IMPERIAL

Advanced Programming

Assessment 3: Group Project

Image Filters, Projections and Slices

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RSM 4.85

Core task: Image Processing with C++

- Build a C++ program using the programming techniques you have learned during the Advanced Programming course.
- Take inputs of 2D images or 3D data volumes (e.g. CT scans)
- Apply image filters, orthographic projections and slices
- Output result as an image

Advanced Programming Schedule

- Possible to complete project in **one week**.
- Focus on the lectures and second individual assessment this week
- Apply knowledge learned over weeks 1 & 2 during the project in week 3

Group working

Expectation is that you will work on campus with your group for most of the week

Any concerns about group work (e.g., a member is not in contact with the group) please let me know ASAP so we can fix the situation!

GTA support Monday, Tuesday and Thursday afternoon

	Monday	Tuesday	Wednesday	Thursday	Friday
am	**Group work** 1.49/50, 1.51, additional rooms if needed (ask)	**Lecture by Tom** 1.49/50, 1.51	**Group work** 1.49/50, 1.51, 3.01D/E	**Lecture by Tom** 1.49/50, 1.51	**Group work** 1.49/50, 1.51, 3.01D/E
pm	**Group work** 1.49/50, 1.51, additional rooms if needed (ask) GTA support	**Group work** 1.49/50, 1.51, additional rooms if needed (ask) GTA support	**Group work** 1.49/50, 1.51, 3.01D/E	**Group work** 1.49/50, 1.51, 3.01D/E GTA support	**Group work** 1.49/50, 1.51, 3.01D/E

Groups

- Groups have been automatically generated
- Aim to balance the number of ACSE/EDSML students in each group
- Also balance the average grade in other modules to date, to make it as fair as possible

- Repositories will be released shortly (by tomorrow afternoon)
- We are **not** creating group channels in Teams, up to you to decide how best to communicate with your group

Group names: Algorithms

Apriori	Monte-Carlo
Bellman-Ford	Naive-Bayes
Binary-Search	Otsu
Canny-Edge-Detection	Prim
Depth-First-Search	QuickSort
Dijkstra	Radix-Sort
Euclidean	Selection-Sort
Fibonacci	Tarjan
Gradient-Descent	Ukkonen
Huffman	Viterbi
Insertion-Sort	Warshall
Johnson	Xavier-Initialization
Kruskal	Yen
Linear-Regression	Ziggurat
MergeSort	

Image processing

Colour spaces

Most images we will work with will be in one of a few colour spaces:

- **Grayscale**: single channel, denotes brightness
  - Ranging from 0 (black) to 255 (white)

- **RGB**: three channels, brightness of red, green and blue component of each channel

- **RGBa**: four channels, RGB + alpha
  - Alpha is the transparency
  - Generally ignored for this project (i.e. can leave it as it is, or remove it and save as RGB)

Image Processing

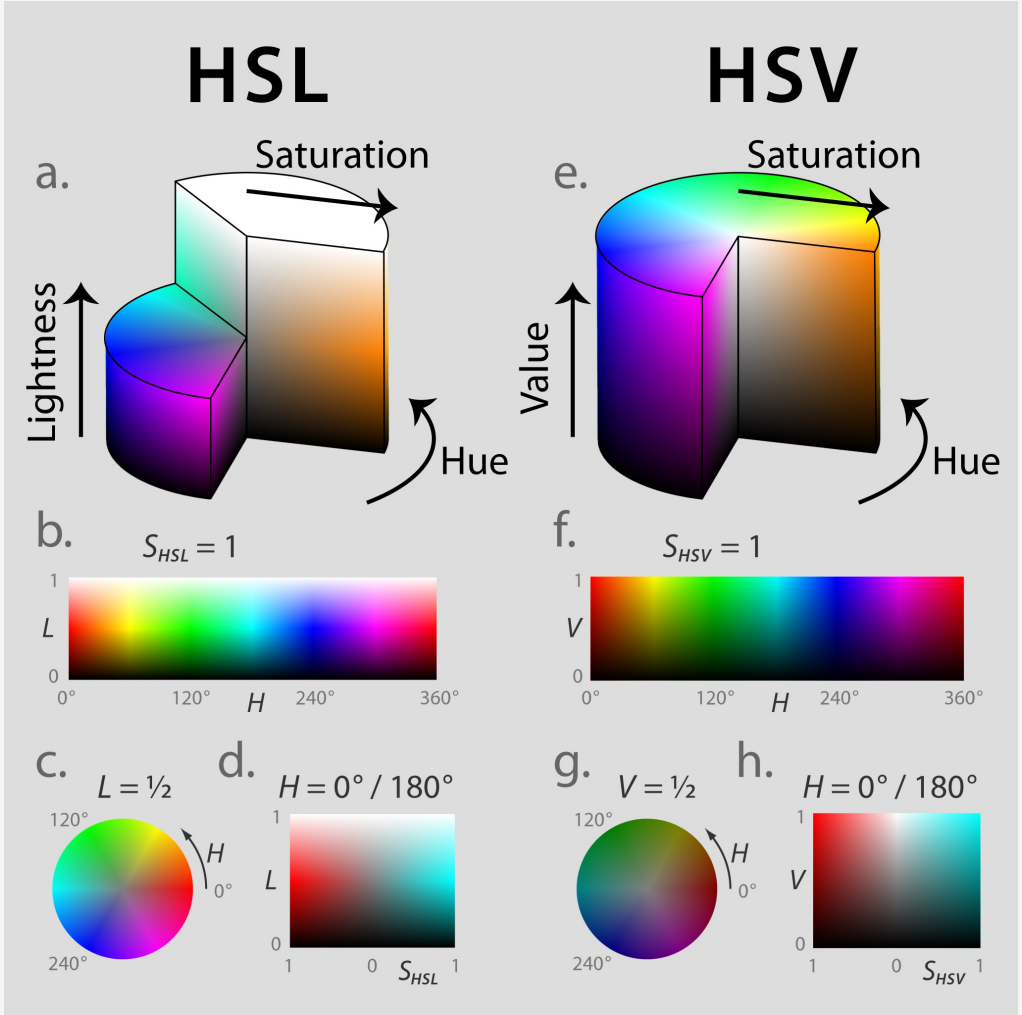
Colour space conversions

- Sometimes it is helpful to store the pixel information in a different colour space.

- Common examples include **HSV** and **HSL:**
  - **HSV**: Hue, Saturation, Value
  - **HSL**: Hue, Saturation, Luminance

- Note: Saturation is defined **differently** between HSL and HSV.

