



Universidad Católica
San Pablo



Departamento de Ciencia
de la Computación

Centro de Investigación
e Innovación en
Ciencia de la Computación



Deep Learning Techniques in Urban Security Perception Analysis

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Advisor: Prof. Jorge Poco Medina



FONDO NACIONAL DE DESARROLLO CIENTÍFICO,
TECNOLÓGICO Y DE INNOVACIÓN TECNOLÓGICA



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TECNOLOGÍA E INNOVACIÓN TECNOLÓGICA

About me



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www.fmorenovr.com

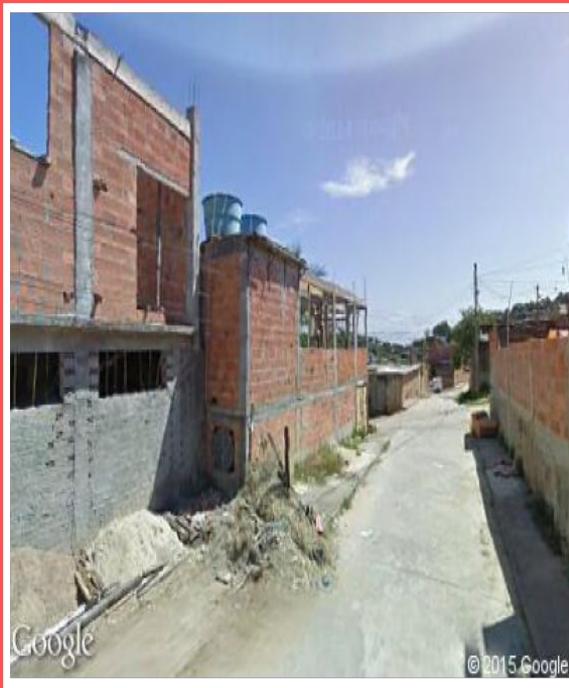


Content

- Context & Motivation
- Dataset
 - Place Pulse
- Methodology
 - Dataset Preparation
 - Exploratory Data Analysis
 - Dataset Limitations
- Urban Safety Perception
 - Data Pre-processing
 - Models Configurations
 - Experiments and Results
- Conclusions

Context & Motivation

Which one looks safer?



Bangú (RJ)



City Center (RJ)

Context

Urban perception is shaped by a complex interplay of factors. Such as physical design, architectural styles, street layouts, landmarks, and the quality of infrastructure all contribute to the visual characteristics that define a city's identity.

Motivation

By understanding how people perceive and experience cities, we can create more inclusive, attractive, and functional urban solutions that meet the needs and aspirations of their diverse populations.

Key contributions

- We **propose a methodology** to analyze the **Place Pulse 2.0 dataset** since we thought that is better to focus on data first instead of model complexity.
- We **study** the **Place Pulse dataset limitations**, some of them based on how the dataset was built and others based on the pre-processing.
- We **evaluate and compare** semi-supervised models performance with supervised methods, showing that semi-supervised models fit the necessity of training this complex dataset with the limitations explained before.
- We **solved** the problem of imbalance, individual city identification, and lack of samples per city using a semi-supervised GAN model. In other words, we can fix 3 dataset limitations in Place Pulse.

Place Pulse

Place Pulse dataset

Which place looks livelier ? ▾



For this question: **362,708** clicks collected

Goal: **500,000** clicks

[SEE REAL-TIME RANKINGS](#)

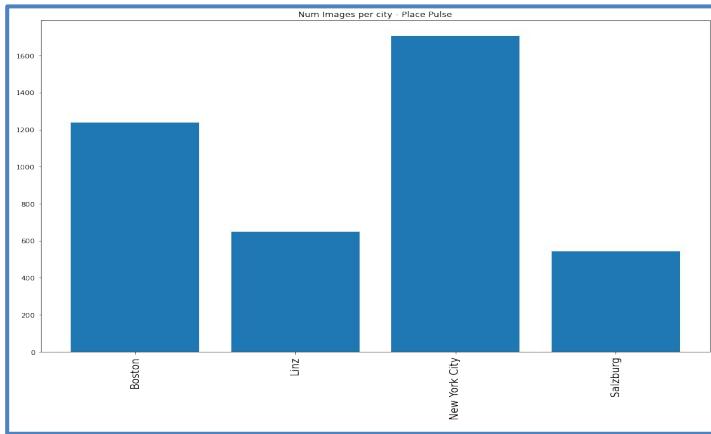
RANK	CITY	CLICKS	TREND	RANK	CITY	CLICKS	TREND
1	Washington DC	6296	_____	54	Cape Town	16228	_____
2	London	17982	███████	55	Belo Horizonte	12728	█████
3	New York	22424	_____	56	Gaborone	4717	██████

<http://pulse.media.mit.edu/>

* Comparisons were made using two random images from random cities.

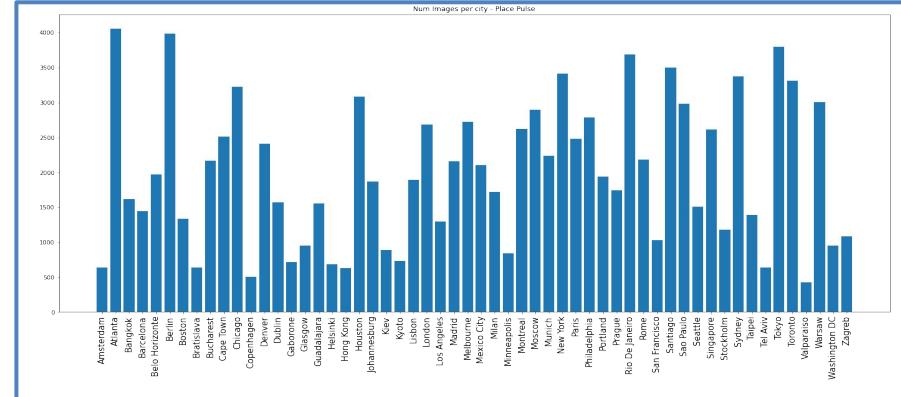
Place Pulse 1.0

- Release date: 2013
 - 73 806 Comparisons
 - 4 136 images
 - 2 Countries
 - 4 cities
 - 3 categories



Place Pulse 2.0

- Release date: 2016
 - 1 223 649 Comparisons
 - 111 390 images
 - 32 countries
 - 56 cities
 - 6 categories



Methodology

Pipeline

Data pre-processing

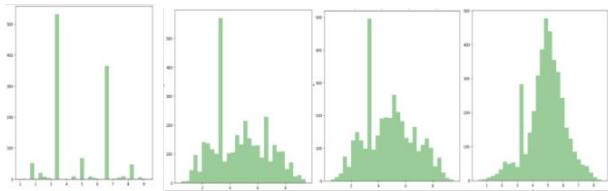
left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left



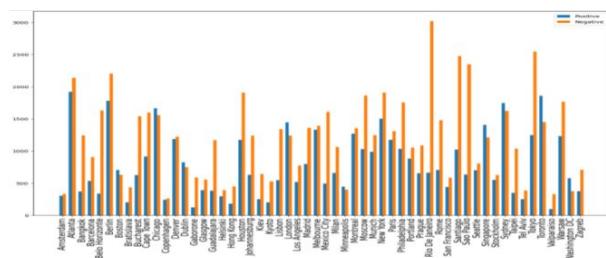
- (, 8.35)
- (, 7.16)
- ...
- (, 5.01)
- ...
- (, 1.29)
- (, 0.55)

Exploratory Data Analysis

Perceptual scores histograms

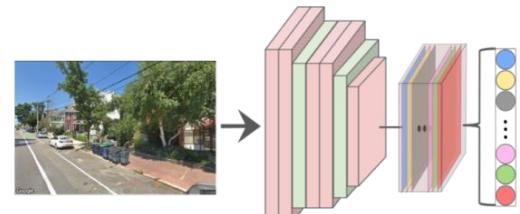


Imbalance of classes

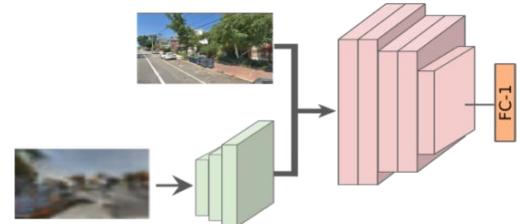


Model evaluations

Base line models



Generative models



Pipeline

Data pre-processing

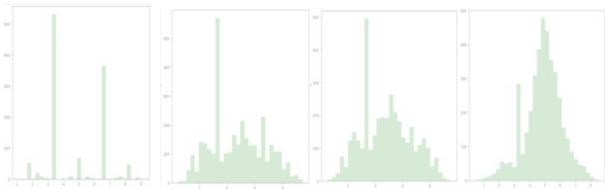
left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left



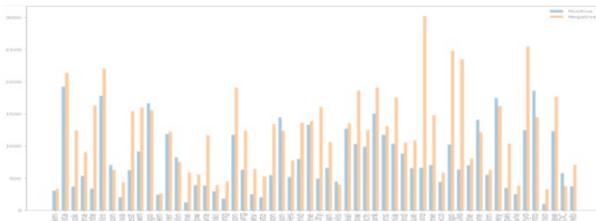
- (, 8.35)
- (, 7.16)
- ...
- (, 5.01)
- ...
- (, 1.29)
- (, 0.55)

