Remote and interactive image processing programming laboratories with Jupyter

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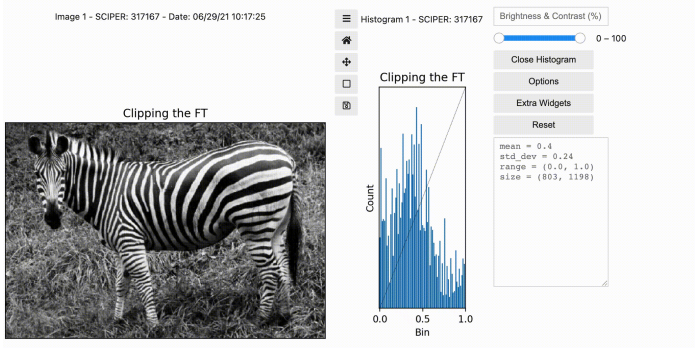


IEEE Finland Joint Chapter of the Signal Processing and Circuits and Systems Societies

Webinar - June 30, 2021

1

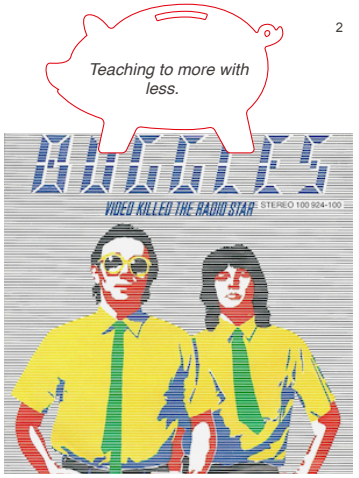
A visual summary

2

2000

2020

- Java, ImageJ → jupyter, JS
- 



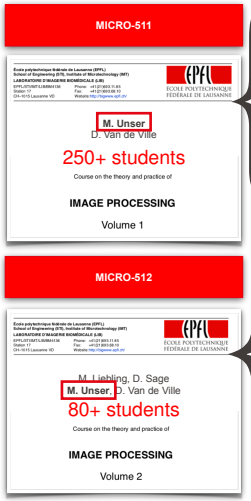
Video killed the radio star, by The Buggles (1979)

Image: Owned by studio, fair use to represent work.

2

Image Processing @ EPFL - Biomedical Imaging Group (BIG)

3



1. Continuous images and the Fourier transform
2. Image sampling, acquisition, quantization
3. Discrete images and filtering
4. Point-wise, filtering, and morphological operations
5. Segmentation, edges, and detection
6. Directional image processing
7. Continuous vs discrete: interpolation and splines
8. Image transforms, wavelets, denoising, and coding
9. Image deconvolution
10. Tomography: reconstructing from projections
11. Statistical pattern classification and neural networks
12. Image analysis: shapes and textures

Study programmes:

A. Life sciences eng.

B. Micro-eng.

C. Electrical eng.

D. Computer eng.

E. and more.

3

Image Processing Programming Laboratories (2000s)

4

Pedagogical goals

- Student engagement
  - Theory ↦ practice. Abstract formulas to concrete code
  - Application of IP algorithms to real images
  - Interactive visual feedback
  - Provide a setup for students to implement their own pipelines
- Adaptation to diverse backgrounds
  - Programming *by example*: minimal prerequisites
- Learning outcomes: *The student should be able to*
  - Implement important IP algorithms down to the pixel level
  - Implement important IP pipelines end to end
- Democratization of education: levelling the field
  - Based on open-source technology (no need for software licenses for revision / reuse)

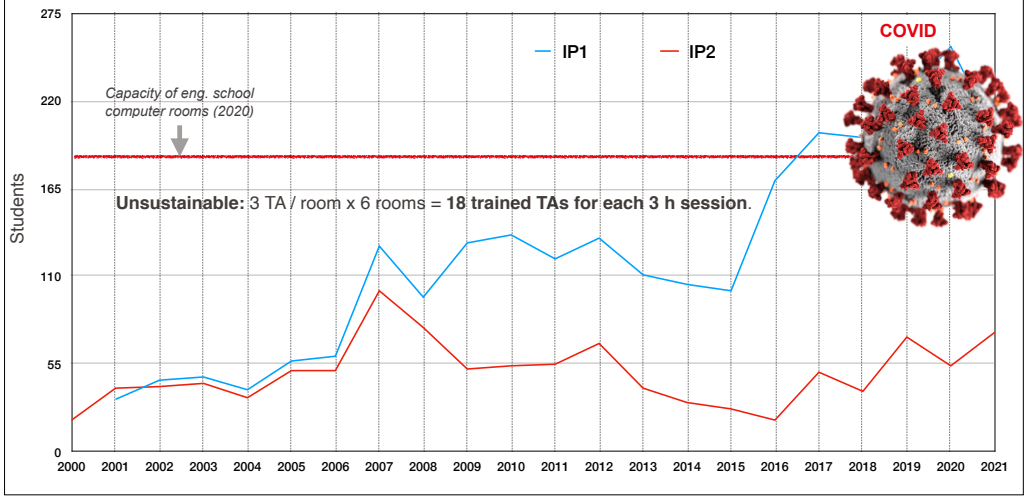
"The best way to understand an algorithm is obviously to code it and to test it"

