Investigating Image Quality Loss in Grayscale Gaussian Noise Filters for Low-light Photography

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Outline

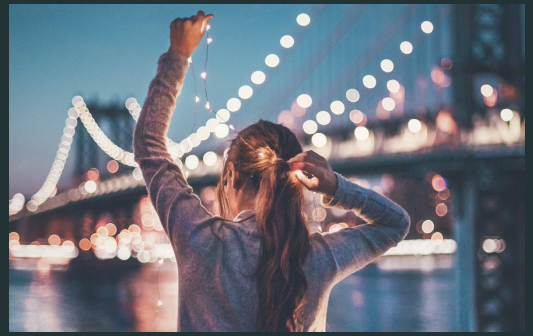
1. Introduction & Background

Low-light Photography

Source:
https://www.canon.com.cy/cameras/low-light-cameras/

Source:
https://nextshark.com/filipino-photographer-will-teach-take-aesthetic-af-vaporwave-photos/

Source:
https://blogs.windows.com/devices/2013/06/17/low-light-long-exposures-top-tips-for-getting-started/



Source:
https://twitter.com/brandonwoelfel/status/795124002939404288

Source:
https://www.ephotozine.com/article/tips-on-low-light-photography-17741

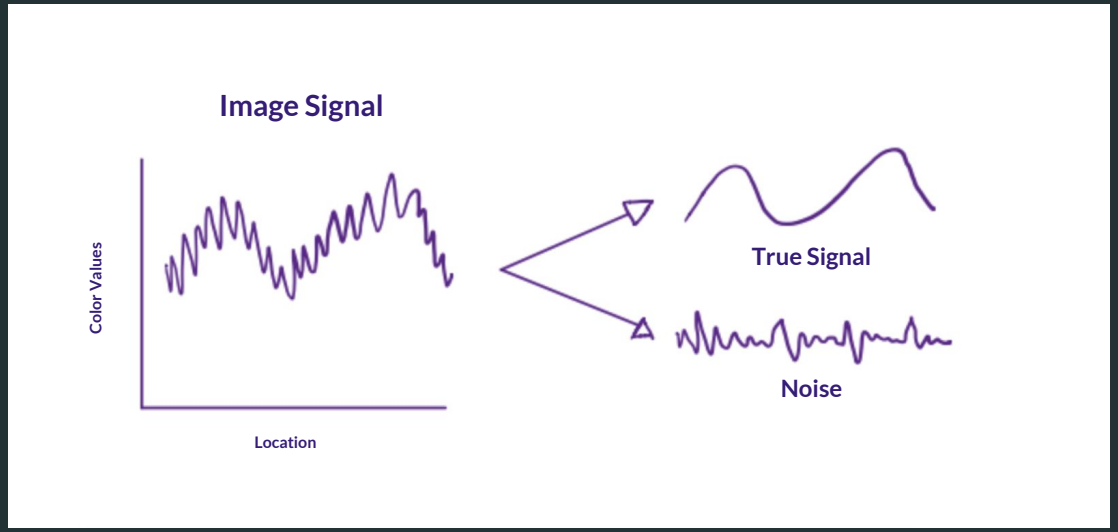
Source: https://unsplash.com/photos/msnyz9L6gs4

Low-light Photography (cont.)

Qualities of low-light photographs:

- Nighttime or lack of sunlight
- Artificial lighting
- Requires a tripod and long exposure or high ISO setting
- Prone to sensor *noise*

What is noise?



Defined as visual distortion.

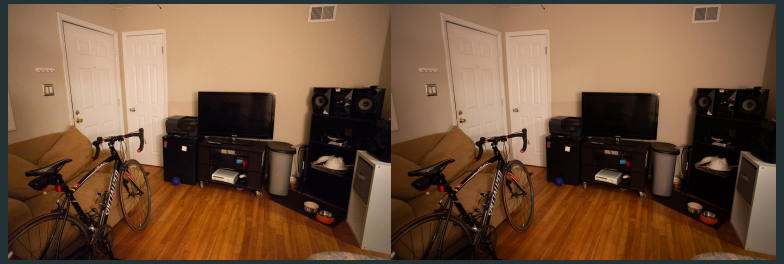
Types of Noise

Gaussian

Poisson

Impulsive
(Salt-and-pepper)

