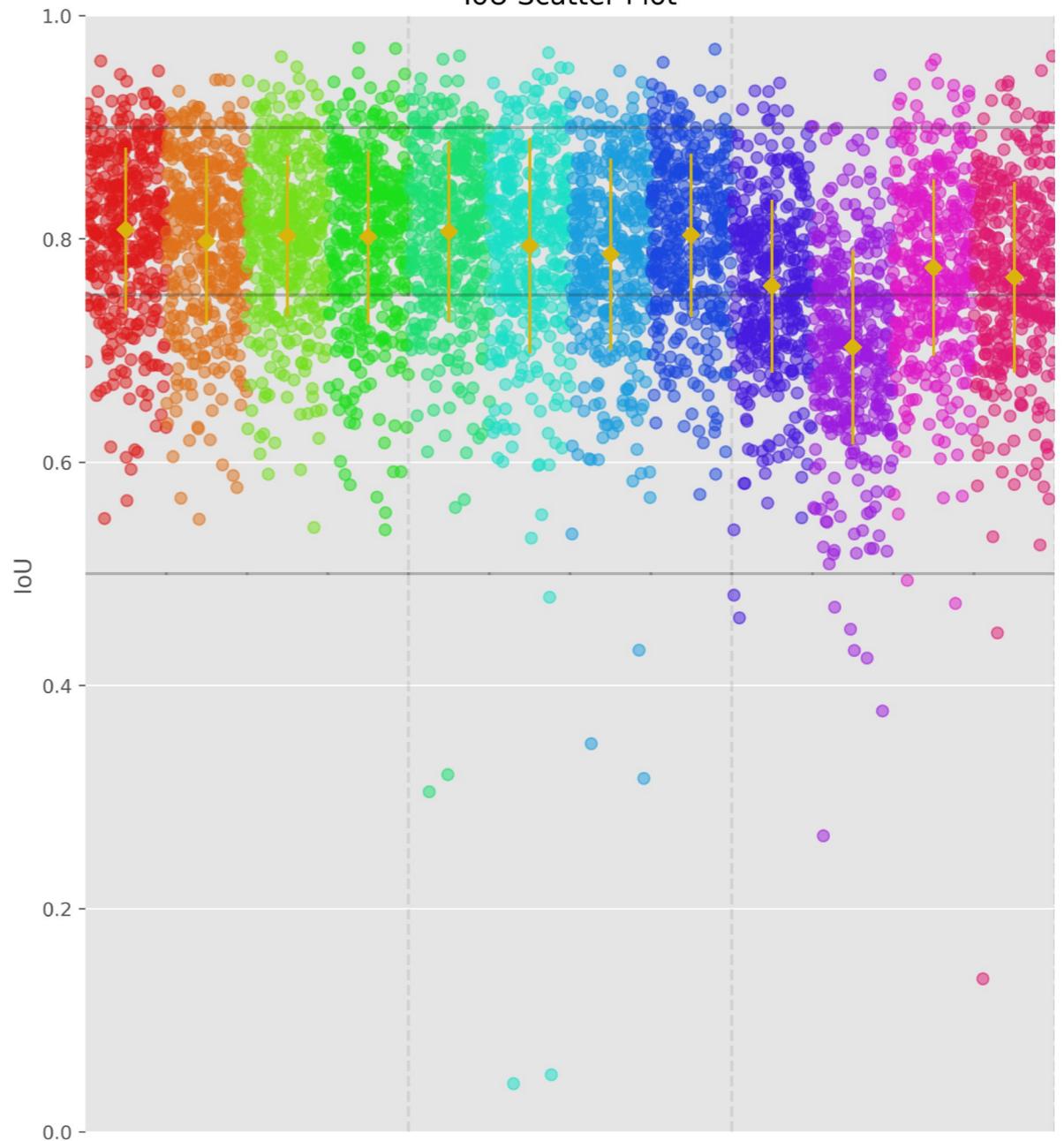
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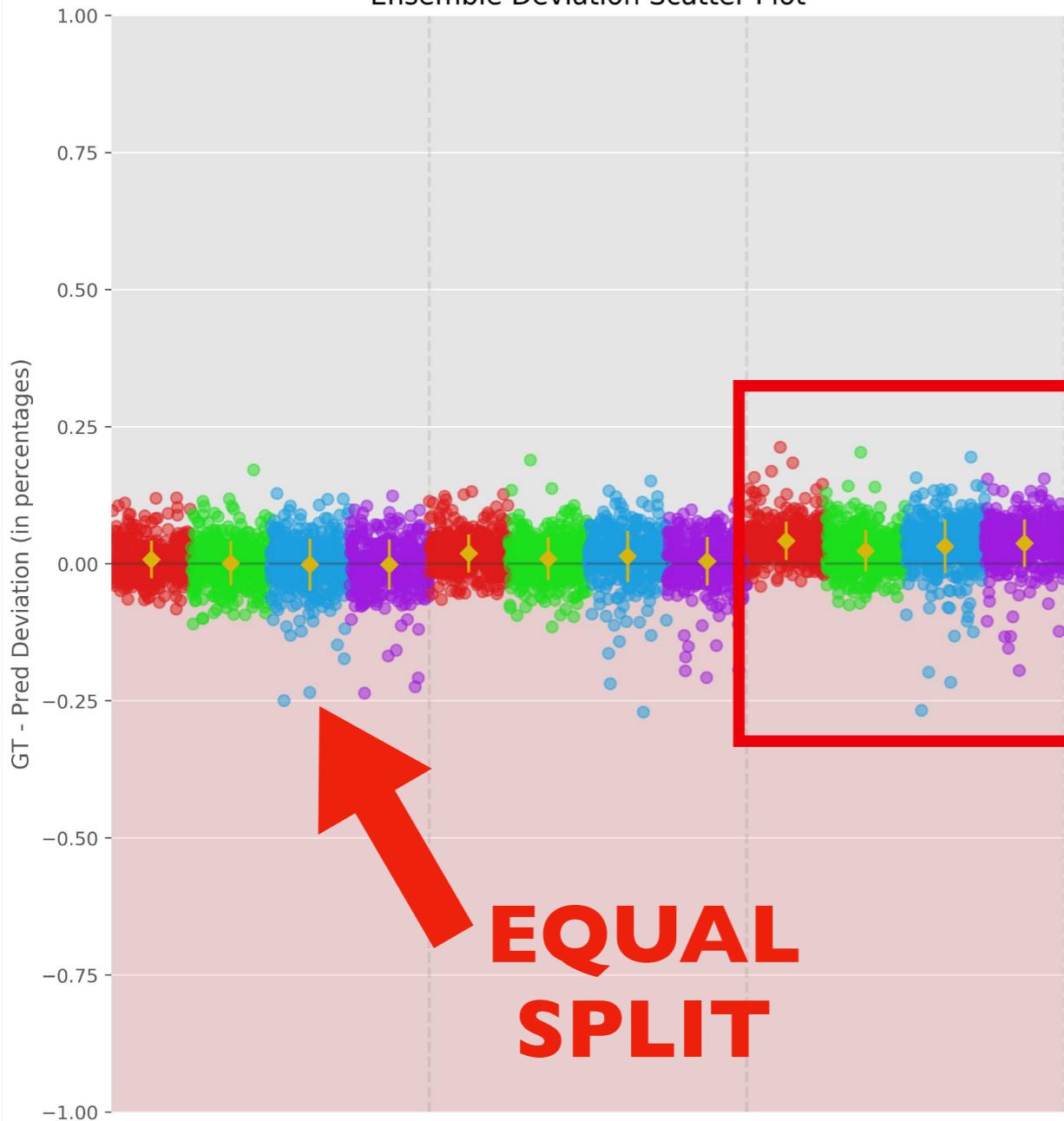