Exploratory Data Analysis

Perceptual scores histograms

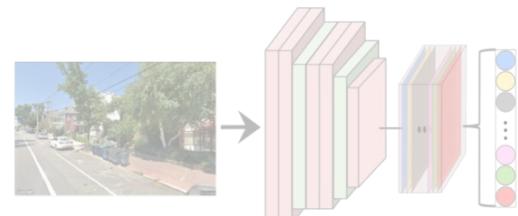


Imbalance of classes

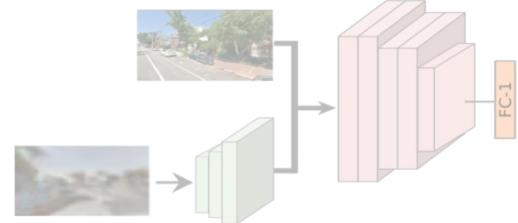


Model evaluations

Base line models



Generative models



Pipeline

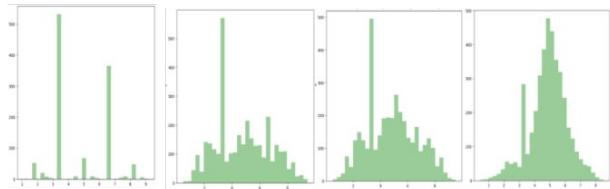
Data pre-processing

left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left

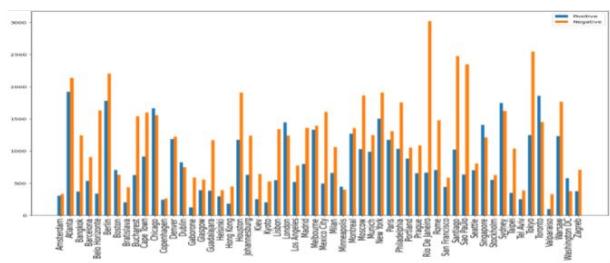


Exploratory Data Analysis

Perceptual scores histograms

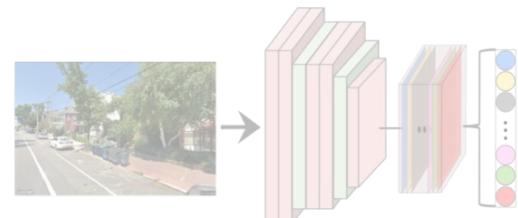


Imbalance of classes

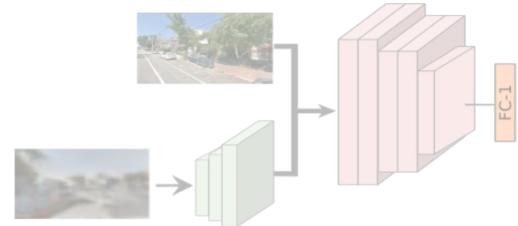


Model evaluations

Base line models



Generative models



Pipeline

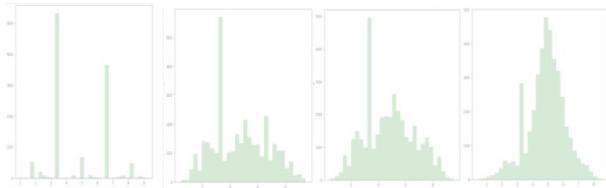
Data pre-processing

left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left

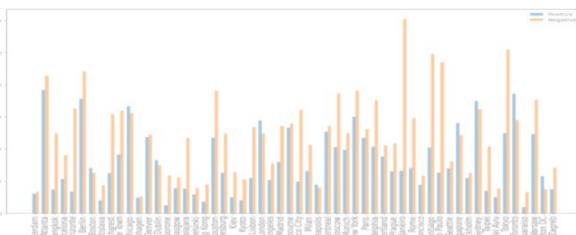


Exploratory Data Analysis

Perceptual scores histograms

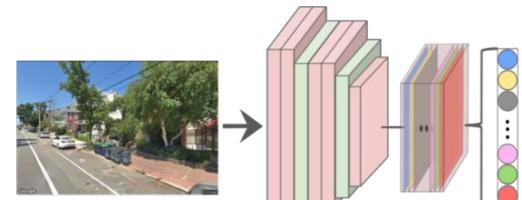


Imbalance of classes

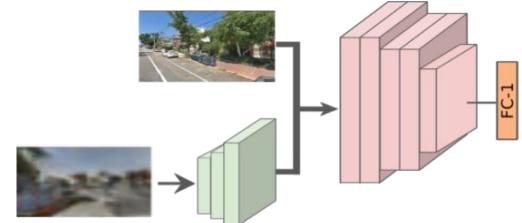


Model evaluations

Base line models



Generative models



Data Preparation

Data samples

left-id	right-id	winner	left-lat	left-long	right-lat	right-long	category
513d7e23fdc9f	513d7ac3fdc9f	equal	40.744156	-73.93557	-33.52638	-70.591309	depressing
513f320cfdc9f	513cc3acfcd9f	left	52.551685	13.416548	29.76381	-95.394621	safety
513e5dc3fdc9f	5140d960fdc9f	right	48.878382	2.403116	53.32932	-6.231007	lively

Perceptual Scores

$$W_i = \frac{w_i}{w_i + d_i + l_i}$$

$$L_i = \frac{l_i}{w_i + d_i + l_i}$$

$$q_{i,k} = \frac{*}{3}(W_{i,k} + \frac{1}{n_{i,k}^w}(\sum_{j_1} W_{j_1,k}) - \frac{1}{n_{i,k}^l}(\sum_{j_2} L_{j_2,k}) + 1)$$

*Nassar et al, "The evaluative image of the city", 1990

Salesse et. al, "The Collaborative Image of The City: Mapping the Inequality of Urban Perception", 2013

Rank Scores

$$\mu_x \leftarrow \mu_x + \frac{\sigma_x^2}{c} \cdot f\left(\frac{(\mu_x - \mu_y)}{c}, \frac{\varepsilon}{c}\right)$$

$$\mu_y \leftarrow \mu_y - \frac{\sigma_y^2}{c} \cdot f\left(\frac{(\mu_x - \mu_y)}{c}, \frac{\varepsilon}{c}\right)$$

$$\sigma_x^2 \leftarrow \sigma_x^2 \cdot \left[1 - \frac{\sigma_x^2}{c} \cdot g\left(\frac{(\mu_x - \mu_y)}{c}, \frac{\varepsilon}{c}\right)\right]$$

$$\sigma_y^2 \leftarrow \sigma_y^2 \cdot \left[1 - \frac{\sigma_y^2}{c} \cdot g\left(\frac{(\mu_x - \mu_y)}{c}, \frac{\varepsilon}{c}\right)\right]$$

$$c^2 = 2\beta^2 + \sigma_x^2 + \sigma_y^2$$

$$q_{i,k} = \frac{**}{c_{max,k}}(c_{i,k})$$

**Minka et al, "TrueSkill 2: An improved Bayesian skill rating system", 2018

Dubey et. al, "Deep Learning the City : Quantifying Urban Perception At A Global Scale", 2016

Processed samples

Image	ID	Safety	Lively	Wealthy	Beauty	Boring	Depressive
	513d7e23fdc9f	7.42	8.58	6.5	7.3	2.64	1.23
	513f320cfdc9f	6.07	4.97	7.13	8.61	1.67	0.86

Statistics

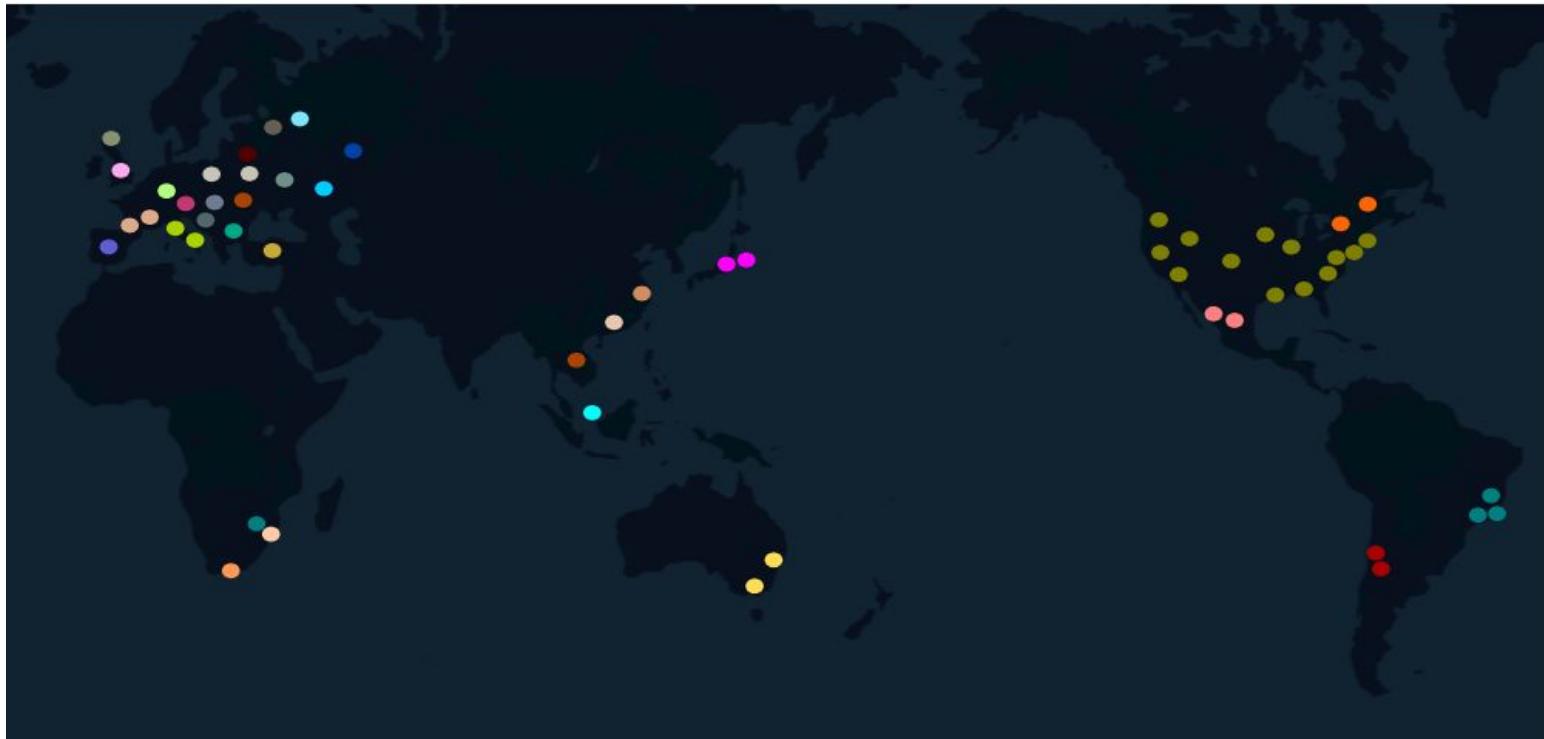
Place Pulse 1.0				
City	# images	<i>safe mean</i>	<i>wealth mean</i>	<i>unique mean</i>
Linz	650	4.85	5.01	4.83
Boston	1237	4.93	4.97	4.76
New York	1705	4.47	4.31	4.46
Salzburg	544	4.75	4.89	5.04
Total	4136			

