HAN AEA - Embedded Vision & Machine Learning

EVD1 Development basics

By Hugo Arends

HAN_UNIVERSITY OF APPLIED SCIENCES

EVD1 – File overview

- evdk5
  - evdk_images
  - evdk_operators
  - evdk_sheets
  - evdk_workspace_apps
  - evdk_workspace_targets

Top level
folder structure

EVD1 – File overview

- evdk5
  - evdk_images
  - evdk_operators
    - coding_and_compression.c
    - coding_and_compression.h
    - graphics_algorithms.c
    - graphics_algorithms.h
    - …
  - evdk_sheets
  - evdk_workspace_apps
  - evdk_workspace_targets

Image processing
source files,
a file per class

EVD1 – File overview

- evdk5
  - evdk_images
  - evdk_operators
  - evdk_sheets
  - evdk_workspace_apps
    - evdk5_histogram_webcam
    - evdk5_img_from_file
    - evdk5_unit_test
    - evdk5_webcam
    - evdk5_apps.code-workspace
  - evdk_workspace_targets

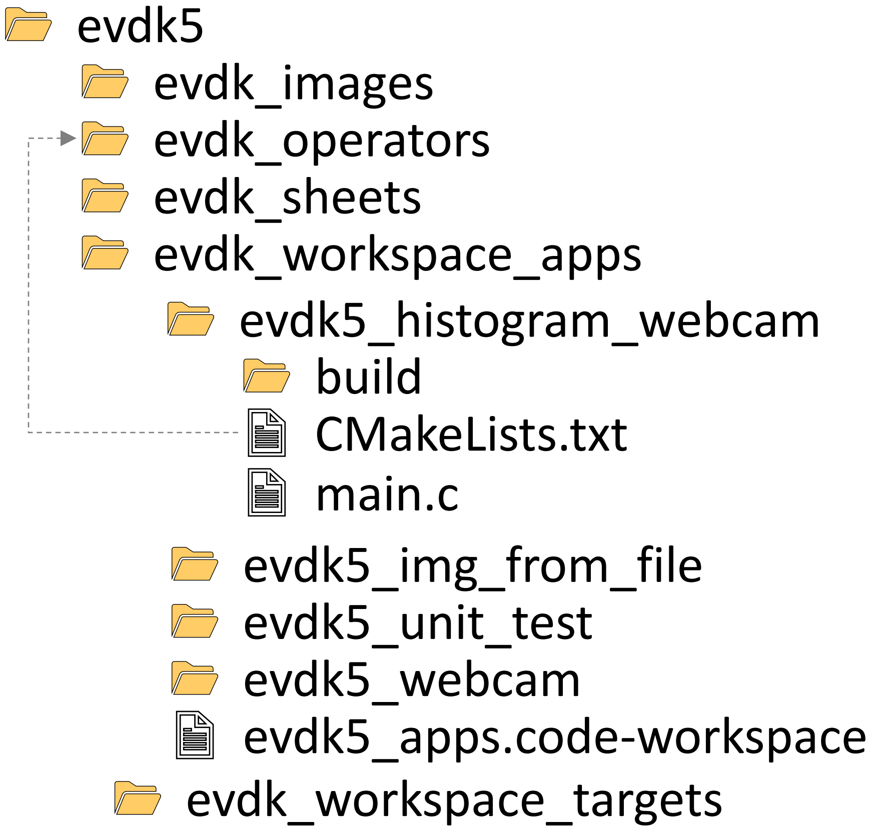
Workspace for PC apps

EVD1 – File overview

- 📁 evdk5
  - 📁 evdk_images
  - 📁 evdk_operators
  - 📁 evdk_sheets
  - 📁 evdk_workspace_apps
    - 📁 evdk5_histogram_webcam
      - 📁 build
      - 📄 CMakeLists.txt
      - 📄 main.c
    - 📁 evdk5_img_from_file
    - 📁 evdk5_unit_test
    - 📁 evdk5_webcam
    - 📄 evdk5_apps.code-workspace
  - 📁 evdk_workspace_targets

Workspace for PC apps

EVD1 – File overview



- evdk5
  - evdk_images
  - evdk_operators
  - evdk_sheets
  - evdk_workspace_apps
    - evdk5_histogram_webcam
      - build
      - CMakeLists.txt
      - main.c
    - evdk5_img_from_file
    - evdk5_unit_test
    - evdk5_webcam
    - evdk5_apps.code-workspace
  - evdk_workspace_targets