**EQUAL
SPLIT**

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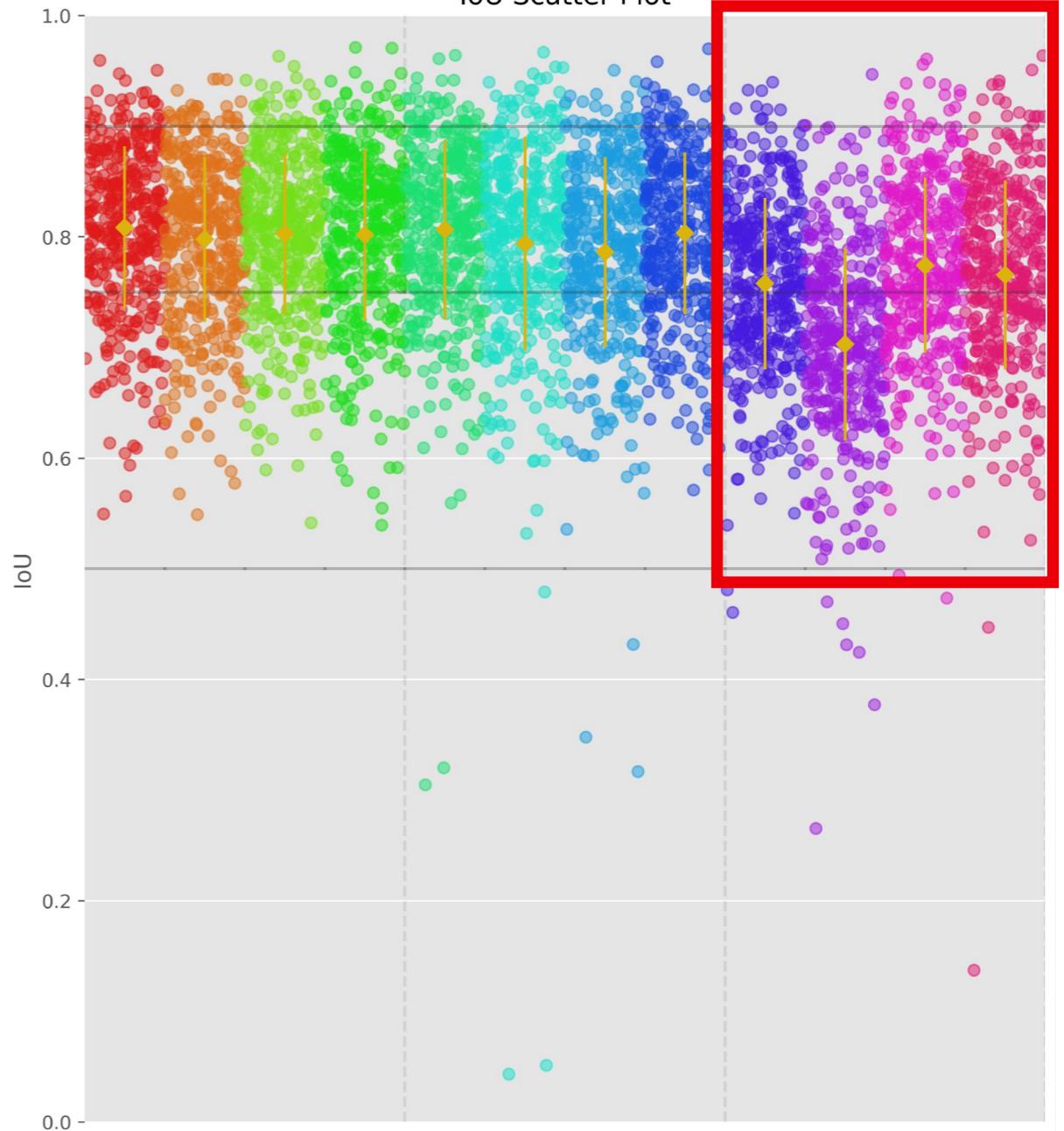
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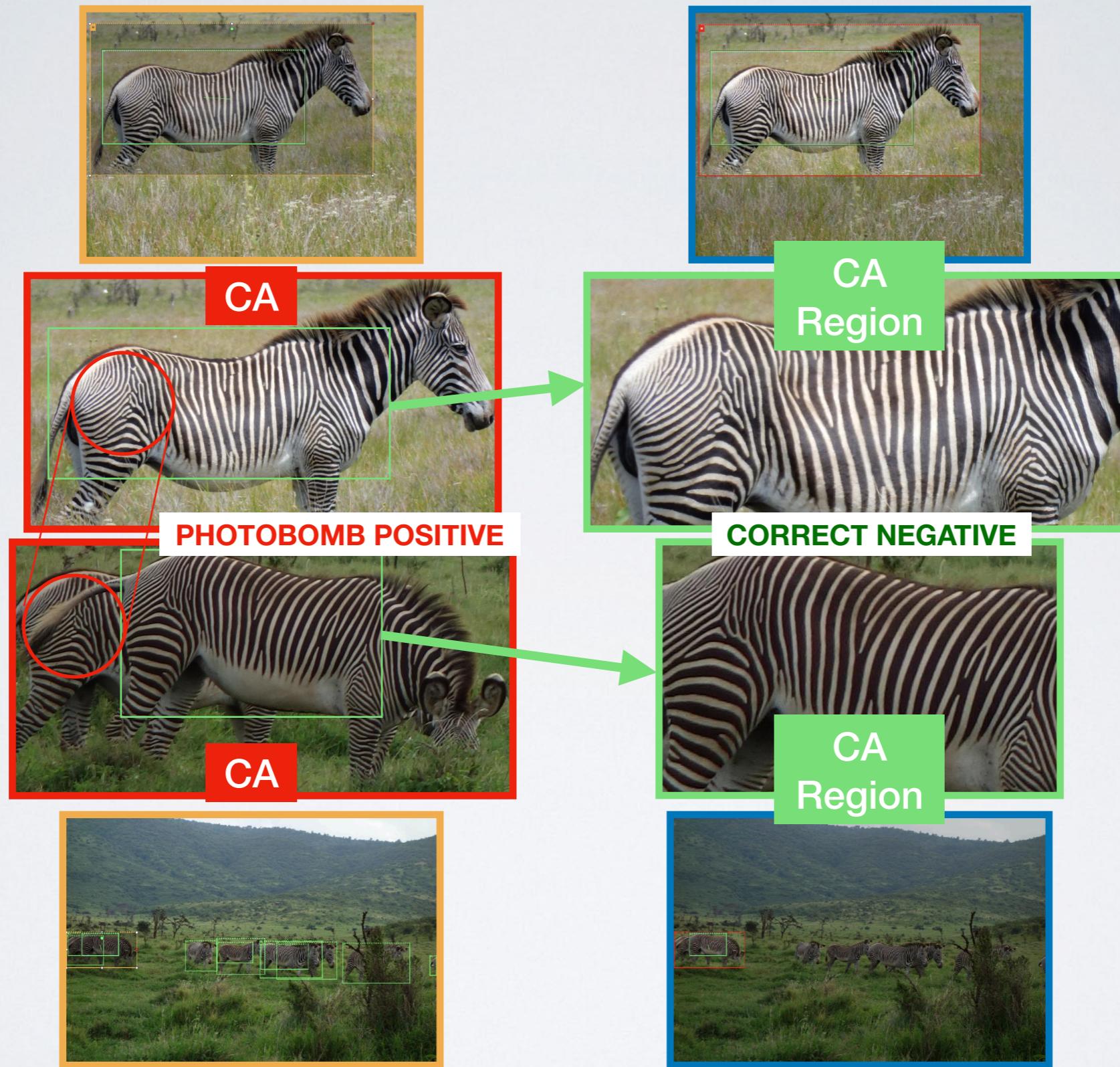
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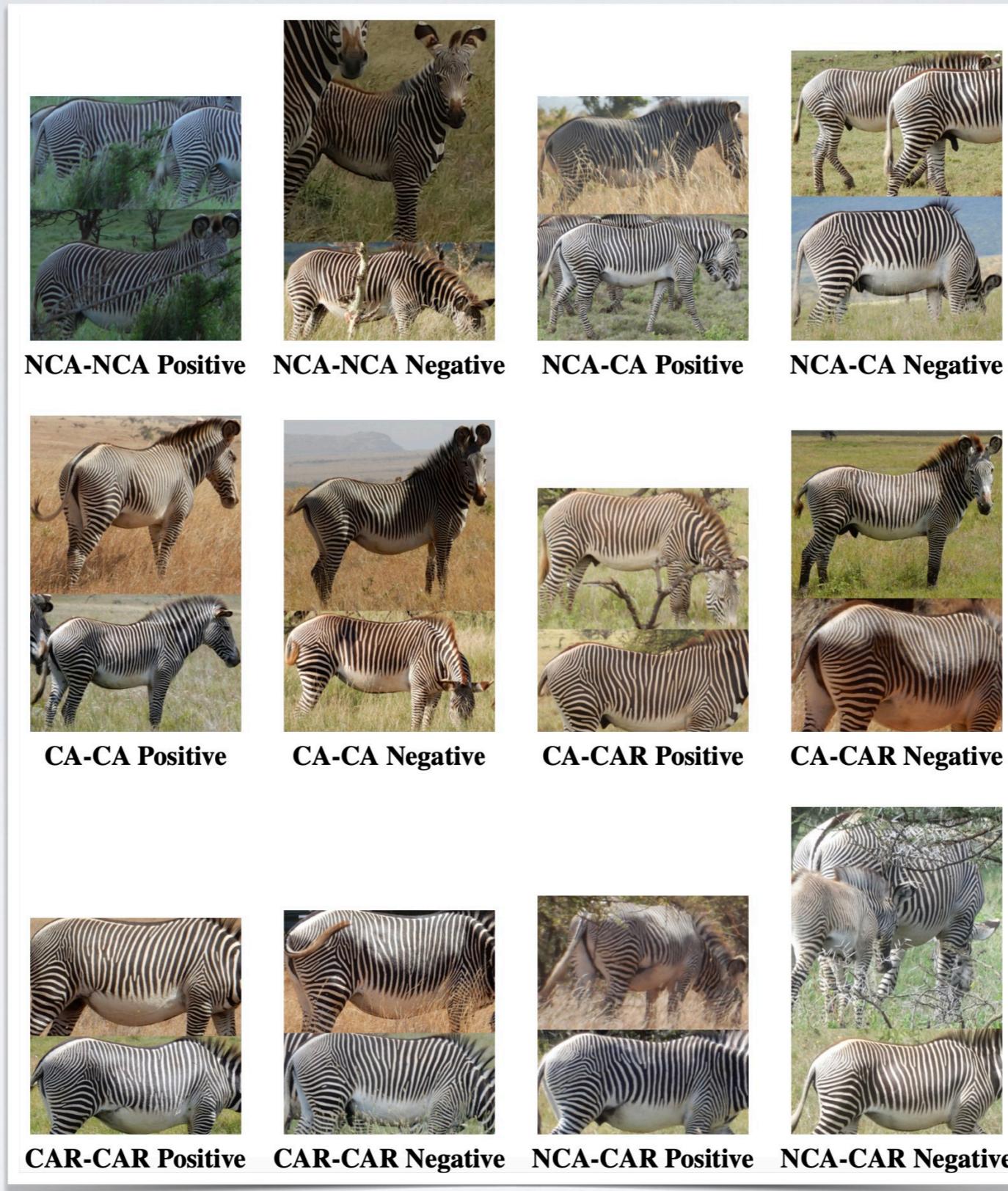
Example Census Annotation Region Predictions



Census Annotation Region Mitigating Photobomb



User Study Dataset



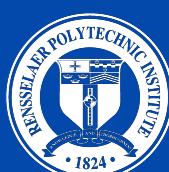
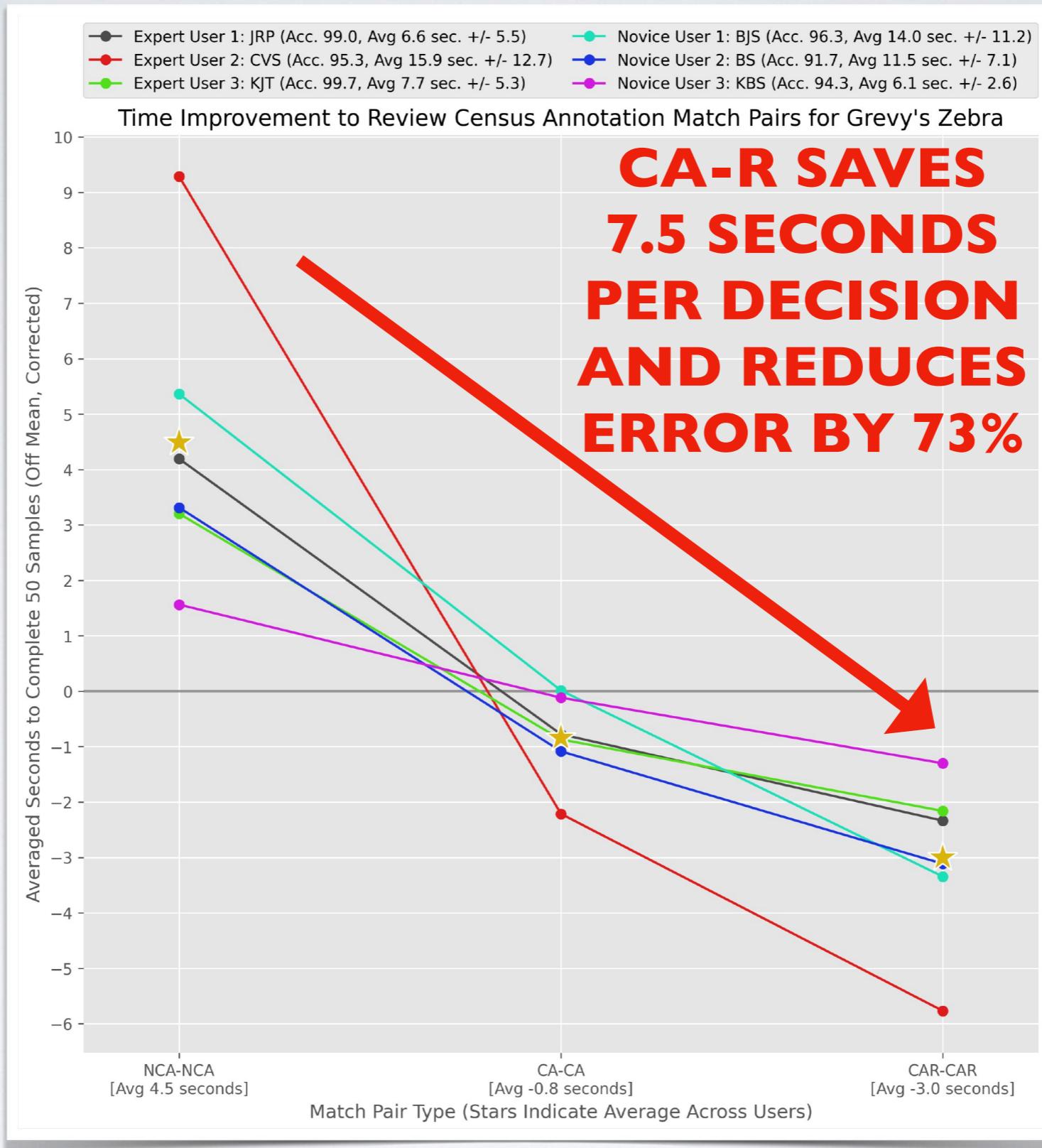
300 Pairs Total