Teaching Image-Processing Programming in Java
D. Sage, M. Unser
IEEE Signal Processing Magazine, 2003

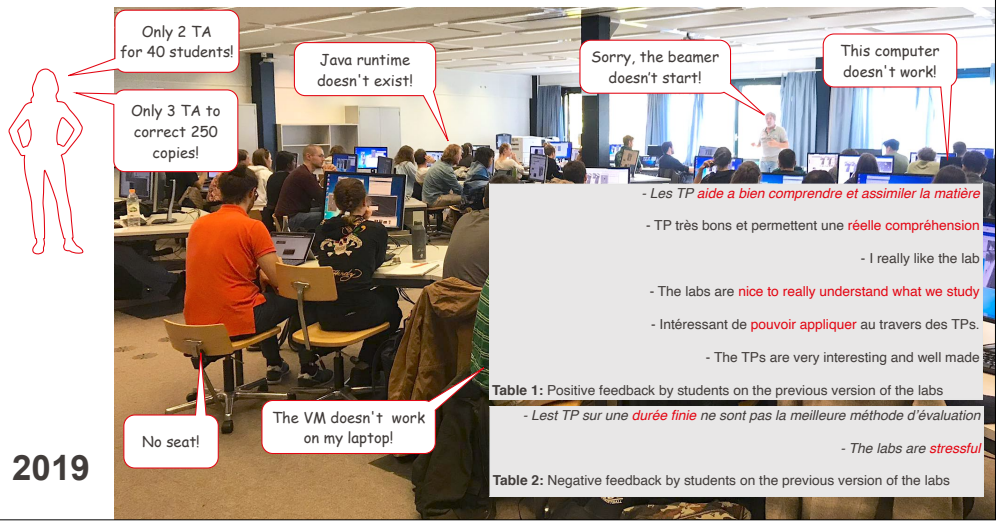
Dr. Daniel Sage, Scientist and Head of Software Development at BIG

4

Need for scalable solutions - Hard limits



Need for scalable solutions - Resource allocation



- *Les TP aide a bien comprendre et assimiler la matière*
- TP très bons et permettent une réelle compréhension
- I really like the lab
- The labs are nice to really understand what we study
- Intéressant de pouvoir appliquer au travers des TPs.
- The TPs are very interesting and well made

Table 1: Positive feedback by students on the previous version of the labs

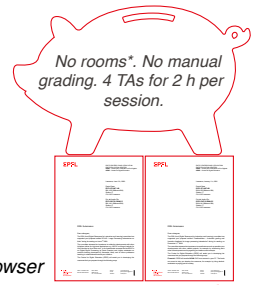
- *Lest TP sur une durée finie ne sont pas la meilleure méthode d'évaluation*
- *The labs are stressful*

Table 2: Negative feedback by students on the previous version of the labs

Remote Image Processing Programming Laboratories (2020s)

Pedagogical goals

- Student engagement
  - Theory ↦ practice. Abstract formulas to concrete code
  - Application of IP algorithms to real images
  - Interactive visual feedback
  - Provide a setup for students to implement their own pipelines
  - Work from home
  - Virtually no time limits
- Adaptation to diverse backgrounds
  - Programming *by example*: minimal prerequisites
  - No installation hurdles - *just a browser*
- Learning outcomes: *The student should be able to*
  - Implement important IP algorithms down to the pixel level
  - Implement important IP pipelines end to end
  - Use industry-relevant technologies for IP programming
- Democratization of education: levelling the field
  - Based on open-source technology (no need for software licenses for revision / reuse)
  - Need of only the most basic hardware to reuse the content

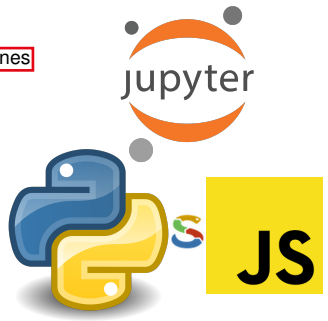


EPFL DRIL Fund (CHF 44k)

- IP1, Lab 0: Introductory
- IP1, Lab 1: Pixel-wise operations and the Fourier transform
- IP1, Lab 2: Digital filtering
- IP1, Lab 3: Morphological operators
- IP2, Lab 4: Directional image analysis
- IP2, Lab 5: Geometric transformations and spline interpolation
- IP2, Lab 6: Wavelet transform
- IP2, Lab 7: Deep learning and backpropagation

Polyglot Notebooks for Image Processing Programs

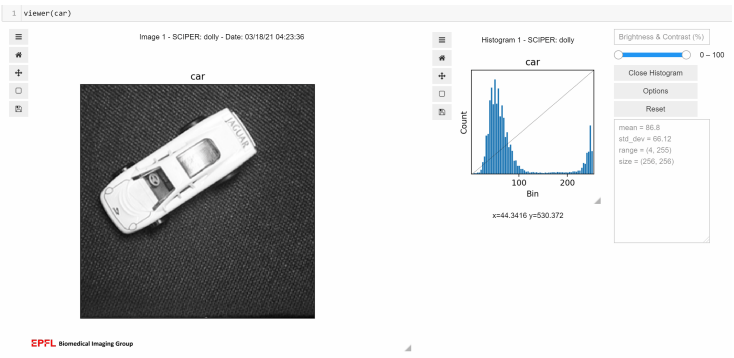
- Learning outcomes: *The student should be able to*
  - Implement important IP algorithms down to the pixel level
  - Implement important IP pipelines end to end
  - Use industry-relevant technologies for IP programming
- Student engagement
  - Provide a setup for students to implement their own pipelines