Speckle



True State

Exposure Settings: ISO 400, f/4.0, 3 ⅕ sec

Noisy

Exposure Settings: ISO 20000, f/4.0, 1/15 sec

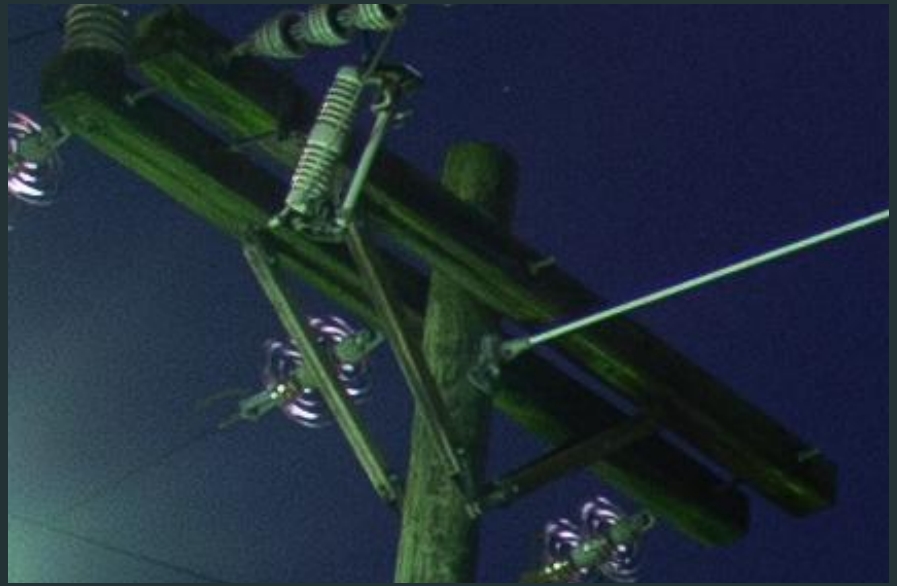
True State

Exposure Settings: ISO 400, f/4.0, 3 ⅕ sec

Noisy

Exposure Settings: ISO 20000, f/4.0, 1/15 sec

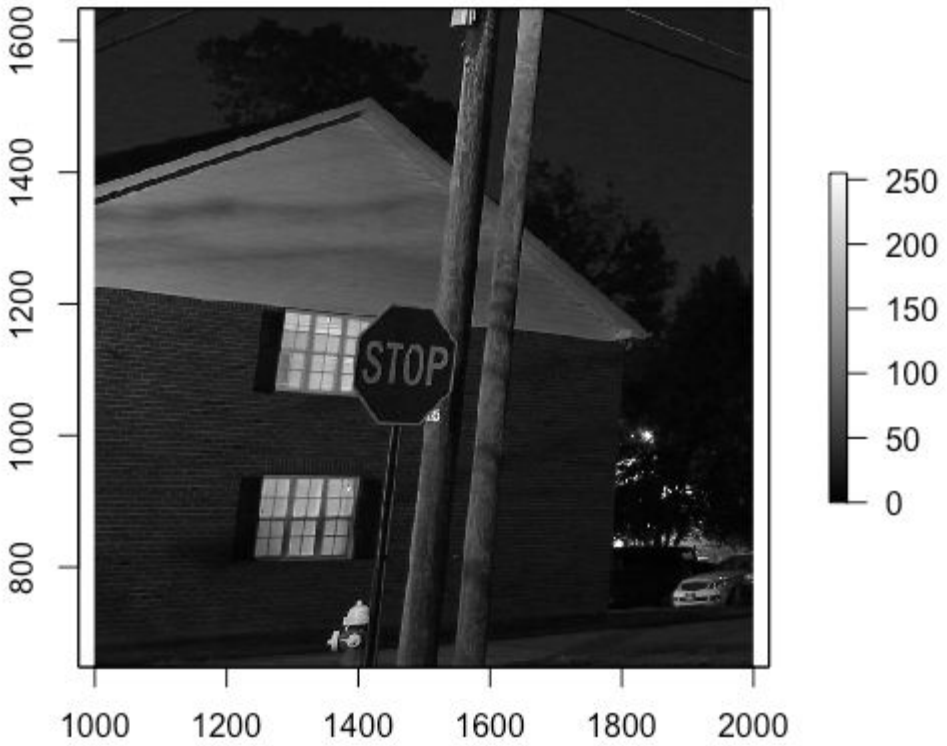
True State

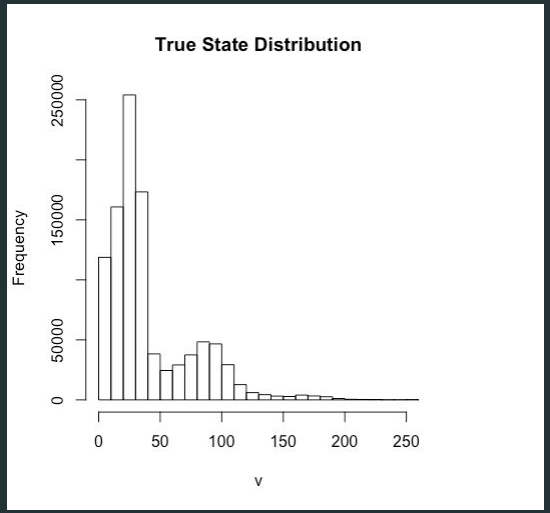


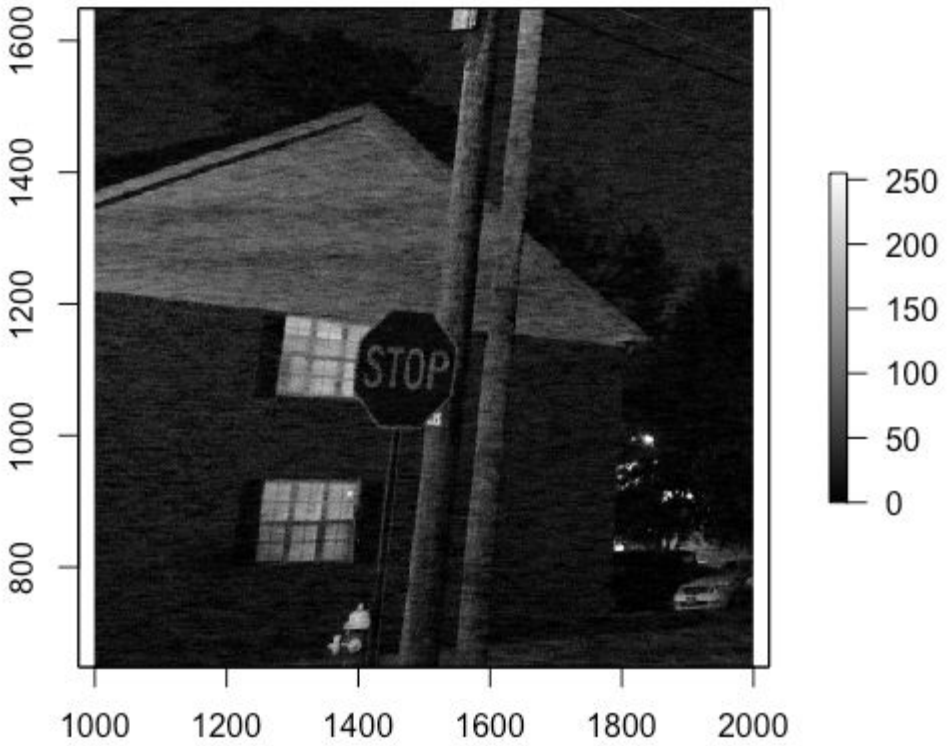
Exposure Settings: ISO 400, f/4.0, 3 ⅕ sec