**50 Pairs for
Each Category**

**50% Positive
50% Negative**

**Randomly
Shuffled**

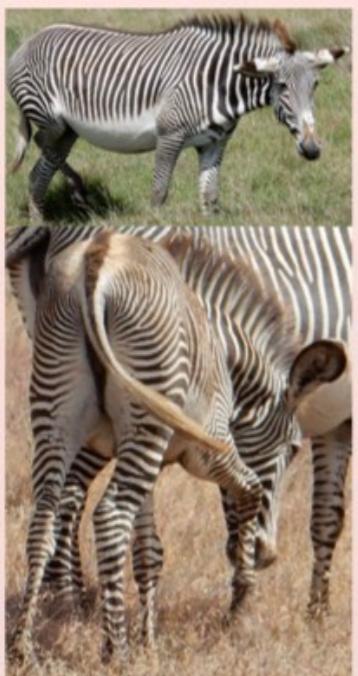
Human Decisions with CA and CA-R



Fastest & Slowest Decisions of User Study

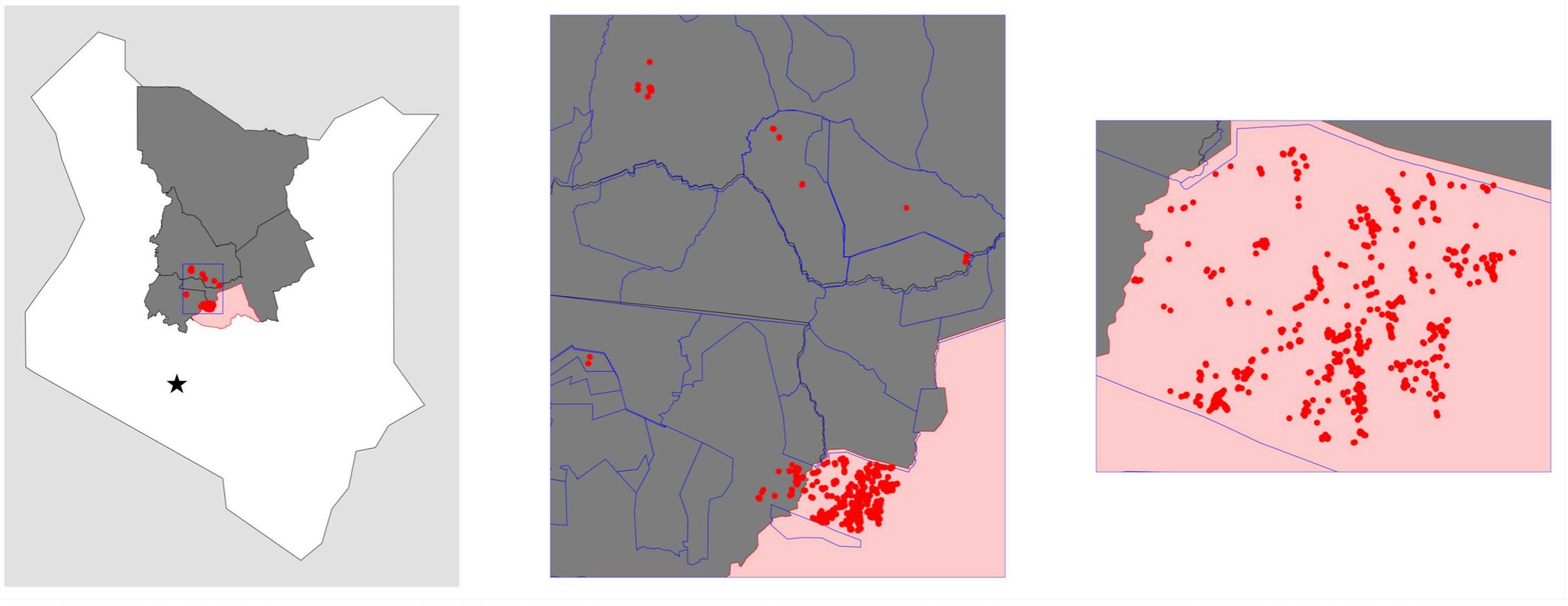


Fastest Match Pairs to Review



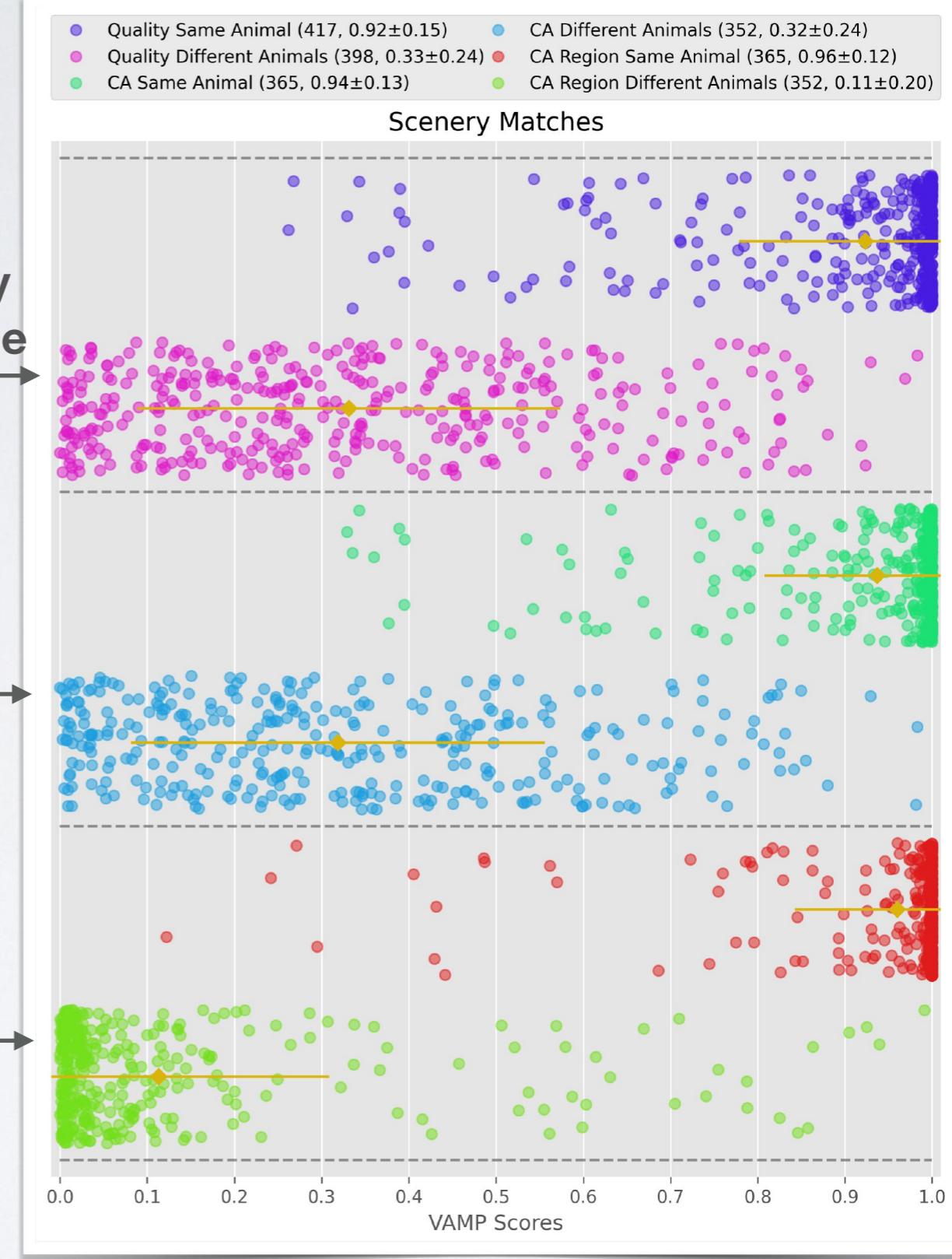
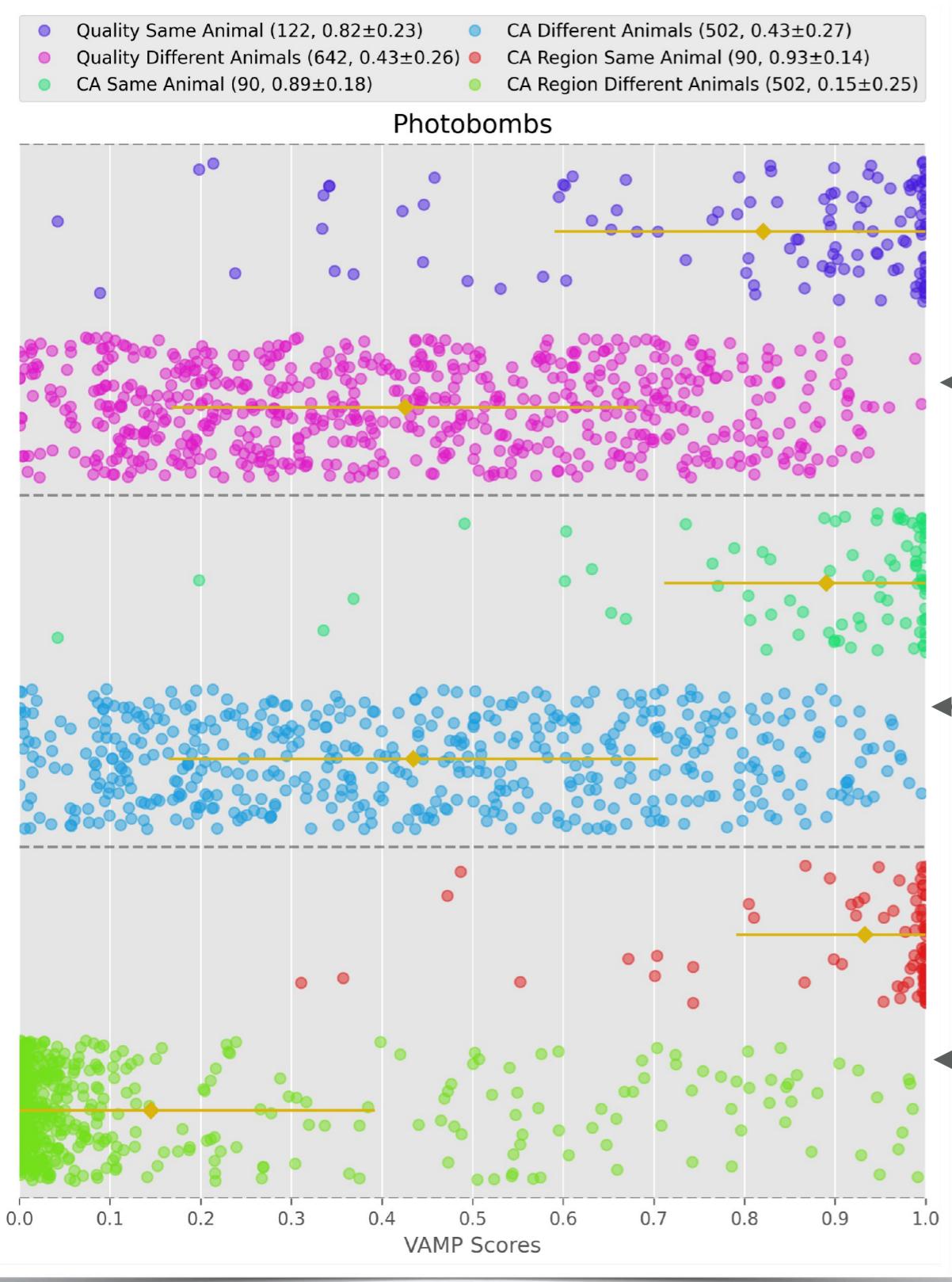
Slowest Match Pairs to Review

Grevy's Zebra Census Dataset (GZCD)



Set Name	Annots.	Names	Singletons	GGR-16 L-P	GGR-18 L-P
CA-R	4,142	468	51	366 ± 27	373 ± 29
CA	4,142	468	51	366 ± 27	373 ± 29
Quality	4,269	487	62	360 ± 27	399 ± 29