Workspace for
PC apps

EVD1 – File overview

- 📁 evdk5
  - 📁 evdk_images
  - 📁 evdk_operators
  - 📁 evdk_sheets
  - 📁 evdk_workspace_apps
  - 📁 evdk_workspace_targets
    - 📁 frdmmcxn947_evdk5_0
    - 📄 evdk5_targets.code-workspace

Workspace for target executables

EVD1 – File overview

- 📂 evdk5
  - 📂 evdk_images
  - 📂 evdk_operators
  - 📂 evdk_sheets
  - 📂 evdk_workspace_apps
  - 📂 evdk_workspace_targets
    - 📂 frdmmcxn947_evdk5_0
      - 📂 .vscode
      - 📂 board
      - 📂 CMSIS
      - …
      - 📄 CMakeLists.txt
      - …
    - 📄 evdk5_targets.code-workspace

Workspace for target executables

EVD1 – File overview

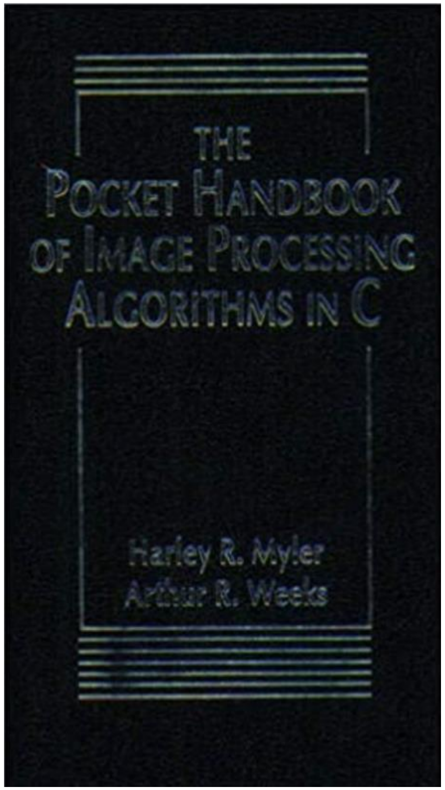
- evdk5
  - evdk_images
  - evdk_operators
  - evdk_sheets
  - evdk_workspace_apps
  - evdk_workspace_targets
    - frdmmcxn947_evdk5_0
      - .vscode
      - board
      - CMSIS
      - …
      - CMakeLists.txt
      - …
    - evdk5_targets.code-workspace

Workspace for target executables

Image basics – attributes

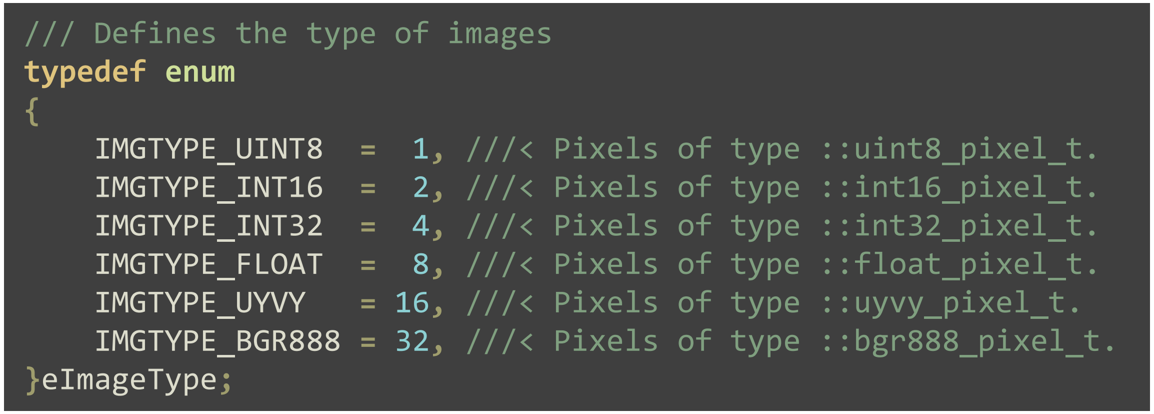
```
/// Defines the attributes of an image
typedef struct
{
    int32_t     cols; ///< Number of columns in the image
    int32_t     rows; ///< Number of rows in the image
    eImageType  type; ///< The type of pixels in the image
    uint8_t    *data; ///< A pointer to the pixel data

}image_t;
```



Myler, H. R., & Weeks, A. R. (2009). *The pocket handbook of image processing algorithms in C.* Prentice Hall Press.