An Interactive Viewer for Image Processing Programming Labs

- Simplify image visualization for students
- Offer a broad range of native capabilities

replacing ImageJ



Alejandro Nogueron Aramburu
Master Student at EPFL
Core developer

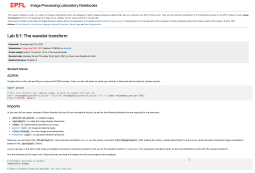
jupyter

ipywidgets: Interactive HTML Widgets github.com/jupyter-widgets

matplotlib

An Interactive Viewer for Image Processing Programming Labs

- Reduce the length of the lab notebooks



replacing ImageJ

- Reduce time spent on code that is not strictly related to the content

```
1  # IPLabViewer
2  viewer(boats, hist = True, axis = True)     1 line, simple and clear
3
4  # MatPlotlib
5  hist, bins = np.histogram(boats, bins = 70, range = (boats.min(), boats.max()))
6  fig, axs = plt.subplots(1, 2)
7  im = axs[0].imshow(boats)                   7 lines, complex object-oriented representation
8  im.set_cmap('gray')
9  axs[0].axes.yaxis.set_visible(True)
10 axs[0].axes.xaxis.set_visible(True)
11 axs[1].bar(bins[:-1], hist, width = (bins[1] - bins[0]) / 1.5)
```

Alejandro Nogueron Aramburu
Master Student at EPFL
Core developer

jupyter

ipywidgets: Interactive HTML Widgets github.com/jupyter-widgets

matplotlib

An Interactive Viewer for Image Processing Programming Labs

- Maximize the didactic capabilities of the labs

replacing ImageJ

Context: IP2, Lab 6: Wavelet transform *Learning wavelet denoising*

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ipywidgets: Interactive HTML Widgets github.com/jupyter-widgets

matplotlib

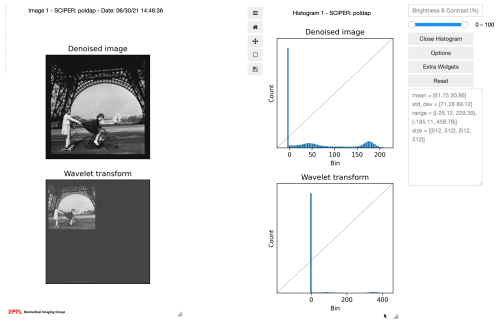
An Interactive Viewer for Image Processing Programming Labs

- Maximize the didactic capabilities of the labs

replacing ImageJ

Context: IP2, Lab 6: Wavelet transform *Learning wavelet denoising*

```
soft_thr_viewer = viewer([doisneau_noise, doisneau_noise], title=['Denoised image','Wavelet transform'], new_widgets=new_widgets,
                         callbacks=[callback_wt, callback_iwt], hist = True, subplots = [2, 1])
```



Alejandro Nogueron Aramburu
Master Student at EPFL
Core developer

jupyter

ipywidgets: Interactive HTML Widgets github.com/jupyter-widgets

matplotlib

Soon to be found in PyPI python Package Index *as part of* `interactive-kit`.

A toolkit for interactive visualization of signal and image processing on Jupyter Notebooks.

- Provides with dedicated error handling (very much lacking in JavaScript)

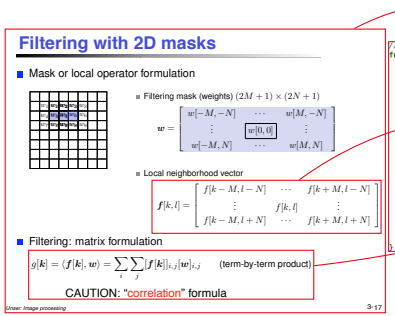
```
In [2]:  1 var a = [1, 2, 3, 4, 5]
         2 var b = a[1.5];
         3 typeof(b)

Out[2]: 'undefined'

In [3]:  1 var a = new Image(1, 5);
         2 var b = a.getPixel(1.5, 0);
         3 typeof(b)

Error: Non-integer index provided in getPixel
    at IPLabImageAccess.getPixel (C:\Users\kay-1\OneDrive\EPFL\Image Processing Lab\IPLabI
0)
```

Kay Lächler
Master Student at EPFL
Core developer

JS

- Is designed to work with neighbourhoods (simplified implementation of IP workflows)
- Handles boundary conditions
- Easy access to pixels, columns, rows, and neighbourhoods

- `getPixel(x, y)`
- `setPixel(x, y)`
- `getNbh(x, y, w, h, padding='mirror')`
- `getRow(y)`
- `putRow(y, newRow)`
- `getColumn(x)`
- `putColumn(x, newColumn)`