Impact of CA and CA-R on VAMP Score Separability

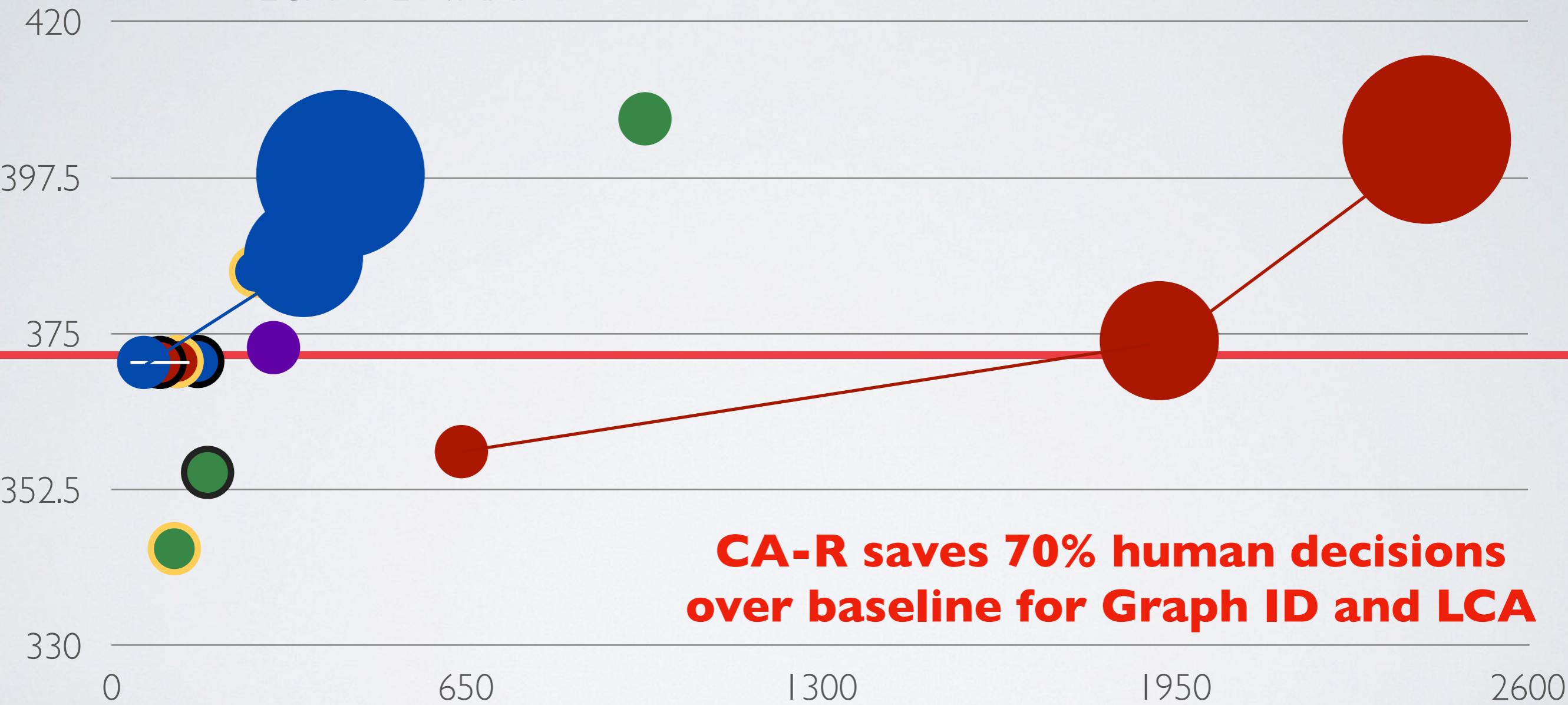


Simulated ID Curation on GZCD GGR-18

- GrID+HS+VAMP
- LCA+HS+VAMP
- LCA+HS+PIE
- LCA+PIE+VAMP

- LCA+CA@31
- LCA+CA@1
- LCA+CA@90

- LCA+Human@100
- LCA+Human@90
- LCA+Human@75

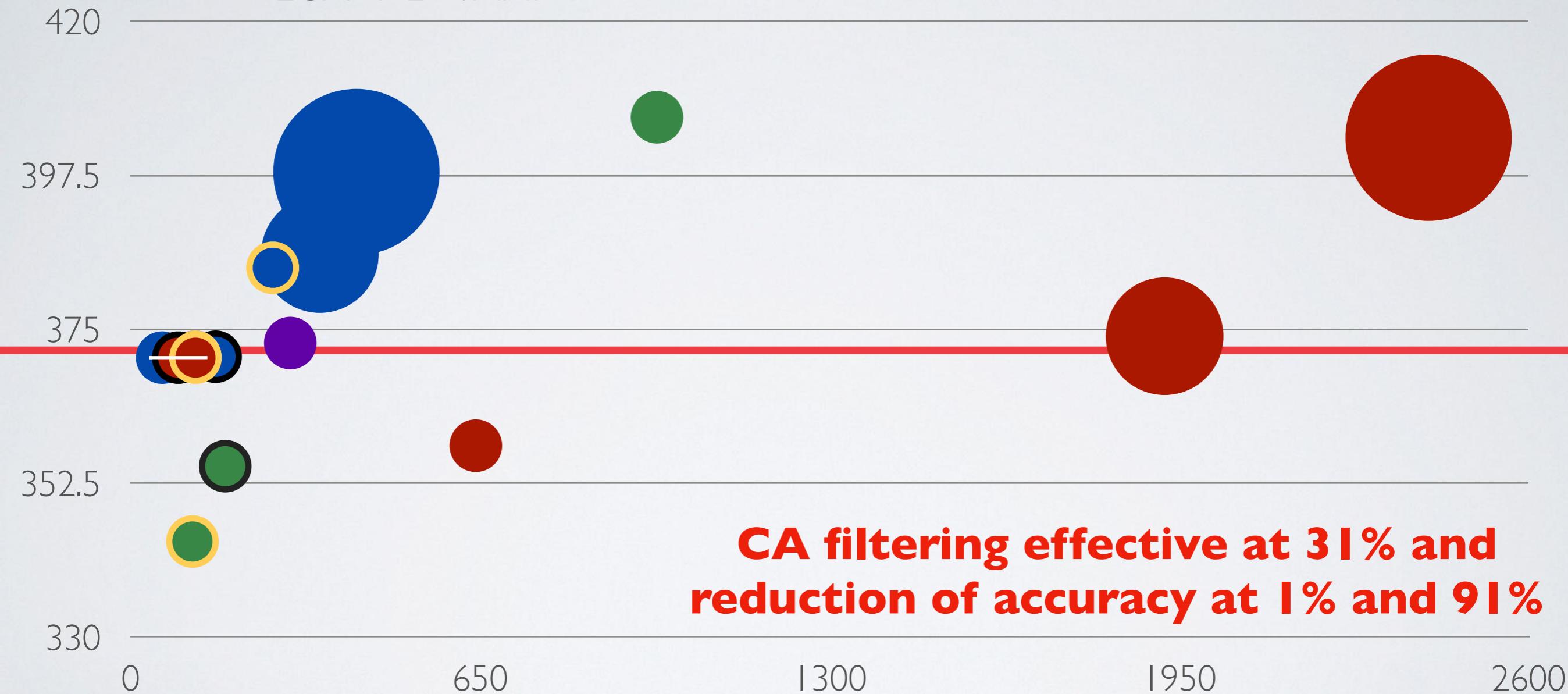


Simulated ID Curation on GZCD GGR-18

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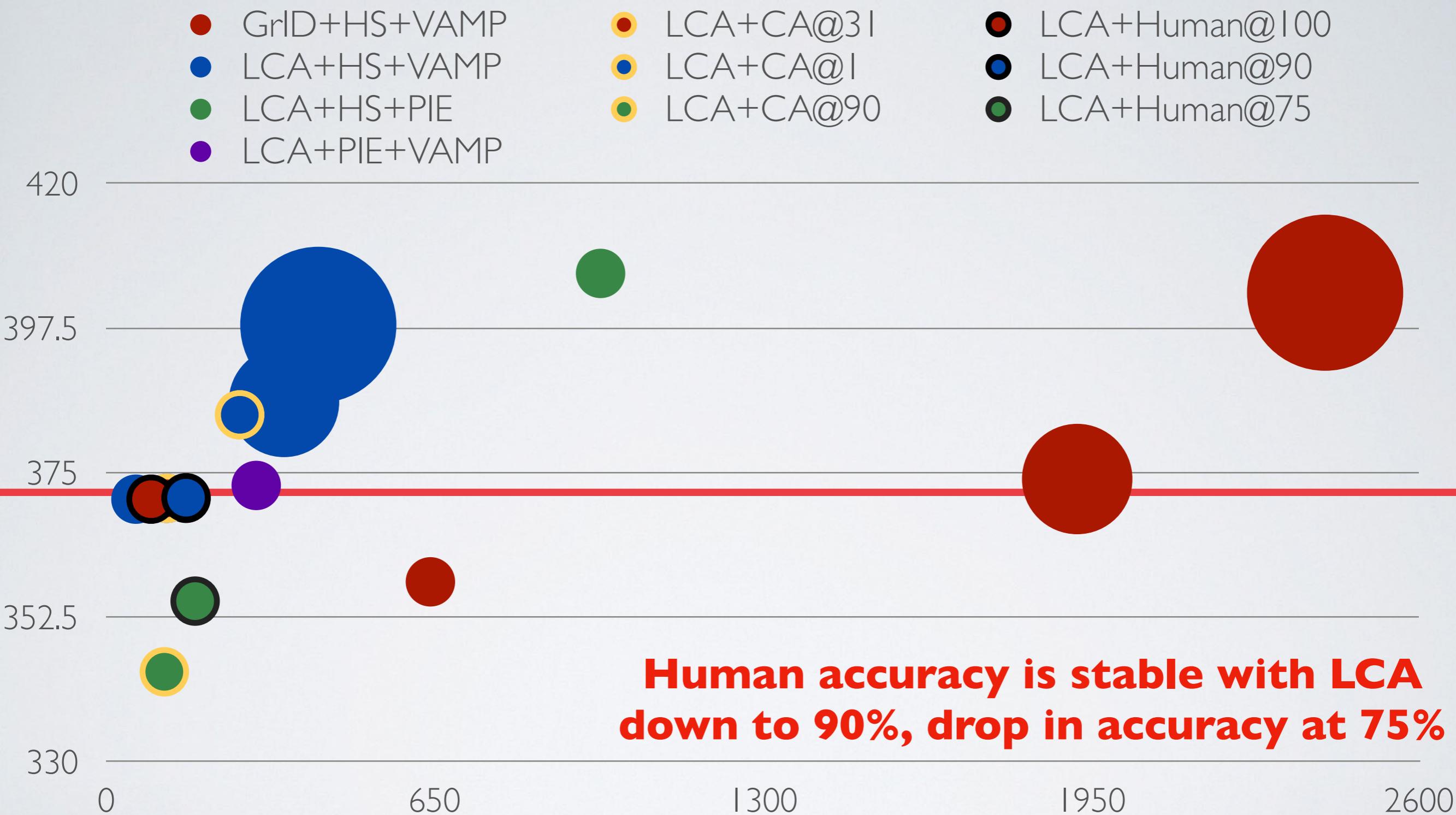
- LCA+CA@31
- LCA+CA@1
- LCA+CA@90

- LCA+Human@100
- LCA+Human@90
- LCA+Human@75



**CA filtering effective at 31% and
reduction of accuracy at 1% and 91%**

Simulated ID Curation on GZCD GGR-18



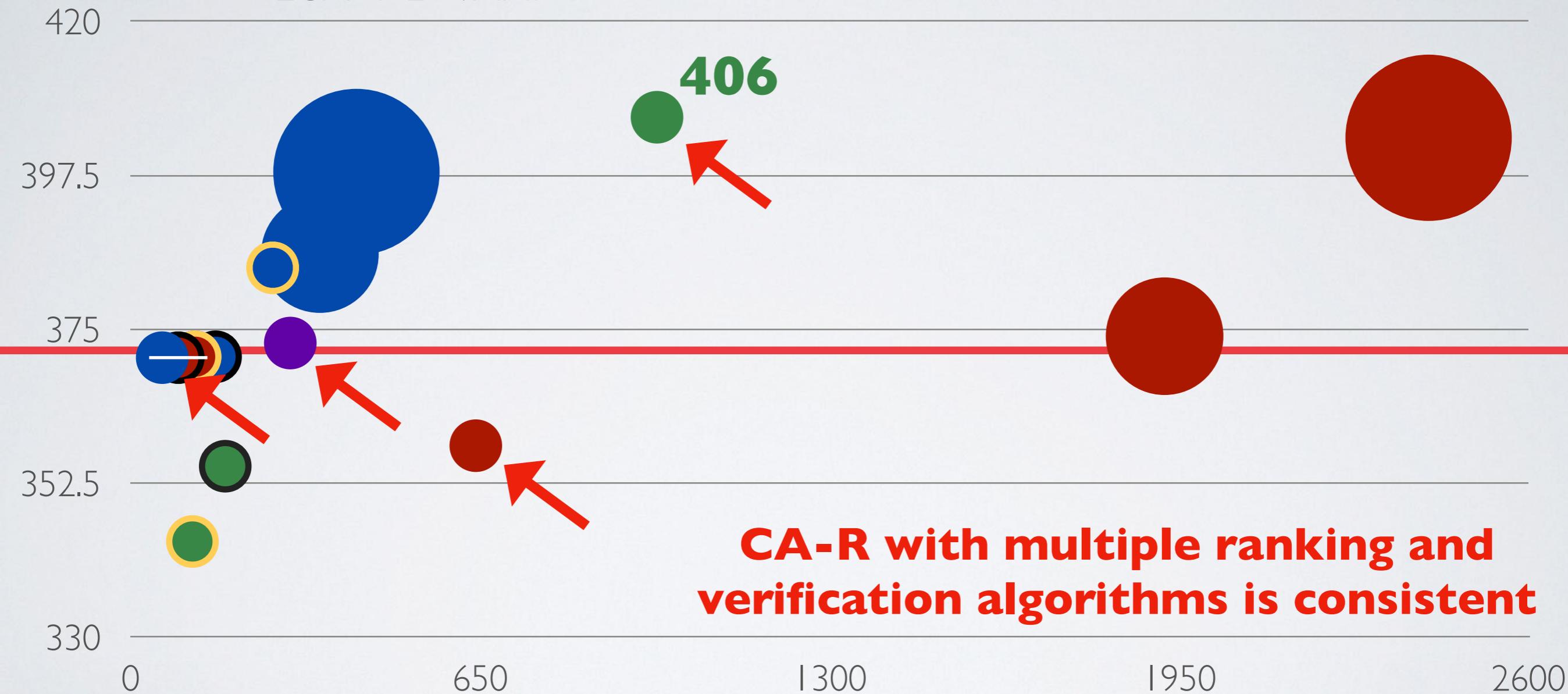
Human accuracy is stable with LCA down to 90%, drop in accuracy at 75%

Simulated ID Curation on GZCD GGR-18

- GrID+HS+VAMP
- LCA+HS+VAMP
- LCA+HS+PIE
- LCA+PIE+VAMP

- LCA+CA@31
- LCA+CA@1
- LCA+CA@90

- LCA+Human@100
- LCA+Human@90
- LCA+Human@75



CA-R with multiple ranking and verification algorithms is consistent

Completed Work

- Census Annotation (CA) and Census Annotation Regions (CA-R) address the incidental matching problem
- User study shows humans are faster and more accurate when reviewing CA and CA-R pairs
- CA and CA-R improve VAMP score separability for photobombs and scenery matches on GZ
- Simulations on GZCD show decrease in human involvement across many ID configurations
 - Detection + CA filtering is not too harsh
 - Human accuracy is tolerable down to 90%
 - Consistent for HotSpotter, VAMP, PIE, & LCA



PhD Defense Outline

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Animal Detection Pipeline

Review of the 5-component detection pipeline

Additional detection components

Overview of Photographic Censusing

Required components & automated Lincoln-Petersen Index

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Culminating experiment on GGR-18

Conclusion

Contributions & future work



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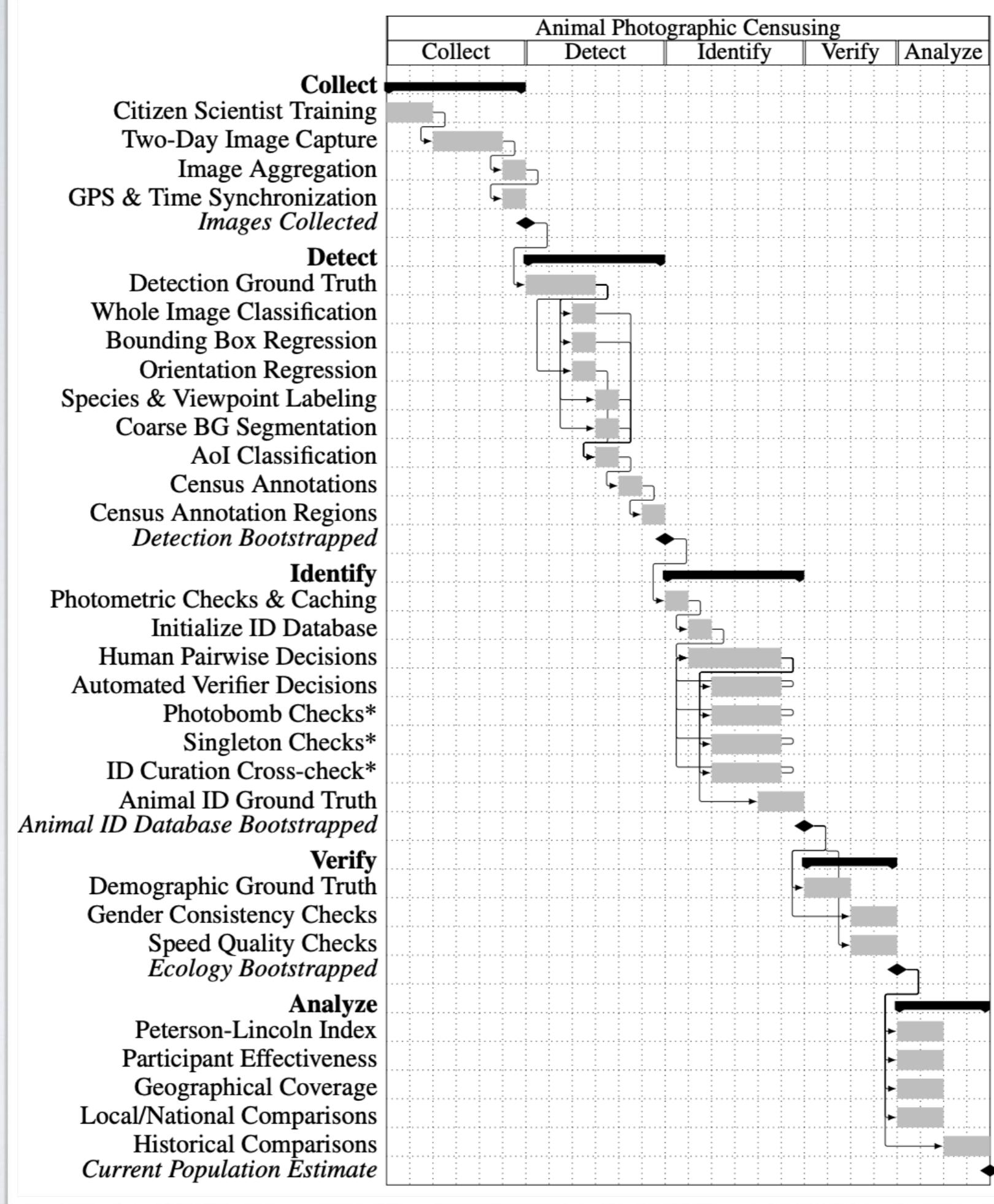
Contributions & future work