Place Pulse 2.0			
Continent	#countries	#cities	#images
Europe	19	22	38,747
North America	3	17	37504
South America	2	5	12,524
Asia	5	7	11,417
Oceania	1	2	6,097
Africa	2	3	5,101
Total	32	56	111,390

Place Pulse 2.0			
Category	# comparisons	# images	<i>mean</i>
<i>Safety</i>	368,926	111,389	5.188
<i>Lively</i>	267,292	111,348	5.085
<i>Beautiful</i>	175,361	110,766	4.920
<i>Wealthy</i>	152,241	107,795	4.890
<i>Depressing</i>	132,467	105,495	4.816
<i>Boring</i>	127,362	106,363	4.810
Total	1,223,649		

Exploratory Data Analysis

Geographical city distribution



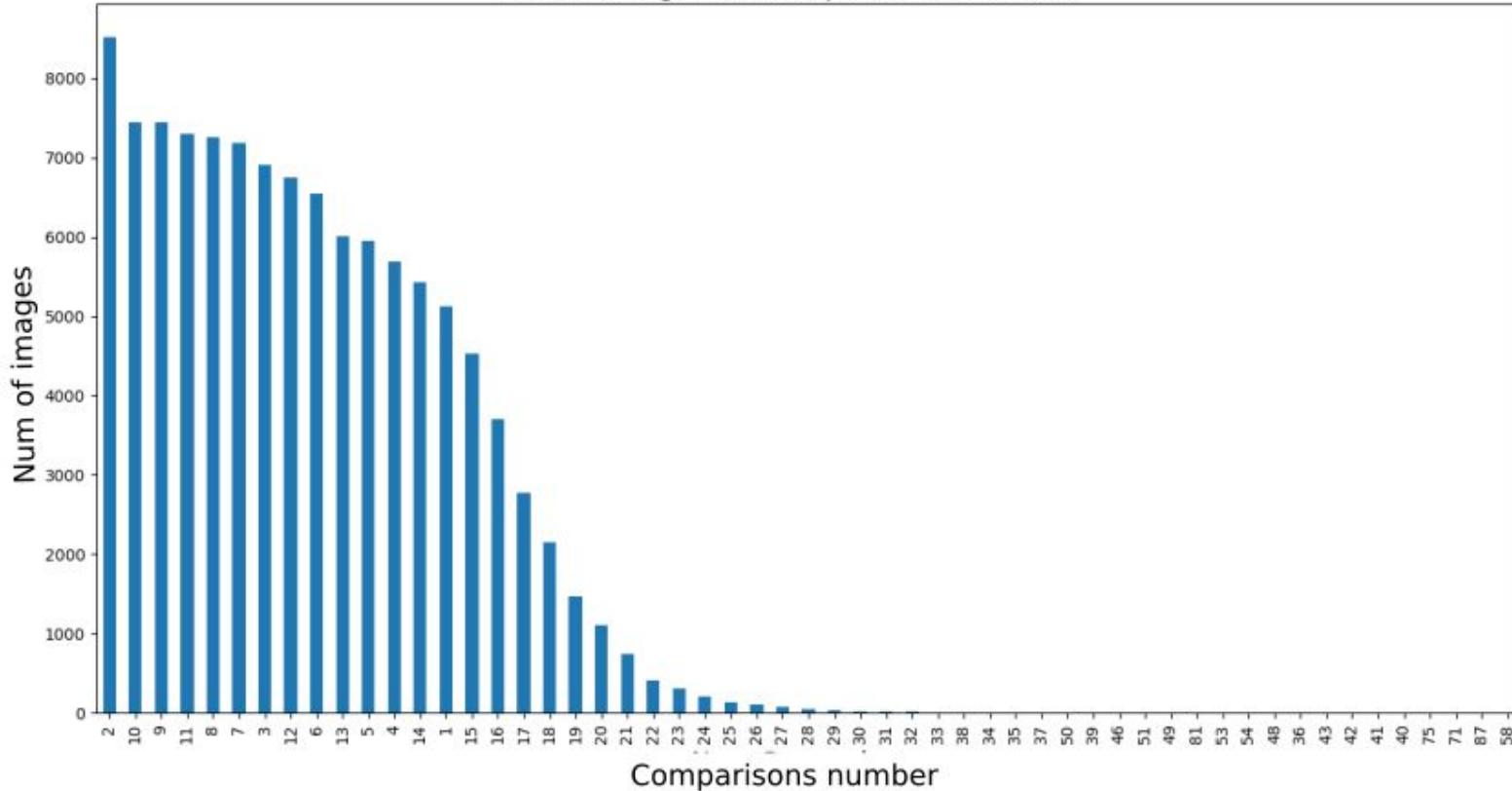
Note: Same color means same country.

Number of images per continent



Number of comparison frequency

Average of comparisons number : 9.088



High scores images



Low scores images



Geographical level vs evaluated images

Place Pulse 2.0				
Category/Level	City	Country	Continent	Global
<i>safety</i>	20,143	45,640	85,890	111,390
<i>lively</i>	14,803	38,216	79,788	111,349
<i>Beautiful</i>	9,410	28,811	66,792	110,767
<i>Wealthy</i>	7,642	24,326	57,780	107,796
<i>Depressing</i>	6,556	21,171	52,504	105,496
<i>Boring</i>	6,148	20,931	52,031	106,364

Dataset Limitations

Individual perception

Safe perception



Unsafe perception



New York*

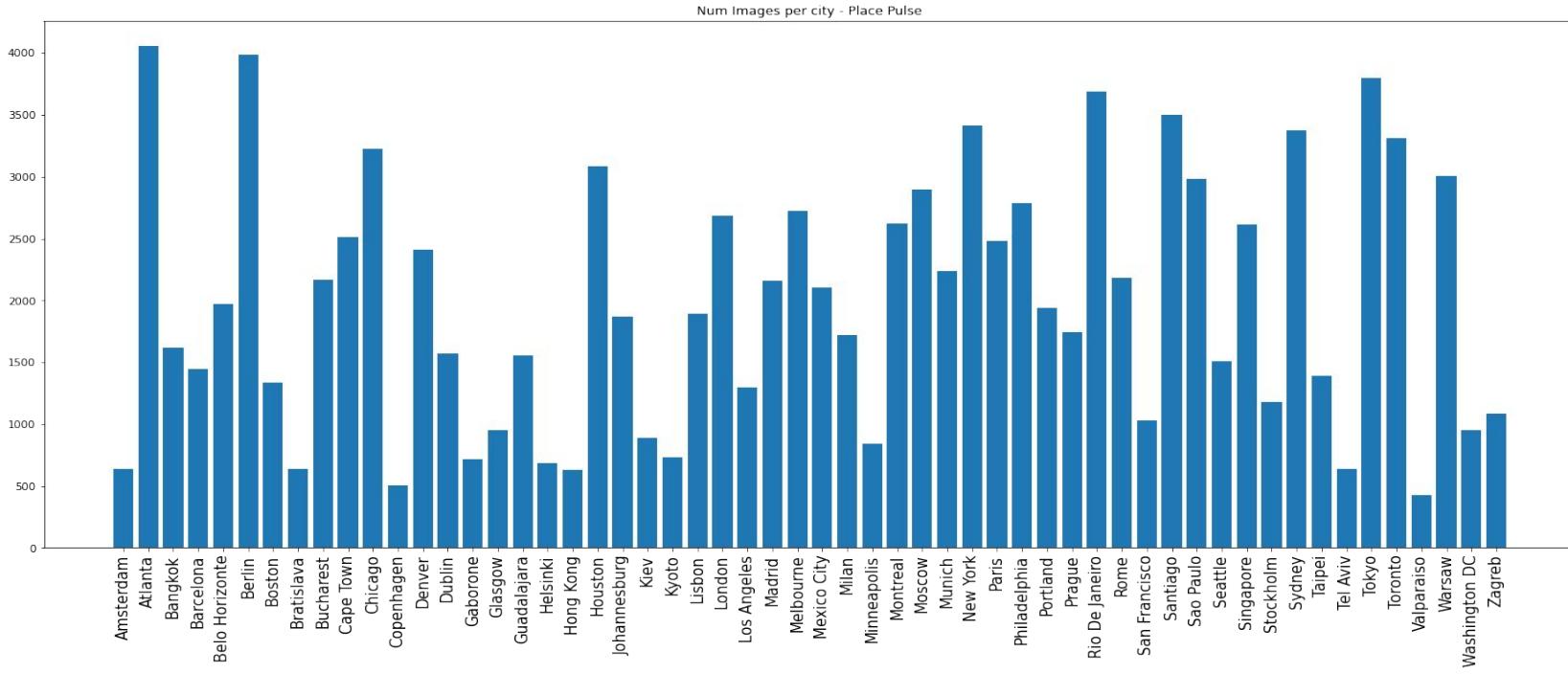


Tokyo**

*<https://www.nytimes.com/2019/08/08/nyregion/newyorktoday/times-square-panic-safety.html#:~:text=Actually%2C%20Times%20Square%20is%20one,23%2C000%20major%20crimes%20were%20recorded>