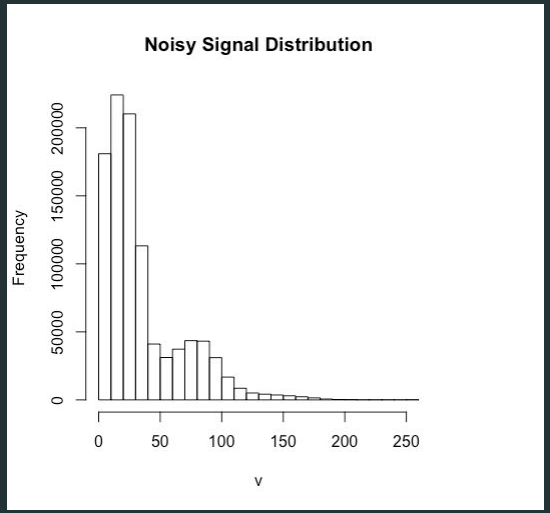
Noisy

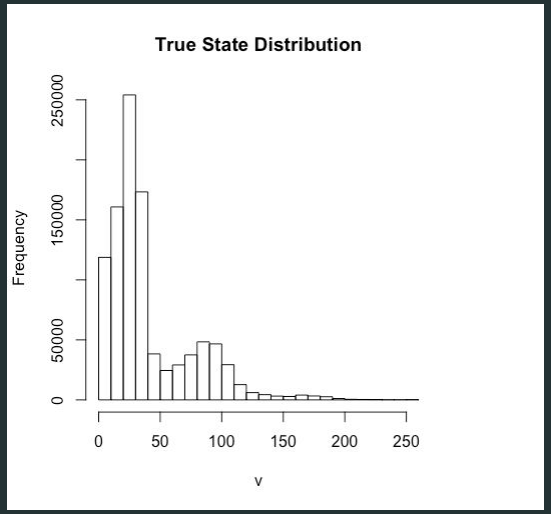
Exposure Settings: ISO 20000, f/4.0, 1/15 sec


STOP
1600
1400
1200
1000
800
1000
1200
1400
1600
1800
2000
250
200
150
100
50
0

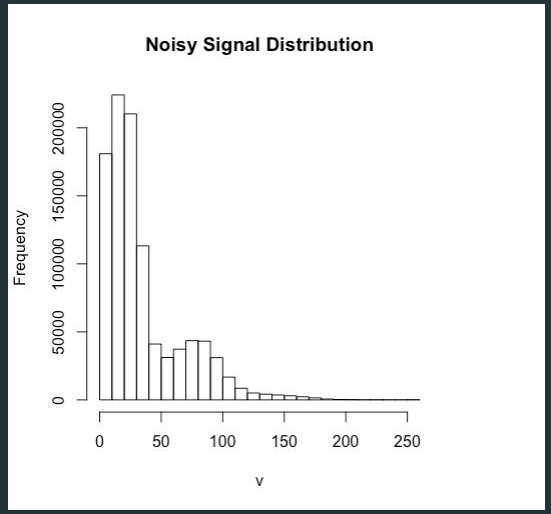

True State Distribution
Frequency
250000
150000
50000
0
0
50
100
150
200
250
v


1600
1400
1200
1000
800
STOP
1000
1200
1400
1600
1800
2000
250
200
150
100
50
0

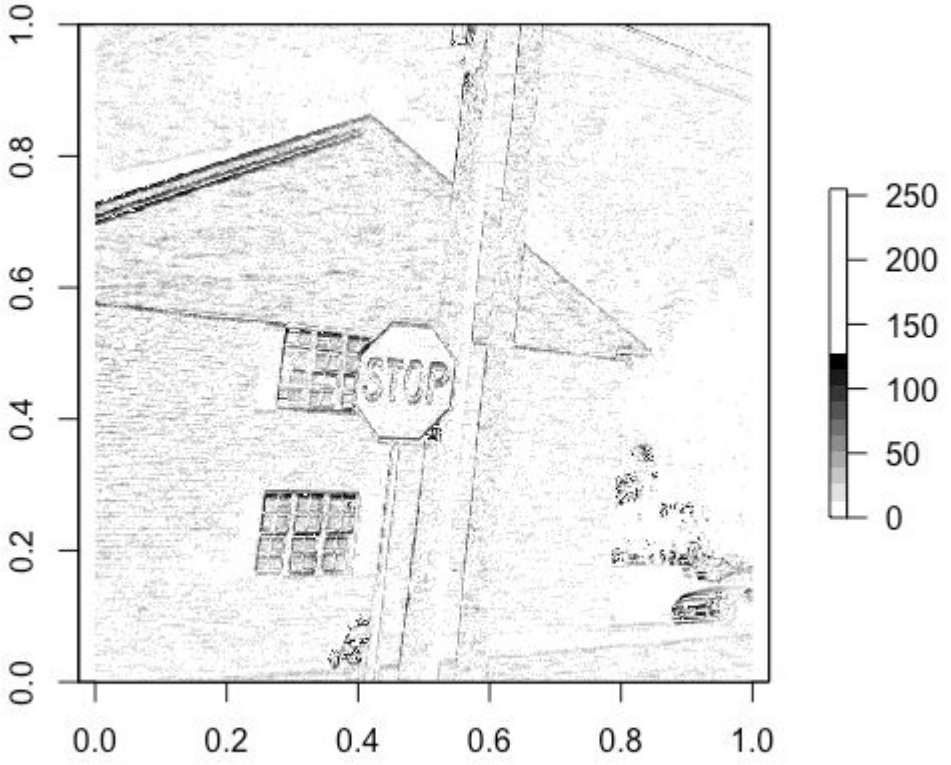

Noisy Signal Distribution
Frequency
0
50000
100000
150000
200000
0
50
100
150
200
250
v