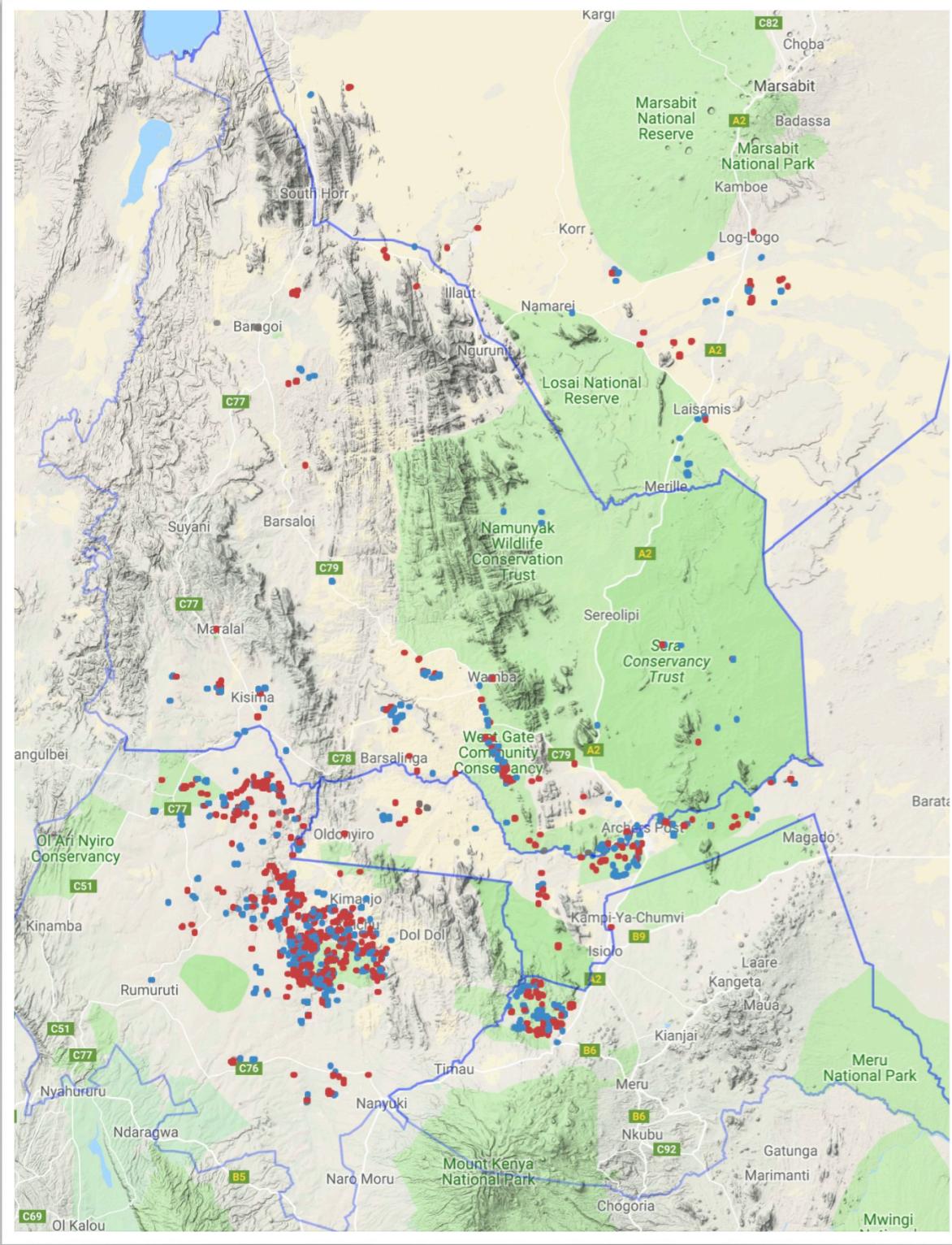
Survey Areas of the GZGC and GGR Rallies



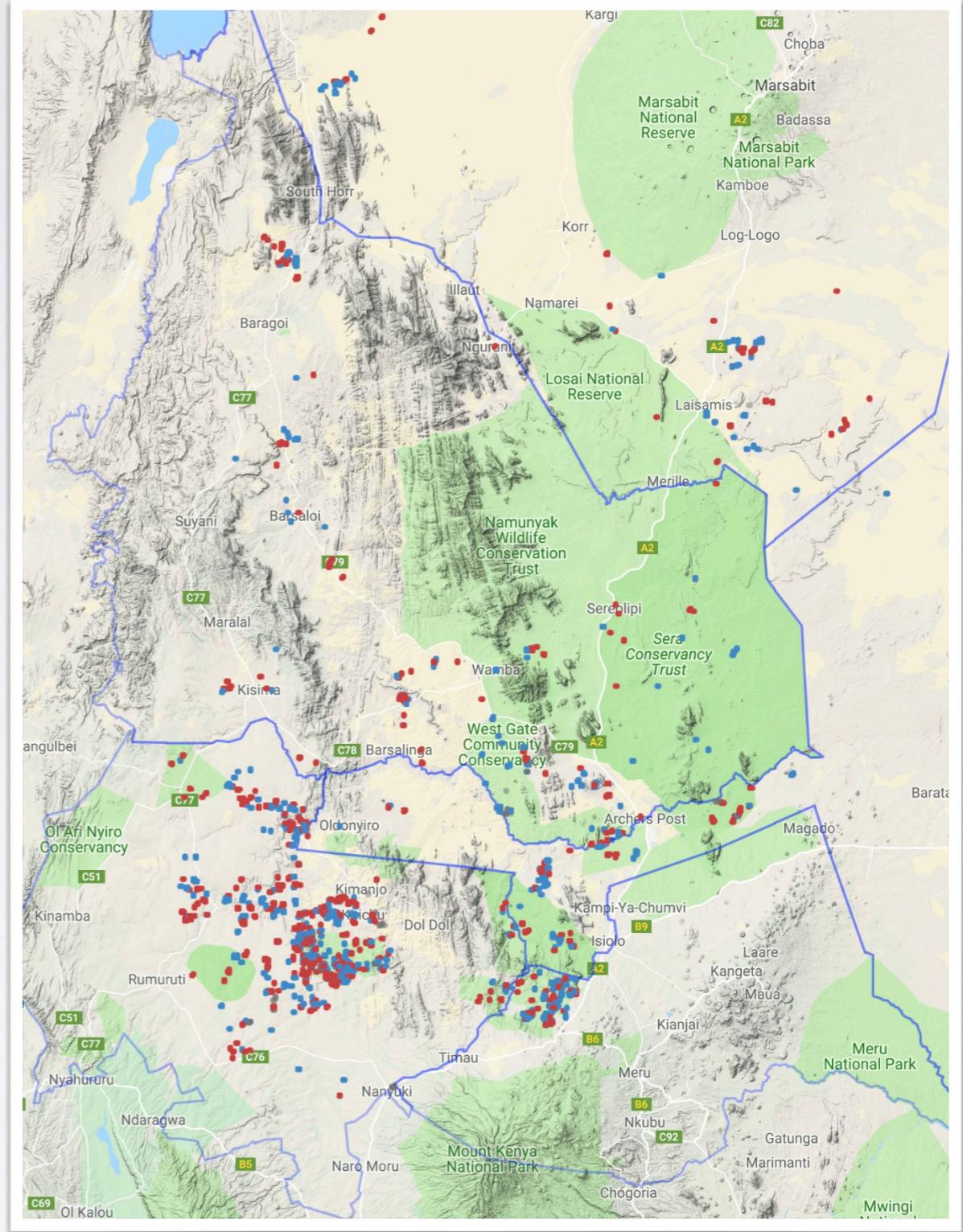
GREAT GREVY'S RALLY



Great Grevy's Rally 2016 & 2018

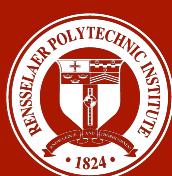


GGR 2016 (GGR-16)



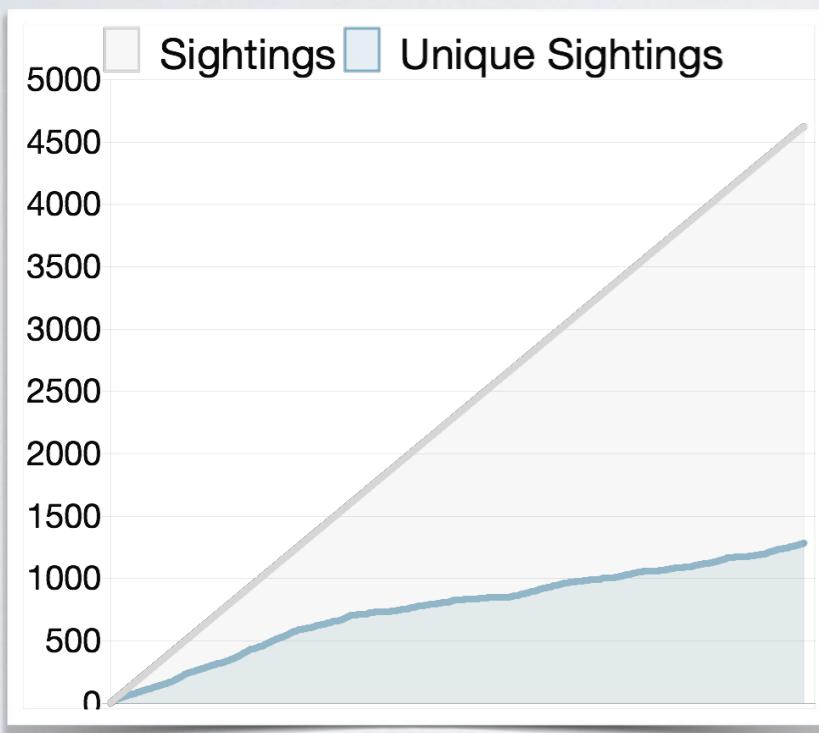
GGR 2018 (GGR-18)