- May find it useful to write some **helper functions** to perform conversions to/from HSL and HSV



https://en.wikipedia.org/wiki/HSL_and_HSV

2D Image Filters

1. Colour correction / simple filters

a) **Greyscale**

b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise

$0.2126R + 0.7152G + 0.0722B$

Grace Hopper:
pioneer of computer
science

2D Image Filters

1. Colour correction / simple filters

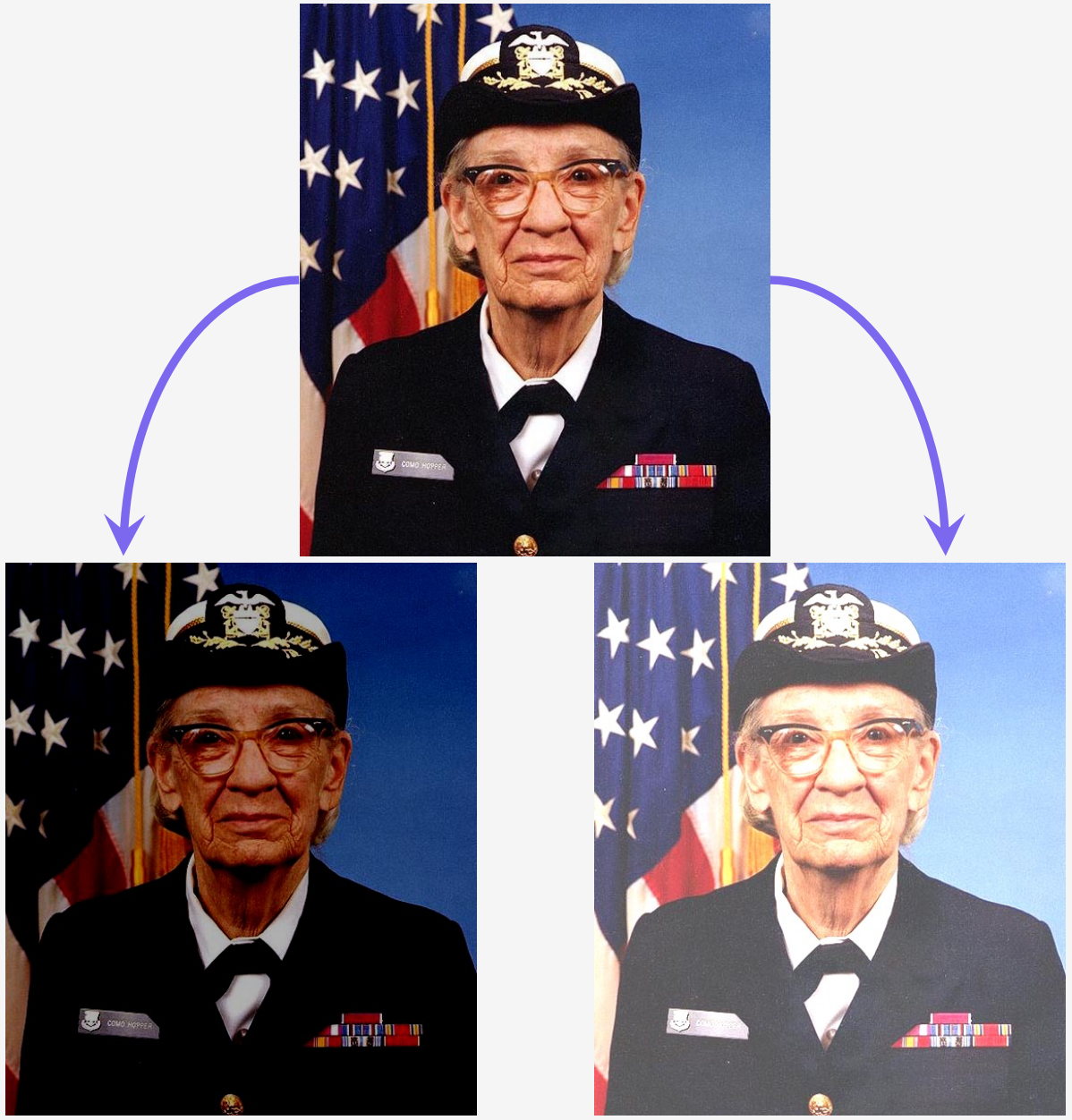
a) Greyscale

b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise



2D Image Filters

1. Colour correction / simple filters

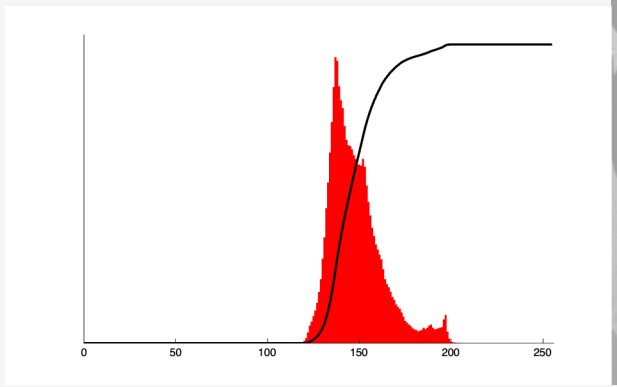
a) Greyscale

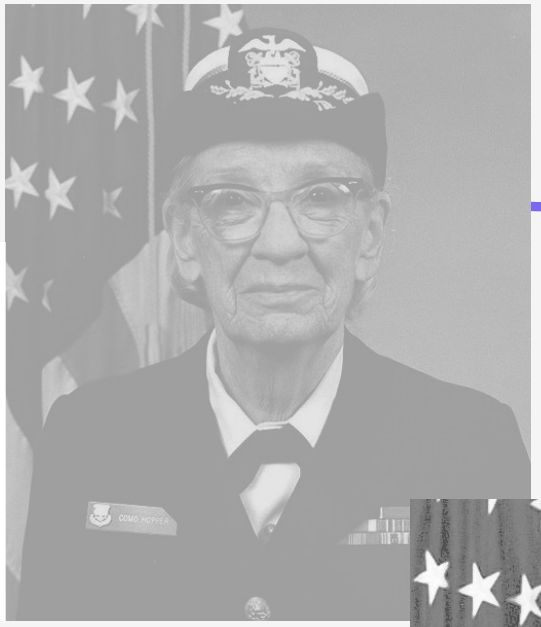
b) Brightness

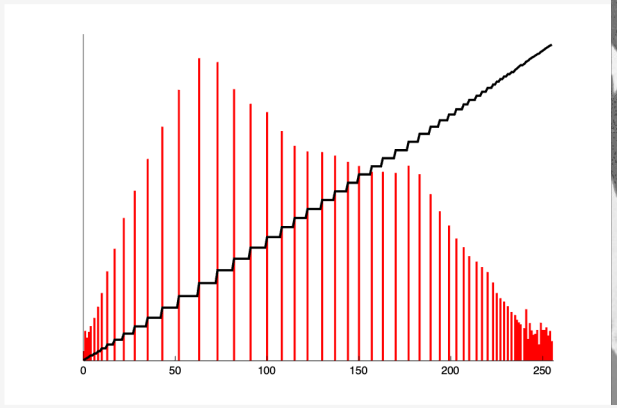
c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise







2D Image Filters

1. Colour correction / simple filters

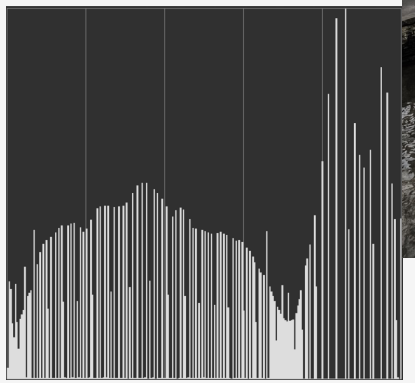
a) Greyscale

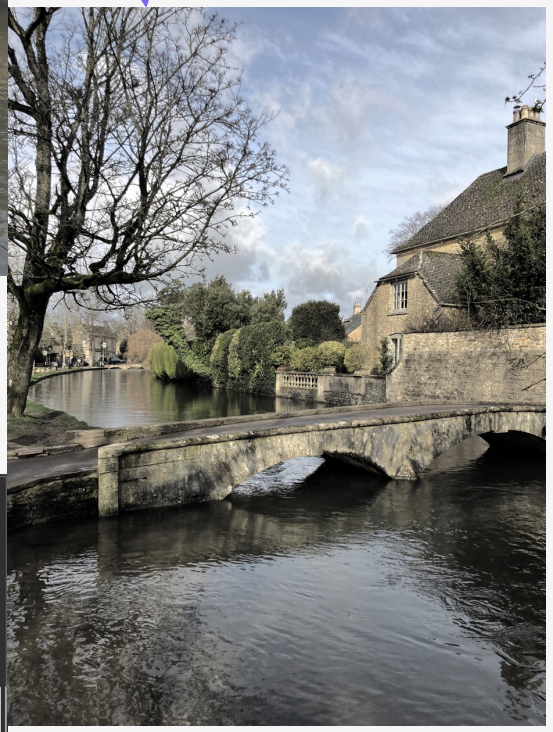
b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise





For RGB images, convert to HSL/HSV, and equalise the histogram of the L or V channel

2D Image Filters

1. Colour correction / simple filters

a) Greyscale

b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise

For RGB images, convert to HSL/HSV, and threshold the L or V channel

Asteroid Dimorphos surface
Image credit: NASA, APL

Threshold at a value of 127

2D Image Filters

1. Colour correction / simple filters

a) Greyscale

b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise

For RGB images, convert to HSL/HSV, and threshold the L or V channel

Threshold luminance at a value of 127

2D Image Filters

1. Colour correction / simple filters

a) Greyscale

b) Brightness

c) Histogram equalisation

d) Threshold

e) Salt and Pepper Noise

Add 10% of salt and pepper noise

2D Image Filters

2. Convolutional filters for image blur (arbitrary kernel size)

a) Median Blur

b) Box Blur

c) Gaussian Blur

a	*b*	*c*
d	*e*	*f*
g	*h*	*i*

3x3 kernel

(Original image)

2D Image Filters

2. Convolutional filters for image blur (arbitrary kernel size)

a) Median Blur

b) Box Blur

c) Gaussian Blur

Example 5x5 Box blur kernel

0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	0.04

Example 5x5 Gaussian blur kernel (st. dev. = 1)

0.003	0.013	0.022	0.013	0.003
0.013	0.060	0.098	0.060	0.013
0.022	0.098	0.162	0.098	0.022
0.013	0.060	0.098	0.060	0.013
0.003	0.013	0.022	0.013	0.003