**<https://www.iapantimes.co.jp/news/2019/10/04/national/media-national/rip-off-bars-japan-tourist-boom/>

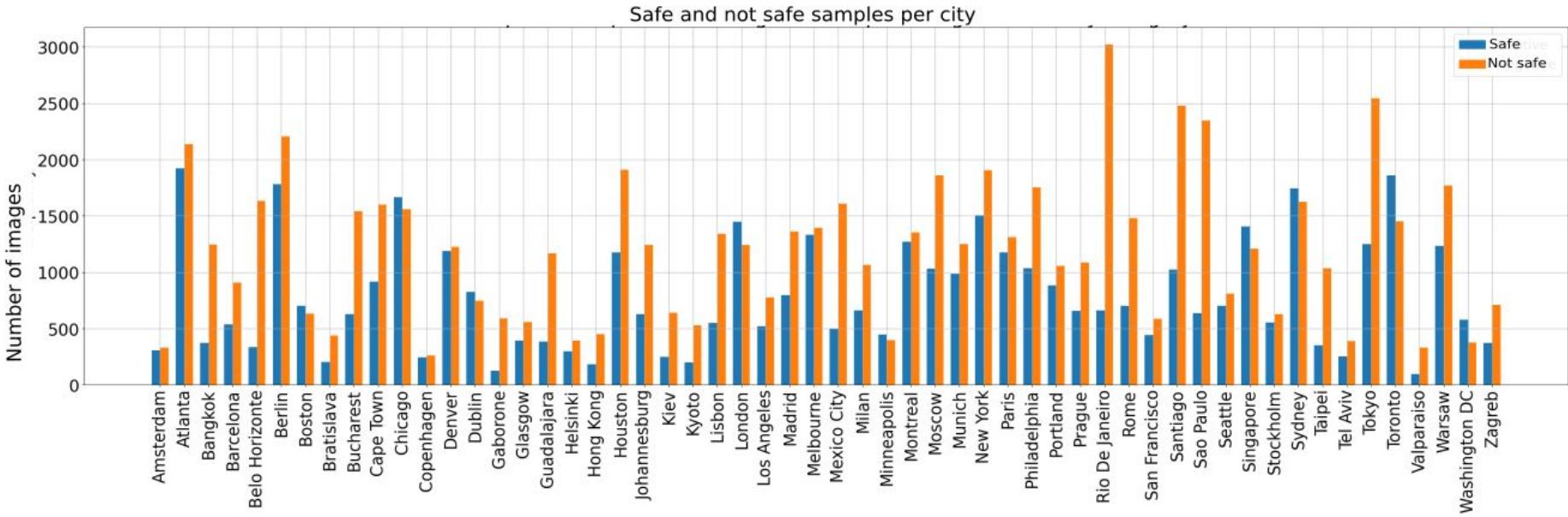
Lack of samples per city



Place Pulse 1.0 < 4 140 Images

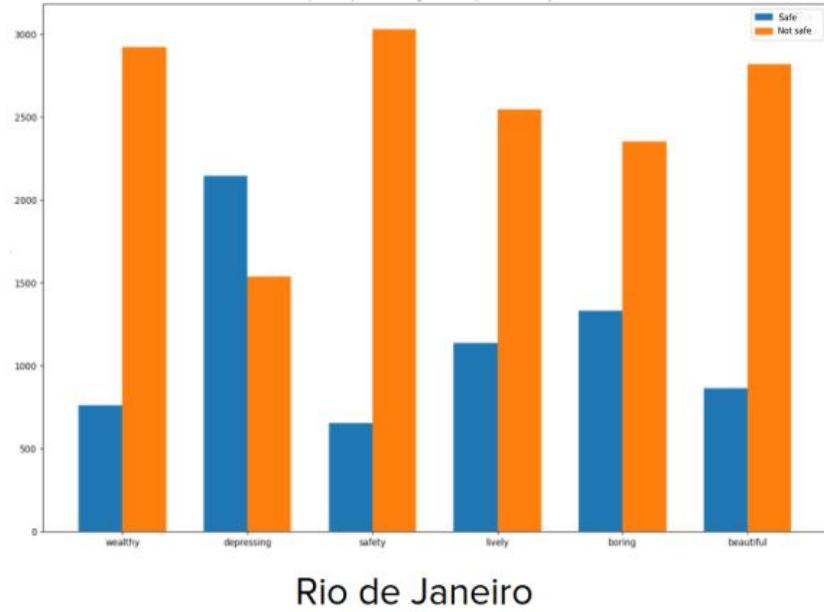
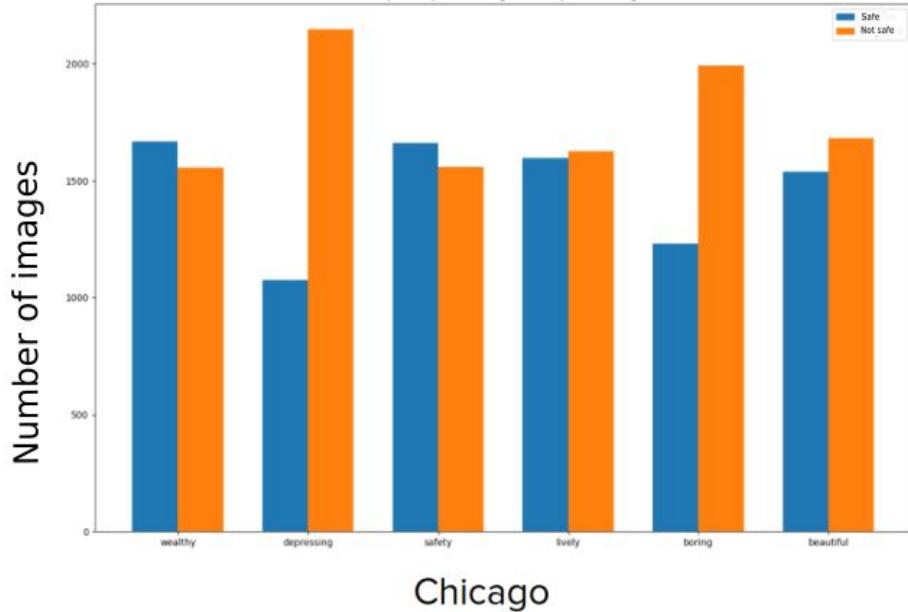
Place Pulse 2.0 < 112 000 Images

Imbalance of samples per city



Imbalance of samples

Imbalance of samples per category in Chicago and Rio de Janeiro



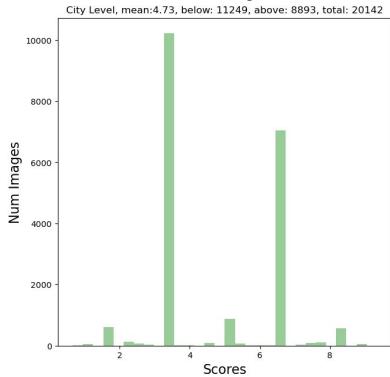
*Positive Samples: safe, beautiful, wealthy, lively, not depressing, not boring.

*Negative Samples: not safe, not beautiful, not wealthy, not lively, depressing, boring.

