Remote practical labs with personalised automated feedback

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Research staff scientist
CIBM Center for Biomedical Imaging
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Postdoctoral researcher
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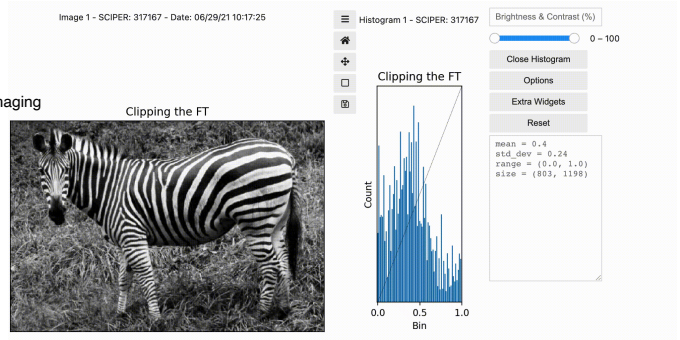

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Dr. Daniel Sage


Alejandro Noguerón Aramburu


Kay Lächler

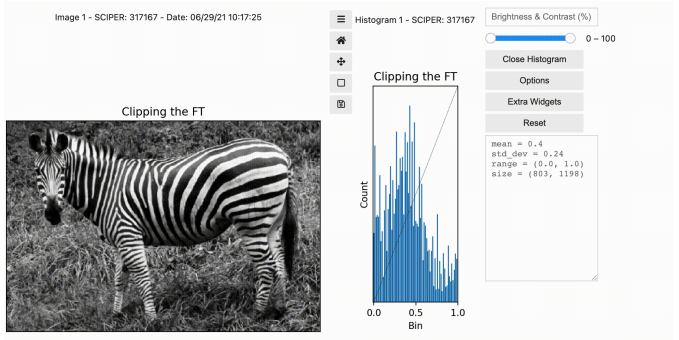
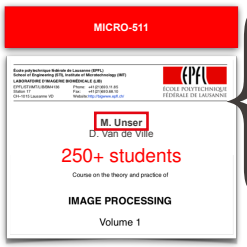
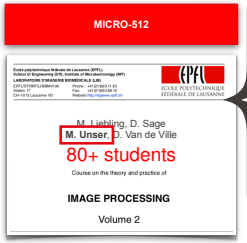


Image Processing @ EPFL - Biomedical Imaging Group (BIG)





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:

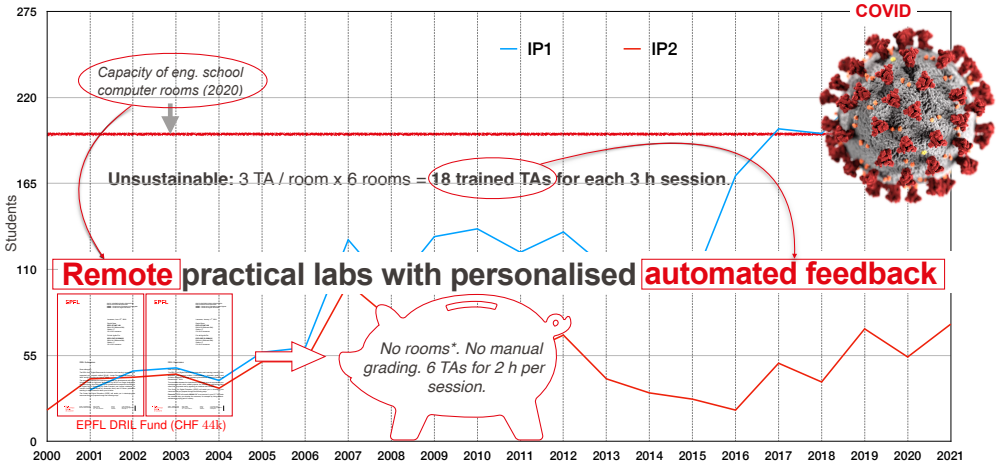
A. Life sciences eng.
B. Micro-eng.
C. Electrical eng.
D. Computer eng.
E. and more.