True State Distribution
Frequency
0
50000
150000
250000
0
50
100
150
200
250
v

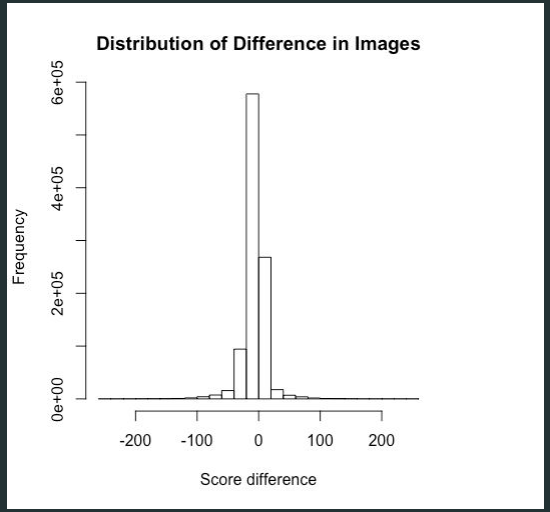
–

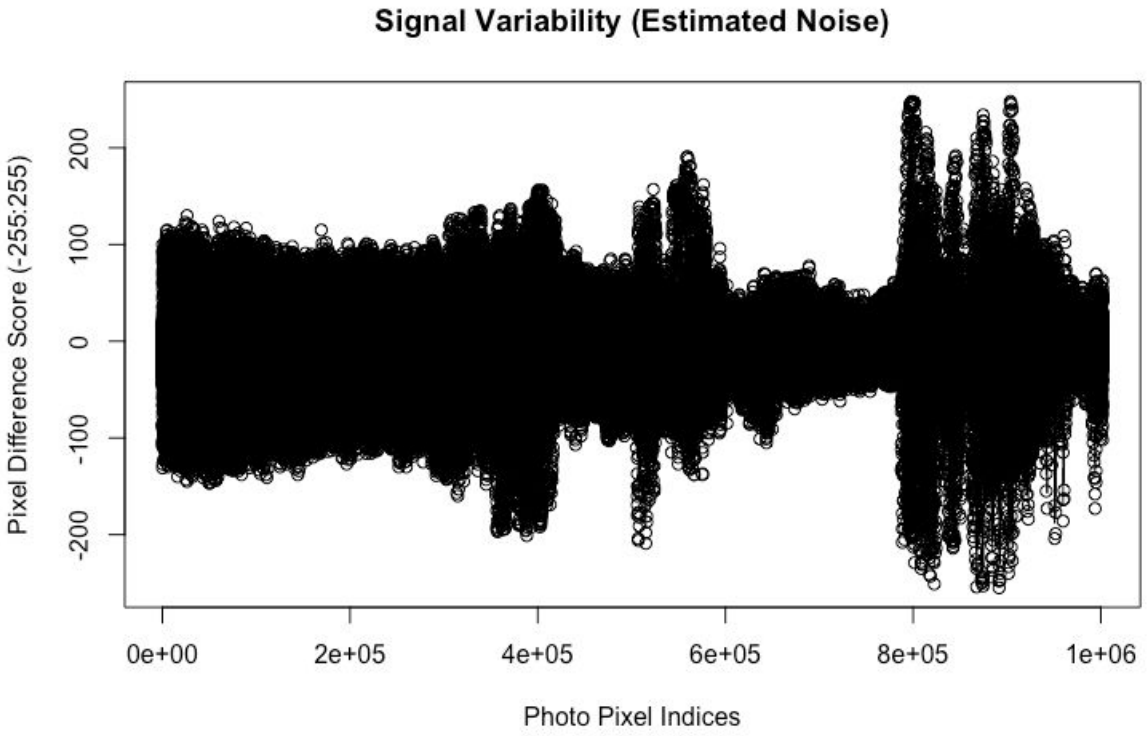

Noisy Signal Distribution
Frequency
0
50000
100000
150000
200000
0
50
100
150
200
250
v

= Noise



Note that the dark lines outlining objects are likely from camera shake or difference in exposure levels.




Signal Variability (Estimated Noise)
Pixel Difference Score (-255:255)
200
100
0
-100
-200
0e+00
2e+05
4e+05
6e+05
8e+05
1e+06
Photo Pixel Indices

Computer Vision Introduction

At the pixel level

$[0, 255]$

140	137	130	82	101	109	108	101
129	123	125	99	115	102	98	99
114	120	112	87	113	105	118	126
89	86	49	84	127	149	128	132
88	75	78	91	103	137	161	154
72	69	92	71	78	94	172	139
56	74	67	89	82	87	98	112
45	80	126	116	117	76	103	115

At the pixel level

$[0, 255]$

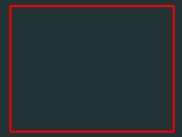
140	137	130	82	101	109	108	101
129	123	125	99	115	102	255	99
114	120	0	87	113	105	118	126
89	86	49	84	127	149	128	132
88	75	78	91	103	137	161	154
72	69	92	71	78	94	0	139
56	255	67	89	82	87	98	112
45	80	126	116	117	76	103	115

Noise

Example of a box filter

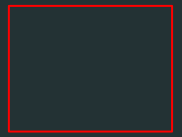
$[0, 255]$

123	145	142
139	0	167
153	142	170

 = Current Pixel

Then, we calculate the expected value with some average (mean or median) or using the formula:

$$E(X) = \Sigma\, x * p(x)$$



= Current Pixel

Gaussian Box Filter

x

123	145	142
139	0	167
153	142	170

X

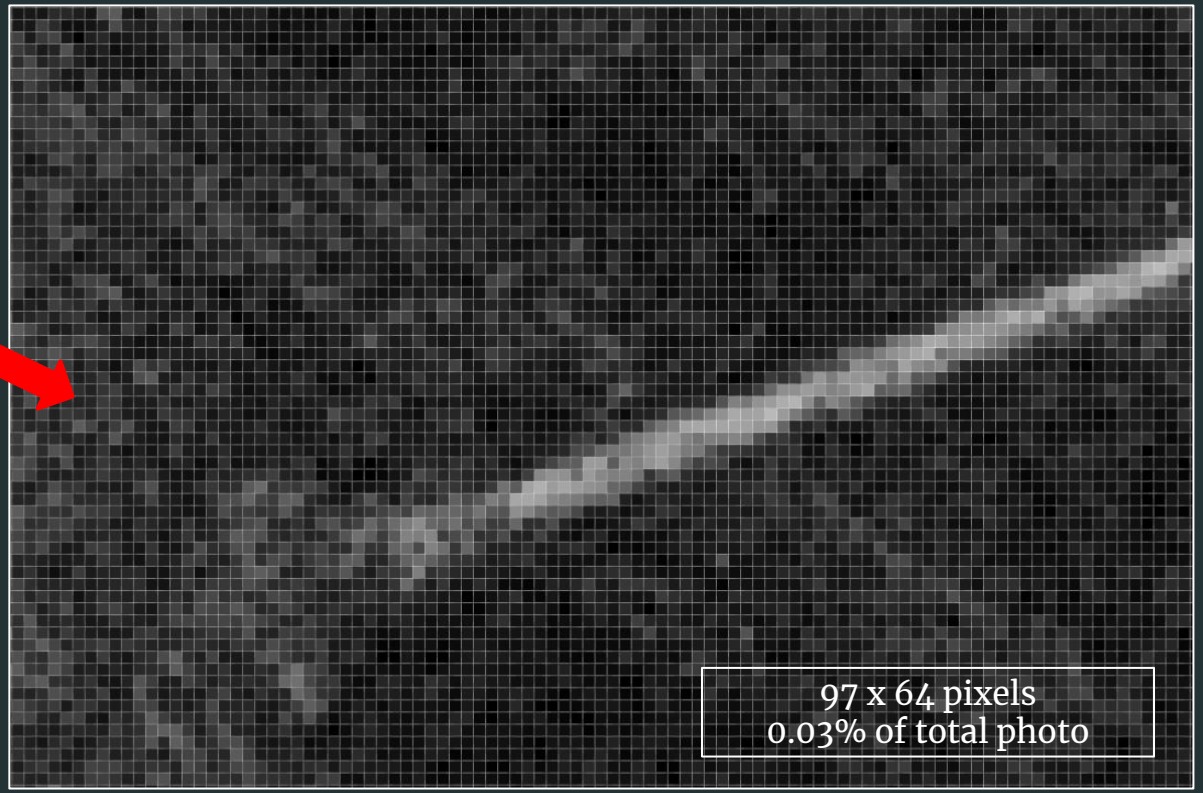
p(x)