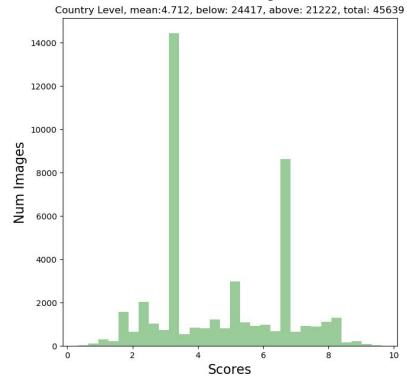
Non-reliable perceptual scores

World

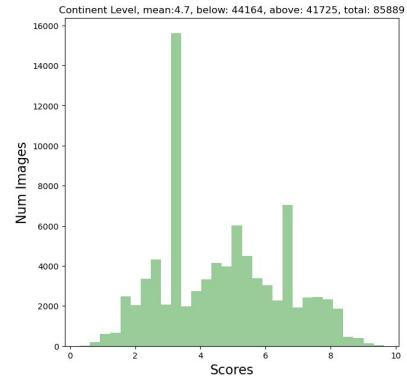
City



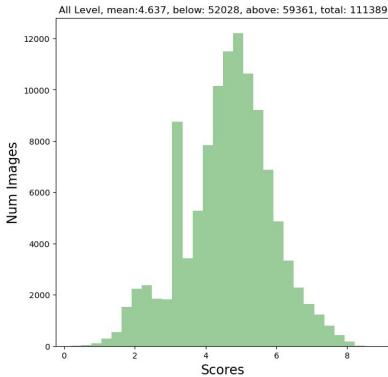
Country



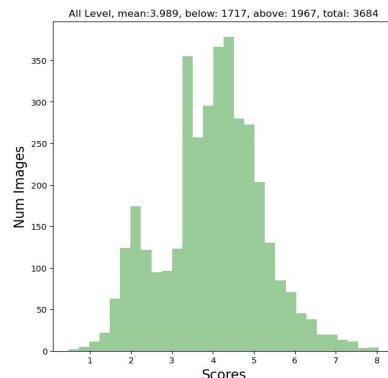
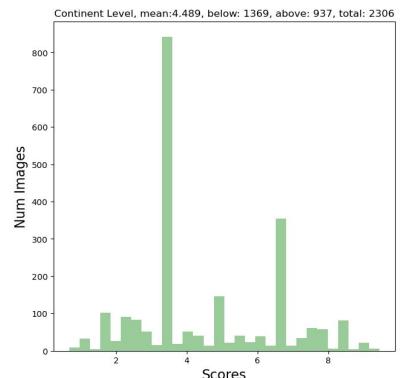
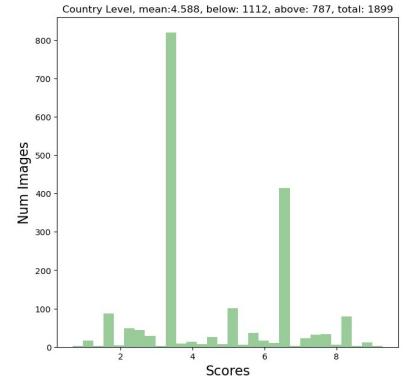
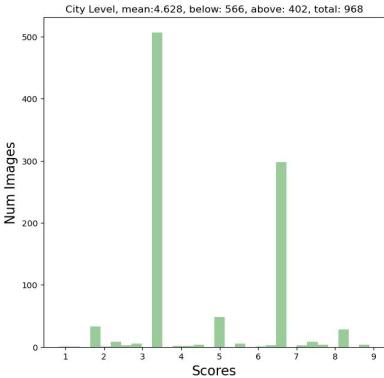
Continent



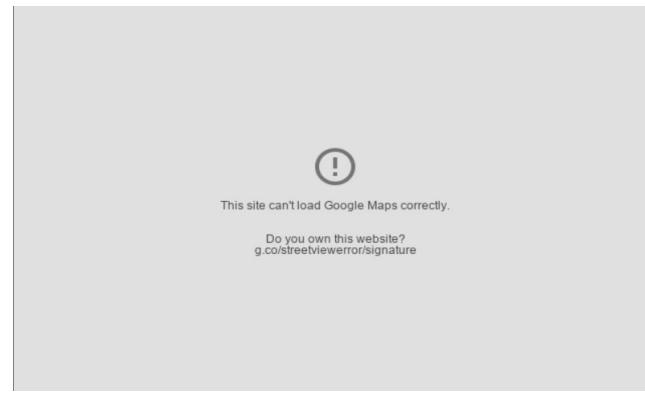
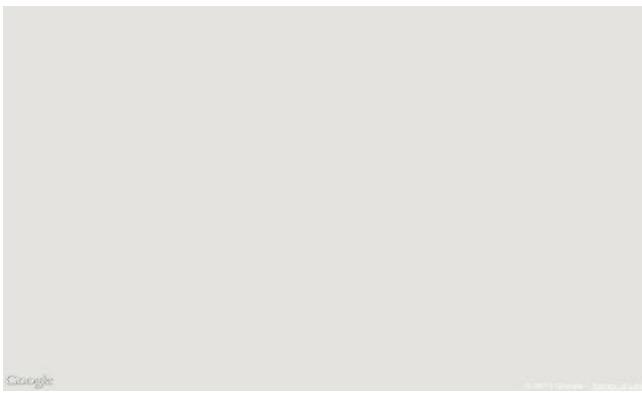
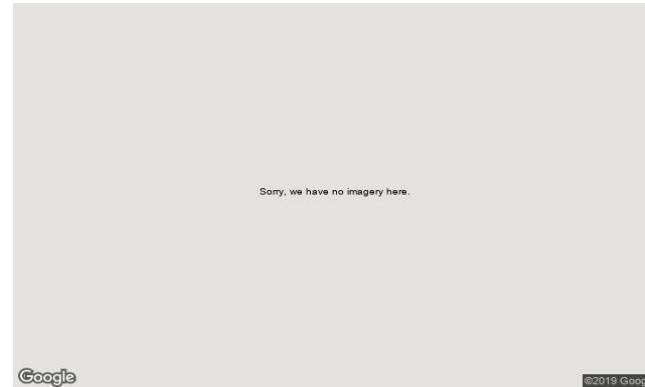
Global



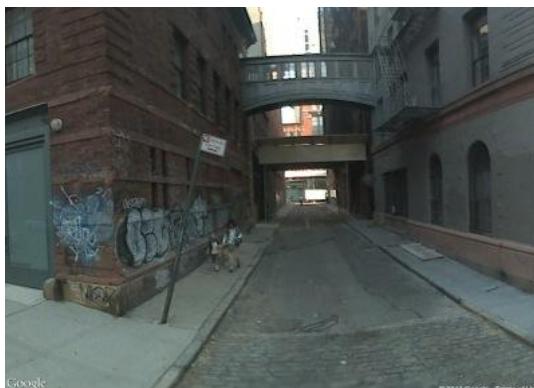
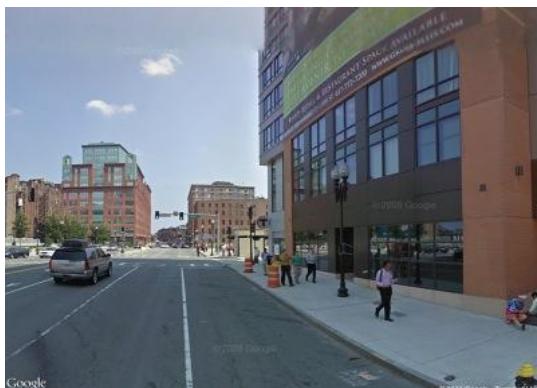
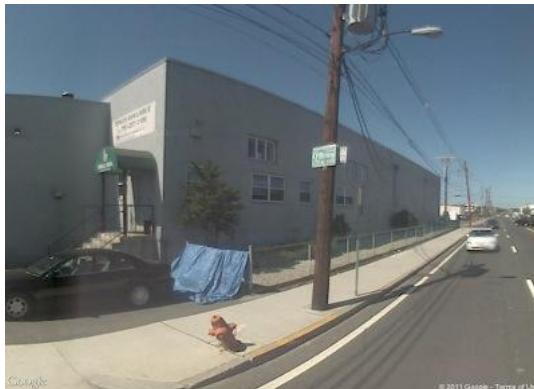
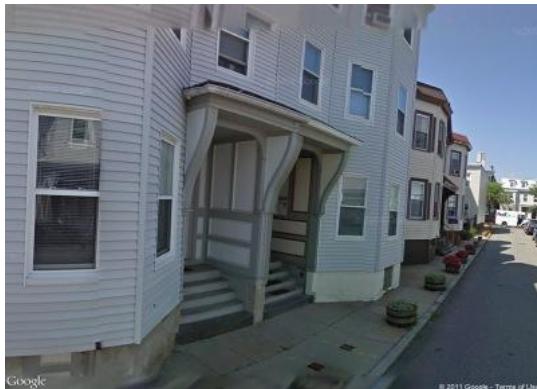
Rio de Janeiro



Blank/None/Faulty samples



Different point of view (PoV)



Panoramic vs angled samples

Angle: 90



Panoramic



Samples changes over time

ID: 3936



ID: 1



2011

2013

2019

Urban Safety Perception

Street View Imagery



Data Pre-processing

Perceptual scores

left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left

$$\hat{y}_{i,k} = q_{i,k}$$



Image, Perceptual Scores
, 8.35)

, 7.16)

...

, 5.01)

...

I: (X,Y)

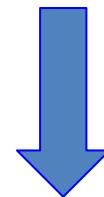
, 1.29)

, 0.55)

Data labeling

We define a parameter δ which will help to label our data.