Kay Lächler
Master Student at EPFL
Core developer

JS

Context: IP1, Lab 2: Digital filtering

Learning the most common techniques and possible bugs when implementing digital filters in image processing


```
function erode_raw(img, b){
    // initialize the output array with the first dimension
    var output = new Array(img.length);
    // for every element of the first dimension, add the second dimension
    for(var i=0; i < output.length; i++){
        // create the second dimension
        output[i] = new Array(img[i].length);
        for(var j=0; j < output[i].length; j++){
            // initialize output value to 0
            output[i][j] = 0;
        }
    }
    // Loop through every pixel of the image
    for(var y = 0; y < img.length; y++){
        for(var x = 0; x < img[y].length; x++){
            var valmin = Number.MAX_VALUE;
            // Loop through every pixel of the neighbourhood
            for(var k = 0; k < b.length; k++){
                for(var l = 0; l < b[k].length; l++){
                    if (b[k][l]){
                        var y_ = y - parseInt(b.length/2) + k;
                        var x_ = x - parseInt(b[k].length/2) + l;
                        // Apply boundary conditions
                        if(y_ < 0){
                            // apply mirror folding
                            y_ = -y_ - 1;
                        }
                        if(y_ >= img.length){
                            // apply mirror folding
                            y_ = img.length - 1 - (y_ % img.length);
                        }
                        if(x_ < 0){
                            // apply mirror folding
                            x_ = -x_ - 1;
                        }if(x_ >= img[y].length){
                            // apply mirror folding
                            x_ = img[y].length - 1 - (x_ % img[y].length);
                        }
                        // perform erosion (calculate new minimum value)
                        valmin = Math.min(img[y_][x_], valmin);
                    }
                }
            }
            // Set the eroded pixel value in the output image
            output[y][x] = valmin;
        }
    }
    return output;
}
```

Context: IP1, Lab 3: Morphological operators

Learning the most common techniques and possible bugs when implementing morphological operators

```
function erode(img, b){
    var output = new Image(img.shape());
    // Loop through every pixel of the image
    for(var x = 0; x < img.nx; x++){
        for(var y = 0; y < img.ny; y++){
            // extract the neighbourhood around pixel (x,y)
            var nbh = img.getNbh(x, y, b.nx, b.ny);
            var valmin = Number.MAX_VALUE;
            // Loop through every pixel of the neighbourhood
            for(var k = 0; k < nbh.nx; k++){
                for(var l = 0; l < nbh.ny; l++){
                    if (b.getPixel(k, l)){
                        // perform erosion (calculate new minimum value)
                        valmin = Math.min(nbh.getPixel(k, l), valmin);
                    }
                }
            }
            // Set the eroded pixel value in the output image
            output.setPixel(x, y, valmin);
        }
    }
    return output;
}
```

Example: Implementing erosion

Kay Lächler
Master Student at EPFL
Core developer

JS

- Tools for image comparison and display in the JavaScript console

```
1 var img1 = new Image([[1, 2, 3], [4, 5, 6]]);
                ...
1 img2 = new Image([[3, 6, 9], [12, 15, 18]]);
2
3 if(!img1.imageCompare(img2, err)){
4     console.log(err.msg);
5 }

Number of mismatched elements: 6 (100%)
Max error: 12
Normalization error: The image should be normalized by a factor of 3

>> console.log(img.visualize())

[[   0   0   0   0   0 255   0   0   0   0   0 ]
 [   0   0   0   0   0 255   0   0   0   0   0 ]
 [ 255 255 255 255 255 255 255 255 255 255 255 ]
 [   0   0   0   0   0 255   0   0   0   0   0 ]
 [   0   0   0   0   0 255   0   0   0   0   0 ]]
```

Soon to be found in Node.js as `image-access`.

A class for didactic implementation of image processing in JavaScript.

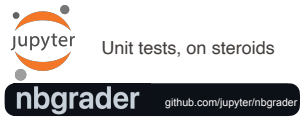
Kay Lächler
Master Student at EPFL
Core developer

JS

EPFL **Automatic Grading and Feedback for Image Processing Programming Labs**

Grading and Summative Feedback

the grading library



Unit tests, on steroids

```
### BEGIN HIDDEN TESTS
### END HIDDEN TESTS
### BEGIN SOLUTIONS
### END SOLUTIONS
```

Context: IP2, Lab 7: Deep learning and backpropagation

Learning to backpropagate without AutoGrad

```
msg_wrong = 'Your value for $\partial L/\partial b$ is incorrect.\
    The right solution is $ \\frac{\\partial L}{\\partial b} = \\frac{\\partial}{\\partial b}\\left\\lbrace (y-b)^2 \\right\\rbrace = 2 (b-y) $, \
    which, evaluated at <code>y = 20</code>, <code>b = 2 + (-4)(-2) = 10</code>, results in <code>dLdb = np.array([-20.])</code>.'
_, _, _ = grading.check_array_almost_equal(np.array(dLdb), np.array(answers.dLdb_TA), msg_wrong=msg_wrong,
                                msg_correct='Well done! The value for $\\partial L / \\partial b$ is correct.',
                                points_lost='You did not get points for your answer.', raise_exception = True)
```

Your value for $\partial L/\partial b$ is incorrect. The right solution is $\frac{\partial L}{\partial b} = \frac{\partial}{\partial b}\left\{(y-b)^2\right\} = 2(b-y)$, which, evaluated at `y = 20`, `b = 2 + (-4)(-2) = 10`, results in `dLdb = np.array([-20.])`. You did not get points for your answer.

