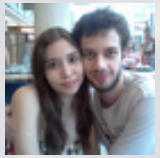
PSI2672 – Práticas em Reconhecimento de Padrões, Modelagem e Neurocomputação

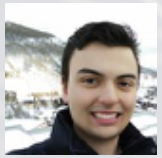
Regressor de Qualidade das Vias

Carlos Grivol

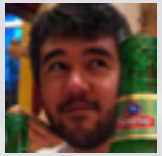


Carlos Prete

Reconhecedor de Moedas



Gabriel Crabbé



Tiago Amano

Regressor: Motivação

De acordo com a Prefeitura de São Paulo, em 2015 foram utilizados **R$ 110 milhões** para recapear **135,5 km** de vias e tapar **294.419 buracos** na cidade, que apresenta uma malha viária de mais de **17 mil km** de vias pavimentadas.

Simultaneamente, o número de solicitações de **reparos cresceu 21%** (de 54.074 para 65.459 solicitações).

*Imagens da Prefeitura de SP

Regressor: Regressor de Qualidade das Vias

Acelerômetro (eixos X, Y e Z)

GPS (Lat, Long, Velocidade)

Pré-processamento em janela de 3 s

Energia Total de Aceleração

Variância Total da Aceleração

Pico da Aceleração Vertical

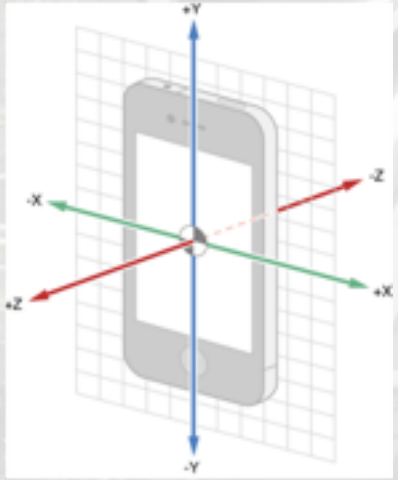
Norma da Derivada Vertical

Velocidade Média

Regressor

Índice de Qualidade do Pavimento (1 a 10)

Escala PASER da Universidade de Wisconsin—Madison



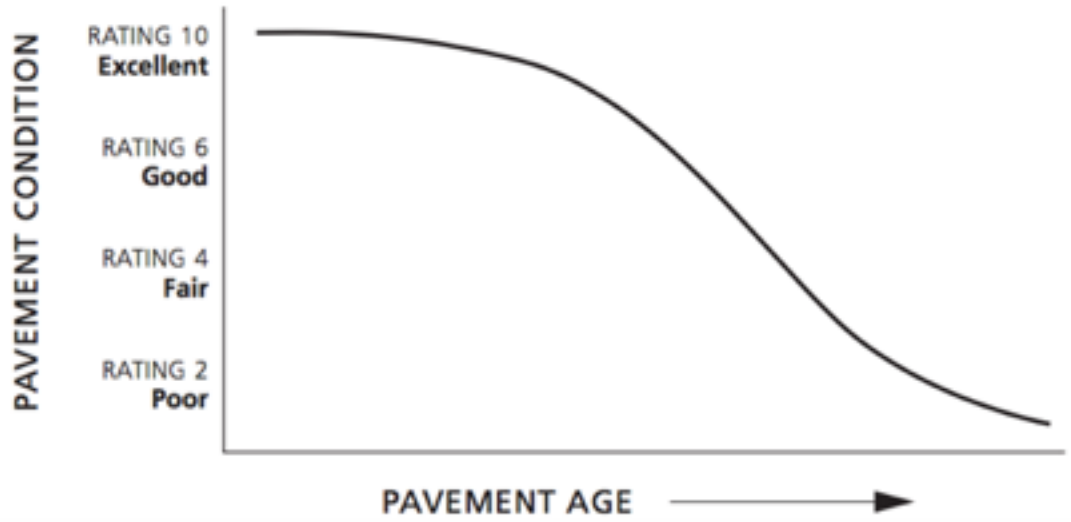
*Imagens do site oficial Android

Regressor: Escala PASER

Transportation Information Center
University of Wisconsin–Madison

PASER Asphalt Roads

RATINGS ARE RELATED TO NEEDED MAINTENANCE OR REPAIR	
Rating 9 & 10	No maintenance required
Rating 8	Little or no maintenance
Rating 7	Routine maintenance, cracksealing and minor patching
Rating 5 & 6	Preservative treatments (sealcoating)
Rating 3 & 4	Structural improvement and leveling (overlay or recycling)
Rating 1 & 2	Reconstruction



Regressor: Escala PASER

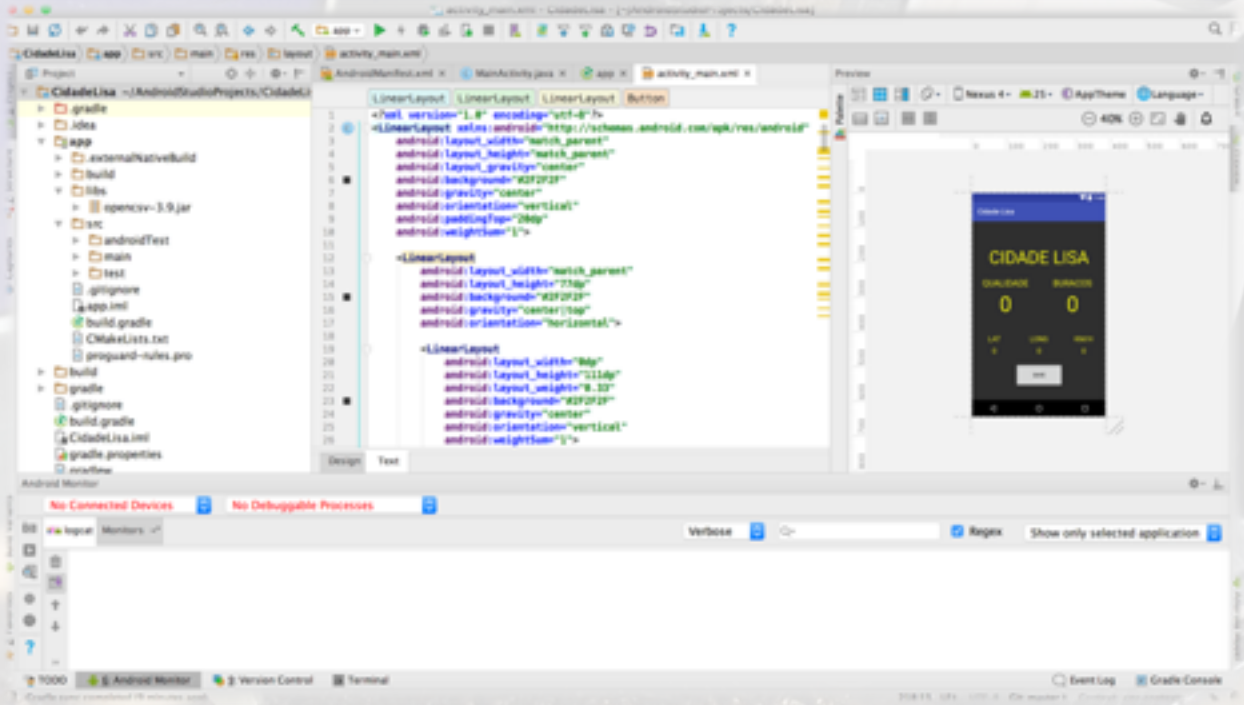
Surface rating	*Visible distress**	*General condition/ treatment measures*
10 Excellent	None.	New construction.
9 Excellent	None.	Recent overlay. Like new.
8 Very Good	No longitudinal cracks except reflection of paving joints. Occasional transverse cracks, widely spaced (40' or greater). All cracks sealed or tight (open less than ¼").	Recent sealcoat or new cold mix. Little or no maintenance required.
7 Good	Very slight or no raveling, surface shows some traffic wear. Longitudinal cracks (open ¼") due to reflection or paving joints. Transverse cracks (open ¼") spaced 10' or more apart, little or slight crack raveling. No patching or very few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6 Good	Slight raveling (loss of fines) and traffic wear. Longitudinal cracks (open ¼"–½"), some spaced less than 10'. First sign of block cracking. Sight to moderate flushing or polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with sealcoat.

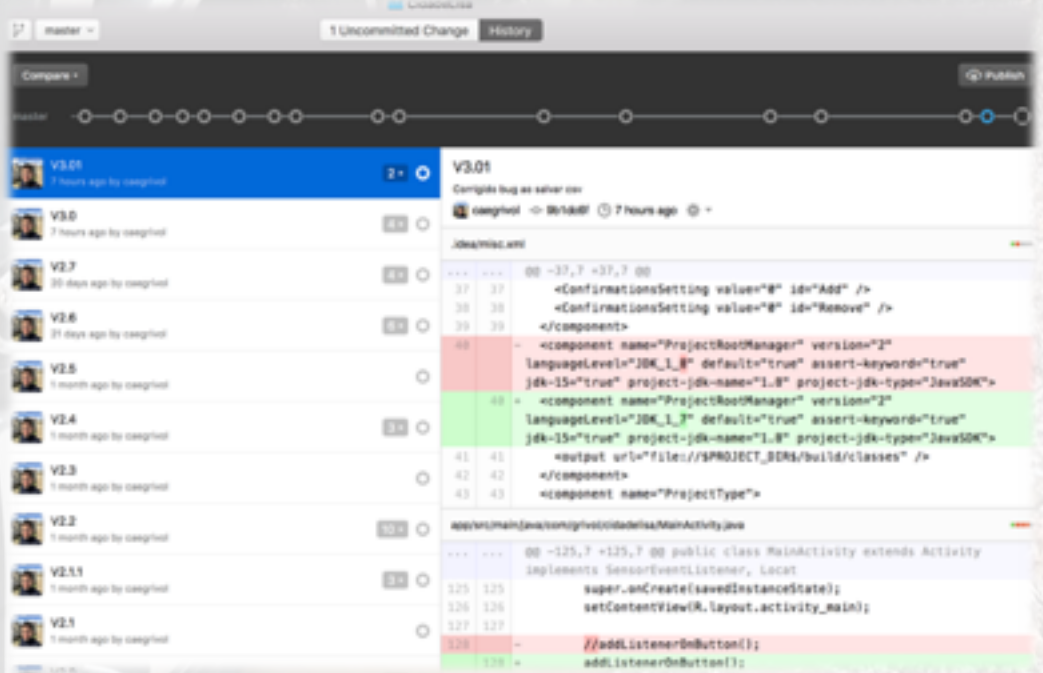
Regressor: Escala PASER

Surface rating	Visible distress*	General condition/ treatment measures
5 Fair	Moderate to severe raveling (loss of fine and coarse aggregate). Longitudinal and transverse cracks (open ½") show first signs of slight raveling and secondary cracks. First signs of longitudinal cracks near pavement edge. Block cracking up to 50% of surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay (less than 2")
4 Fair	Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking (over 50% of surface). Patching in fair condition. Slight rutting or distortions (½" deep or less).	Significant aging and first signs of need for strengthening. Would benefit from a structural overlay (2" or more).
3 Poor	Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion. Severe block cracking. Some alligator cracking (less than 25% of surface). Patches in fair to poor condition. Moderate rutting or distortion (1" or 2" deep). Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of overlay.
2 Very Poor	Alligator cracking (over 25% of surface). Severe distortions (over 2" deep) Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1 Failed	Severe distress with extensive loss of surface integrity.	Failed. Needs total reconstruction.