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

"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

Need for scalable solutions - Resource allocation

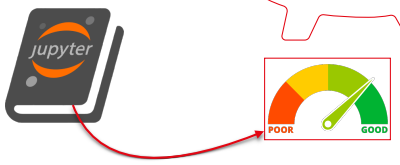


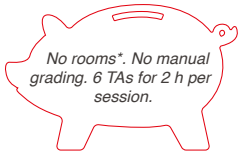
Personalised automated feedback

- *Summative* feedback

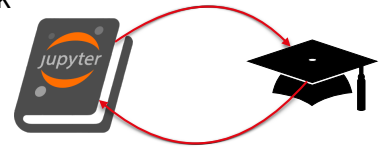
Unit tests, on steroids


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





- The holy grail: *Formative* feedback



- The upcoming grading library

Soon available in PyPI python Package Index as `nbpygrading`.

A collection of grading strategies for Python Jupyter Notebooks.

Automated Formative Feedback for IP Programming Labs

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!
```

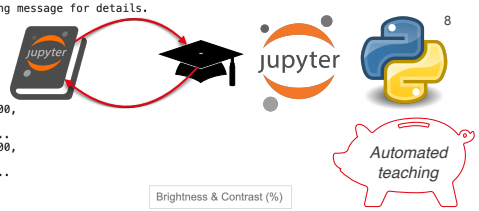
Automated Formative Feedback for IP Programming Labs

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

Context: IP2, Lab 6: Wavelet transform

Learning the polyphase implementation of the Haar wavelet transform.

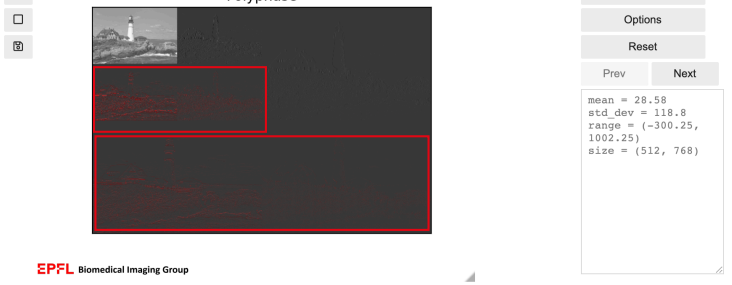
```
# Test polyphase implementation
error_haar = False
try:
    np.testing.assert_array_almost_equal(lighthouse_pywt, lighthouse_poly, decimal = 10)
except Exception as e:
    print('Your polyphase implementation is not correct. Look at the following message for details.\n')
    print(e)
    error_haar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

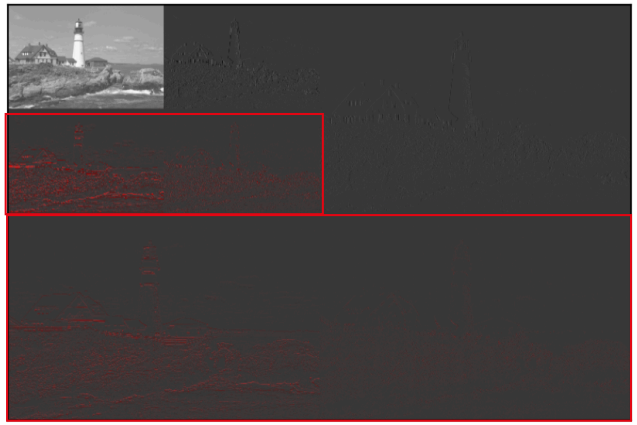

```
Your polyphase implementation is not correct. Look at the following message for details.

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,...
```



Polyphase



Automated Summative Feedback for IP Programming Labs

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.

Soon available in PyPI as `nbpygrading`.

A collection of grading strategies for Python Jupyter Notebooks.

Automated Summative Feedback for IP Programming Labs

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.

Soon available in PyPI as `nbpygrading`.

A collection of grading strategies for Python Jupyter Notebooks.