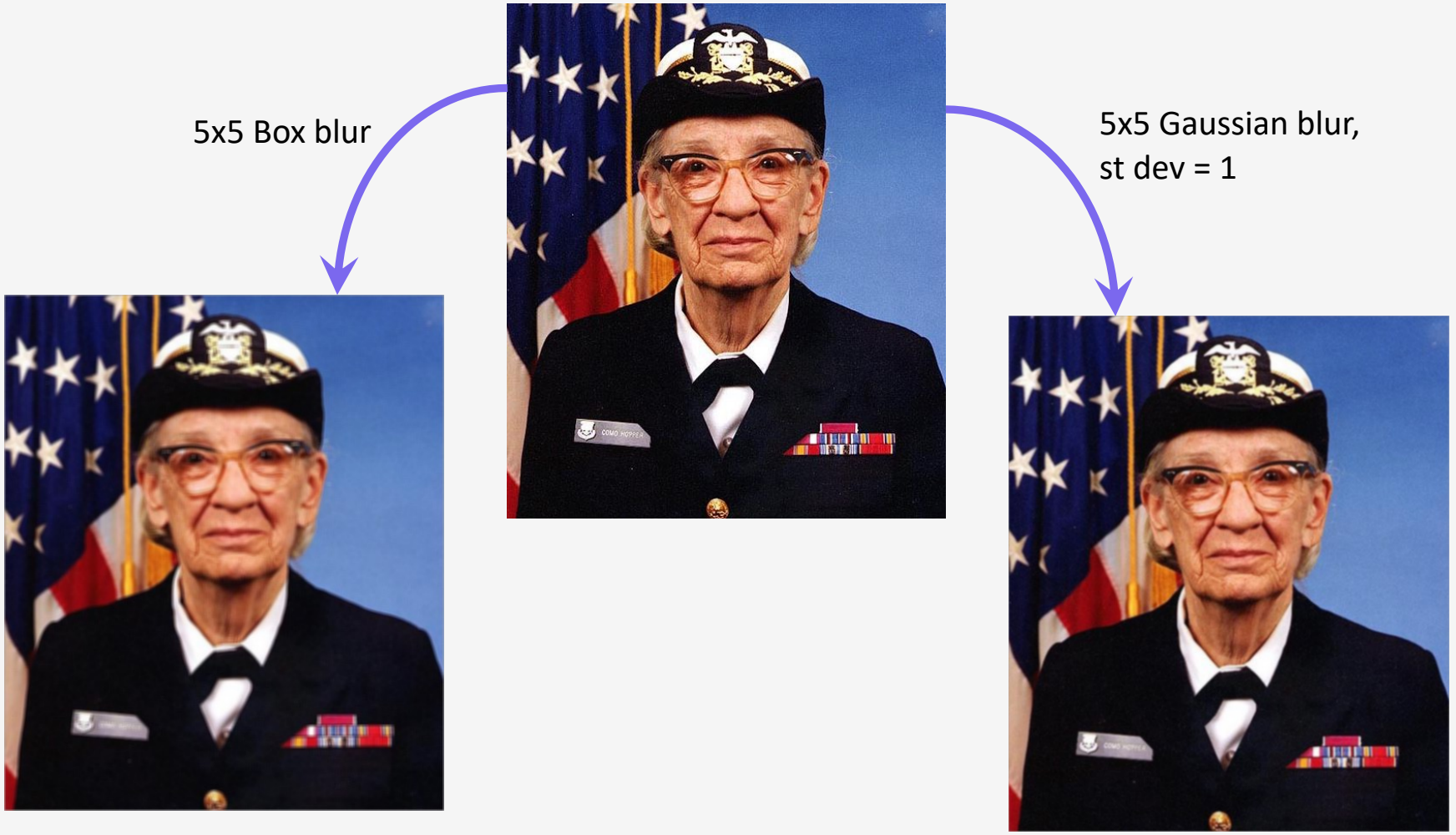
2D Image Filters

2. Convolutional filters for image blur (arbitrary kernel size)

a) Median Blur

b) Box Blur

c) Gaussian Blur



2D Image Filters

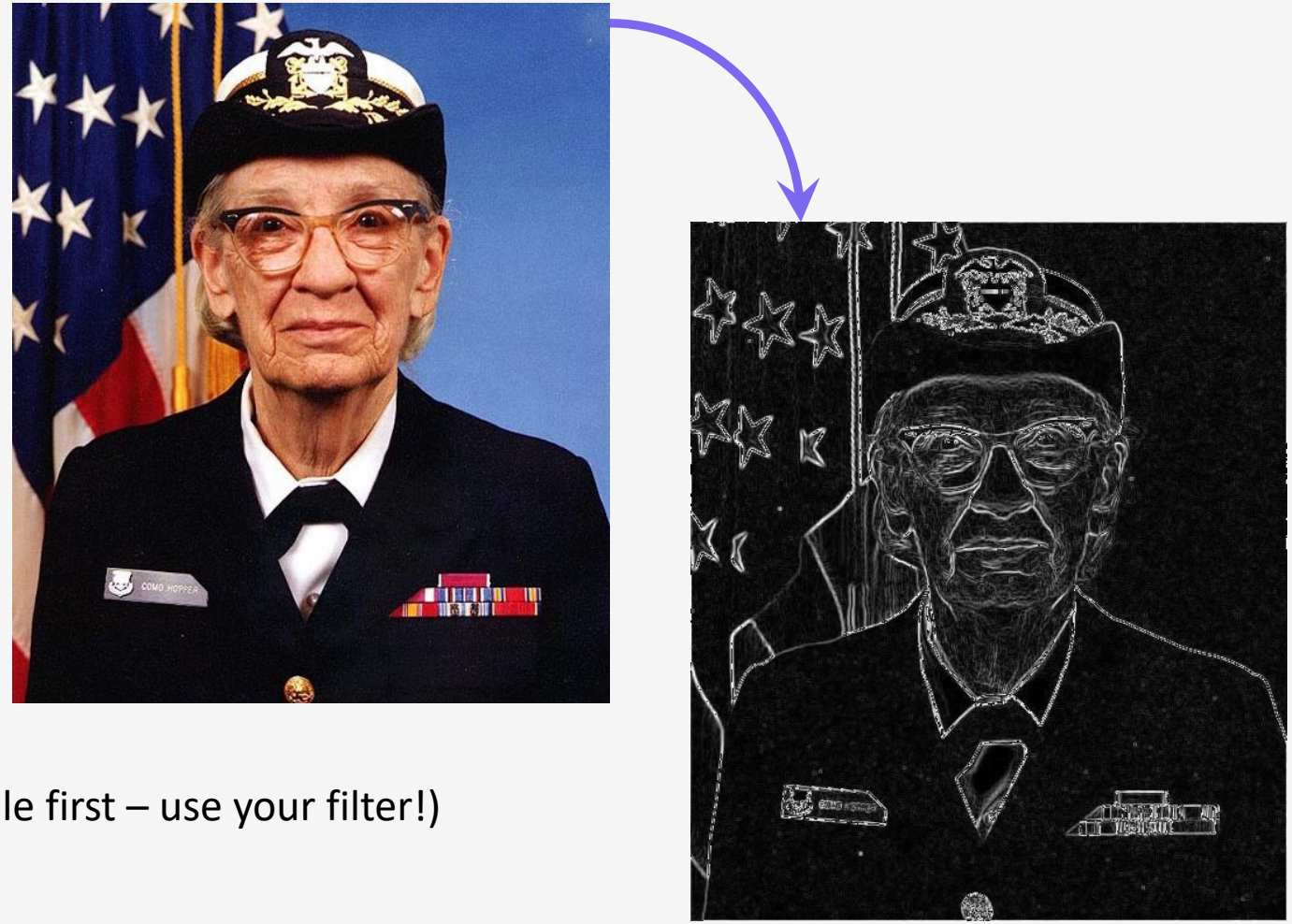
3. Convolution filters for edge detection (fixed kernel size)

a) Sobel

b) Prewitt

c) Scharr

d) Robert's Cross



(convert to grayscale first – use your filter!)

2D image filters

Group working suggestions

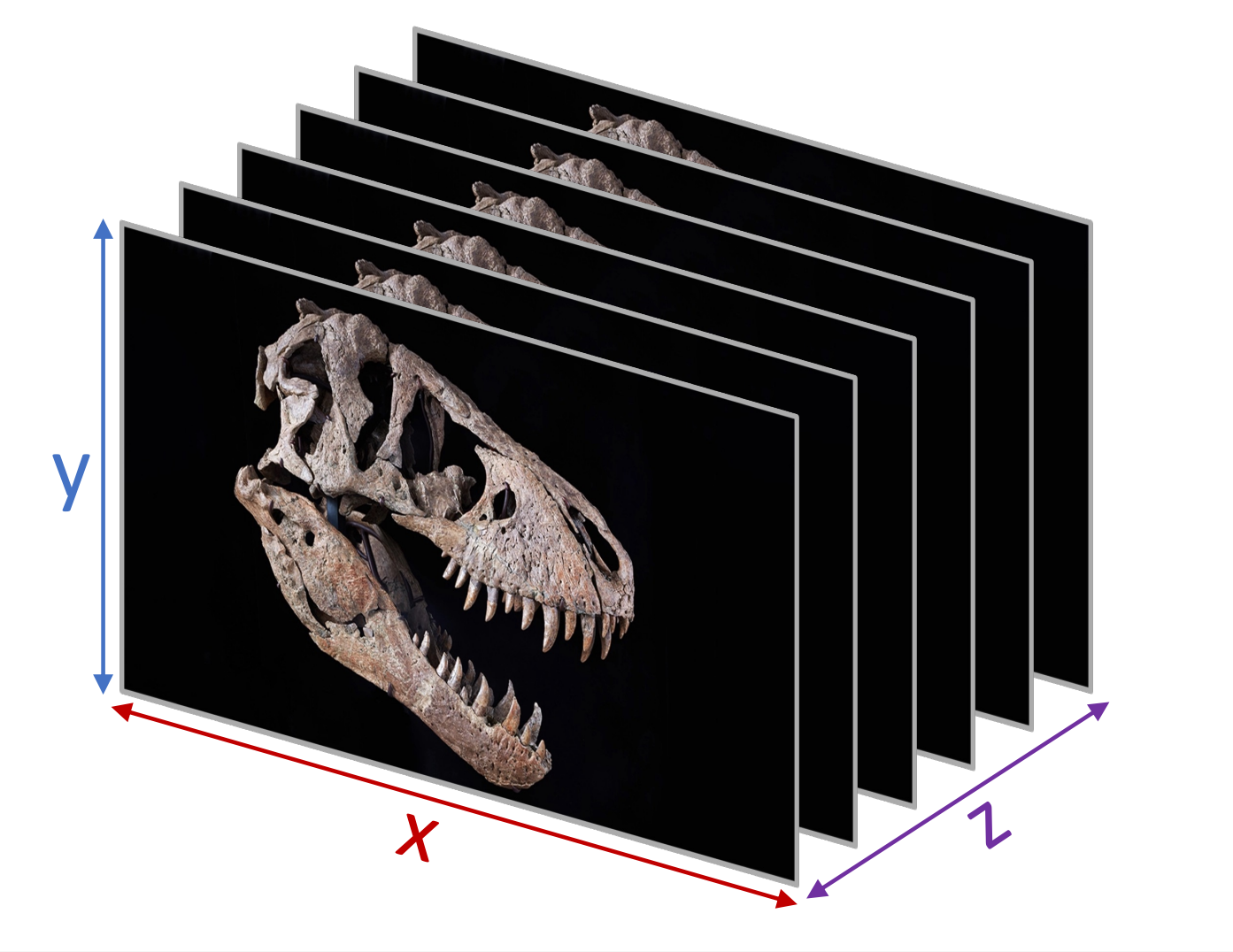
- Each member of the group should write at least one 2D image filter
- Everyone gets a chance to write some code
- Paired programming is fine (write at least 2 filters as a pair)

3D Volumes

CT Scans

- Stack of images to give a data “volume”

- CT scans are good examples of such data, e.g.
  - Medical
  - Palaeontology
  - Porous media