Well done! The value for $\partial L/\partial b$ is correct.

EPFL **Automatic Grading and Feedback for Image Processing Programming Labs**

Grading and Summative Feedback

*the grading library - **advanced usage***


```
### BEGIN HIDDEN TESTS
### END HIDDEN TESTS
### BEGIN SOLUTIONS
### END SOLUTIONS
```

Context: IP2, Lab 6: Wavelet transform

Learning to implement a wavelet transform and to use the most popular libraries in Python.

A challenge for grading!

```
# Check that the students do not use PyWavelets
# First, declare a list with the students function and the necessary parameters
student_function = [analysis, lowlight, answers.analysis_hp, answers.analysis_lp, 1]
# Call our grading function IP_grading
check_error, times, _ = ip_grading.function_used(student_function, '__main__.pywt.dwt2', pywt.dwt2)
if check_error:
    msg = f'You should not have used PyWavelets for this exercise. You used it {times} times.'
    ip_grading.display_html([msg, loss_msg], 'danger', raise_exception = True)
```

You should not have used PyWavelets for this exercise. You used it 2 times. You lost 1 point because of this.

EPFL **Automatic Grading and Feedback for Image Processing Programming Labs**

The holy grail: *Formative* feedback

Context: IP2, Lab 5: Geometric transformations and spline interpolation

Learning the importance of prefiltering for spline interpolation

```
%use javascript
// Define test image and expected output
var impulse = new Image([[0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0]]);
var solution = new Image ([[-0.006, 0.012, -0.042, 0.158, -0.588, 2.196, -0.588, 0.158, -0.042, 0.012, -0.006]]);
// Get the coefficients
var test = cubicSplineCoefficients(impulse);
console.log('Input sequence:\n' + impulse.visualize())
console.log('Your cubic spline coefficients:\n' + test.visualize())
// Compare the output to the solution
if(test.imageCompare(solution, tol=1e-3) == false){
        throw new Error("The recursive exponential filter is not working properly, the expected cubic spline coefficients are:\n" +
                        solution.visualize());
}
console.log('Congratulations! Your implementation passed the sanity check.' +
            ' However, this is not a guarantee that it works well for any input! Revise your code! ')
```

```
Input sequence:
[[ 0 0 0 0 0 1 0 0 0 0 0 ]]

Your cubic spline coefficients:
[[ -0.006  0.012 -0.042  0.158 -0.588  2.196 -0.588  0.158 -0.042  0.012 -0.006 ]]

Congratulations! Your implementation passed the sanity check. However, this is not a guarantee that it works well for any input! Revise your code!
```


EPFL **Automatic Grading and Feedback for Image Processing Programming Labs**

The holy grail: **Visual** *Formative* feedback

Context: IP2, Lab 6: Wavelet transform

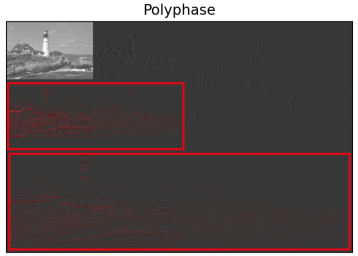
Learning the polyphase implementation of the Haar wavelet transform.

```
# Test polyphase implementation
error_haar = False
try:
    np.testing.assert_array_almost_equal(lighthouse_pywt, lighthouse_poly, decimal = 10)
except Exception as e:
    print('Your polyphase implementation is not correct. Look at the following message for details.\n')
    print(e)
    error_haar = True
    plt.close('all')
    viewer([lighthouse_poly,lighthouse_pywt],
           title = ["Polyphase", "PyWavelets (Ground truth)"], compare = True, widgets = True)
```

```
Your polyphase implementation is not correct. Look at the following message for details.

Arrays are not almost equal to 10 decimals

Mismatched elements: 231417 / 393216 (58.9%)
Max absolute difference: 684.
Max relative difference: 8.54247233
 x: array([[ 4.9900e+02,  5.0050e+02,  4.9500e+02, ...,  2.5000e+00,
         2.0000e+00, -2.5000e+00],
       [ 5.0750e+02,  5.0725e+02,  5.0875e+02, ...,  3.5000e+00,...
 y: array([[ 4.9900e+02,  5.0050e+02,  4.9500e+02, ...,  2.5000e+00,
         2.0000e+00, -2.5000e+00],
       [ 5.0750e+02,  5.0725e+02,  5.0875e+02, ...,  3.5000e+00,...
```

Image 1 - SCIPER: 317167 - Date: 06/29/21 22:03:58

Polyphase



Brightness & Contrast (%)