0.0625	0.125	0.0625
0.125	0.25	0.125
0.0625	0.125	0.0625

= E(X)

Then, we calculate the expected value with some average (mean or median) or using the formula:

$$E(X) = \Sigma\, x * p(x)$$


97 x 64 pixels
0.03% of total photo

Filtering Methods

Three main subdomains:

- **CV** - Bilateral, Nonlocal Means, Mean Box Filter, Gaussian Box Filter
- **Machine learning** - Supervised Box Filters, Unsupervised Neural Nets
- **Statistics** - Markov Random Field, Nonlinear Total Variation

2. Analysis


R


Lr

Filters Tested

Mean 3 x 3 Box:

$$I^{filtered}(x) = \frac{1}{n}\sum_{x_i \in \Omega} x_i$$

Bilateral:

$$I^{filtered}(x) = \frac{1}{W_p}\sum_{x_i \in \Omega} I(x_i) f_r(\|I(x_i) - I(x)\|) g_s(\|x_i - x\|)$$

Nonlocal Means:

$$I^{filtered}(p) = \frac{1}{C(p)}\int_{\Omega} v(q) f(p,q) dq$$

Adobe LR/ACR: Undisclosed.

Experiment Design

- Six of the same image processed with different filters
- Calculate benchmark scores
- Shiny App in R to survey Elon students
- Several mathematics and statistics classes took our survey
- Collected 20 responses about a single image's quality (120 total)
    - Students responded to three photos as training to handle potential nuisance factors
    - Presented the true-signal image and then, the filtered photo and
    - Students rated the photo based on its quality in comparison to the true-signal

Experimental Design (cont.)

Benchmark scores used:

- PSNR = $20 * \log_{10}(\text{R-squared} / \text{MSE})$
- MSE = $|\text{noisy state} - \text{true state}|^2 / N_{\text{True State}}$
- R-Squared = $1 - (\text{true state} - \text{filtered state})^2 / (\text{true state} - \boldsymbol{\mu}_{\text{true state}})^2$
- * SSIM = $(2\boldsymbol{\mu}_{\text{true state}}\boldsymbol{\mu}_{\text{filtered state}} + c_1) * (2\sigma_{\text{true, filtered}} + c_2) / (\boldsymbol{\mu}_{\text{true state}}^2 + \boldsymbol{\mu}_{\text{filtered state}}^2 + c_1) * (\sigma_{\text{true}}^2 + \sigma_{\text{filtered}}^2 + c_2)$
- * Running Time = time (in seconds) for algorithm to finish

** = Work in progress.*

Which photo looks the best to you?


2
STOP

3

5


6
STOP

Benchmark Results

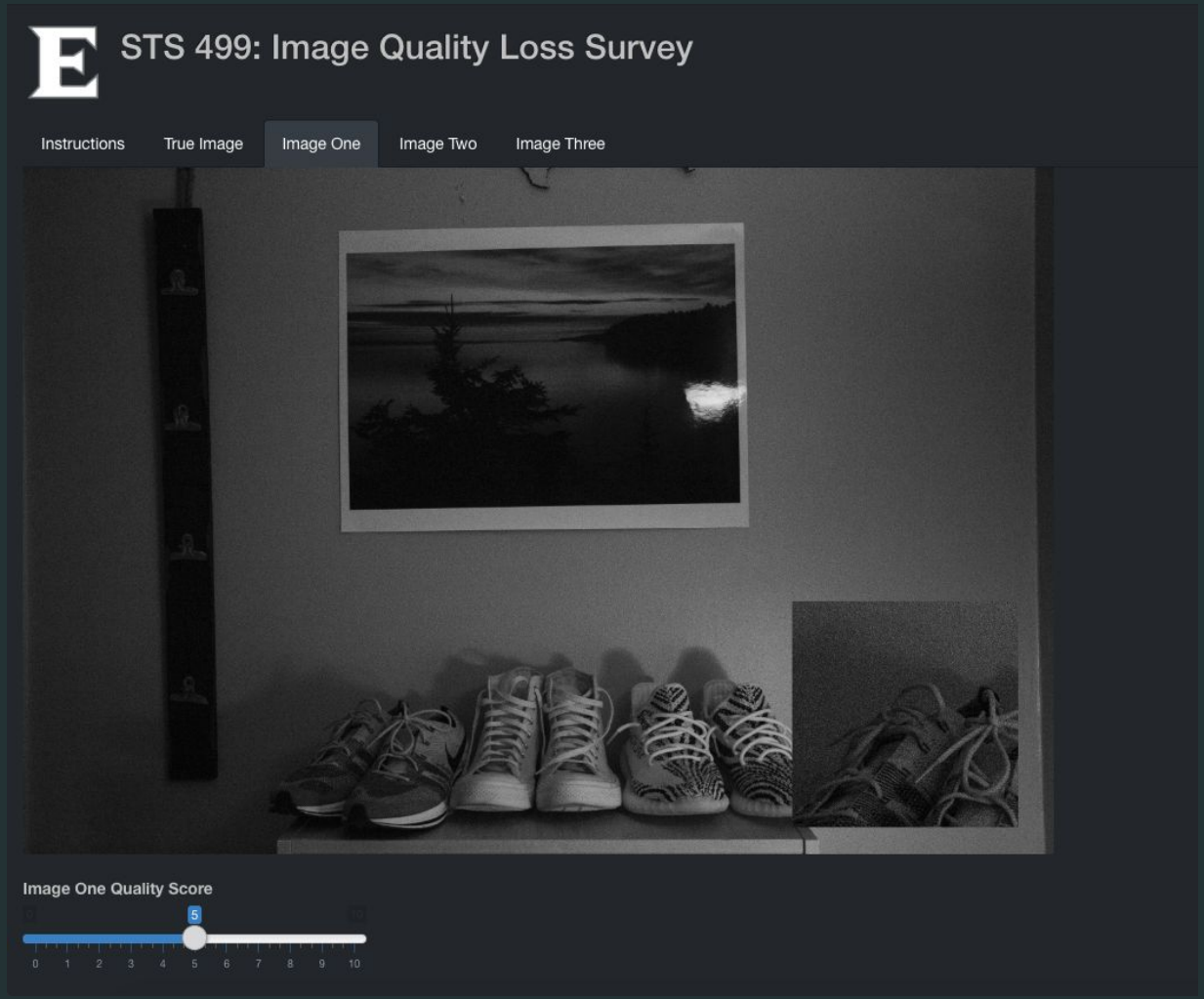
	1	2	3	4	5	6
	Mean	Bilateral	Nonlocal	MRF	Adobe 50%	Adobe 100%
PSNR	46.8833	47.8103	46.9004	TBD	46.3890	47.5747
MSE	294.3851	264.8607	293.8056	TBD	311.6243	271.8604
R-squared	0.6732	0.7217	0.6913	TBD	0.6732	0.7143