3D Volumes

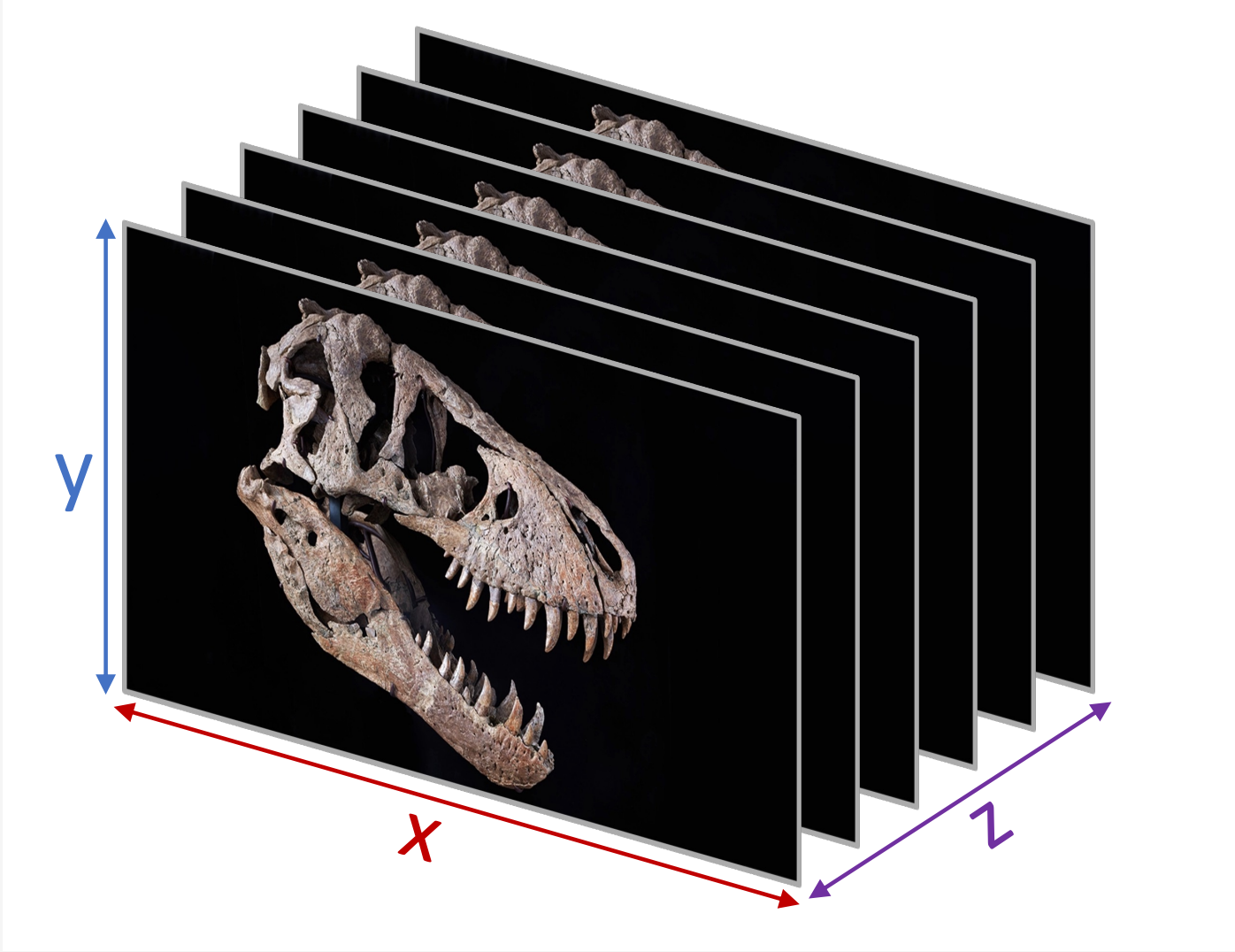
1. Filters

3D filters work in much the same way as 2D filters, but over the 3D volume

i.e., also need to consider *neighbouring images* in the stack as well as neighbouring pixels in the image

a) 3D Gaussian blur

b) 3D Median blur



3D Volumes

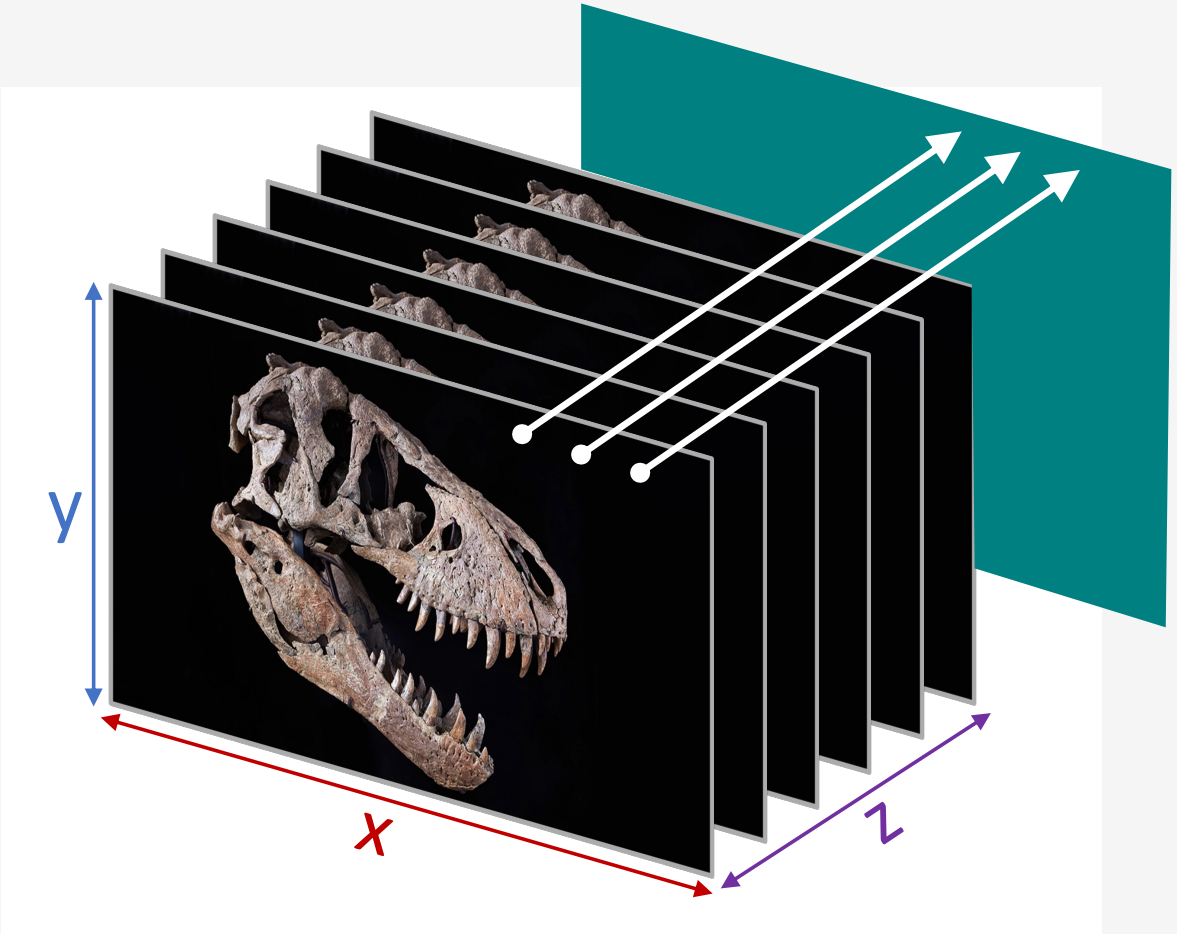
2. Orthographic projections

a) Maximum intensity projection (MIP)

b) Minimum intensity projection (MinIP)

c) Average intensity projection (AIP) using the mean
[**Additional challenge**: AIP using the median; computationally expensive]