Regressor: Desenvolvimento do App

Android Studio





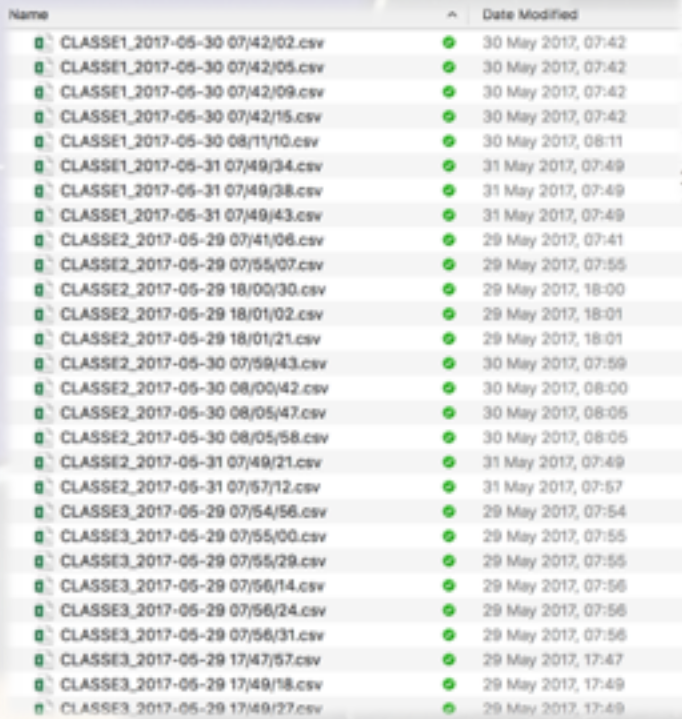
GitHub

Regressor: Coleta de dados

Regressor: Tratamento de Dados

Exemplo de log

	A	B	C	D	E	F	G	H	I	J
1	AccelerationX	-0.307	1.301	-0.077	0.267	-1.3030001	-0.345	-1.3410001	0.267	0.038000003
2	AccelerationY	-0.9189997	-1.1869993	-0.4979992	0.03900051	-0.88099957	-1.7229996	-0.9569998	-0.037999153	-0.22899914
3	AccelerationZ	1.8009999	1.4559999	-0.153	-0.574	-0.99600005	0.4979999	-0.037999988	1.4559999	0.19199991
4	Speed	29.647999	29.647999	30.315079	30.315079	30.315079	30.315079	30.315079	30.315079	30.315079
5	AverageSpeed	30.567627	EventOrder	0	Latitude	-23.619678333333333	Longitude	-46.69822666666667		
6	AverageX	-0.20152001	AverageY	-0.6439195	AverageZ	0.40875998				
7	MinX	-1.763	MinY	-2.0299997	MinZ	-1.149				
8	MaxX	1.301	MaxY	1.1500006	MaxZ	2.299				
9	StdX	0.70752364	StdY	0.81862694	StdZ	0.83702767				
10	GravityX	-0.114	GravityY	9.921	GravityZ	1.608				



Pasta com logs coletados

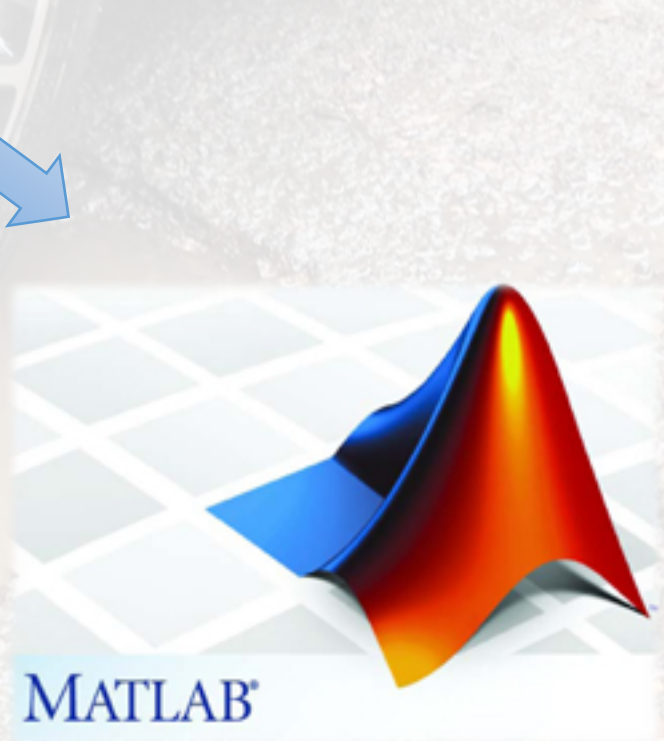
```java
package traindataparser;

import java.io.File;
import java.io.FileNotFoundException;
import java.io.PrintWriter;
import java.util.Scanner;

/**
 *
 * @author Carlos Eduardo Grivol Júnior
 */
public class TrainDataParser {

    /**
     * @param args the command line arguments
     * @throws java.io.FileNotFoundException
     */
    public static void main(String[] args) throws FileNotFoundException {

        PrintWriter pwr = new PrintWriter(new File("/Users/grivol/Desktop/data.txt"));
        StringBuilder sbr = new StringBuilder();

        File dir = new File("/Users/grivol/Desktop/logs");
        File[] directoryListing = dir.listFiles();

        String[] strArray;

        File tmpFile = directoryListing[0];
        Scanner in = new Scanner(tmpFile);
        StringBuilder sb = new StringBuilder();
```

Parser desenvolvido em Java

Regressor: Tratamento de Dados

I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
MinY	MinZ	MaxX	MaxY	Max2	StdX	StdY	StdZ	GravityX	GravityY	GravityZ	AmpX	AmpMaxY	AmpMinY	AmpY	Y / SpeedX	Y/X	Classe
-0,46	-0,958	0,612	0,7659998	1,073	0,2897824	0,3176609	0,5006886	-0,421	9,462	1,072	1,186	0,67657965	-0,14942019	1,2259998	0,1424386638	1,033723668	5
-0,651	0,0769999	0,689	0,6520004	2,49	0,2139784	0,3052168	0,4544403	-0,268	9,04	1,302	1,349	0,769960376	-0,5330440024	1,3030004	0,1483779666	1,134023994	5
-1,4549999	-0,421	0,46	0,3450003	1,1710001	0,3136821	0,412441	0,4953008	-0,174	9,613	1,915	1,878	0,7391201	-1,060688007	1,8030002	0,083711944	0,958446654	5
-1,302	-1,647	1,608	0,5749998	0,766	0,3391636	0,4147047	0,5327261	-1,225	9,883	1,915	1,532000003	0,79400018	-1,08299962	1,8769998	0,105653493	1,225191567	5
-1,302	-3,907	1,378	0,8049994	0,191	0,4424614	0,4254096	0,9993767	-1,225	9,883	1,915	2,221000005	1,053059564	-1,053933971	2,1069994	0,202744797	0,948671146	5
-1,2639999	-3,638	1,8759999	1,3030005	-0,1149999	0,6814123	0,6026918	0,8203865	-0,134	9,613	1,532	3,026	1,211520416	-1,351479984	2,5670004	0,083176129	0,848314774	5
-1,302	-3,6	1,761	1,4560003	1,6470003	0,6612392	0,6179839	0,9905286	-0,421	9,002	2,758	3,34	1,21920005	-1,53880025	2,7580003	0,123363601	0,87834404	5
-1,3789997	-1,494	1,379	1,533	1,264	0,3728875	0,7707375	0,6048797	-0,383	9,613	1,532	1,762	1,509659858	-1,405339842	2,9119997	0,089983487	1,652266725	5
-2,413	0,115000001	1,3999999	0,6520004	3,064	0,3535518	0,7019641	0,6728324	-0,174	9,613	1,379	1,454999991	1,014060335	-2,050940305	3,0650004	0,126839179	2,106523961	5
-1,9160004	-1,799	1,6850001	1,1870003	2,605	0,5001702	0,7083373	0,8507268	-0,268	9,807	0,191	2,7570001	1,351374037	-1,749260333	3,1030007	0,124472729	1,125498894	5
-1,8390002	-1,801	1,034	1,3029995	2,336	0,6091399	0,7918111	0,8371418	0,076	9,385	1,877	2,6419999	1,551111973	-1,59087997	3,1419997	0,084104506	1,18925105	5
-1,3410006	-2,029	2,451	1,9539995	1,226	0,7250879	0,7623225	0,6674354	-0,174	9,347	0,804	3,141000006	1,513275956	-1,762240254	3,2950001	0,136352255	1,049318958	5
-1,533	-1,37	1,608	2,106	1,1790001	0,722703	0,8105021	1,0510243	-0,268	9,807	0,191	2,757	2,164760309	-1,474239991	3,639	0,104106101	1,319991295	5
-2,0300002	-2,106	2,221	1,8769999	1,609	1,0831652	0,7969875	0,8707642	-0,191	9,385	1,417	4,405	1,728312009	-2,17868001	3,9070001	0,202101739	0,886944667	5
-1,7620001	-1,455	3,447	2,184	2,232	0,9844312	1,0271385	0,9870611	-0,191	9,385	1,417	4,032	1,96782024	-1,97817986	3,9460001	0,08954425	0,981110995	5
-1,8389997	-2,4899998	2,144	2,9130003	2,2220001	0,66477	1,113401	1,2392241	-0,421	9,002	2,758	3,101999994	2,629020214	-2,12097986	4,75	0,175161618	1,53127018	5
-1,9150004	-1,3030001	4,175	3,7539997	3,2559998	0,8652809	1,0693913	1,0833727	-0,191	9,385	1,417	4,098	3,697099866	-1,971900234	5,6690001	0,195682453	1,383317776	5
-2,2219996	-3,447	1,8	3,946	1,532	0,47003	1,1767781	1,041414	-0,306	9,613	1,532	2,375	3,75037988	-2,417619372	6,1679996	0,194455134	2,59720246	5
-0,6899996	-1,494	0,306	0,8039999	0,7280002	0,2198909	0,2688409	0,5754447	-0,344	9,615	2,106	0,919000006	0,90517969	-0,58881981	1,4939995	0,504068941	1,625679944	4
-1,1879997	-1,3019999	0,574	1,1880007	0,6900001	0,5898938	0,5521634	0,4337445	0,038	9,615	1,8	2,335	1,311300396	-1,064700004	2,3760004	0,076277938	1,01759906	4
-0,6899996	-1,493	1,646	1,724	2,069	0,6130524	0,6809179	0,7860561	-0,804	9,462	0,229	2,45	1,31357976	-1,10061984	2,4139996	0,175272846	0,981301096	4
-1,6089997	-0,9959999	1,646	1,3410006	2,9130003	0,6127503	0,6784363	0,9442563	-0,344	9,462	1,494	2,7570001	1,415580252	-1,534419978	2,9500003	0,10518036	1,0700037	4
-1,6860008	-0,038	0,881	1,3789997	2,2979999	0,6901882	0,8158054	0,6452544	0,153	9,692	0,038	2,911100004	1,468320054	-1,596680446	3,0650005	0,091445021	1,052902294	4
-1,8000002	-2,757	2,7189999	1,3789997	2,5279999	0,9864503	0,7144088	0,9448332	-0,766	9,538	1,532	4,4429999	1,252939974	-1,926036016	3,1789999	0,097981564	0,715501753	4
-2,0299997	-1,149	1,301	1,1500006	2,299	0,7075236	0,8186269	0,8370277	-0,114	9,921	1,608	3,064	1,7939201	-1,3860802	3,1800003	0,104001638	1,03789911	4
-2,1289998	-2,336	0,115	0,7659998	1,4160001	0,4231595	0,6772577	0,7244644	0,268	9,96	1,685	1,83799998	1,2111799	-2,0836187	3,2949996	0,138277279	1,76270927	4
-1,6479003	-1,8389999	1,761	1,593	2,8730001	0,5000416	0,8882431	1,0022867	-0,306	8,81	2,758	2,374000004	1,8370604	-1,8029399	3,6400003	0,133710246	1,533277277	4
-1,5709996	-1,6479999	1,6850001	2,2220001	2,758	0,6162406	0,7082351	0,9329981	-0,421	9,002	2,758	2,8720001	2,167639992	-1,625359978	3,7929997	0,114175069	1,3206823	4

Arquivo com todos os logs compilados



Regressor: Metodologia

Escolha das variáveis

Otimização da topologia

k-fold cross-validation

Re-treino

Algoritmo *greedy*:

Comparar a rede de *n* variáveis com as *n* redes de *n-1* variáveis.

- A melhor rede de *n-1* foi melhor que a rede de *n*? Repetir a operação.
- Caso contrário, parar por aqui.

Resultado: guardamos as 5 features.

Regressor: Metodologia

Escolha das variáveis

Otimização da topologia

k-fold cross-validation

Re-treino

Busca extensiva:

Todas as combinações possíveis de topologias (número e tamanho das camadas escondidas) e variáveis foram geradas e testadas *overnight*.

Resultado: uma camada escondida com 4 neurônios sigmoidais.