Image Processing Programming Laboratories

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)

2000

2020

Remote Image Processing Programming Laboratories

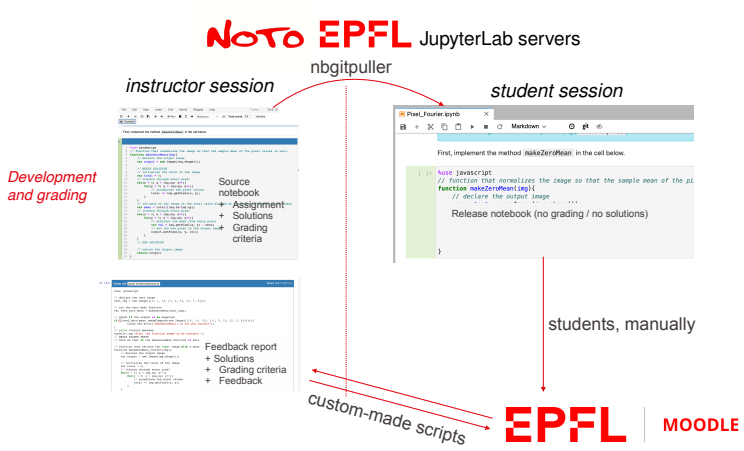
Pedagogical goals

- 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

2000

2020

Infrastructure for the Image Processing Programming Labs



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

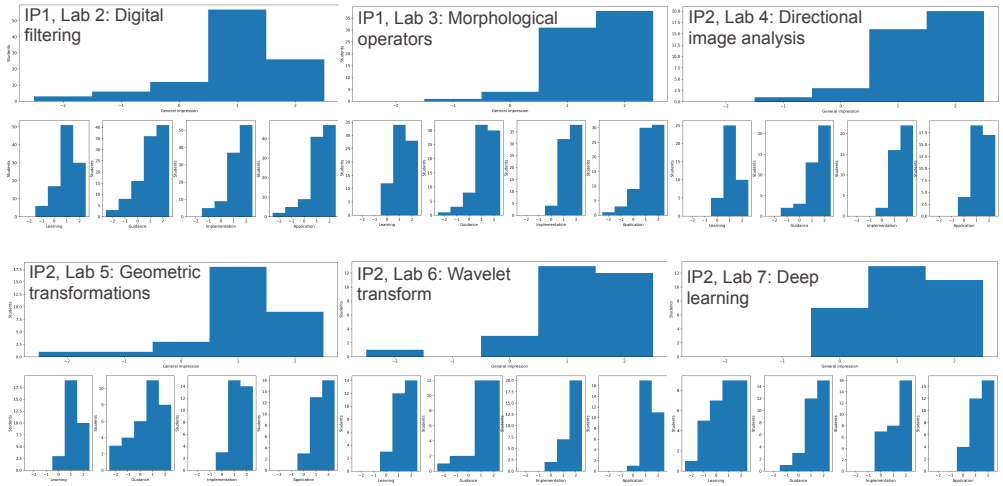
Table 3: Examples of feedback from the **Course evaluation for MICRO-511 (Image Processing I)** by anonymous students, November 2020

- 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



EPFL Want to use our labs in your course? Contact me!
pol.delaguilapla@epfl.ch, @polsocjo, epfl.zoom.us/my/poldap
poldap.github.io, www.linkedin.com/in/poldap

Thank you!

Our giants to stand upon

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

IJavascript github.com/n-riesco/ijavascript

Core team

Kay Lächler
Master Student at EPFL
Core developer

Alejandro Noguerón Aramburu
Master Student at EPFL
Core developer

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

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CEDE, EPFL

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Teaching Advisor
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Dr. Patrick Jermann
Exec. Director
CEDE, EPFL

EPFL Questions?