Projections look through each image in the stack, and project a feature onto a single image of the same dimensions

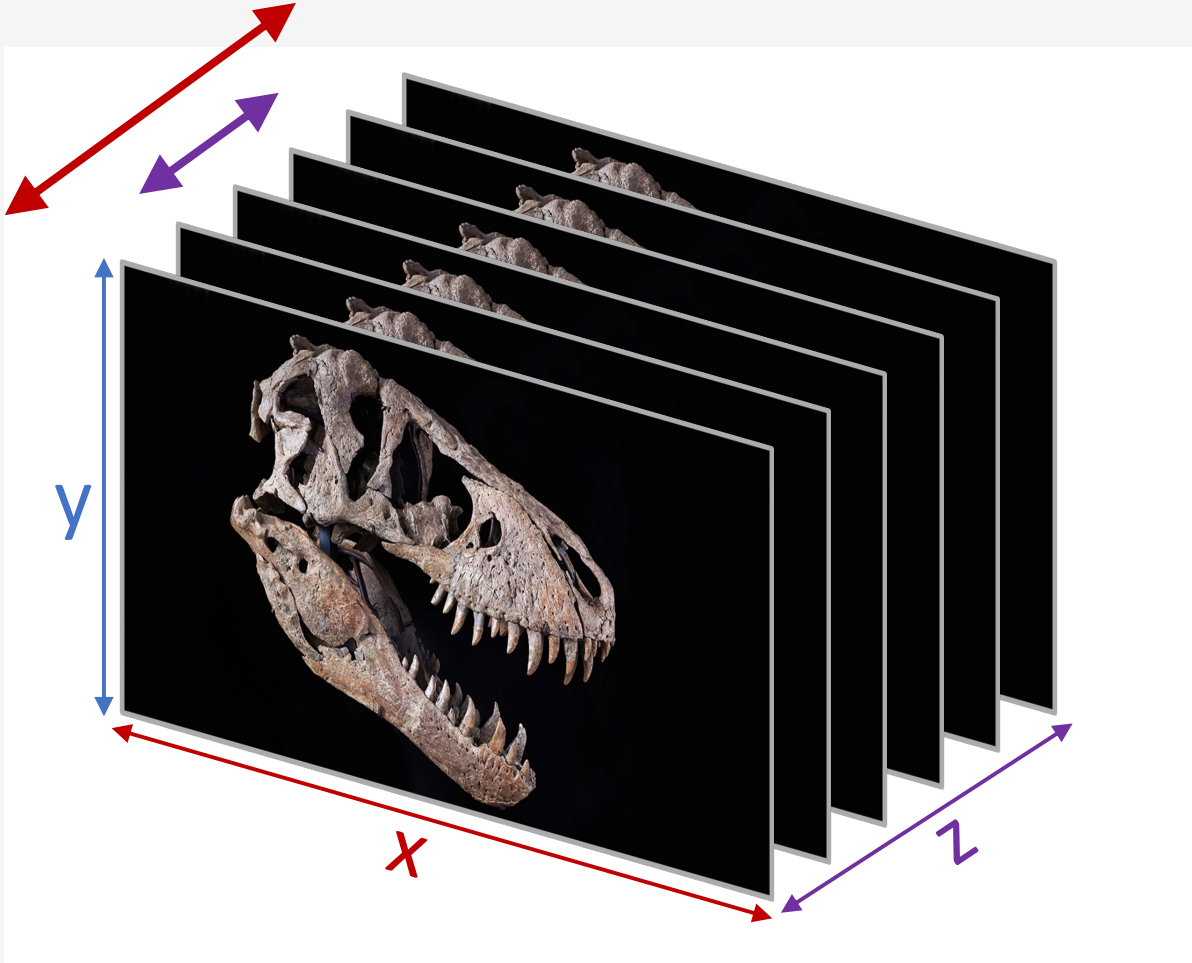


3D Volumes

2. Orthographic projections

Projections can operate on either:

- The whole volume available
- A thin slab (user defined region) in the z-direction



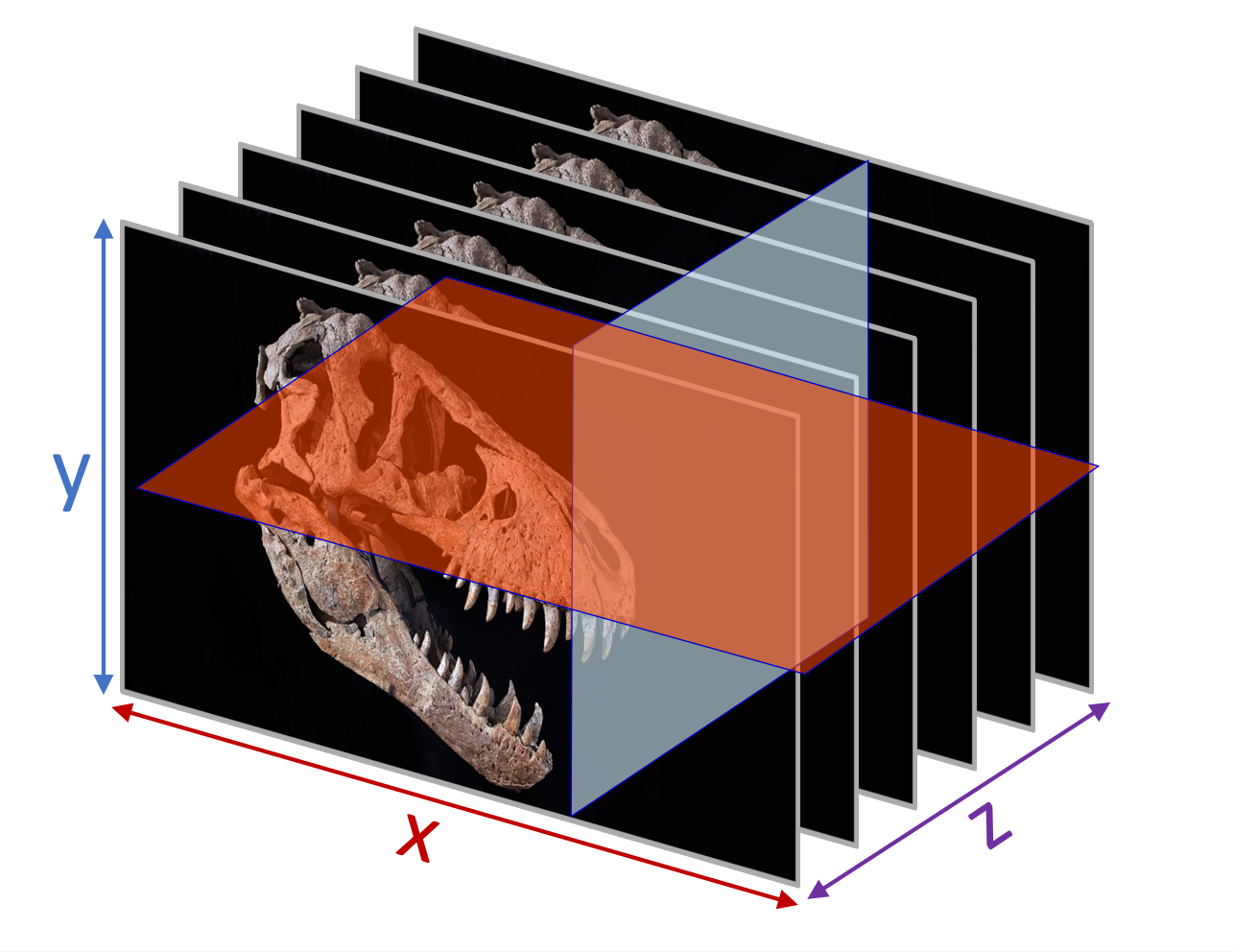
3D Volumes

3. Slicing

Images provided in the *x*-*y* orientation
Your code should be able to output an image in a different plane:

- *y*-*z* (user defined *x*)
- *x*-*z* (user defined *y*)

[**note**, index starting from 1 for each dimension; do not use individual image numbers]

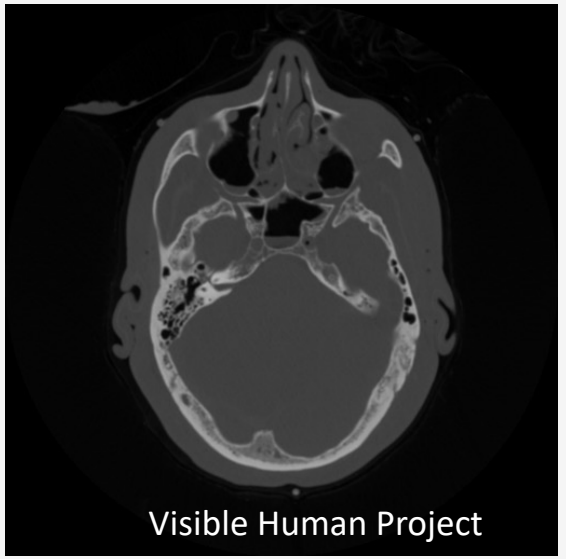


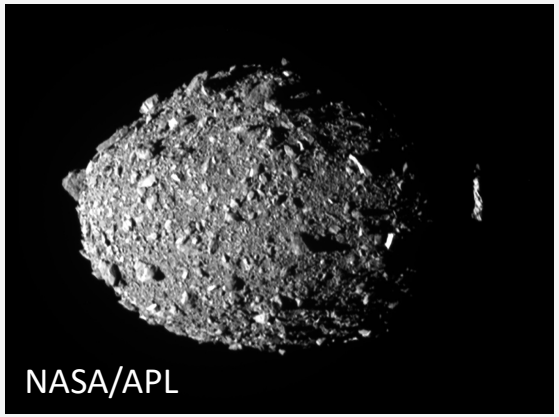
Example images

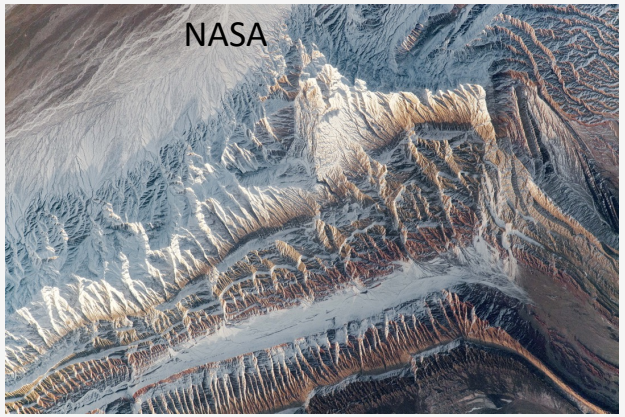
We have provided you with a set of example images

Please feel free to find other images which can demonstrate the capabilities of your code

Project description contains a list of all the output images we want you to upload