Regressor: Metodologia

Escolha das variáveis

Otimização da topologia

k-fold cross-validation

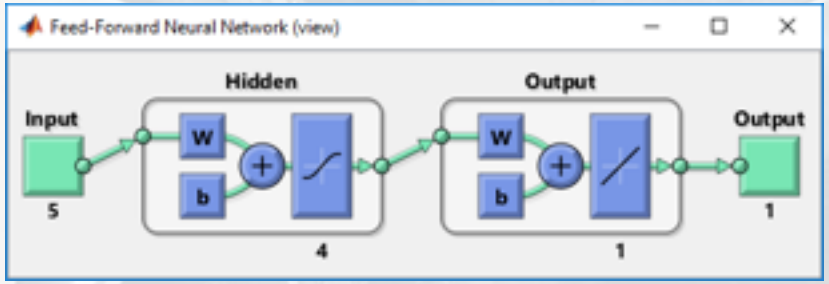
Re-treino

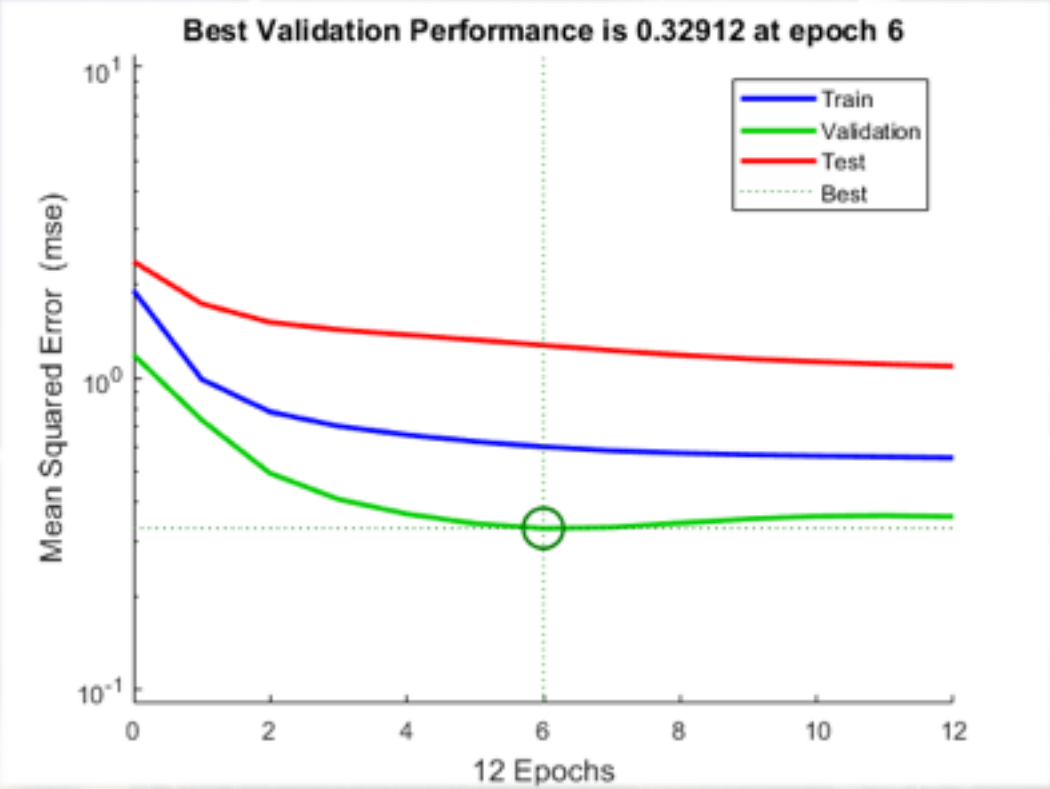
10-fold cross validation:

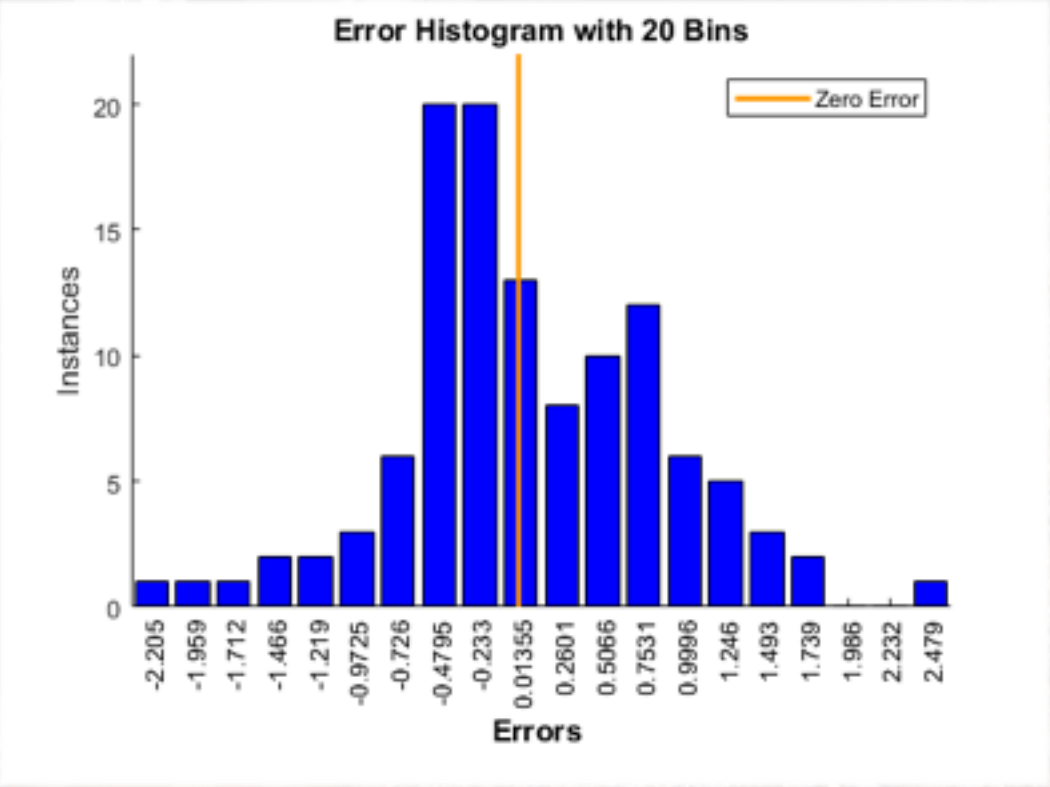
Treino	Treino	Treino	Treino	Treino
Treino	Treino	Treino	Valid.	Teste

20 re-treinos para evitar mínimos locais

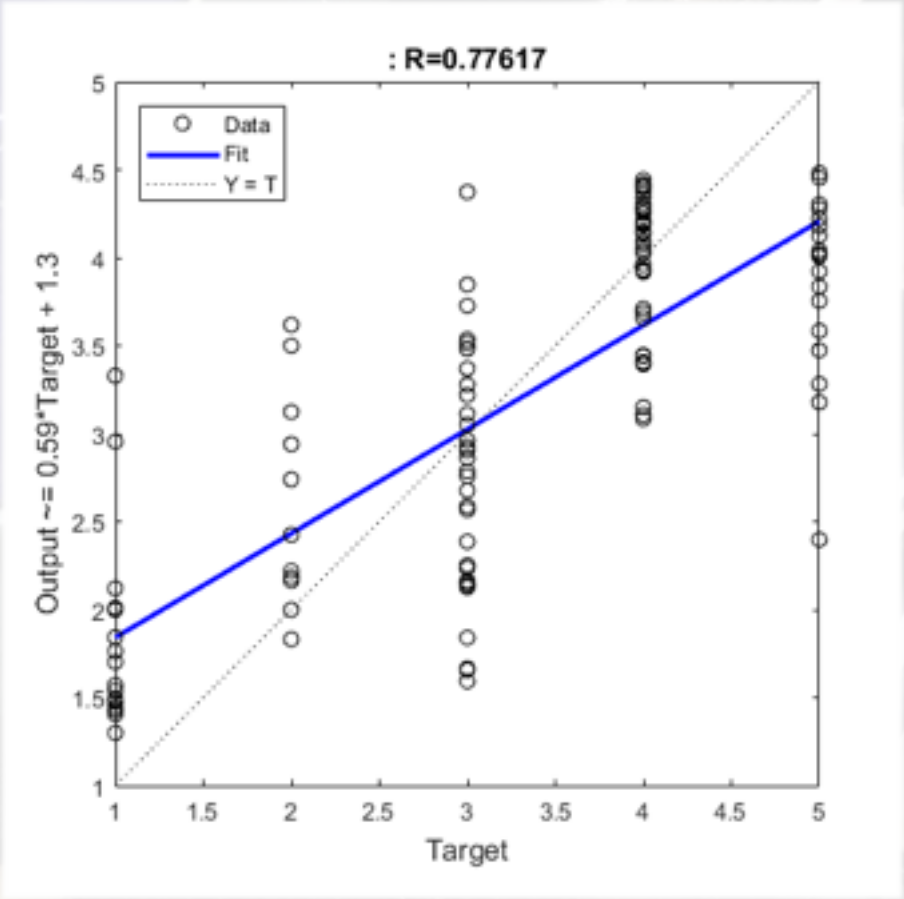
Regressor: Resultados

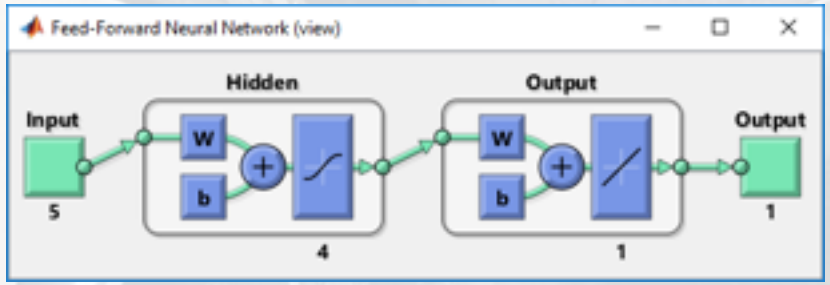






Regressor: Resultados





Indicator	Value
Mean Error	0.0671
Standard Deviation	0.8025
Mean Absolute Error	0.6257
Mean Squared Error	0.6429
Root Mean Squared Error	0.8018
Median	-0.0622
Maximum Positive Error	2.6020
Maximum Negative Error	-2.3284