0 – 100

Show Histogram

Options

Reset

Prev Next

```
mean = 28.58
std_dev = 118.8
range = (-300.25, 1002.25)
size = (512, 768)
```

EPFL Biomedical Imaging Group

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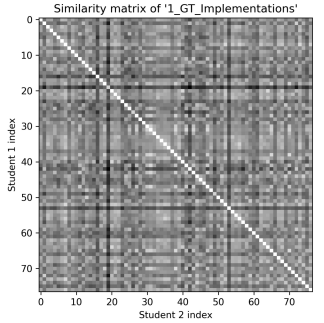
Plagiarism Detection for Image Processing Programming Labs

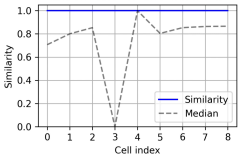
. . . a work in progress

```
plt.close('all')
PV = Plagiarism_visualization(lab_name = 'Geometric_Transformation_Lab', notebook_name = '1_GT_Implementations')
```

executed in 126ms, finished 09:59:23 2021-06-30

Figure 1





Student 1: 321084
Student 2: 321084
Similarity: 100.00 %

Compare

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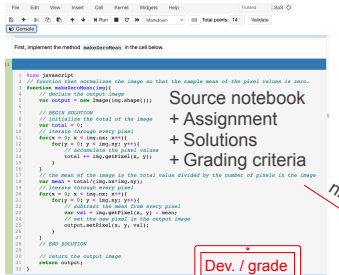
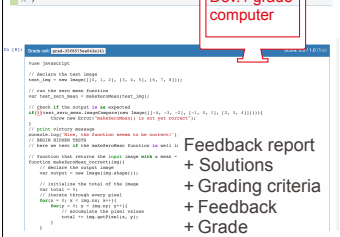
Infrastructure for the Image Processing Programming Labs



Source notebook
+ Assignment
+ Solutions
+ Grading criteria

Dev. / grade computer



Feedback report
+ Solutions
+ Grading criteria
+ Feedback
+ Grade

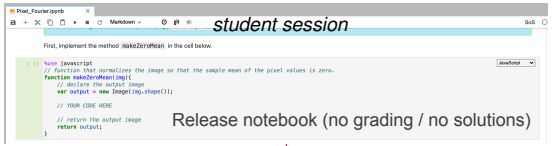
nbgitpuller

custom-made scripts

The model we've mostly used

NOTO EPFL JupyterLab servers

student session



Release notebook (no grading / no solutions)

students, manually

EPFL MOODLE

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Infrastructure for the Image Processing Programming Labs

NOTO EPFL JupyterLab servers

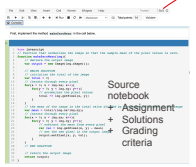
The model we're using now

nbgitpuller

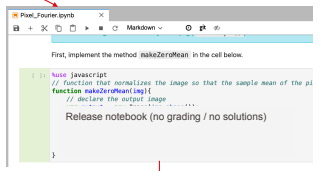
instructor session

student session

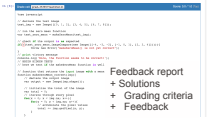
Development and grading



Source notebook
+ Assignment
+ Solutions
+ Grading criteria



Release notebook (no grading / no solutions)



Feedback report
+ Solutions
+ Grading criteria
+ Feedback

students, manually

custom-made scripts

EPFL MOODLE

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Student feedback for the Image Processing Programming Labs

- The labs are amazing! It is the first time in my EPFL life that I enjoy doing these kind of exercises.

- (The labs) are by far the best I have encountered.

- Super labos, j'adore le format et l'interactivité

Table 3: Examples of feedback from the **Course evaluation for MICRO-511 (Image Processing I)** by anonymous students, November 2020

- it could be nice to allow submitting a little after the deadline, even for no points, ***to still get feedback***

- The labs are amazing and really helpful to understand and visualize the main concepts. Thank you for that !

Table 4: Examples of feedback from the **Course evaluation for MICRO-512 (Image Processing II)** by anonymous students, May 2020

Student feedback for the Image Processing Programming Labs

(General impression) My general impression of the Lab was Not selected (-2)Very bad (-1)Bad (0)Neutral (1)Good (2)Very good Edit

(Learning) How much do you feel you have learned completing this lab? Not selected (-2)Nothing (-1)Not much (0)A fair amount (1)Quite a bit (2)A lot Edit

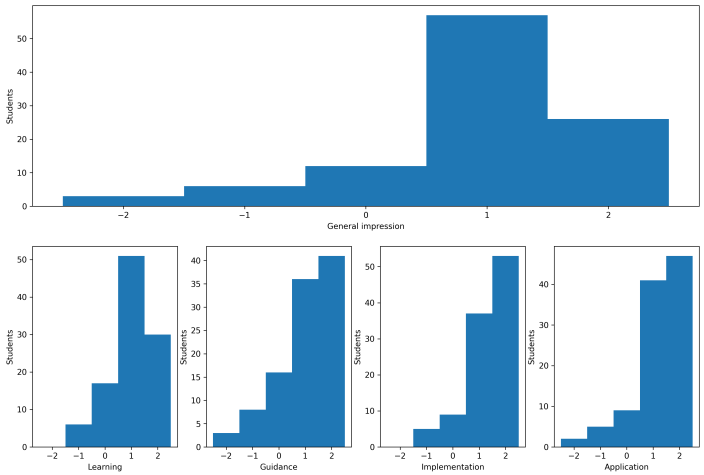
(Guidance) The level of guidance and documentation in the Lab was optimal for learning Not selected (-2)Strongly disagree (-1)Disagree (0)Neutral (1)Agree (2)Strongly agree Edit