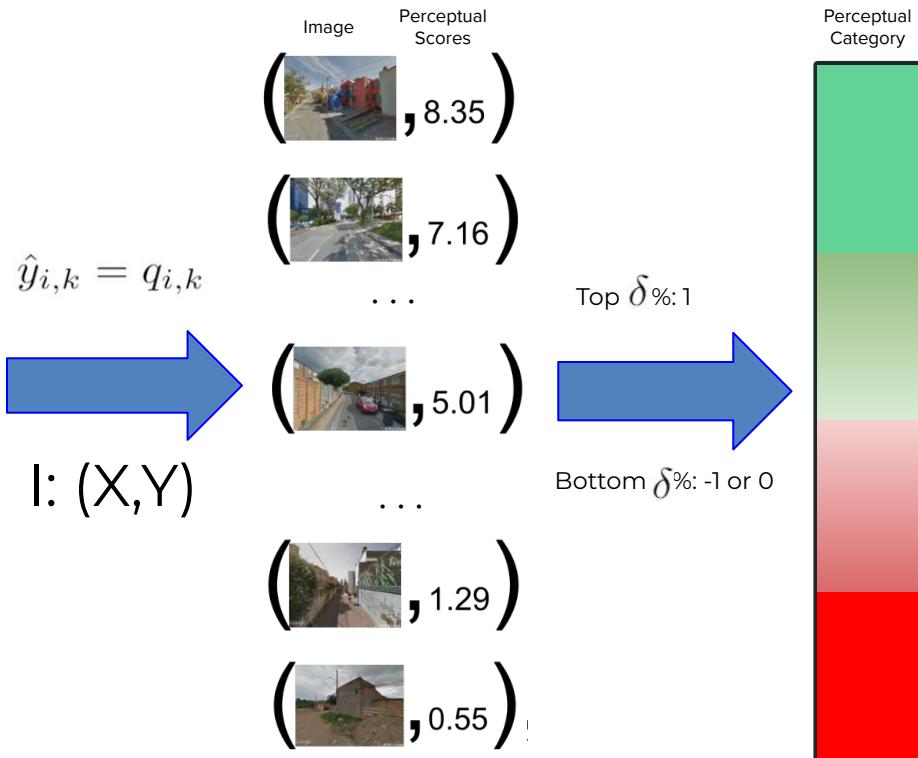
$$\hat{y}_{i,k} = q_{i,k}$$



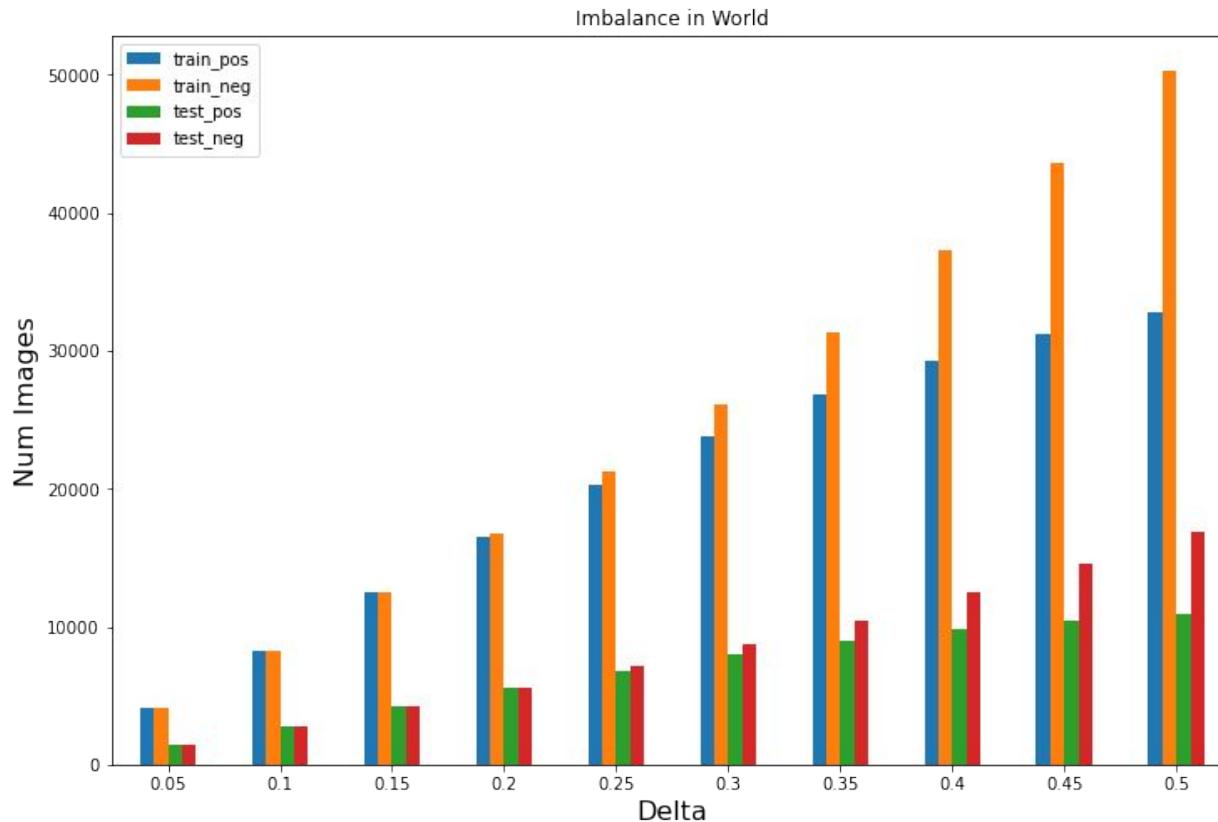
$$y_{i,k} = \begin{cases} 1 & \text{if } (q_{i,k}) \text{ in the top } \delta\% \\ -1 & \text{if } (q_{i,k}) \text{ in the bottom } \delta\% \end{cases}$$