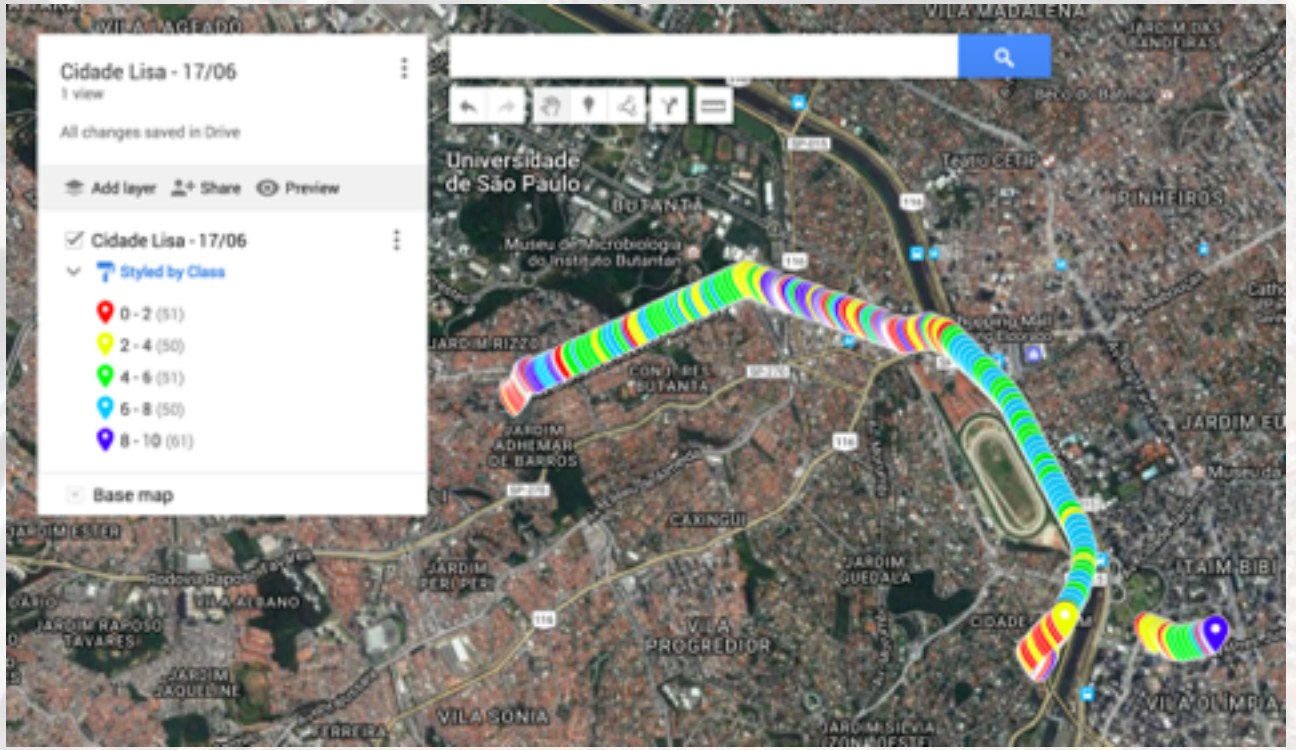
Regressor: Prova de Conceito

https://youtu.be/dC_tfyN0lp4

Regressor: Pós-Processamento de Dados

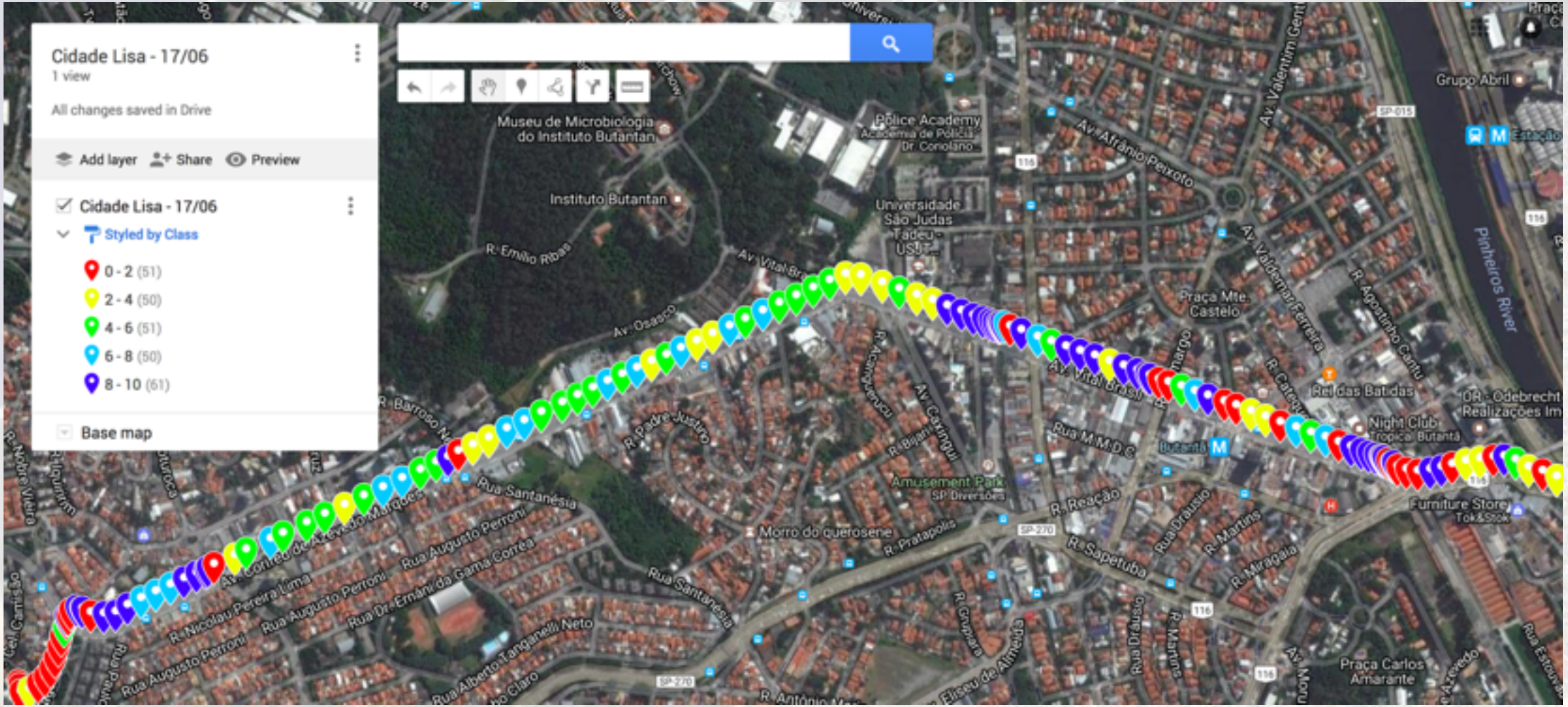
Time	Latitude	Longitude	Class
16:00:07	-23.576443333333334	-46.73081833333334	6.670848802612243
16:00:10	-23.57646333333333	-46.730761666666666	2.5069078406896965
16:00:13	-23.57642	-46.73065	8.717083007626286
16:00:16	-23.57636166666667	-46.73047499999999	2.000417211374395
16:00:19	-23.576249999999998	-46.73032166666667	2.039868149866655
16:00:22	-23.57609	-46.73021666666667	7.819218864936794
16:00:25	-23.575916666666664	-46.73015	2.048814660980271
16:00:28	-23.575705000000003	-46.73009833333334	2.0044471170424294
16:00:32	-23.575513333333333	-46.730046666666674	6.519351837180351
16:00:35	-23.575305000000004	-46.72997333333333	5.089785699837046
16:00:38	-23.575188333333337	-46.72991166666667	4.701097129842713
16:00:41	-23.57509	-46.72987666666666	6.474466593684389
16:00:44	-23.57507333333333	-46.72987833333333	6.400082338435934
16:00:47	-23.57507333333333	-46.72987833333333	8.717083007626286
16:00:50	-23.57507333333333	-46.72987833333333	8.717083007626286
16:01:36	-23.575055	-46.72999	8.71563442217452
16:01:39	-23.57505	-46.72999166666667	8.717083007626286
16:01:42	-23.57505	-46.72999166666667	8.717083007626286
16:02:00	-23.574994999999998	-46.72993666666666	5.414752701813974
16:02:03	-23.57501666666667	-46.72981333333334	9.957695099722656
16:02:06	-23.575041666666667	-46.729761666666676	7.957299865241671
16:02:09	-23.57504833333333	-46.72974166666666	8.717083007626286
16:02:12	-23.57504833333333	-46.72974166666666	8.717083007626286
16:02:25	-23.57506	-46.72964166666667	8.717083007626286
16:02:28	-23.575071666666666	-46.729625000000006	8.717083007626286
16:02:31	-23.57514666666667	-46.729575000000004	4.977347054346976
16:02:34	-23.575296666666667	-46.729546666666664	8.12357747692614
16:02:37	-23.575429999999997	-46.72958166666675	6.902104480453204
16:02:40	-23.575588333333332	-46.72963500000001	2.0229601743972045
16:02:43	-23.57578	-46.72969166666667	3.6445495332235778
16:02:46	-23.576008333333334	-46.72975666666666	5.689440978722795
16:02:49	-23.576251666666668	-46.729843333333335	6.2685682655168575
16:02:52	-23.576486666666664	-46.72994333333333	5.344399714113996
16:02:55	-23.576729999999998	-46.730066666666666	5.973421138545221
16:02:58	-23.576976666666663	-46.73024	5.409925430973388