GREAT GREVY'S RALLY

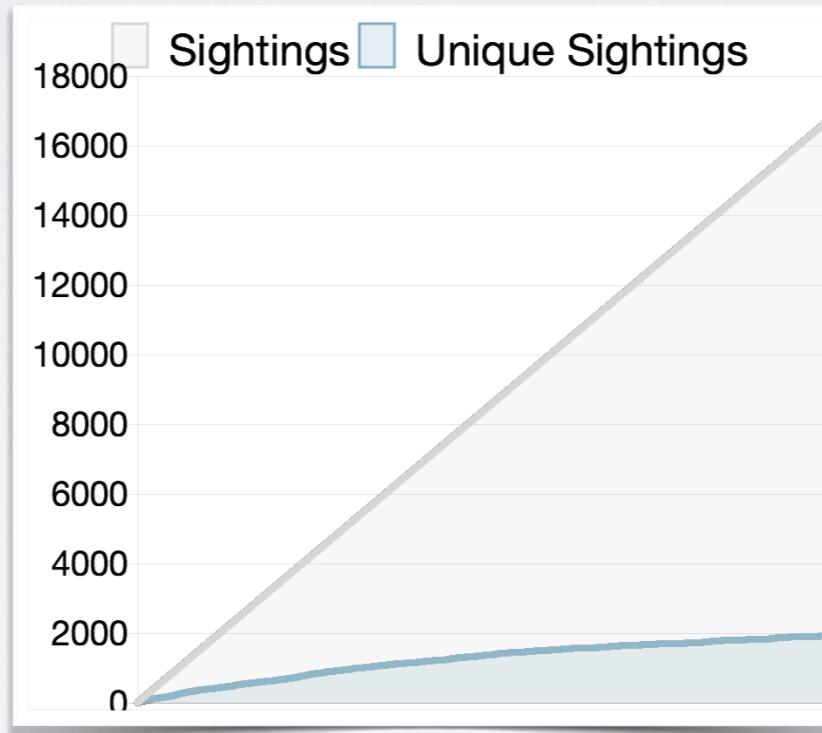


Population Estimate Convergence

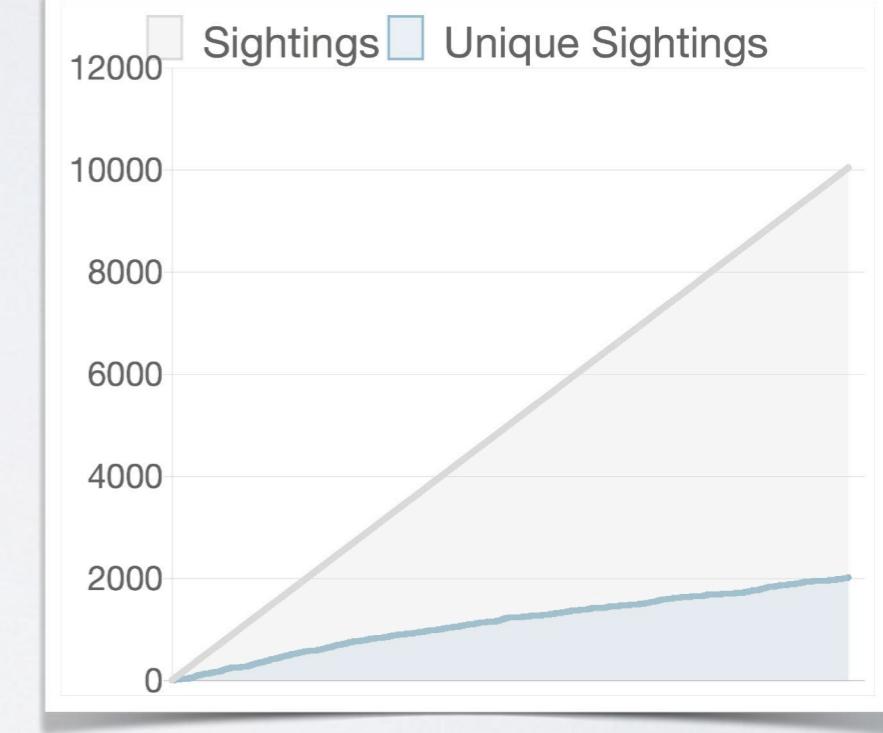
	Cars	Cameras	Photographs
GZGC	27	55	9,406
GGR-16	121	162	40,810
GGR-18	143	214	49,526



GZGC
(baseline)



GGR-16



GGR-18

Better convergence

Population Estimate Results

Censusing Rally	Annotations	Individuals	L-P Estimate
GZGC Masai	466	103	119 ± 4
GZGC Plains	4,545	1,258	$2,307 \pm 366$
GGR-16 Grévy's	16,866	1,943	$2,269 \pm 95$
GGR-18 Grévy's	10,044	1,972	$2,812 \pm 171$
GGR-18 Reticulated	4,018	992	$2,309 \pm 332$

Kenyan County	GGR-16 L-P Estimate	GGR-18 L-P Estimate
Isiolo	299 ± 54	597 ± 182
Laikipia	1199 ± 59	1328 ± 105
Marsabit	66 ± 17	250 ± 166
Meru	344 ± 30	384 ± 36
Samburu	452 ± 80	642 ± 172
<i>Northern Blocks</i>	80 ± 21	545 ± 265

GGR-18 Grevy's estimate accepted by Kenyan gov. as official numbers



Automated Lincoln-Petersen Index

$$n_{LP} = \mu_{LP} \pm z_{\alpha/2} * \sigma_{LP}$$
$$\approx \left\lfloor \frac{\hat{n}_1 * \hat{n}_2 * \beta}{\hat{n}_B} \right\rfloor$$
$$\pm 1.96 * \sqrt{\frac{\hat{n}_1 * \hat{n}_2 * \beta * (\hat{n}_1 - \hat{n}_B * \gamma) * (\hat{n}_2 - \hat{n}_B * \gamma)}{\hat{n}_B^3 * \gamma^2}}$$

where

$$\textbf{2%} \quad \textbf{0%}$$

$$\beta = 1 + \hat{p}_{mm}(\theta) - \hat{p}_{ms}(\theta)$$

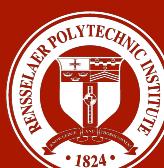
$$\gamma = 1 - \hat{p}_{dm}(\theta)$$

6%

Culminating Experiment on GGR-18

Metric	Original Estimate	New Estimate
Annotations	10,044	11,916
Names	1,972	2,022
Human Reviewers	>10	1
Human Decisions	18,556	1,297
Processing Days*	~90	2
Population Estimate	$2,812 \pm 171$	$2,820 \pm 167$

*GGR-18 processing included ground-truth annotation and training new detection models



Culminating Experiment on GGR-18

Metric	Original Estimate	New Estimate
Annotations	10,044	11,916
Names	1,972	2,022
Human effort	>10	1
Consistent result within +0.3% with 93% reduction in human effort	18,556	1,297
	~90	2
Population Estimate	$2,812 \pm 171$	$2,820 \pm 167$

*GGR-18 processing included ground-truth annotation and training new detection models



Completed Work

- End-to-end photographic censusing process with citizen scientists applied at scale
- GGR-16 and GGR-18 datasets of Grevy's zebra pop.
- Automated Lincoln-Petersen Index to calculate better population estimates when machine learning methods are involved
- Culminating experiment on GGR-18 demonstrates an accurate estimate is possible with minimal human effort

[3] J. Parham, et al., “Animal Population Censusing at Scale with Citizen Science and Photographic Identification,” AAAI AI for Social Good Worksop, Stanford, CA, USA, Mar. 2017.

[4] J. Parham, et al., “The Great Grevy’s Rally: A Review on Procedure,” in AI for Wildlife Conserv. Workshop, Stockholm, Sweden, Jul. 2018.

[5] T. Berger-Wolf et al., “The Great Grevy’s Rally: The Need, Methods, Findings, Implications and Next Steps,” Grevy’s Zebra Trust, Nairobi, Kenya, Tech. Rep., Aug. 2016.

[6] D. Rubenstein et al., “The State of Kenya’s Grevy’s Zebras and Reticulated Giraffes: Results of the Great Grevy’s Rally 2018,” Grevy’s Zebra Trust, Nairobi, Kenya, Tech. Rep., Jun. 2018.



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Contributions

- Detection Pipeline with 5 components (plus 3 additional)
 - Whole-Image Classifier (WIC)
 - Annotation Localization
 - Annotation Classification
 - Coarse Background Segmentation
 - Annotation of Interest (AoI)
- Census Annotation (CA) & Census Annotation Regions (CA-R)
 - User study showed decrease in human decision times
- LCA Integration & Simulations on Human Effort
- System for Photographic Censusing of Animal Populations
 - Detection Pipeline
 - Ranking Algorithm
 - Decision Management Algorithm
 - Verification Algorithm
 - Human-in-the-Loop Reviewer
 - Population Estimator
- Auto. Lincoln-Petersen Index with error terms for detect and ID



Contributions

- Animal Detection Datasets: DETECT & WILD
- Grevy's Zebra Census Dataset (GZCD)
 - 5,281 Grevy's zebra annotations for 554 names
 - Over 24,000 automated and 43,000 human pair decisions
 - Used CA + CA-R + HotSpotter + VAMP + PIE + Graph ID + LCA
- Photographic Censusing Rallies: GGR-16 and GGR-18
 - Citizen scientists for wide-area data collection over two-days
 - Data wrangling and standardizing of metadata for synchronization
 - Machine learning components bootstrapped with minimal data
 - Computer vision algorithms for detection and ID curation
 - Final population estimates for Grevy's zebra and Reticulated giraffe in Kenya for 2016 and 2018 (used by Kenyan government)
- GGR-18 Culminating Experiment on Grevy's Zebra
 - Audited GGR-18 data with pre-trained detection models, CA, CA-R, LCA, and Automated Lincoln-Petersen Index
 - New population estimate consistent with existing value within 0.3%, used 93% reduction in human effort, and took 2 days



Future Work & Acknowledgements

- There needs to be a focus on building large animal ID datasets that offer good examples for real-world detection and enough re-sightings to train newer ML approaches
- Need better cryptographic approaches for sensitive ecological metadata, especially for critically endangered and poached species
- Segmentation methods are needed to properly address problems like mother/foal photobombs, but cannot come with a high data review burden for conservation researchers
- Better citizen scientist contribution guidelines that allow for the sustainable and ethical collection of ecological data for ML

Thanks to my wife (Lindsay), children (Heidi, Lincoln), family, advisor and committee members, lab and research partners, employers and co-workers, the Moore foundation, the KWS, and Dr. Jon Crall for co-investigating animal re-ID with Grevy's zebra.



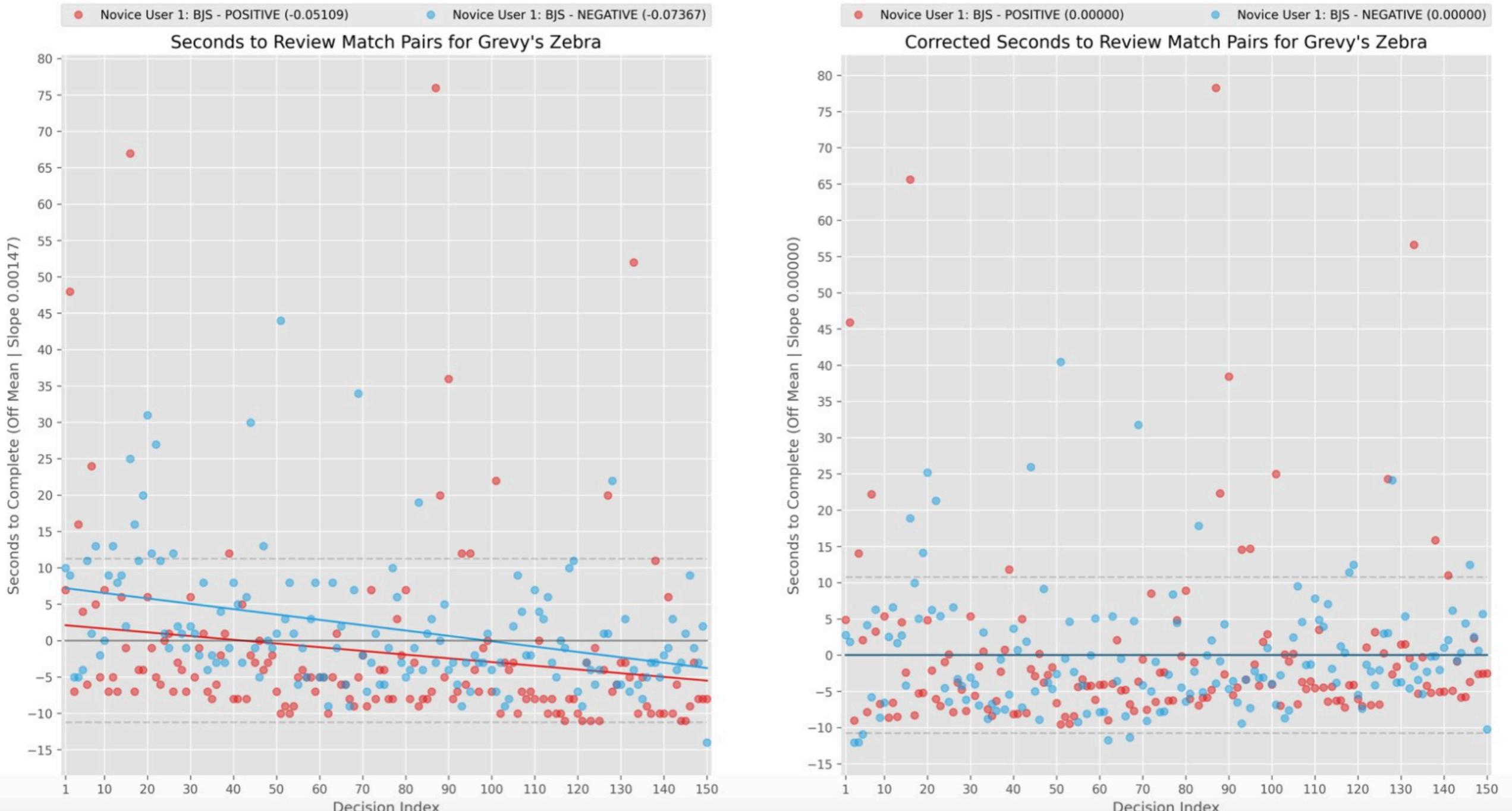


QUESTIONS

A black and white photograph of a zebra standing in a field of tall, dry grass. The zebra's stripes are clearly visible against its dark coat. It is facing towards the right of the frame.