Perceptual label

left	right	winner
		draw
		left
		right
⋮	⋮	⋮
		right
		left

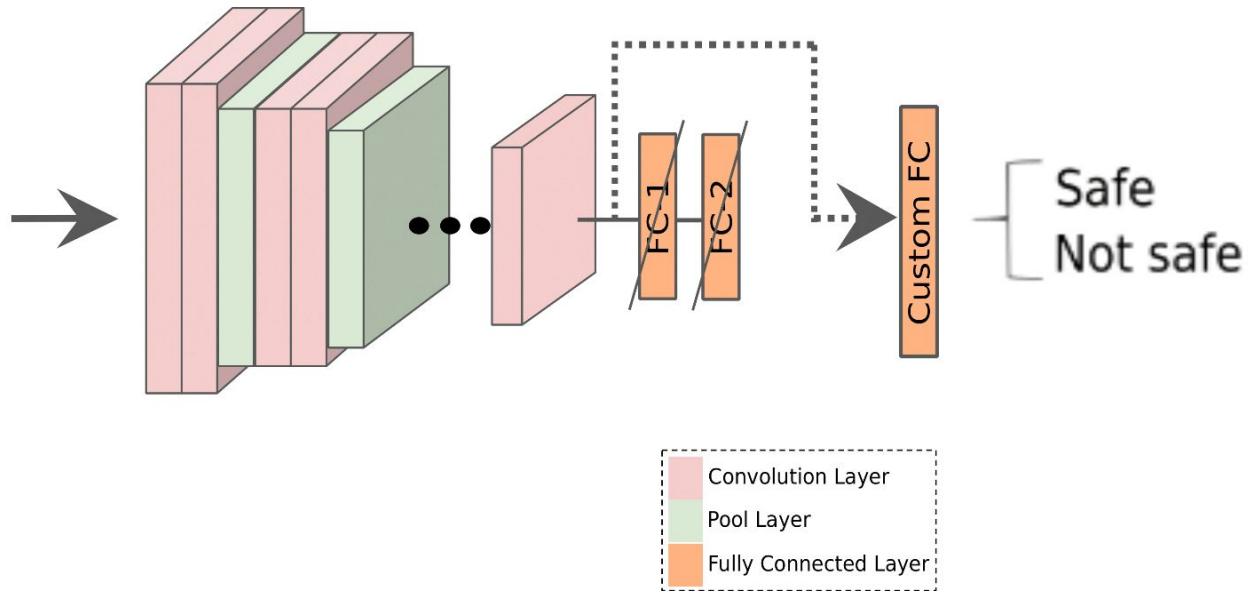


Evaluating δ values



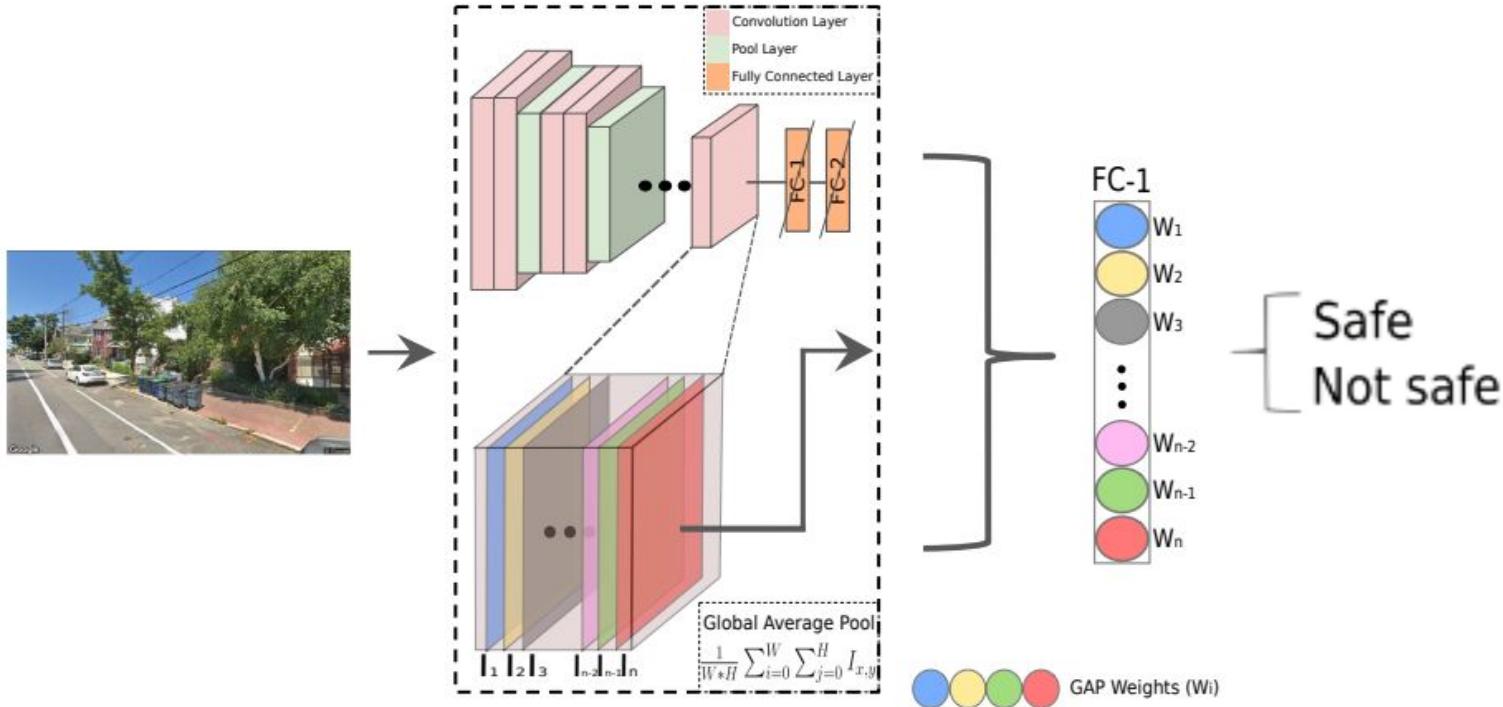
Models Configurations

Transfer learning & Fine-tuning



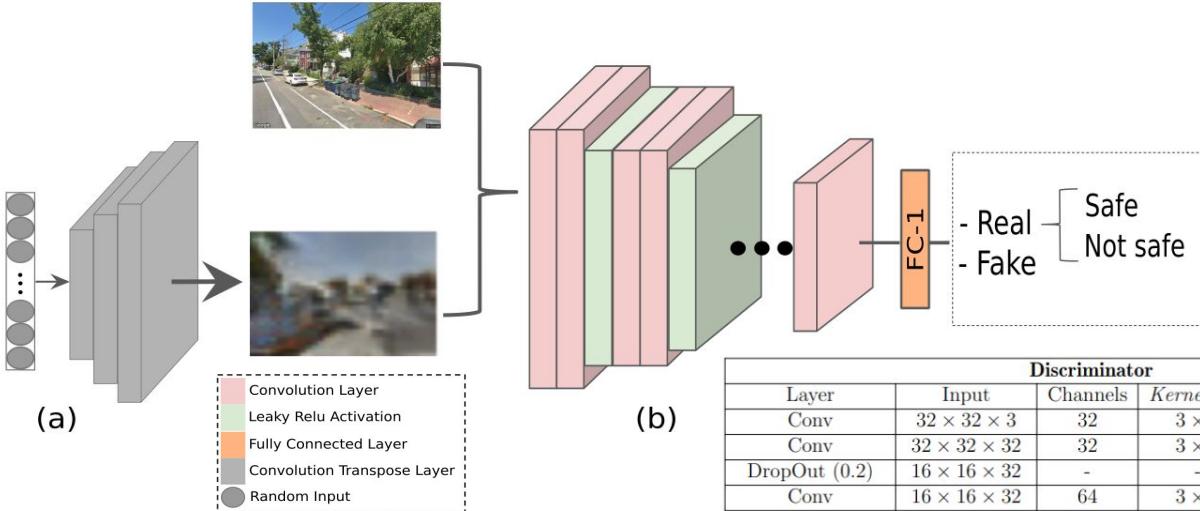
- VGG, ResNet, and Xception
- Input shape: 224x244

Global Average Pooling



- VGG, ResNet, and Xception
- Input shape: 224x244

Generative Adversarial Network (GAN)



Generator					
Layer	Input	Channels	Kernel size	Stride	Activation
Latent	100	-	-	-	-
Dense	4096	-	-	-	LeakyReLU
Re-shape	$4 \times 4 \times 256$	-	-	-	-
Deconv	$4 \times 4 \times 256$	256	4×4	2	LeakyReLU
Deconv	$8 \times 8 \times 256$	128	4×4	2	LeakyReLU
Deconv	$16 \times 16 \times 128$	64	4×4	2	LeakyReLU
Conv	$32 \times 32 \times 64$	3	3×3	1	Tanh
Total parameters	2 119 811				

Discriminator					
Layer	Input	Channels	Kernel size	Stride	Activation
Conv	$32 \times 32 \times 3$	32	3×3	1	LeakyReLU
Conv	$32 \times 32 \times 32$	32	3×3	2	LeakyReLU
DropOut (0.2)	$16 \times 16 \times 32$	-	-	-	-
Conv	$16 \times 16 \times 32$	64	3×3	1	LeakyReLU
Conv	$16 \times 16 \times 64$	64	3×3	2	LeakyReLU
DropOut (0.2)	$8 \times 8 \times 64$	-	-	-	-
Conv	$8 \times 8 \times 64$	128	3×3	1	LeakyReLU
Conv	$8 \times 8 \times 128$	128	3×3	2	LeakyReLU
DropOut (0.2)	$4 \times 4 \times 128$	-	-	-	-
Conv	$4 \times 4 \times 128$	256	3×3	1	LeakyReLU
Flatten	$4 \times 4 \times 256$	-	-	-	-
Dense	128	-	-	-	-
DropOut (0.4)	128	-	-	-	-
Dense	3	-	-	-	Softmax
Total parameters	1 107 882				

Model hyperparameters

Summary of model parameters							
Name	Model hyperparameters						Data
Method	Input	Batch	Opt	LR	Ep/It	CV	Geo. level
TL_VGG	4096	-	lbfgs	-	1000	5	Global/City
TL_VGG_GAP	512	-	lbfgs	-	1000	5	Global//city
FT_VGG	$224 \times 224 \times 3$	128	Adam	$1e^{-3}$	100	5	Global/City
FT_VGG_GAP	$224 \times 224 \times 3$	128	Adam	$1e^{-3}$	100	5	Global/City
SSL_GAN_Dis	$32 \times 32 \times 3$	128	Adam	$1e^{-3}$	100	5	Global
SSL_GAN_Gen	100	128	Adam	$1e^{-3}$	100	5	Global

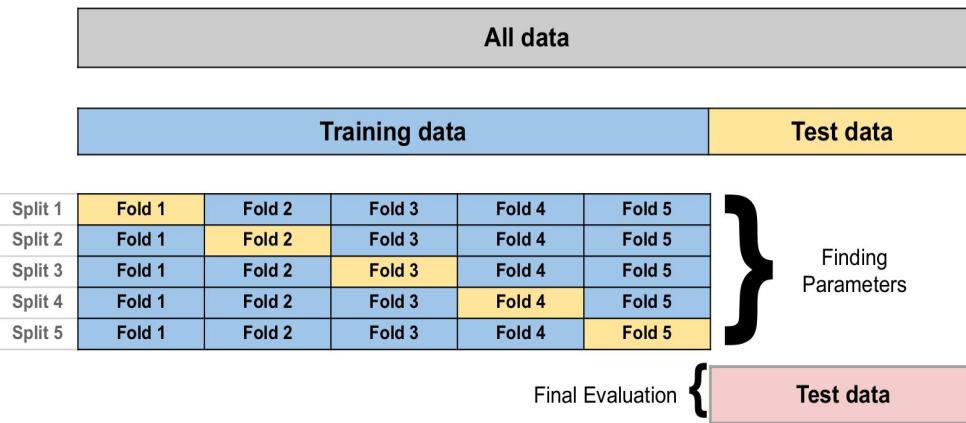
* Parameters were found using GridSearchCV.

* Trained on GPU NVIDIA GeForce GTX 1070, 8 Gb VRAM.

* EarlyStop in 30 epochs and DecayLR every 8 epochs.

Data split

- Oversampling method to balance classes and split data into 75% and 25%, respectively
- Hyperparameters tuning: Grid search using Stratified 5 Cross-Validation



Metrics

- Accuracy — What percent of the data were predicted correct?
- Precision — What percent of your predictions were correct?
- Recall — What percent of the positive cases did you catch?
- F1 score — What percent of positive predictions were correct?