Arquivo importado no Google Maps

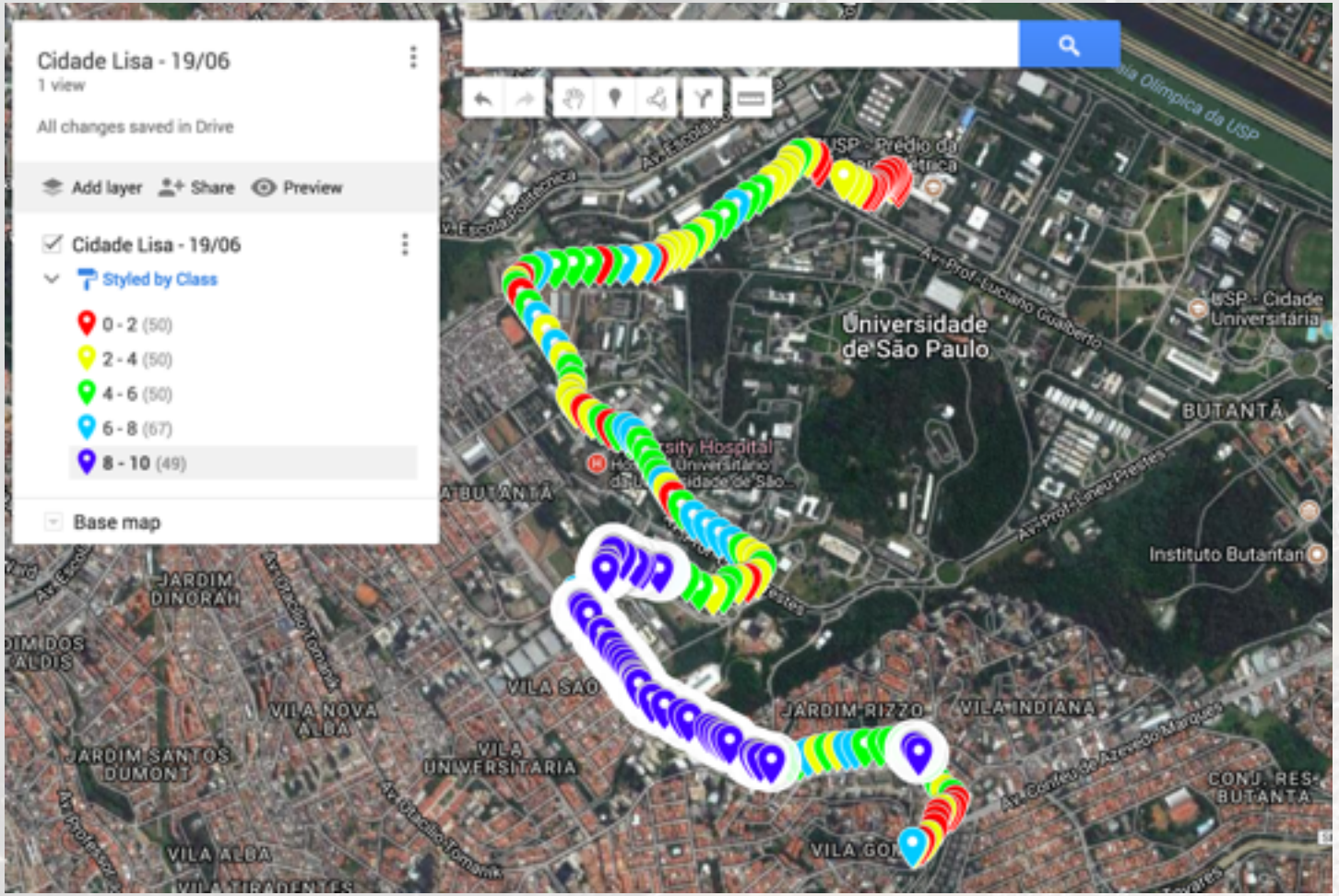


Arquivo salvo ao final da rota

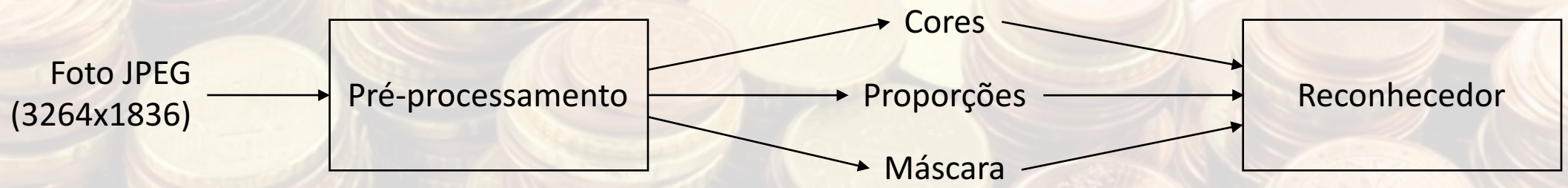
Regressor: Pós-Processamento de Dados



Regressor: Pós-Processamento de Dados



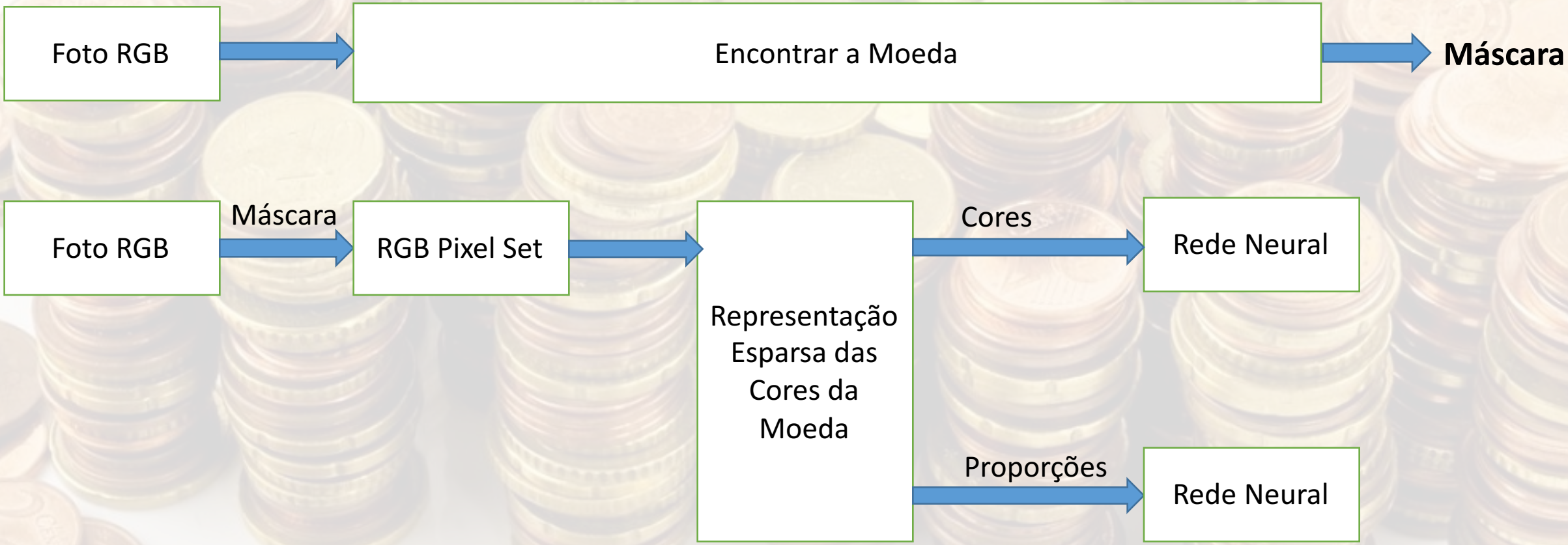
Reconhecedor: Identificação de moedas



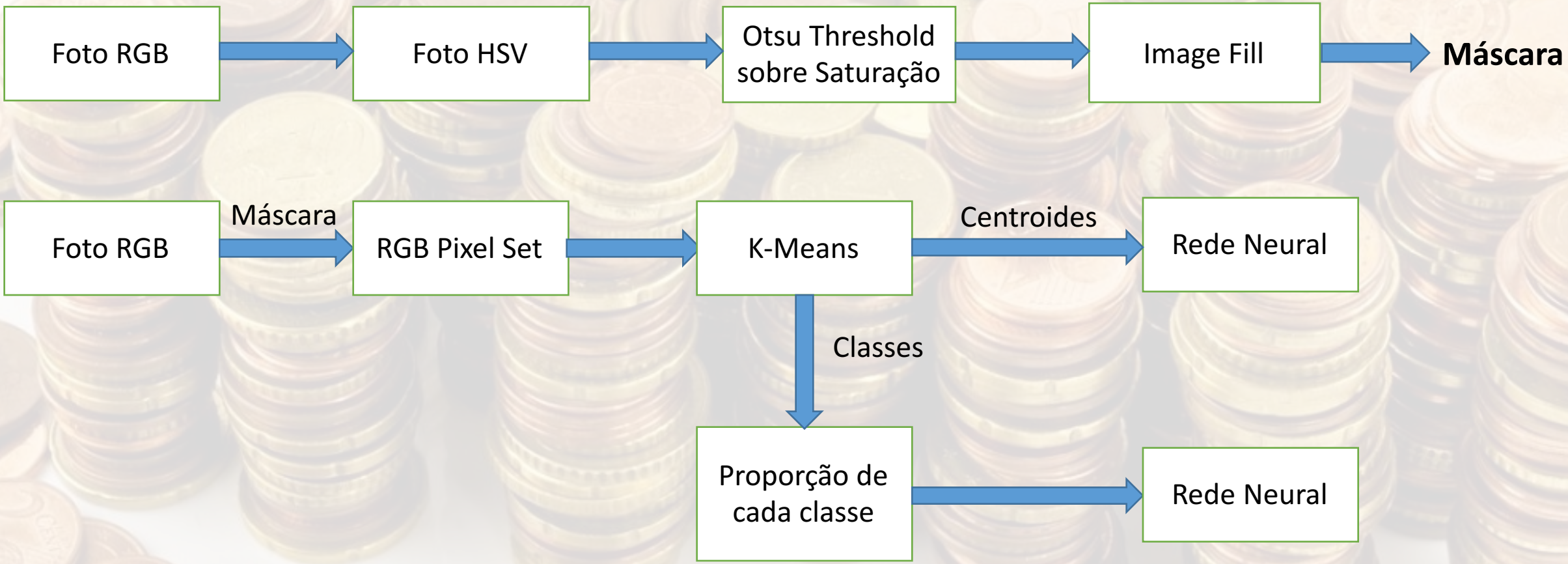
Saída: Valor nominal da moeda



Reconhecedor: Pré-processamento

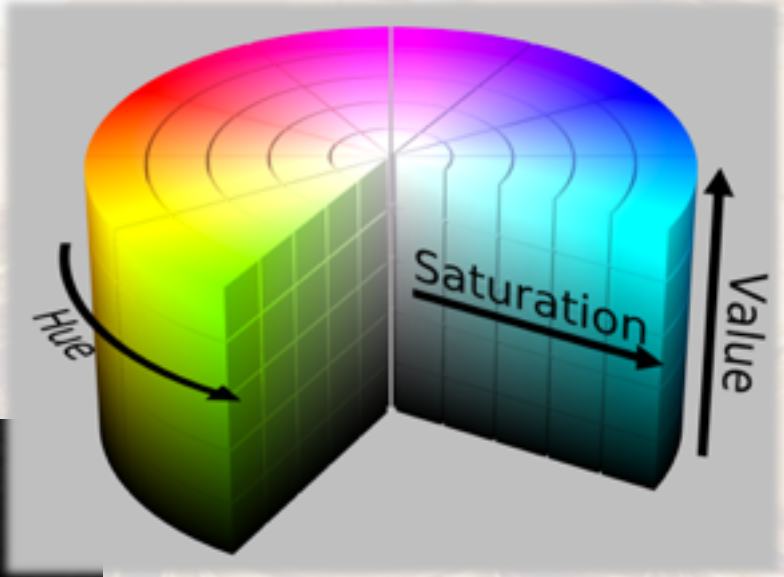


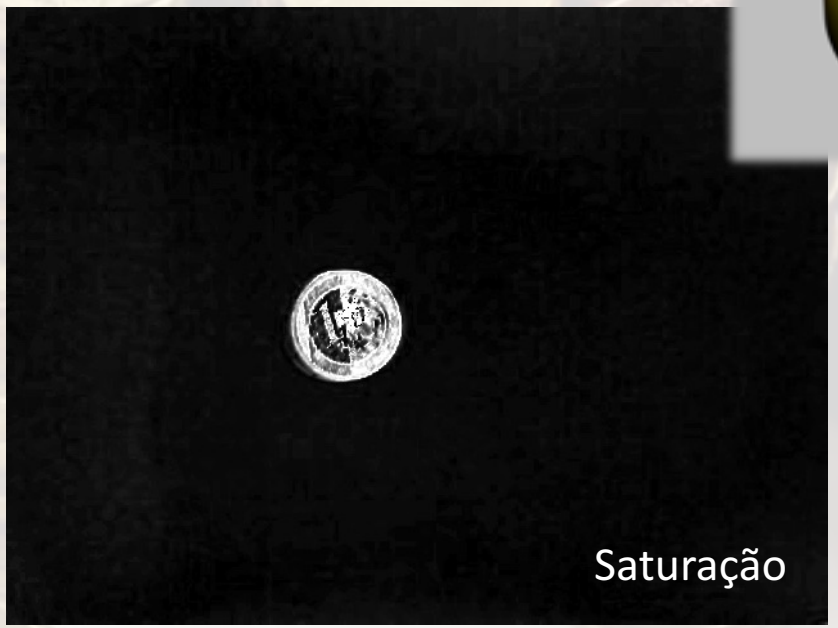
Reconhecedor: Pré-processamento



Reconhecedor: Pré-processamento

Foto RGB → Foto HSV → Saturação





Reconhecedor: Pré-processamento

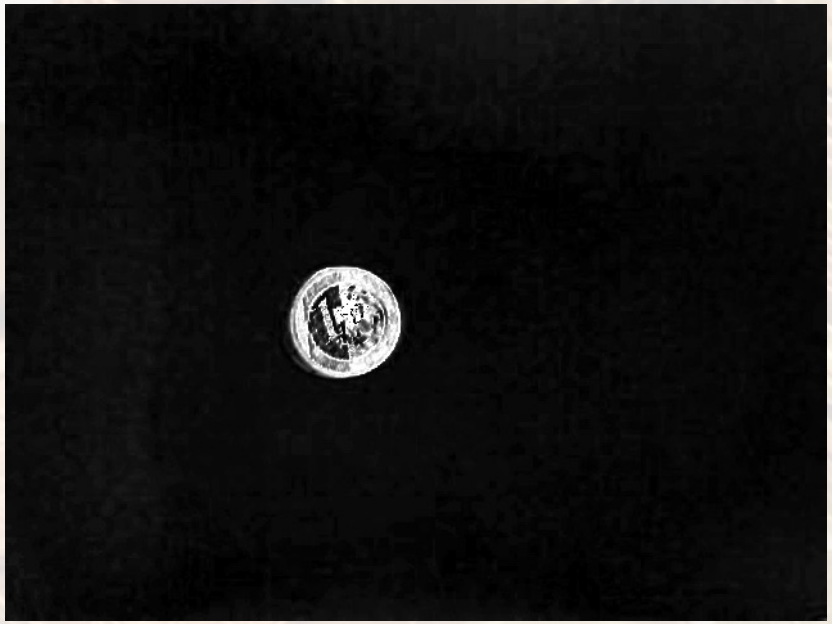
Foto HSV → Otsu Threshold sobre Saturação

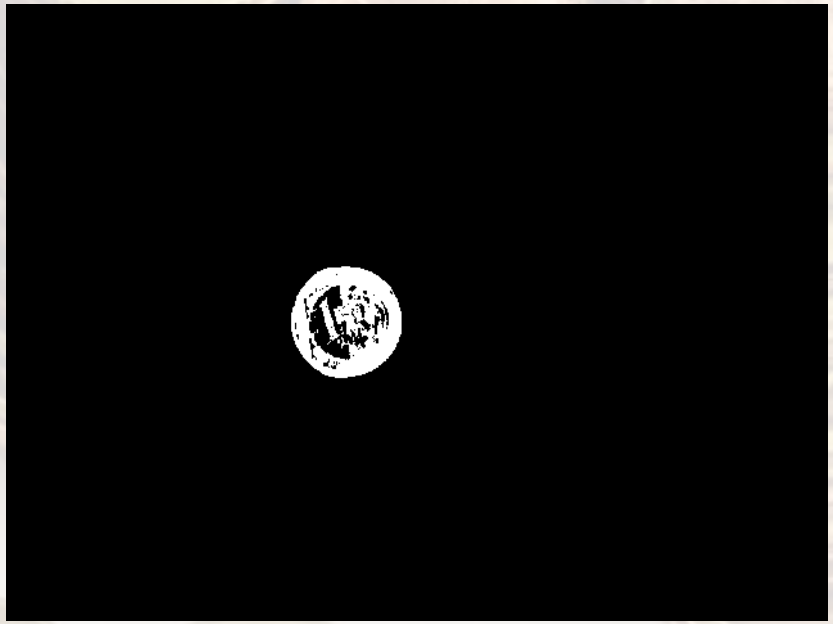
Encontra o threshold T que minimiza a variância intra-classes

$$T = \arg\min_T \sigma_b^2(T)$$

$$\sigma_b^2(T) = p(X \leq T)(\mu_0(T) - \mu)^2 + p(X > k)(\mu_1(T) - \mu)^2$$

$$\mu = E[X];\ \mu_0(T) = E[X|X \leq T];\ \mu_1(T) = E[X|X > T]$$





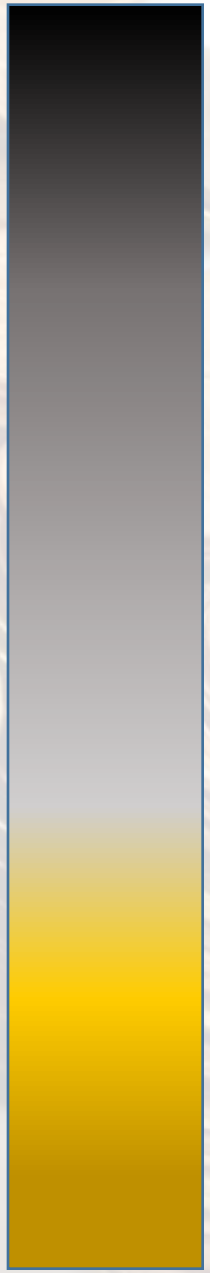
Reconhecedor: Pré-processamento

Otsu Threshold sobre Saturação → Image Fill → **Máscara**

Preenche o interior de regiões fechadas!
Mais de uma região conexa: Escolhemos a maior!