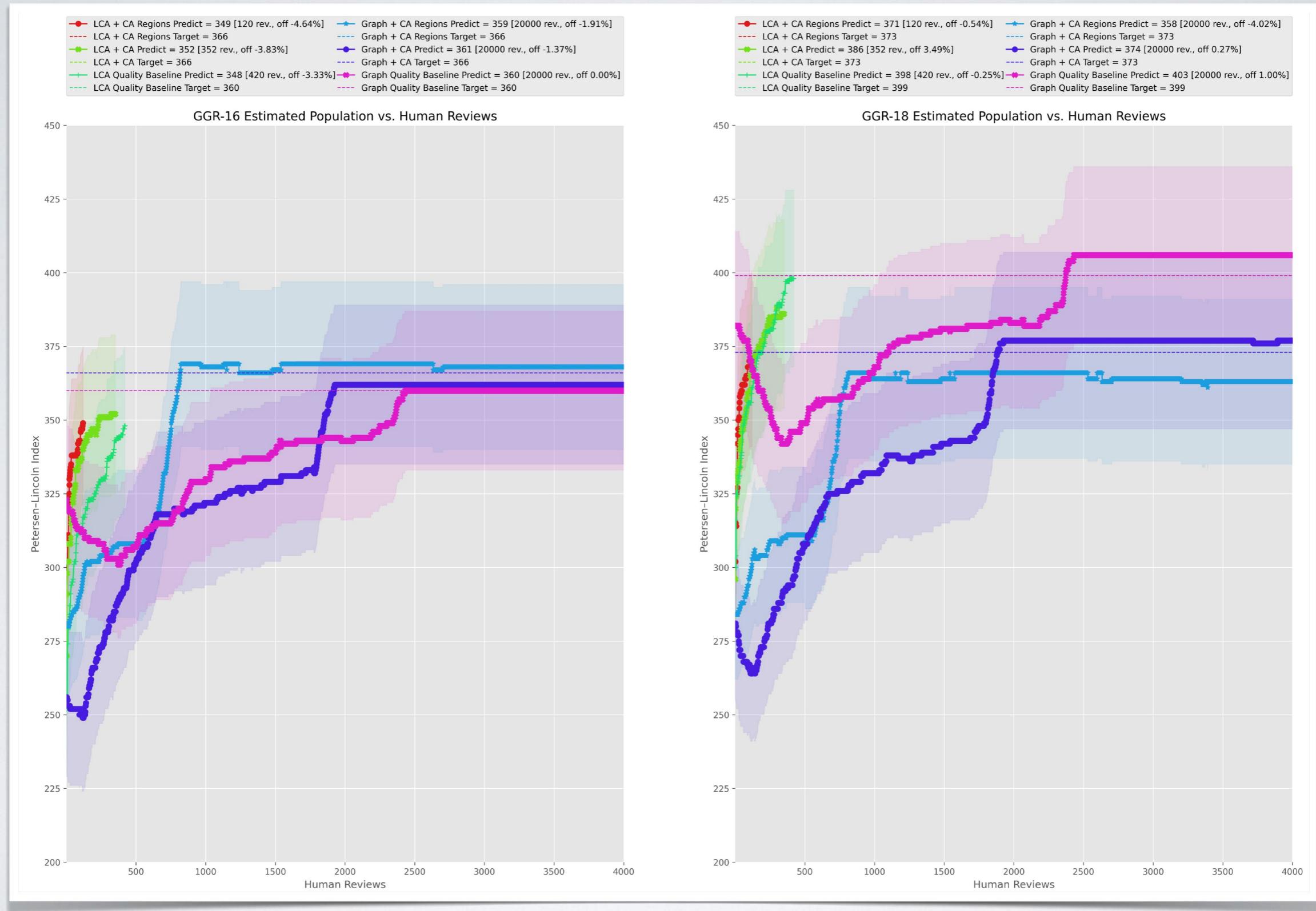
SUPPLEMENTARY MATERIALS

User Study Decisions from Novice Reviewer

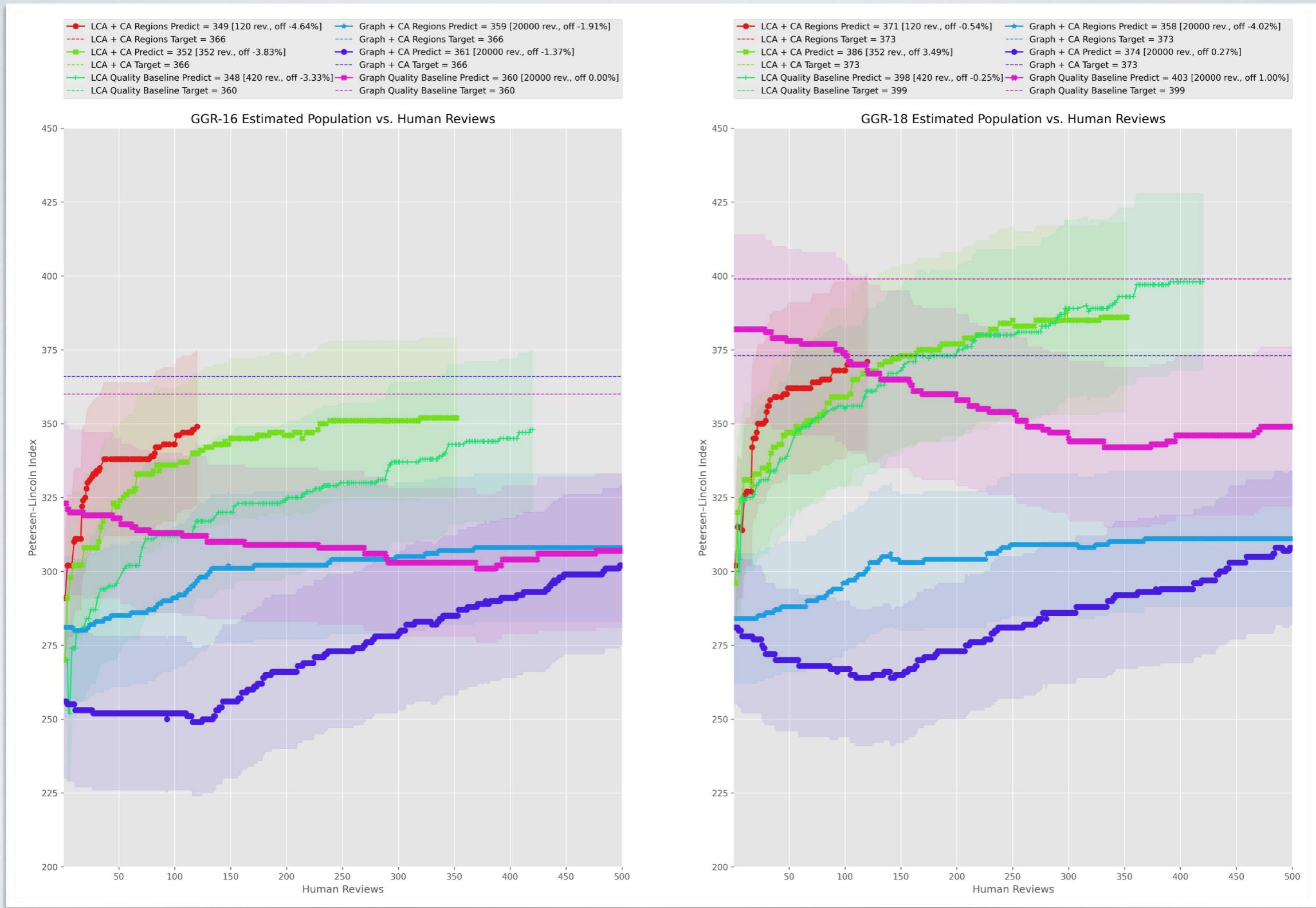


The decision times for each user were normalized to prevent bias

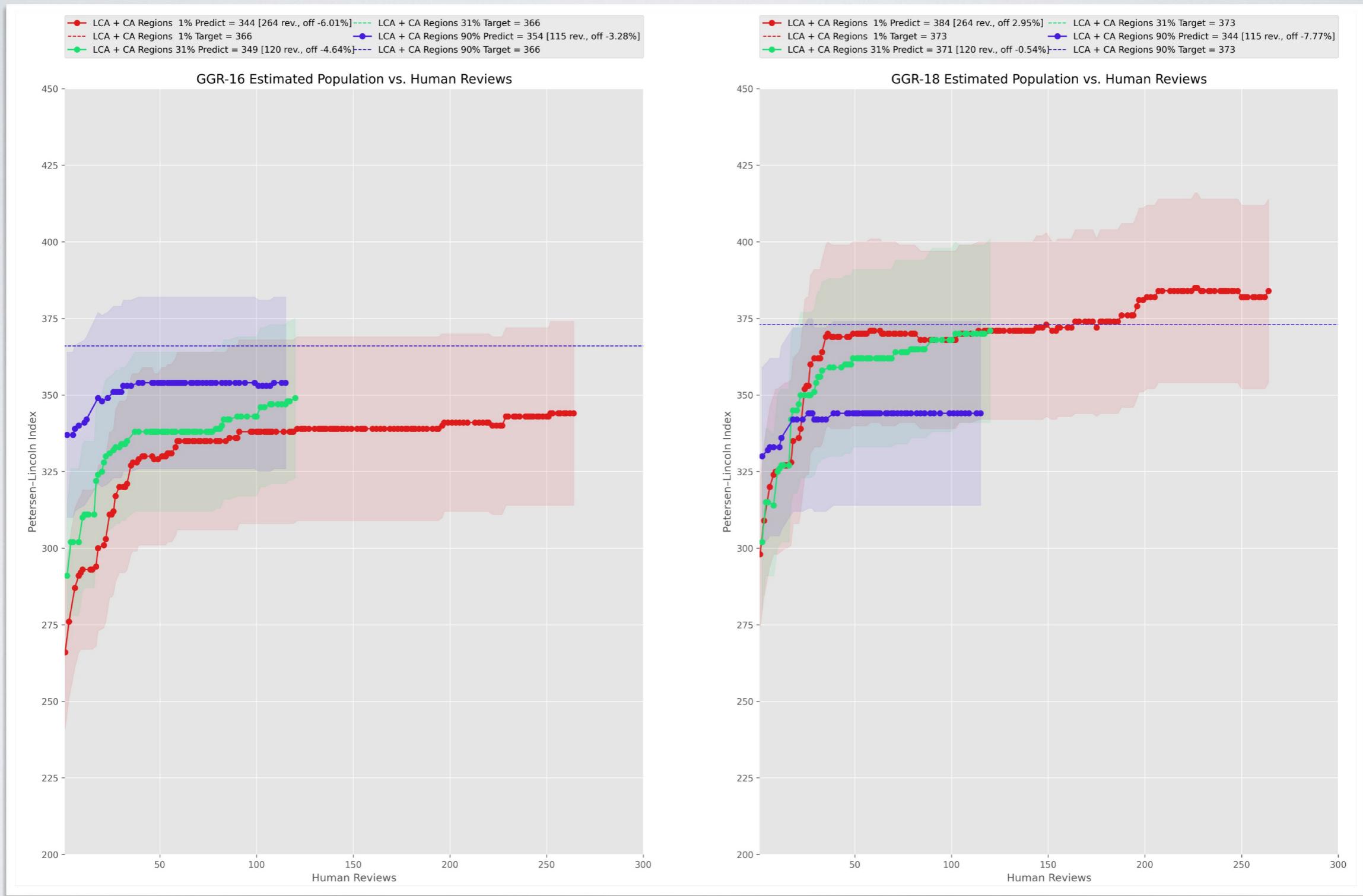
Simulated GZCD Curation with CA and CA-R



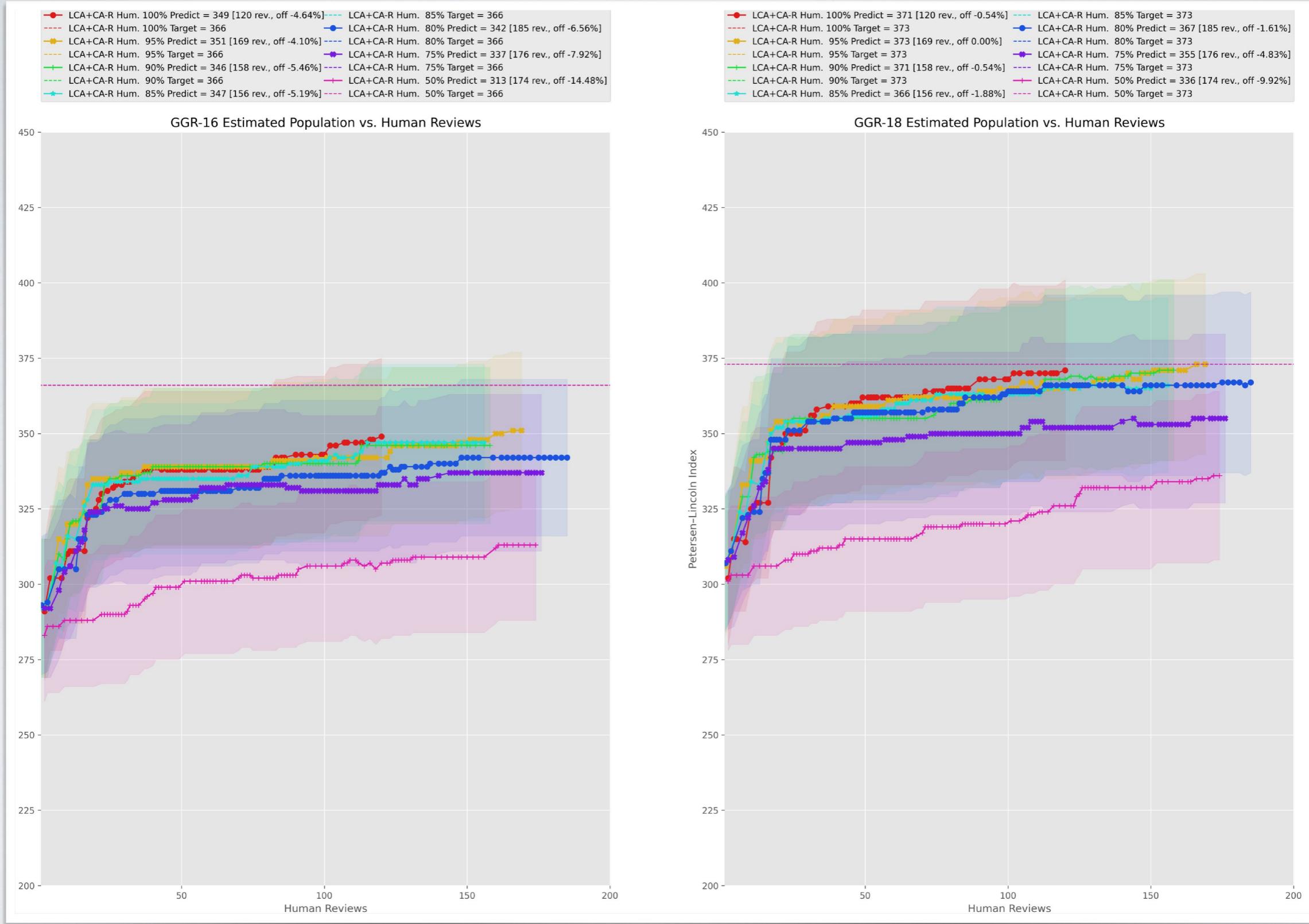
Simulated GZCD Curation with CA and CA-R