Survey on Elon Students

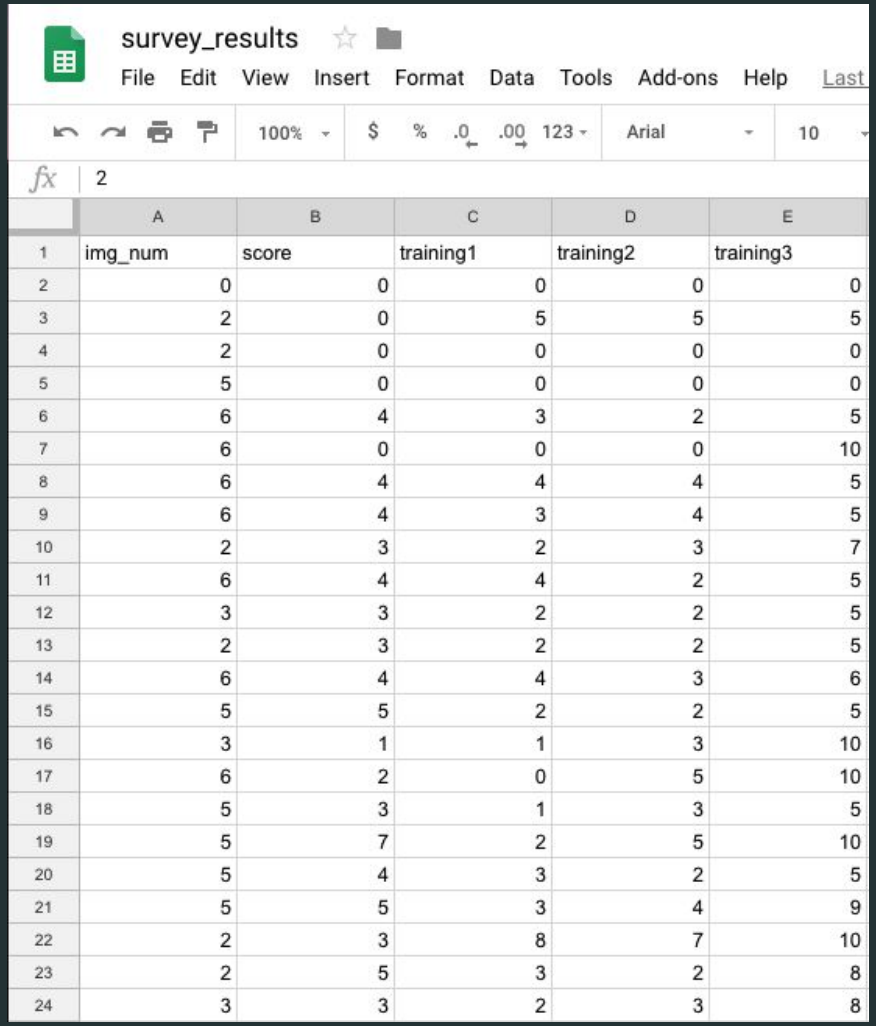
STS 499: Image Quality Loss Survey

Thank you for taking the time to participate in our research study. In this study, you will be asked to view several versions of the same image and report a score on a scale of 1 to 10 for how well the image represents an unaltered version. We expect this survey will take approximately 3 minutes or less to complete. The only data we will collect are your four numerical scores of the images. Your course instructor has agreed to share this link with you, but they will not know if you agree to participate in this study. Your participation is completely voluntary, and you may choose to close the browser without submitting your answers at any time. There are no incentives for participation. If you have any questions about this study, please feel free to contact Dr. Laura Taylor (ltaylor18@elon.edu) or Aidan Draper (adraper2@elon.edu). Please click "Acknowledge" to indicate you have read this statement and agree to participate in the study.