(?????? implementation) The lab has helped me to understand how to implement the ?????? in image processing Not selected (-2)Strongly disagree (-1)Disagree (0)Neutral (1)Agree (2)Strongly agree Edit

(?????? application) The lab has helped me to understand how to use ?????? in image processing Not selected (-2)Strongly disagree (-1)Disagree (0)Neutral (1)Agree (2)Strongly agree Edit

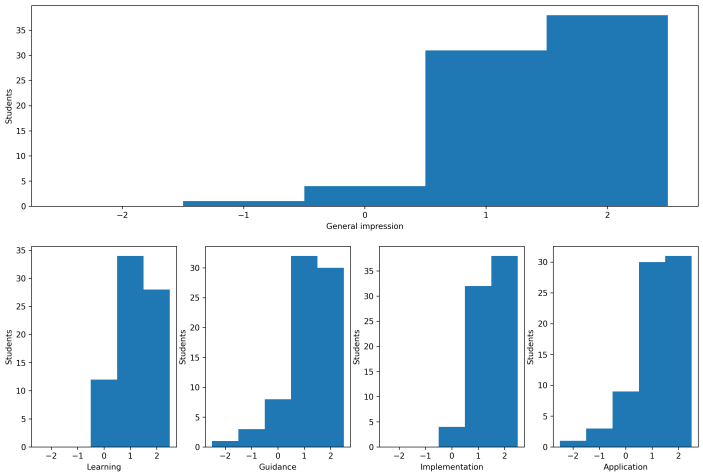
Student feedback for the Image Processing Programming Labs

Student feedback: IP1, Lab 2: Digital filtering - 104 responses



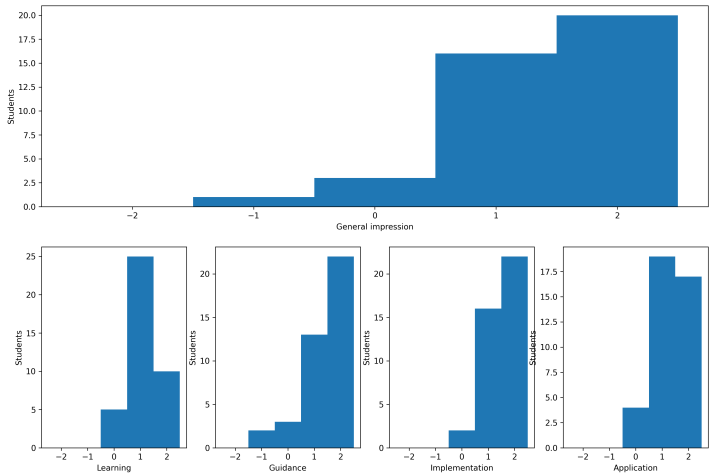
Student feedback for the Image Processing Programming Labs

Student feedback: IP1, Lab 3: Morphological operators - 74 responses



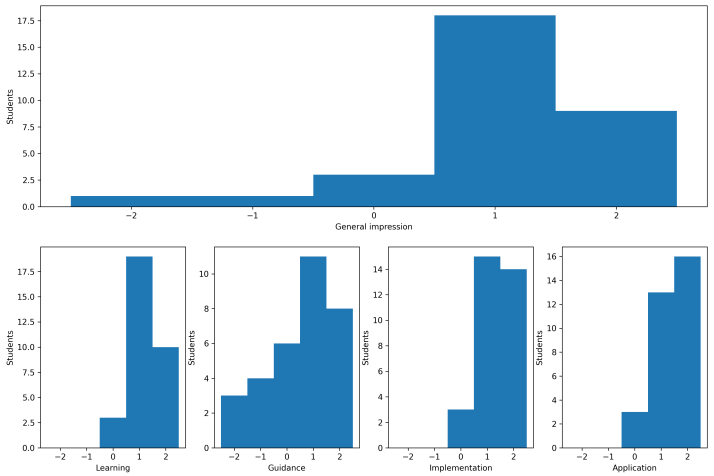
Student feedback for the Image Processing Programming Labs

Student feedback: IP2, Lab 4: Directional image analysis - 40 responses



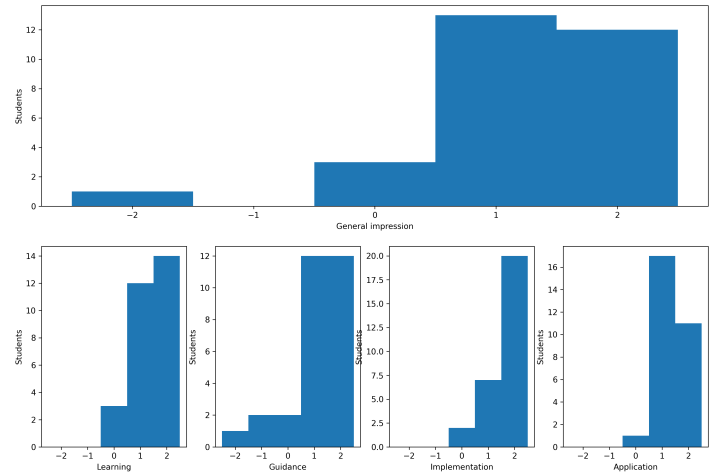
Student feedback for the Image Processing Programming Labs