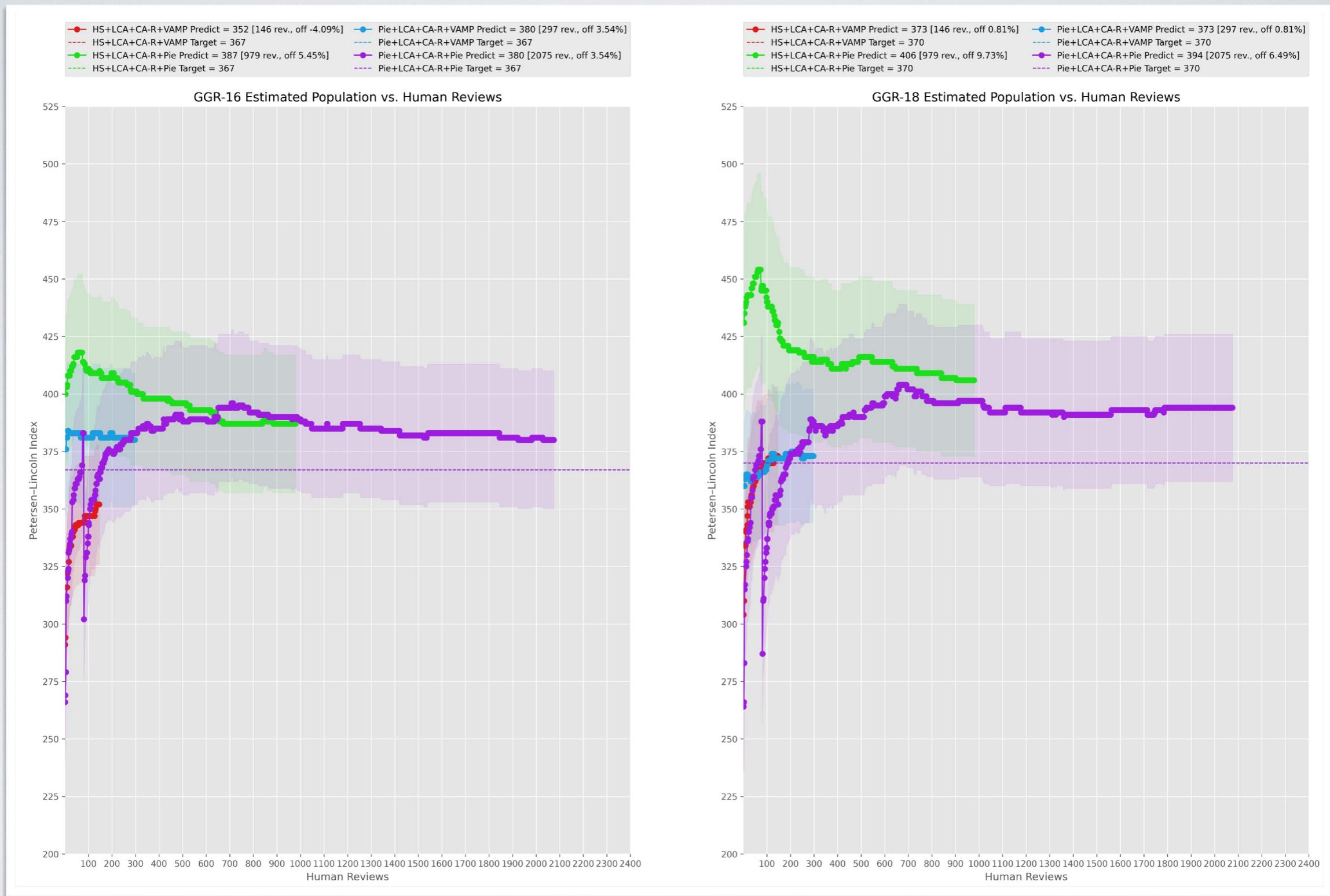
Simulated GZCD Curation with CA-R Thresholds



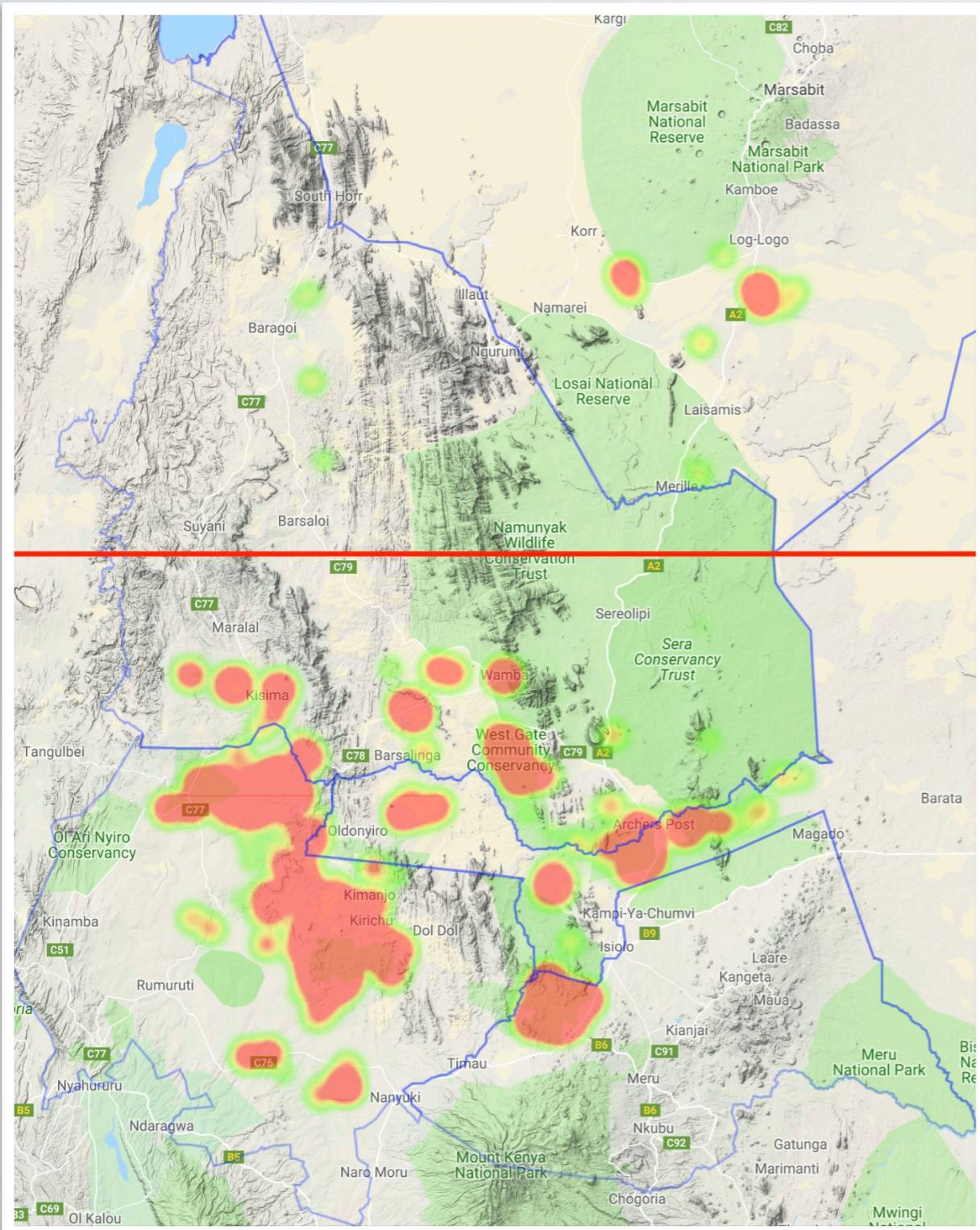
Simulated GZCD Curation with Human Error



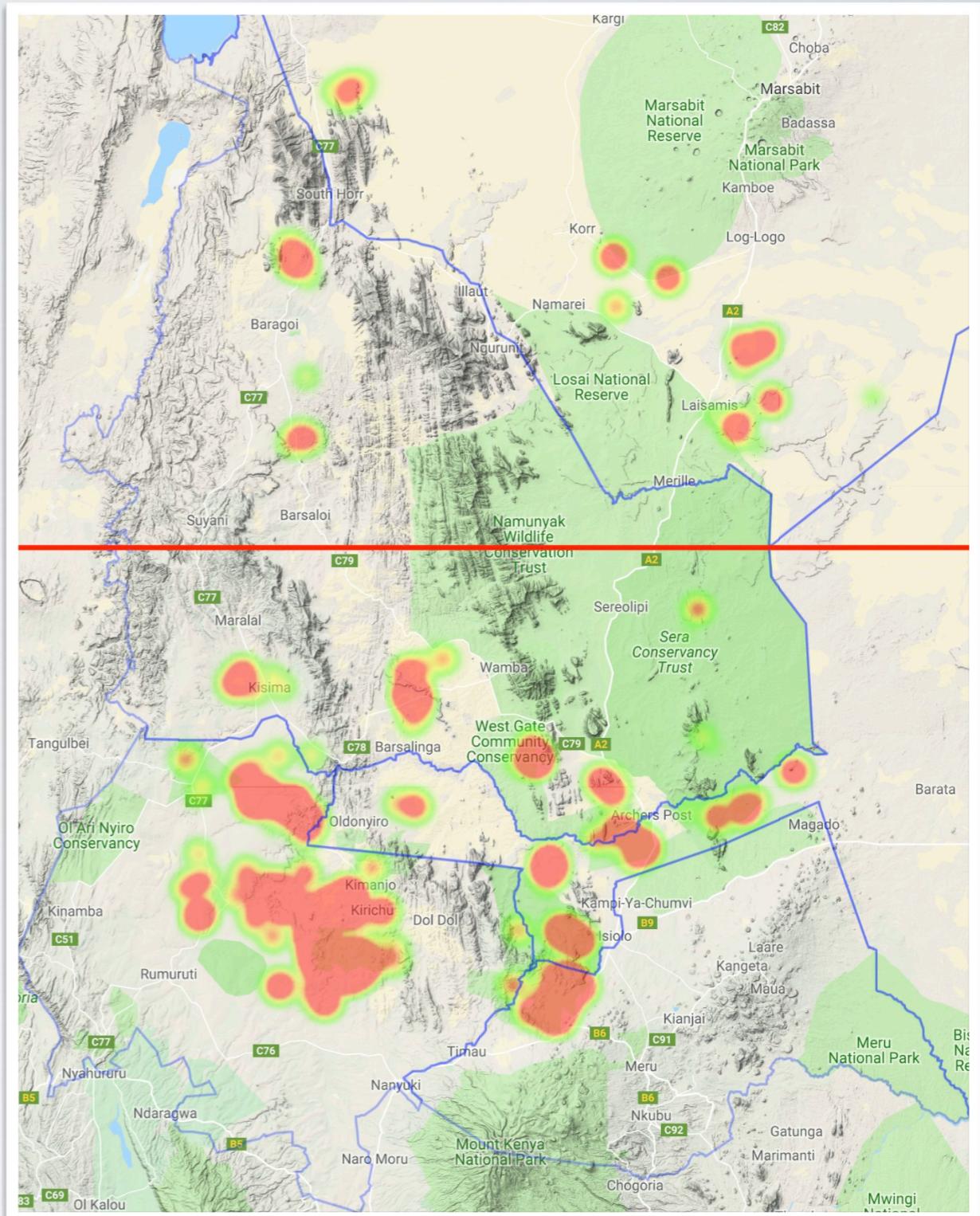
Simulated GZCD Curation for ID Configurations



GGR-16 & GGR-18 Northern Block Sampling



GGR-16



GGR-18

SUPPLEMENTARY MATERIALS