Acknowledge


STS 499: Image Quality Loss Survey
Instructions
True Image
Image One
Image Two
Image Three
Image One Quality Score
5
0 1 2 3 4 5 6 7 8 9 10


STS 499: Image Quality Loss Survey
Instructions
True Image
Filtered Image
Scroll down to give the image a score.
STOP
Image Quality Score
5
0 1 2 3 4 5 6 7 8 9 10
Submit Part 2



survey_results

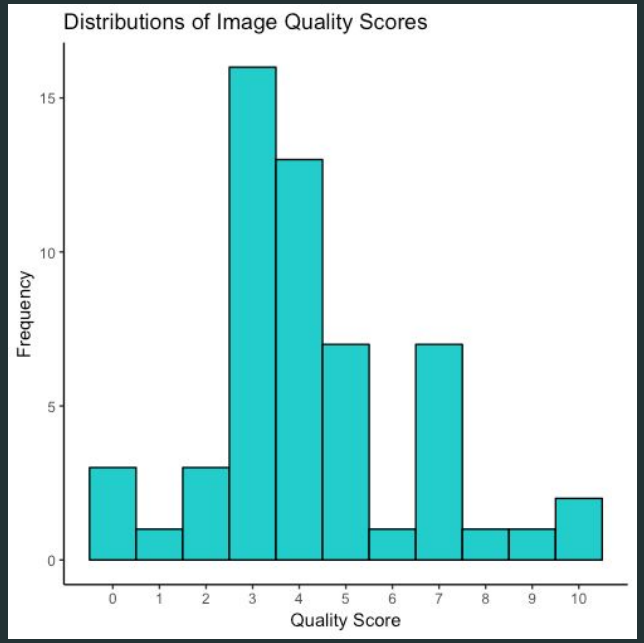
File Edit View Insert Format Data Tools Add-ons Help Last

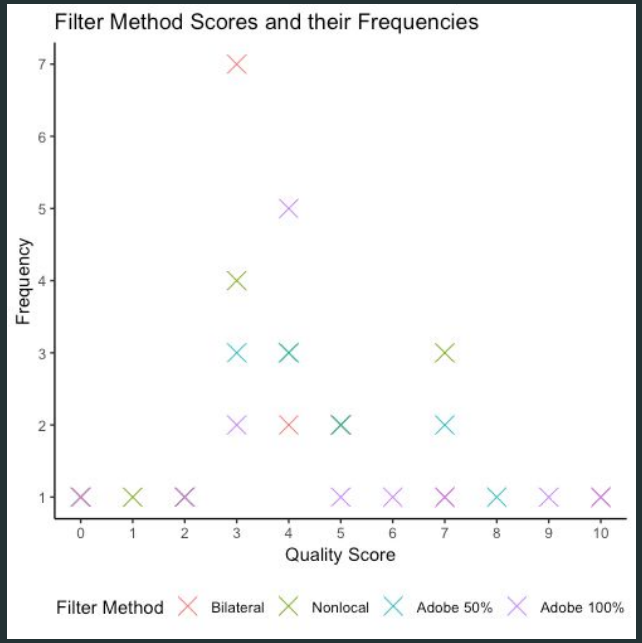
100% $ % .0 .00 123 Arial 10

fx 2

	A	B	C	D	E
1	img_num	score	training1	training2	training3
2	0	0	0	0	0
3	2	0	5	5	5
4	2	0	0	0	0
5	5	0	0	0	0
6	6	4	3	2	5
7	6	0	0	0	10
8	6	4	4	4	5
9	6	4	3	4	5
10	2	3	2	3	7
11	6	4	4	2	5
12	3	3	2	2	5
13	2	3	2	2	5
14	6	4	4	3	6
15	5	5	2	2	5
16	3	1	1	3	10
17	6	2	0	5	10
18	5	3	1	3	5
19	5	7	2	5	10
20	5	4	3	2	5
21	5	5	3	4	9
22	2	3	8	7	10
23	2	5	3	2	8
24	3	3	2	3	8