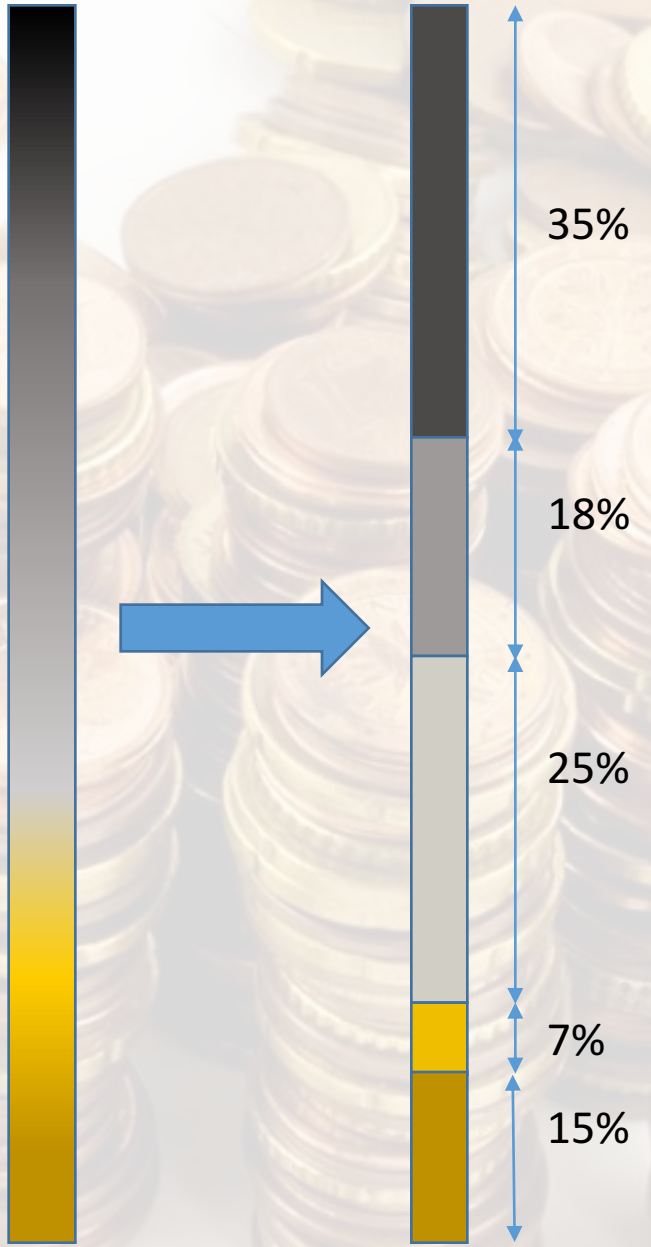
Reconhecedor: Pré-processamento

Foto RGB → Máscara → RGB Pixel Set



Reconhecedor: Pré-processamento

RGB Pixel Set → K-Means → Centroides e Proporções



5 cores principais

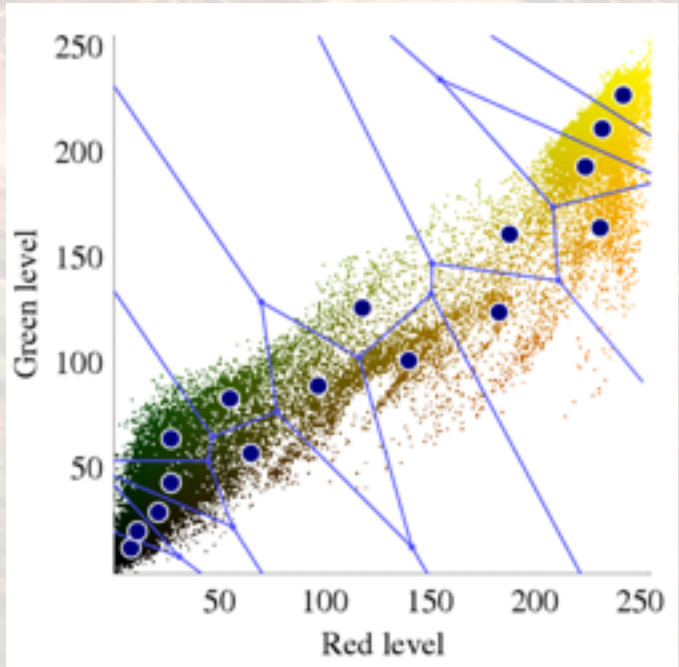
K-Means

- Baixa complexidade: $\approx \mathcal{O}(n)$
- Fronteiras de separação lineares
- Usuário escolhe o número de clusters K

Inicie os K centroides aleatoriamente.

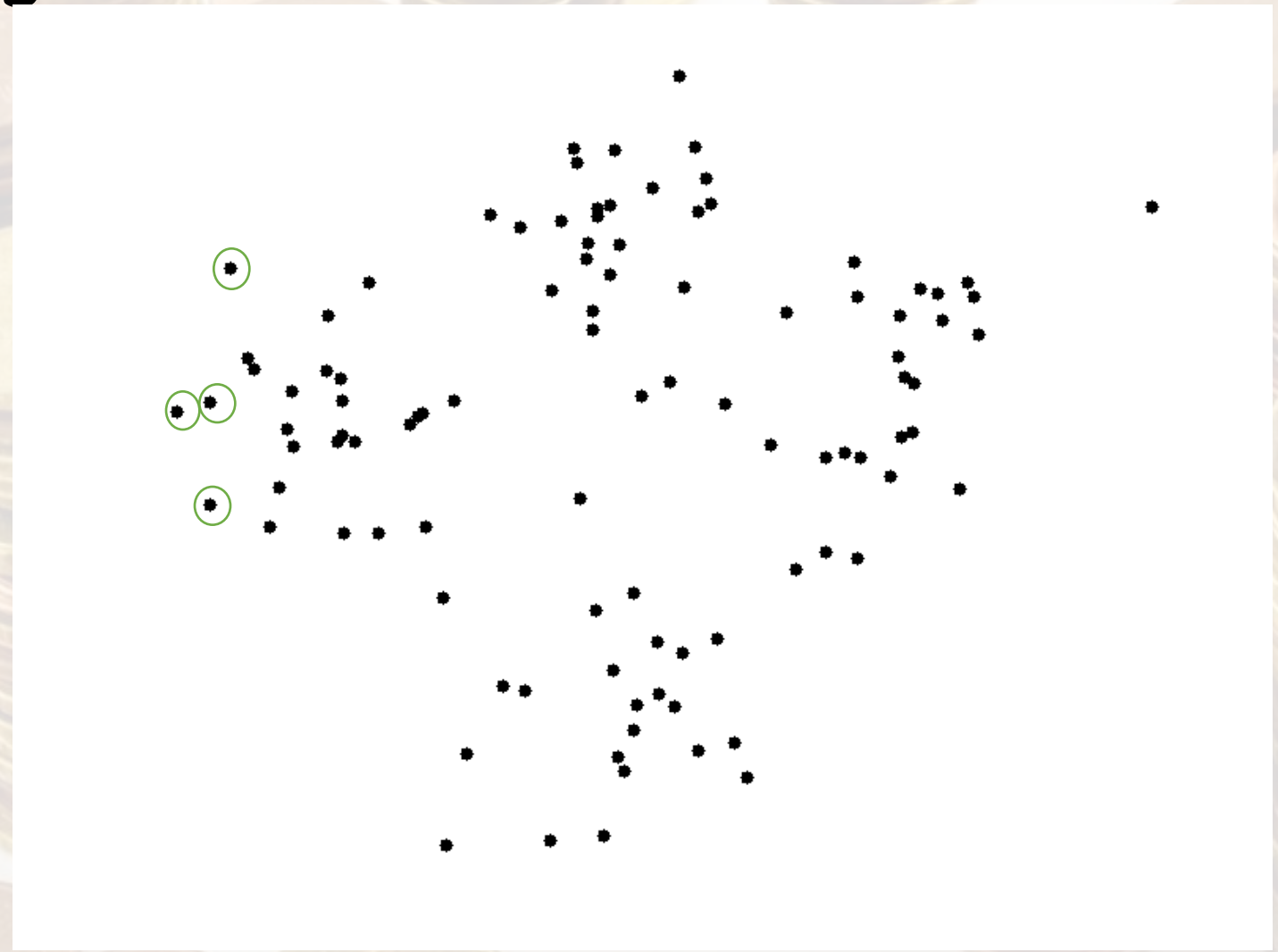
A cada iteração:

1. Rotule cada ponto com a classe do centroide mais próximo.
2. Os novos centroides são os centroides de cada classe.

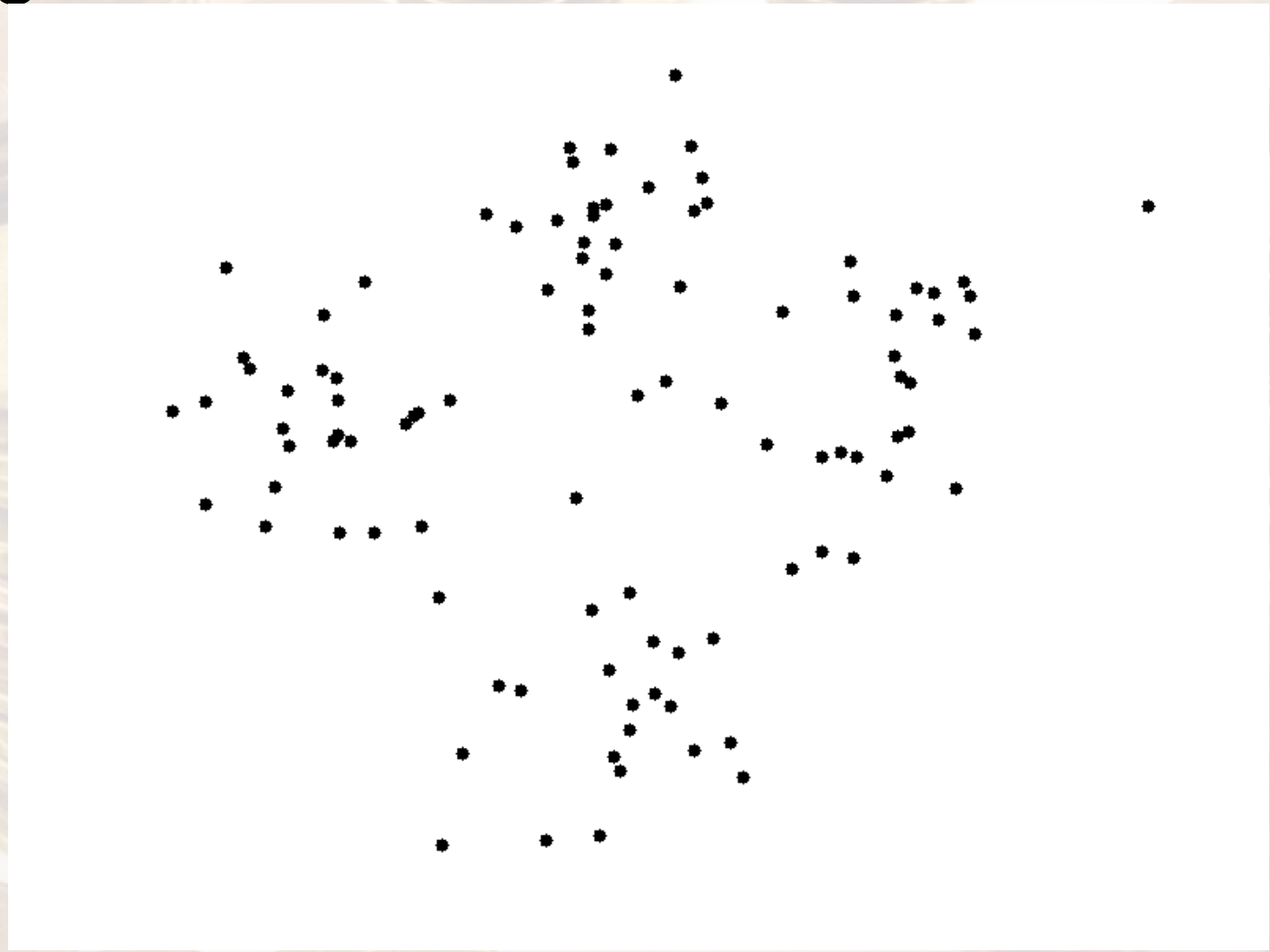


K = 16

K-Means



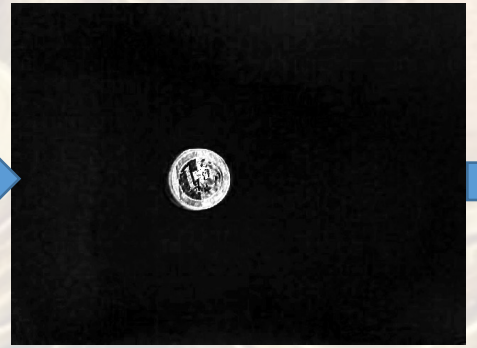
K-Means



Reconhecedor: Pré-processamento

Foto RGB

Saturação



Otsu Threshold

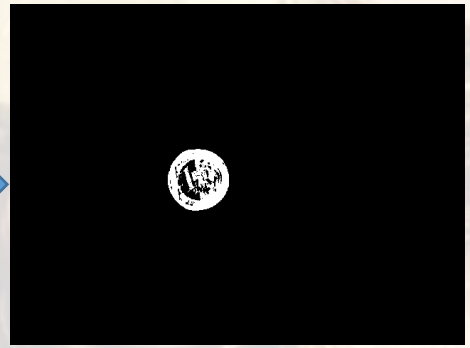
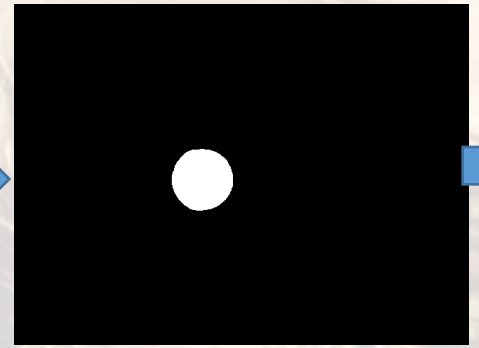
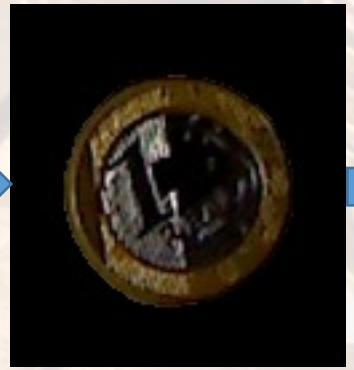
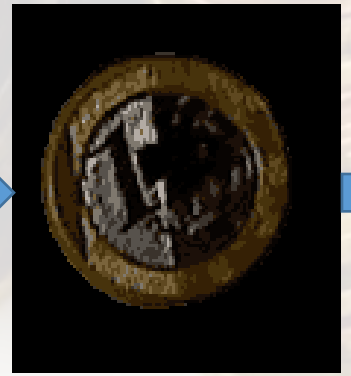


Image Fill





Aplicação da Máscara



K-Means
K=5

Centroides e Proporções

Rede Neural

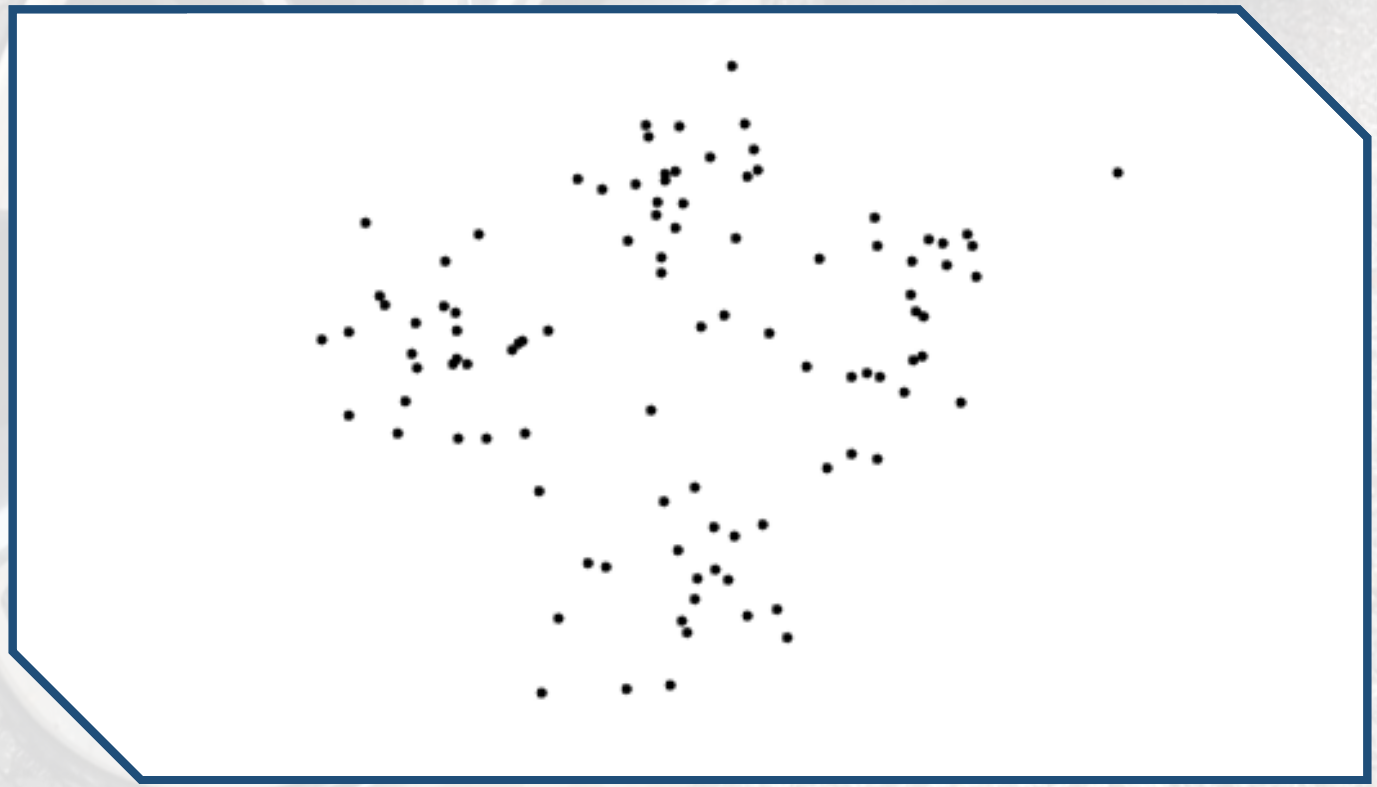
Reconhecedor: Metodologia

Resorteio do kmeans

Otimização da topologia

k-fold cross-validation

Re-treino



Reconhecedor: Metodologia

Resorteio do kmeans

Otimização da topologia

k-fold cross-validation

Re-treino

Busca extensiva:

Todas as combinações possíveis de topologias (número e tamanho das camadas escondidas) e variáveis foram geradas e testadas *overnight*.

Resultado: duas camadas escondidas com 10 e 7 neurônios sigmoidais.

Reconhecedor: Metodologia

Resorteio do kmeans

Otimização da topologia

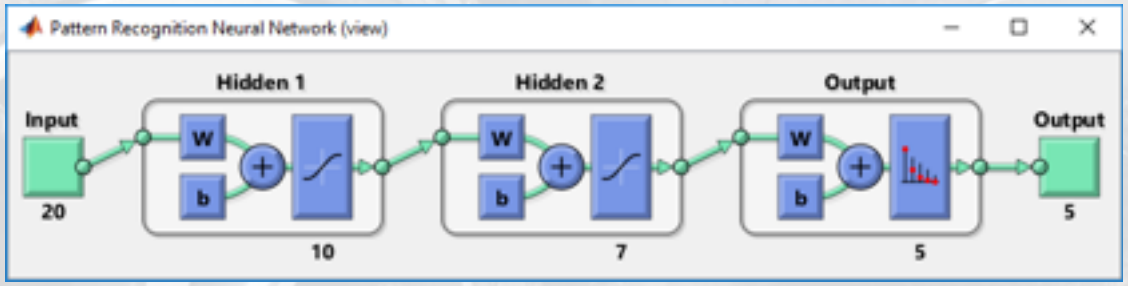
k-fold cross-validation

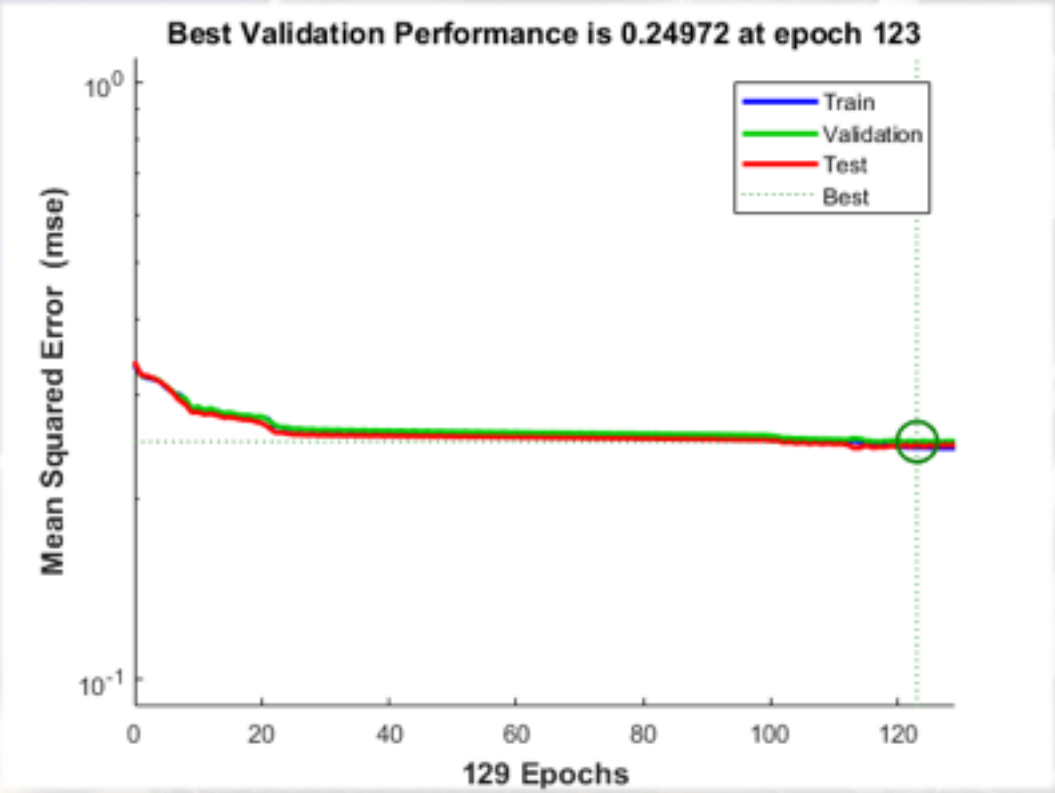
Re-treino

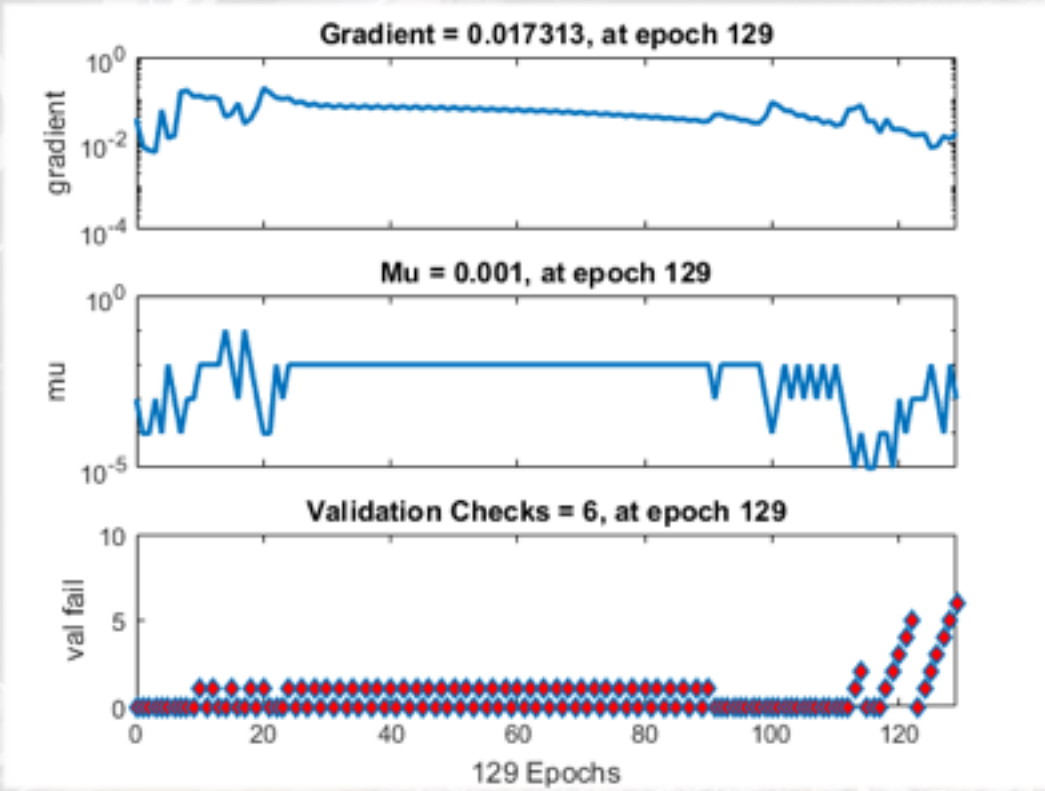
10-fold cross validation:

10 re-treinos para evitar mínimos locais

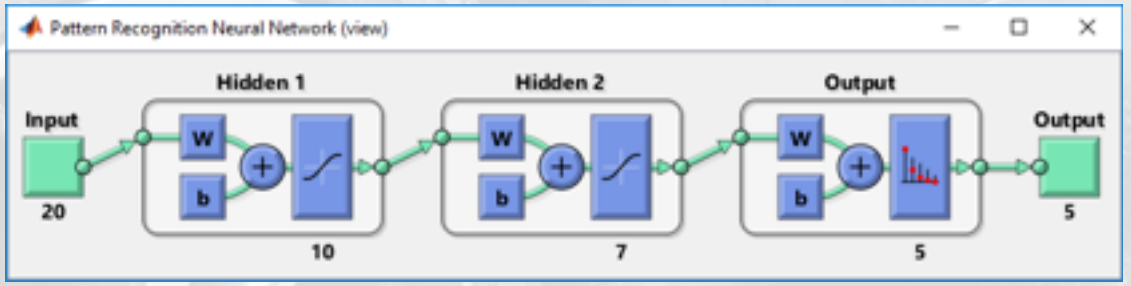
Reconhecedor: Resultados

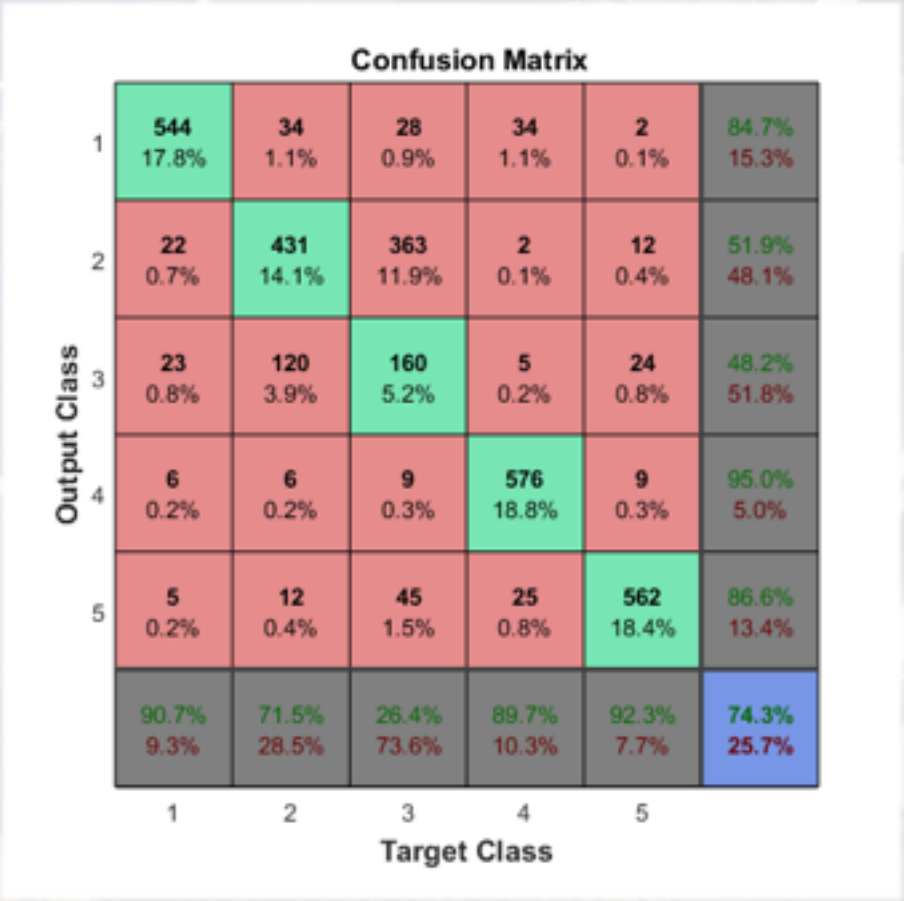


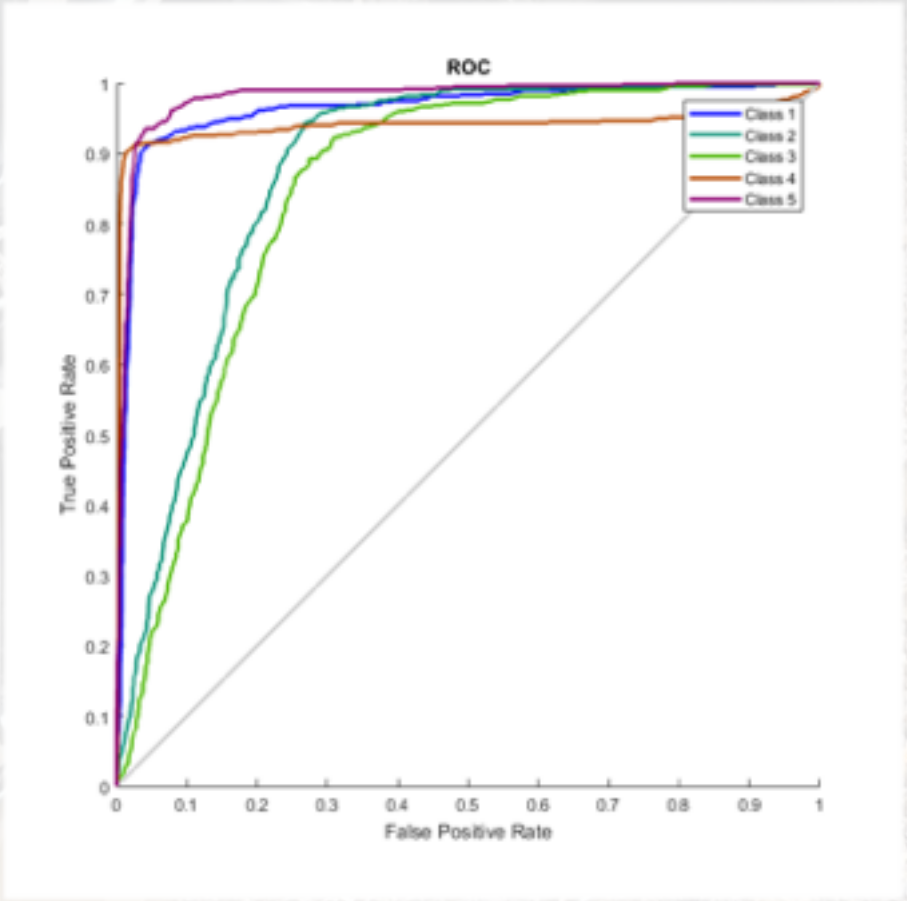




Reconhecedor: Resultados



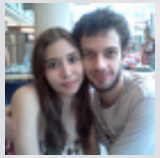




MUITO OBRIGADO! PERGUNTAS?

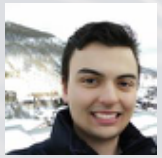
Regressor de Qualidade das Vias

Carlos Grivol

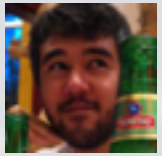


Carlos Prete

Reconhecedor de Moedas



Gabriel Crabbé



Tiago Amano

Regressor: Referências

[1] BALAKUNTALA, S.; VENKATESH, S. An Intelligent System to Detect, Avoid and Maintain Potholes: A Graph Theoretic Approach. *Seventh International Conference on Mobile Computing and Ubiquitous Networking (ICMU)*, 6-8 jan. 2014.

[2] CHUGH, G.; BANSAL, D.; SOFAT, S. Road Condition Detection Using Smartphone Sensors: A Survey. *International Journal of Electronic and Electrical Engineering, ISSN 0974-2174, v. 7, n. 6, p. 595-602, 2014*.

[3] ERIKSSON, J.; GIROD, L.; HULL, B.; NEWTON, R.; MADDEN, S.; BALAKRISHNAN, H. • The Pothole Patrol: Using a Mobile Sensor Network for Road Surface Monitoring. *The Sixth Annual International conference on Mobile Systems, Applications and Services (MobiSys 2008)*, Breckenridge, Estados Unidos., jun. 2008.

[4] GORADE, P.; KARDE, D.; KHILARE, P.; SONTAKKE, A.; KEDAR, R. M. Real Time Pothole Tracking System Using Android Smart Phone. *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, v. 3, ed. 5, maio 2014.

[5] KALRA, N.; CHUGH, G.; BANSAL, D. Analyzing Driving and Road Events via Smartphone. *International Journal of Computer Applications*, ISSN 0975-8887, v. 98, no. 12, jul. 2014.

[6] KULKARNI, A.; MHALGI, N.; GURNANI, S.; GIRI, N. Pothole Detection System using Machine Learning on Android. *International Journal of Emerging Technology and Advanced Engineering*, ISSN 2250-2459, v. 4, ed. 7, jul. 2014.

[7] LANJEWAR, B. U.; SAGAR, R.; PAWAR, R.; KEDKHAR, J.; GOSAVI, K. Road Bump and Intensity Detection using Smartphone Sensors. *International Journal of Innovative Research in Computer and Communication Engineering*, v. 4, ed. 5, maio 2016.

[8] MEDNIS, A.; STRAZDINS, G.; ZVIEDRIS, R.; KANONIRS, G.; SELAVO, L. Real Time Pothole Detection Using Android Smartphones with Accelerometers. *7th IEEE International Conference on Distributed Computing in Sensor Systems and Workshops (DCOSS),* 2011.

[9] MOHAN, P.; PADMANABHAN, V. N.; RAMJEE, R.; MURPHY, M. Nericell: Rich Monitoring of Road and Traffic Conditions using Mobile Smartphones. *Microsoft Research India*, Bangalorev. 2008.

[10] WANG, H. W.; CHEN, C. H.; CHENG, D. Y.; LIN, C. H.; LO, C. C. A Real-Time Pothole Detection Approach for Intelligent Transportation System. *Mathematical Problems in Engineering*, v. 2015, id 869627, 2015.

Reconhecedor: Referências

[1] MONEDA, L. (2016) Brazilian Coins Dataset. Retrieved from: http://lgmoneda.github.io/

[2] Nobuyuki Otsu (1979*). "A threshold selection method from gray-level histograms". IEEE Trans. Sys., Man., Cyber.* ***9*** *(1): 62–66.*

[3] Arthur; Abhishek Bhowmick (2009). A theoretical analysis of Lloyd's algorithm for k-means clustering (Tese)

[4] Soille, P., *Morphological Image Analysis: Principles and Applications*, Springer-Verlag, 1999, pp. 173-174.

[5] K. D. Joshi,B. W. Surgenor, V. D. Chauhan - Analysis of methods for the recognition of Indian coins: A challenging application of machine vision to automated inspection - 2016 23rd International Conference on Mechatronics and Machine Vision in Practice (M2VIP)– January 2017

[6] Digital Image Processing (3rd Edition) – Rafael C. Gonzalez, Richard E. Woods - Pearson