Want to use our labs and/or software in your course? Contact us!
pol.delaguilapla@epfl.ch, @polsocjo, epfl.zoom.us/my/poldap
poldap.github.io, www.linkedin.com/in/poldap

See more at:

https://go.epfl.ch/AutoPersonalFeedback

https://go.epfl.ch/JupyterEPFL

Available in Node.js as `image-access`. *A class for didactic implementation of image processing in JavaScript.*

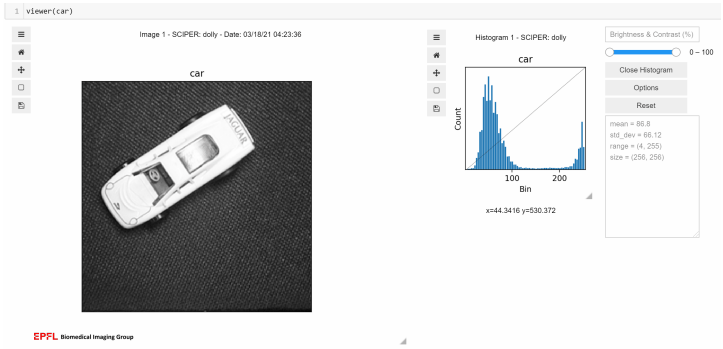
Available in PyPI as part of `interactive-kit`. *A toolkit for interactive visualization of signal and image processing on Jupyter Notebooks.*

Soon available in PyPI as `nbpygrading`. *A collection of grading strategies for Python Jupyter Notebooks.*

EPFL An Interactive Viewer for Image Processing Programming Labs

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

replacing ImageJ



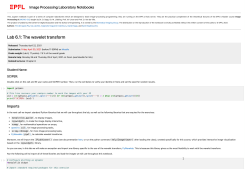
Alejandro Noguerón Aramburu
Master Student at EPFL
Core developer

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

matplotlib

EPFL 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 Noguerón Aramburu
Master Student at EPFL
Core developer

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*

```
viewer([doisneau, doisneau_noise], subplots = [1, 2])
```

Alejandro Noguerón Aramburu
Master Student at EPFL
Core developer

jupyter

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

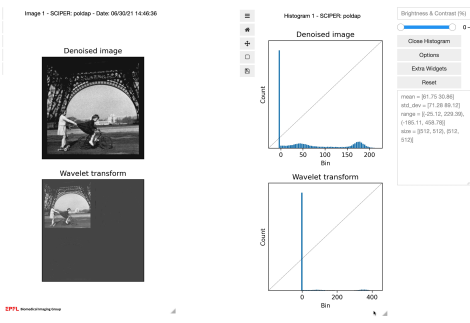
matplotlib

An Interactive Viewer for Image Processing Programming Labs

- Maximize the didactic capabilities of the labs

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

```
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 Noguerón Aramburu
Master Student at EPFL
Core developer

jupyter

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

matplotlib

Available in PyPI python Package Index *as part of* `interactive-kit`. *A toolkit for interactive visualization of signal and image processing on Jupyter Notebooks.*

Image Processing Programming in Javascript for everyone

replacing Java

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

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

Out[2]: 'undefined'

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

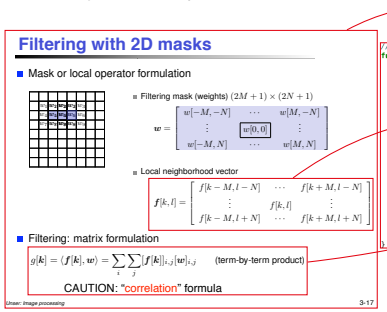
JS

Image Processing Programming in Javascript for everyone

replacing Java

- 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)`



Context: IP1, Lab 2: Digital filtering
Learning the most common techniques and possible bugs when implementing digital filters in image processing

Kay Lächler
Master Student at EPFL
Core developer

JS

replacing Java

```
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

replacing Java

- Tools for image comparison and display in the JavaScript console

```
var img1 = new Image([[1, 2, 3], [4, 5, 6]]);
...
img2 = new Image([[3, 6, 9], [12, 15, 18]]);

if(!img1.imageCompare(img2, err)){
    console.log(err.msg);
}
```

```
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 ]]
```

Available in Node.js node (JS) as `image-access`. *A class for didactic implementation of image processing in JavaScript.*

Kay Lächler
Master Student at EPFL
Core developer

JS

2000 Java ImageJ

2020 jupyter JS

Image: *EPFL students in a computer room learning IP programming.*

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

Teaching to more with less.

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

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