Descriptive Analysis





55 Total Responses:

$n_{bilateral} = 15$

$n_{nonlocal} = 15$

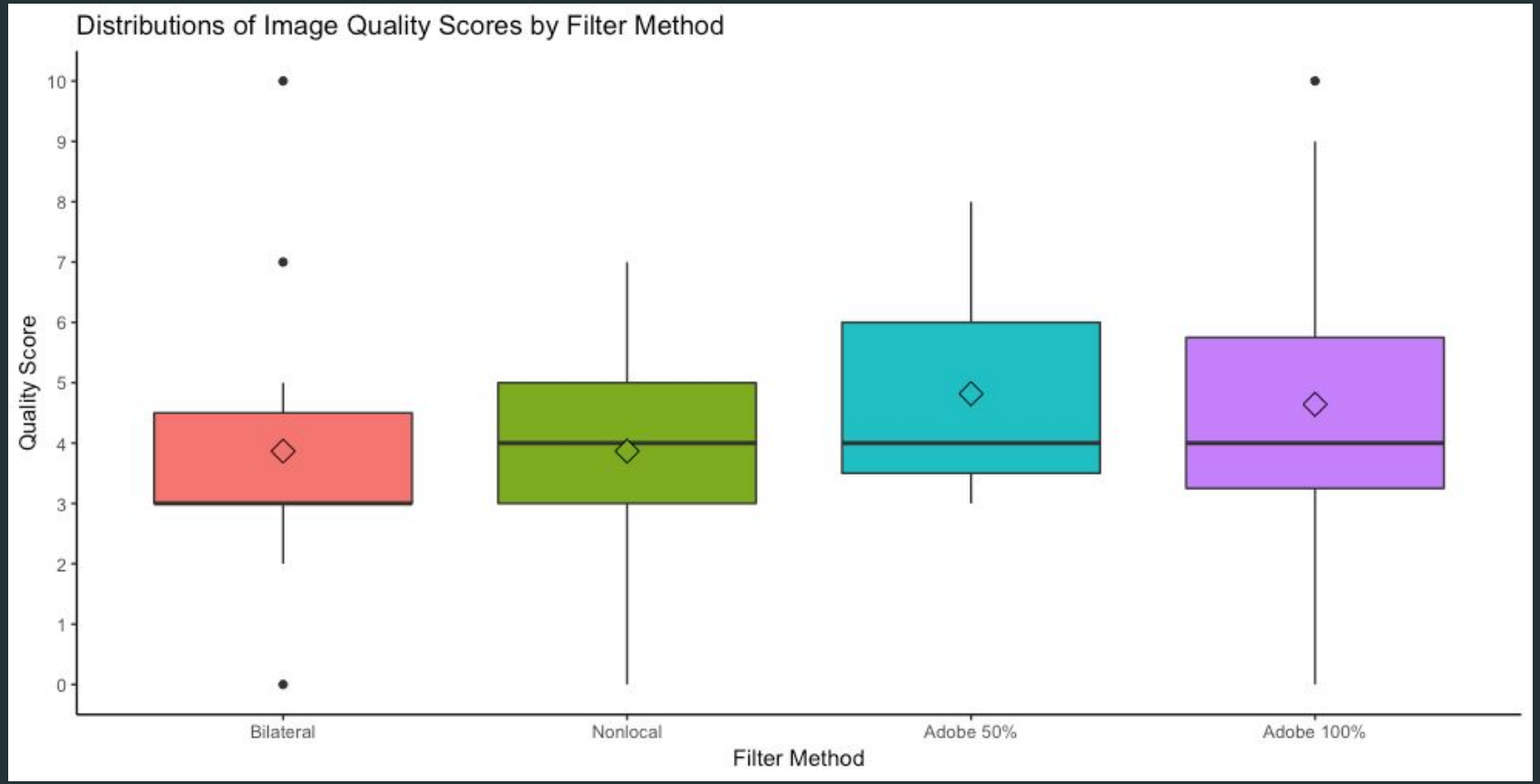
$n_{Adobe\ 50\%} = 11$

$n_{Abobe\ 100\%} = 14$

Mean = 4.255

Median = 4

Note that our training image 3 had a mean of 7.722.


Distributions of Image Quality Scores by Filter Method
Quality Score
10
9
8
7
6
5
4
3
2
1
0
Bilateral
Nonlocal
Adobe 50%
Adobe 100%
Filter Method

Preliminary One-way ANOVA

	Sum of Squares	Degrees of Freedom	Mean Square	F-score	p-value
Treatment	46.8833	3	3.373	0.666	0.577
Error	294.3851	51	5.065		
Total	341.2684	54			

Note: We have only collected 45% of our desired responses.

3. Conclusions

Results

- Failed to reject H_0 in ANOVA testing
- More error is attributed to residuals than the treatment
    - Likely due to poor quality of data (some respondents likely misinterpreted our scale)

Sum of Squares	Mean Square
46.8833	3.373
294.3851	5.065
341.2684	

- Some indication that benchmark scores may not relate to users opinions about image quality, but further survey participants, and possibly a more clear scale, are needed to properly perform the ANOVA

Limitations

- Only 6 methods were analyzed with rather similar benchmark scores
- Collected just 45% of our total sample and for only 4 of our 6 methods
- Violated assumptions of ANOVA using unequal factor level sizes
- Poor responses from some respondents (image 3 mean)
- One single image used, which contains camera shake

Future Work

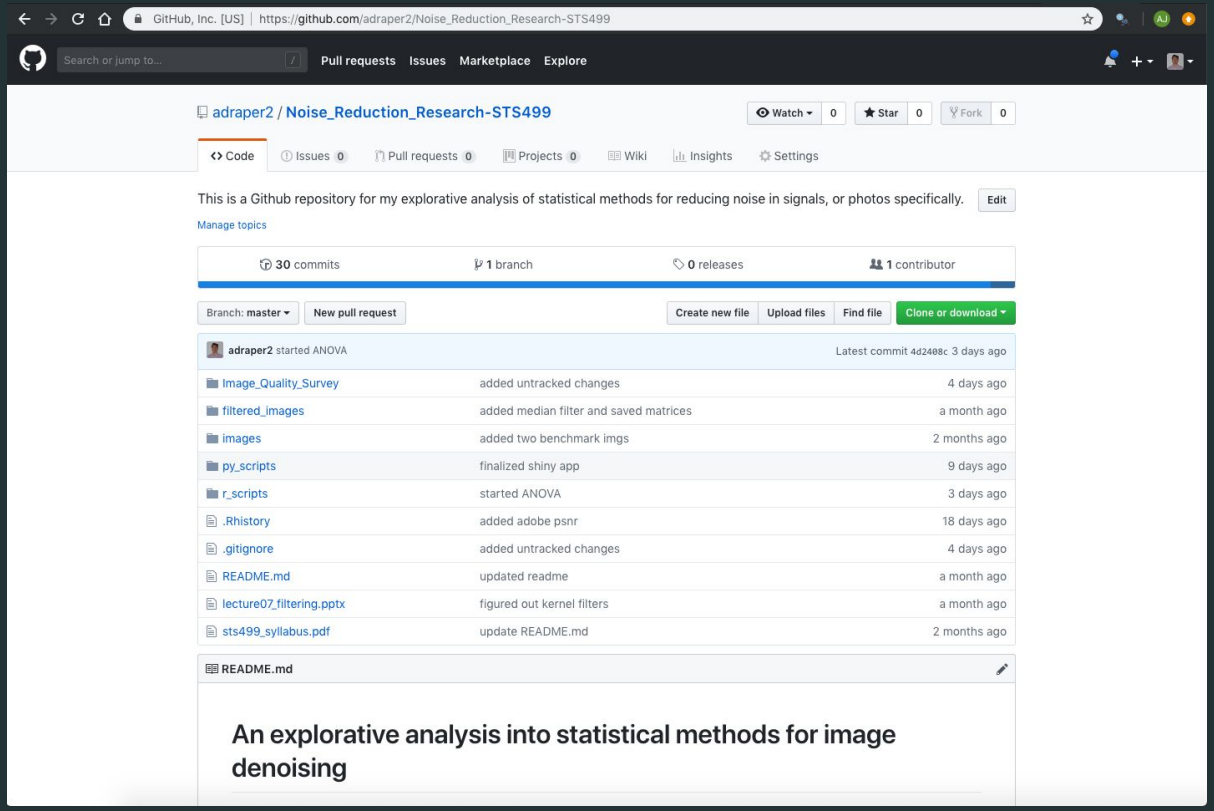
For us currently:

- Markov Random Field Filter
- Add benchmark scores - running time and structural similarity
- Finish collecting survey and rerun ANOVA
- Writeup our results and submit them to the conference proceedings

For the project:

- Include additional filters
- Rerun the experiment with multiple images as a SPRM[1;1]
- Collect more respondents from a larger population
- Calculate correlations between benchmark scores and visual scores

https://github.com/adraper2/Noise_Reduction_Research-STS499



Follow us on Github to stay updated!

Thank you for your time and attention!