Student feedback:IP2, Lab 5: Geometric transformations and spline interpolation - 32 responses



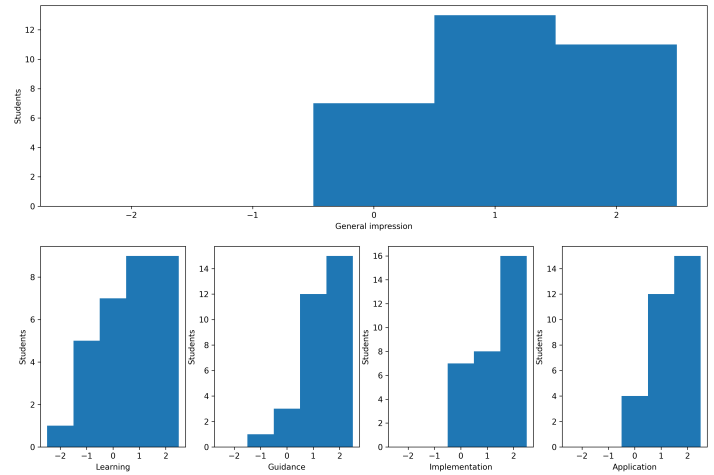
Student feedback for the Image Processing Programming Labs

Student feedback: IP2, Lab 6: Wavelet transform - 29 responses

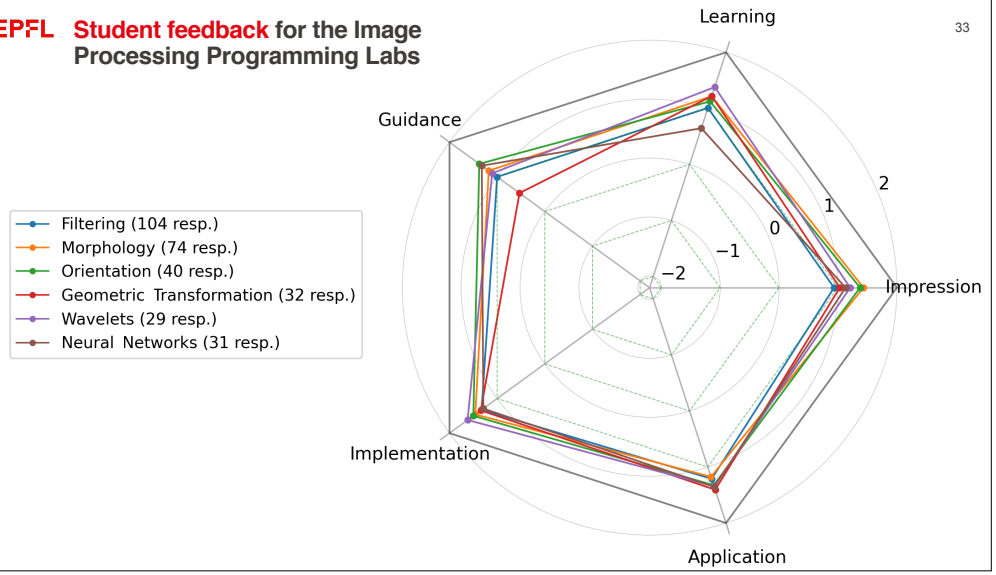


Student feedback for the Image Processing Programming Labs

Student feedback: IP2, Lab 7: Deep learning and backpropagation - 31 responses



Student feedback for the Image Processing Programming Labs



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Thank you!

Our giants to stand upon

ipywidgets: Interactive HTML Widgets github.com/jupyter-widgets

IJavascript github.com/n-riesco/ijavascript

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Post-doc at BIG
Developer for Lab 7

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EPFL DRIL Fund (CHF 44k)

Questions?

- 2000 Java ImageJ → 2020 jupyter JS

Image: EPFL students in a computer room

Image: Rutmer Zijlstra, obtained from Noun Project, CC License

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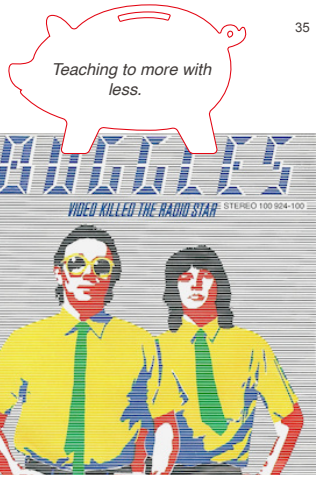

Video killed the radio star, by The Buggles (1979)

Image: Owned by studio, fair use to represent work.