$$Accuracy = \frac{T_P + T_N}{T_P + T_N + F_P + F_N}$$

$$Recall = \frac{T_P}{T_P + F_N} \quad Precision = \frac{T_P}{T_P + F_P}$$

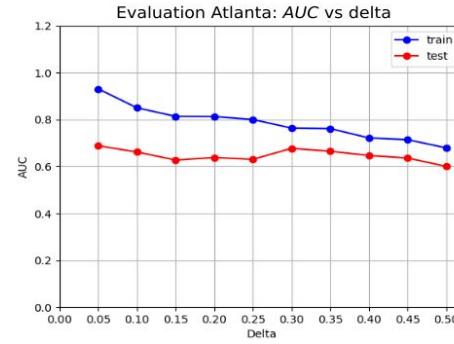
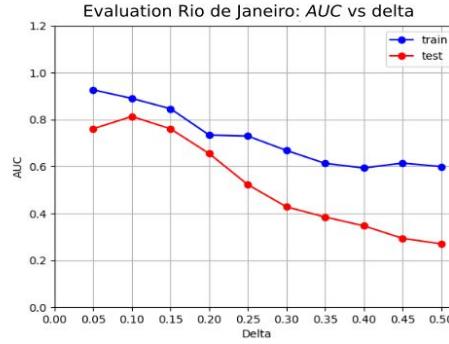
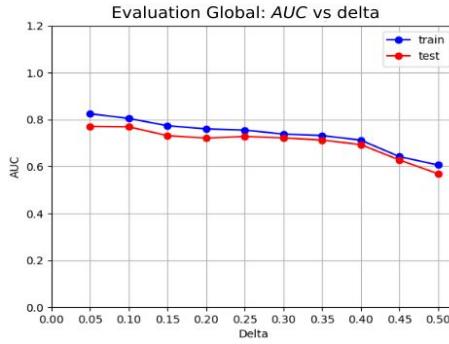
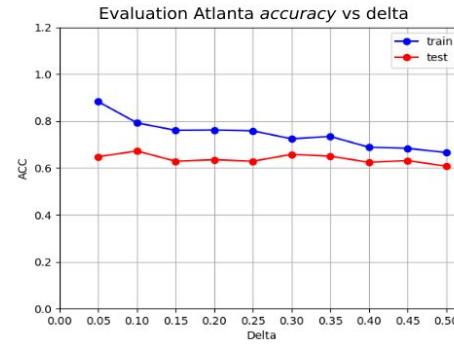
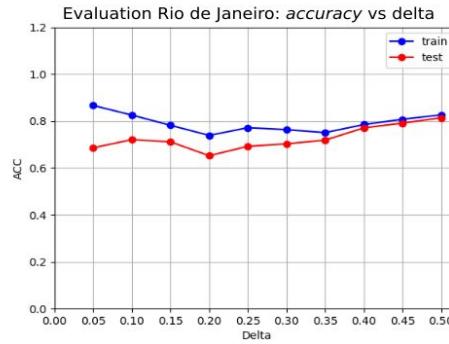
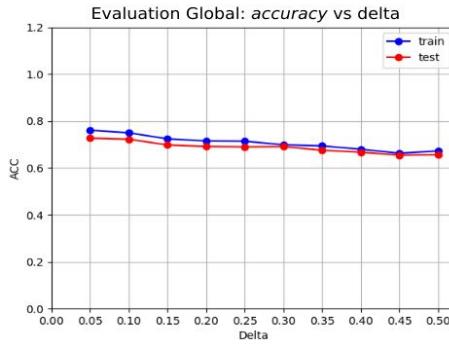
$$F1_{score} = 2 \cdot \frac{Precision * Recall}{Precision + Recall}$$

Experiments and Results

Publications

- **Quantifying Urban Safety Perception on Street View Images**
Felipe Moreno-Vera, Bahram Lavi, and Jorge Poco. *In IEEE/WIC/ACM International Conference on Web Intelligence (WI-IAT)*, 2021.
- **Urban Perception: Can We Understand Why a Street Is Safe?**
Felipe Moreno-Vera, Bahram Lavi, and Jorge Poco. *In Mexican International Conference on Artificial Intelligence (MICAI)*, 2021.
- **Understanding Safety based on Urban Perception**
Felipe Moreno-Vera. *In International Conference on Intelligent Computing (ICIC)*, 2021.

Transfer learning



* Results of testing using different values of δ .

Transfer learning

Model	Method	auc		accuracy		<i>f1 score</i>	
		train	eval	train	eval	entrena	eval
<i>VGG</i>	<i>LinearSVC</i>	63.62	56.50	68.85	65.22	54.78	49.41
	<i>Logistic</i>	60.63	57.52	67.25	65.72	51.42	49.07
	<i>Ridge Classifier</i>	64.72	54.75	69.44	64.38	56.50	49.34
	<i>RBF SVC</i>	45.14	42.42	52.13	52.37	46.93	46.59
<i>VGG_GAP</i>	<i>LinearSVC</i>	59.01	57.93	66.51	66.09	49.52	49.06
	<i>Logistic</i>	58.07	57.57	65.95	65.59	46.06	45.61
	<i>Ridge Classifier</i>	59.20	57.93	66.59	65.89	50.27	49.76
	<i>RBF SVC</i>	42.93	41.70	50.25	50.35	47.16	46.75
<i>VGG_Places</i>	<i>LinearSVC</i>	64.44	57.14	69.48	65.79	56.39	51.20
	<i>Logistic</i>	61.74	58.35	68.16	66.44	53.77	51.28
	<i>Ridge Classifier</i>	65.20	55.76	69.84	64.86	57.56	50.67
	<i>RBF SVC</i>	47.32	45.25	56.56	55.69	44.78	44.21

Transfer learning

Model	Method	auc		accuracy		f1 score	
		train	eval	train	eval	entrena	eval
<i>VGG_GAP_Places</i>	<i>LinearSVC</i>	60.26	59.76	67.38	66.96	51.65	51.04
	<i>Logistic</i>	59.40	58.97	66.81	66.62	49.16	48.90
	<i>Ridge Classifier</i>	60.45	59.15	67.45	66.94	52.23	51.53
	<i>RBF SVC</i>	44.40	42.47	52.59	52.54	43.39	45.05
<i>ResNet50</i>	<i>Linear SVC</i>	61.62	59.10	68.10	66.42	53.63	50.80
	<i>Logistic</i>	60.04	59.15	67.25	66.37	51.47	49.70
	<i>Ridge Classifier</i>	62.11	58.38	68.36	66.08	54.59	51.00
	<i>RBF SVC</i>	45.36	44.07	53.46	53.57	44.99	44.98
<i>Xception</i>	<i>LinearSVC</i>	55.29	53.25	64.43	63.33	41.66	39.69
	<i>Logistic Regression</i>	53.48	52.75	63.56	63.14	36.72	35.87
	<i>Ridge Classifier</i>	57.23	52.22	65.22	63.04	45.63	42.11
	<i>RBF SVC</i>	45.575	44.99	49.12	49.12	55.01	55.05

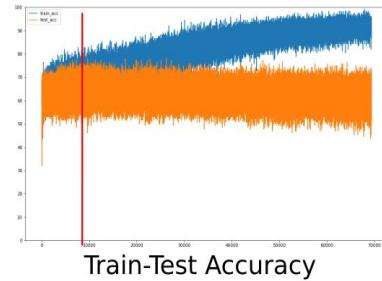
Fine-tuning

Models “FT”	<i>auc</i>		<i>accuracy</i>		<i>f1 score</i>	
	train	eval	train	eval	train	eval
<i>VGG</i>	77.83	77.42	74.01	64.71	74.01	64.69
<i>VGG_GAP</i>	76.145	75.59	69.40	66.88	69.41	66.87
<i>VGG_Places</i>	77.98	77.35	70.52	67.28	70.52	67.28
<i>VGG_GAP_Places</i>	74.95	74.75	68.71	67.26	68.71	67.27
<i>ResNet50</i>	76.362	72.71	70.36	65.64	67.35	64.98

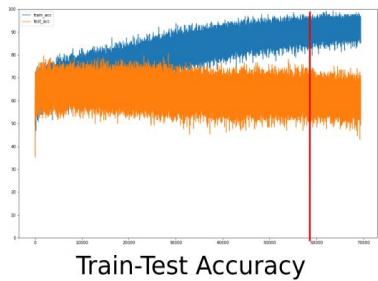
GAN

		<i>auc</i>		<i>accuracy</i>		<i>f1 score</i>		
Model 32x32x3		CV	train	eval	train	eval	train	eval
SSL-GAN	0	80.95	80.97	90.26	59.06	90.26	59.04	
	1	81.43	81.45	89.42	61.50	89.42	61.48	
	2	81.43	81.45	89.56	62.58	89.56	62.57	
	3	80.59	80.66	90.01	61.52	90.01	61.54	
	4	80.61	80.63	89.38	61.14	89.38	61.13	

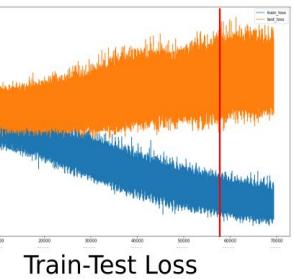
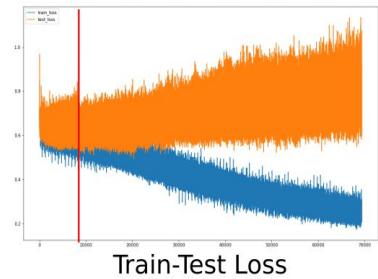
cv 4



cv 1



			<i>auc</i>		<i>accuracy</i>		<i>f1 score</i>	
Model 32x32x3			CV	iteration	train	eval	train	eval
SSL-GAN	0	23788	73.89	73.89	78.90	78.12	78.90	78.12
	1	58550	80.21	80.22	92.18	81.25	92.18	81.25
	2	21951	73.60	73.60	81.25	79.68	81.25	79.68
	3	23180	73.53	73.53	76.56	78.90	76.56	78.90
	4	8602	69.84	69.84	74.21	78.90	74.21	78.90



GAN: generated images



Website



Training time

Training time for each model		
Method	Data	Average Time
SSL_GAN	Global	1 and a half week
FT_VGG	Global	8 hours
FT_VGG	56 Cities	6 hours
FT_VGG_GAP	Global	7 hours
FT_VGG_GAP	56 Cities	5 hours
TL_VGG	Global	15 minutes
TL_VGG	56 Cities	10 minutes
TL_VGG_GAP	Global	9 minutes
TL_VGG_GAP	56 Cities	6 minutes

Conclusions

Conclusions

- We were able to analyze the safety perception using the **Place Pulse dataset**
- It is feasible to **train** a classifier to **infer** the **safe perception** in **street view images**.
- **Black-box CNN models** help to classify images.
 - It performs better than decision trees, SVM, ridge regression, booster models, etc.
 - We won't be able to use complex architectures, such as transformers, due to limited computational resources.
- It has **high performance** in distinguishing safe perceptions between images, it is possible to improve results using generative models such as semi-supervised GAN.

Thanks! Any questions?
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THANKS!

Any Questions?