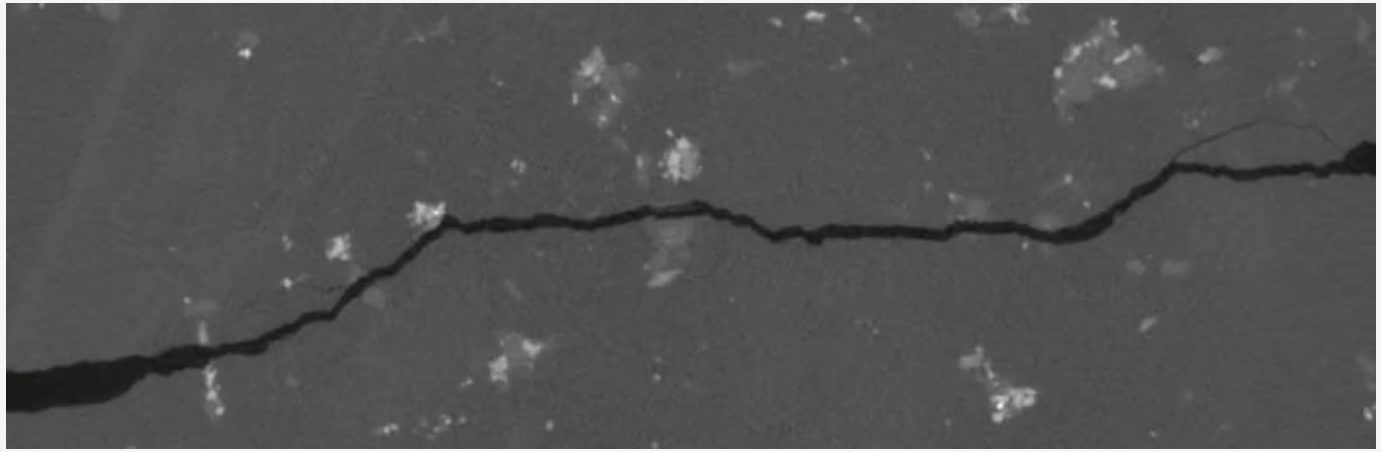


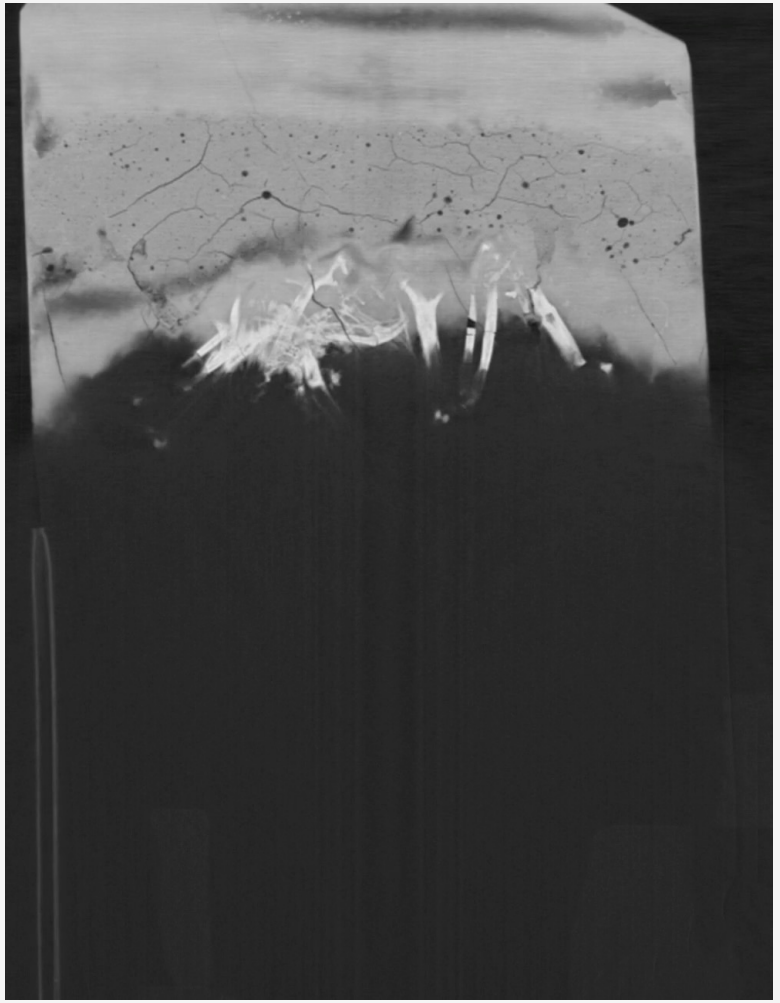
Provided 3D Volumes (CT Scans)

- Fossilized Confuciusornis (prehistoric bird) CT scan
- Fractured granite CT scan

See project description for a list of output images we would like you to provide from these scans

NOTE: DO NOT UPLOAD THESE SCANS TO YOUR GITHUB





https://doi.org/10.6084/m9.figshare.c.1612235_D59.v1

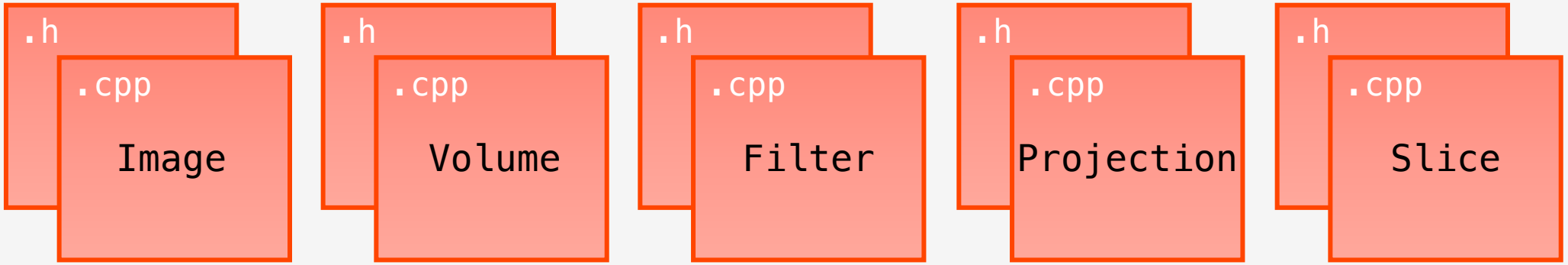
https://doi.org/10.17612/P7QX1X

Code structure

A main program file is required with a `main()` function.

This should run a user interface; simple, text-based interface is sufficient, no need to write a GUI!

You should have a class for (at least) each of the following:



They should all have a `.cpp` and `.h` file

Add more classes/files if you think they are appropriate; you might consider adding derived classes from some of the classes listed above or deriving some of the above classes from each other.

Add a comment header to each source code file with the names and GitHub usernames of each group member

Image reading and writing

stbi image headers

- `stb_image.h` and `stb_image_write.h`
- Provided in your group repositories
- Open-source image I/O library
- Works with a range of image formats, e.g., png, jpeg, gif

- Minimal example in repository showing how to import the headers and how to read and write an image

Image reading and writing with the stbi image library

```cpp
#include <iostream>
#define STB_IMAGE_IMPLEMENTATION
#include "stb_image.h"
#define STB_IMAGE_WRITE_IMPLEMENTATION
#include "stb_image_write.h"

int main() {

    int w, h, c;
    unsigned char* data;

    // Read in image file
    data = stbi_load("example.png", &w, &h, &c, 0);

    // Print image size to screen
    std::cout << "Image loaded with size " << w << " x " << h << " with ";
    std::cout << c << " channel(s)." << std::endl;

    // Save image to new filename
    int success = stbi_write_png("output.png", w, h, c, data, 0);

    // Deallocate memory
    stbi_image_free(data);

    return 0;
}
```

Most useful functions for this project:

- `stbi_load`
- `stbi_write_png`
- `stbi_image_free`

External libraries

- Other than the `stb_image.h` and `stb_image_write.h` headers, **no other external libraries are allowed**
- Standard libraries are fine
  e.g., iostream, string, vector, cmath
- No to OMP / threading
- If you are using a sorting algorithm for one of your filters, must write it yourselves!
- Best way to learn programming is to build something from scratch!
- **Do not copy code from the internet or other sources**
  (that includes sharing code between groups)

Sustainability

- Follow all best-practices you have learned in other courses up to now
- Make sure all code is commented well
- Provide documentation for users to know how to compile and run your code (ok to use documentation packages such as Doxygen)
- Include a readme and license file in your repository
- Use pull requests, code review, issues, etc. on GitHub
- Add a testing framework (unit tests, etc.)
- Add a compiled executable to the repository
  - Windows and/or MacOS (preferably both)

Teamwork

Remember – the main aim of this module and project are for you to learn how to write C++ code collaboratively

- Some of you have more experience than others
- Doesn’t mean we want one or two people writing all the code!
- Everyone should write at least one image filter, but we would prefer you all to write more than that!
- Team effort, work together and support each other

Paired programming can help. Ask each other questions if you are unsure about anything in the code

Use of generative AI tools in this assessment

- As usual, generative AI tools (such as ChatGPT, CoPilot, etc.) are permitted during this assessment, **if used responsibly**
- Any code that is generated by AI should be thoroughly **tested and verified**!
- Remember, any use of AI should be **acknowledged/referenced** in your submitted work
- **If in doubt about what is allowed, ask me**

Recommendations

- Start simple
- Build some of the easy filters and parts of the interface first
- Add comments and unit tests as you go
- Build complexity later (e.g. convolution filters, 3D projections, etc.)

Evaluation

Your code will be compiled and executed as part of your evaluation. Code that does not compile or does not output an image with the appropriate filter/projection applied correctly will not be able to score highly.

We will mark the projects based on:

- Implementation (40%)
- Execution and output images (20%)
- Sustainability (code documentation, commenting, and testing) (15%)
- Short 4-page report (25%)

Report

- Maximum 4 pages (single space, 11pt, pdf)
- Demonstrate you understand the algorithms employed for your filters and projections
- Each group member write about their own filter
- Performance – how well does your library scale with image/volume size and kernel size
- What would you change if you did the project again?
- Breakdown of who worked on which aspects of the project
- Use template provided in repository

Submission

Upload your code by committing to the main branch on GitHub by:

4pm on Friday 22nd March 2024

Anything included in commits after this time/date will not be assessed.

Your repository should include:

1) Your C++ source code.
2) Documentation (and readme) of how to install and use your program.
3) Your code testing framework.
4) An appropriate licence.
5) Your 4-page PDF report.
6) The required output images.
7) Windows and/or MacOS executables.

IMPERIAL

Any questions?

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