Image basics – eImageType



```
/// Defines the type of images
typedef enum
{
    IMGTYPE_UINT8  =  1, ///< Pixels of type ::uint8_pixel_t.
    IMGTYPE_INT16  =  2, ///< Pixels of type ::int16_pixel_t.
    IMGTYPE_INT32  =  4, ///< Pixels of type ::int32_pixel_t.
    IMGTYPE_FLOAT  =  8, ///< Pixels of type ::float_pixel_t.
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```

Myler, H. R., & Weeks, A. R. (2009). *The pocket handbook of image processing algorithms in C.* Prentice Hall Press.

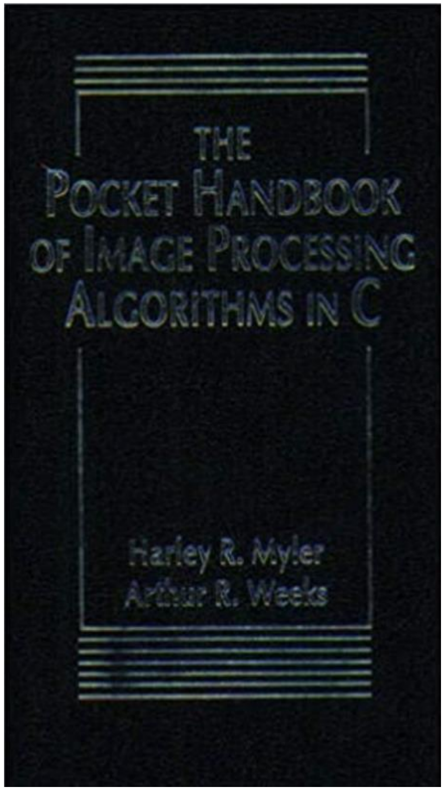
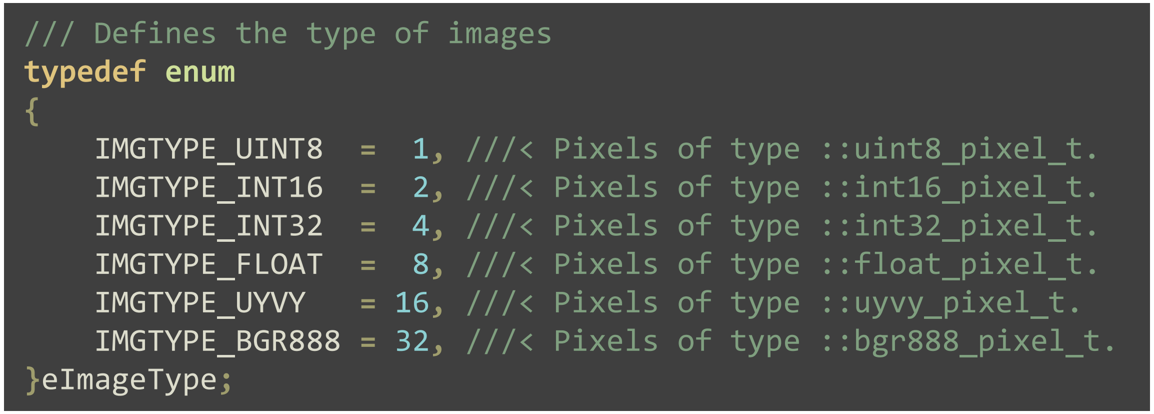


Image basics – eImageType



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    IMGTYPE_FLOAT  =  8, ///< Pixels of type ::float_pixel_t.
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```

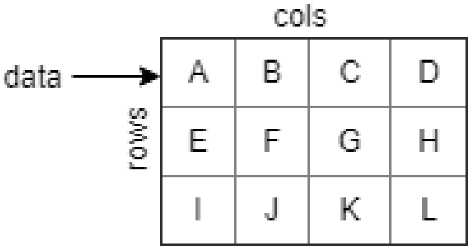

Image basics – eImageType

```
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typedef enum
{
    IMGTYPE_UINT8  =  1, ///< Pixels of type ::uint8_pixel_t.
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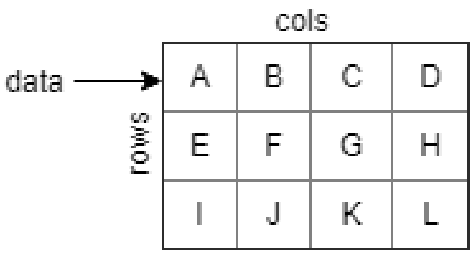
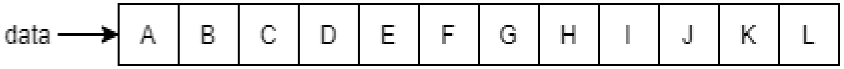
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```



A	B	C	D
E	F	G	H
I	J	K	L

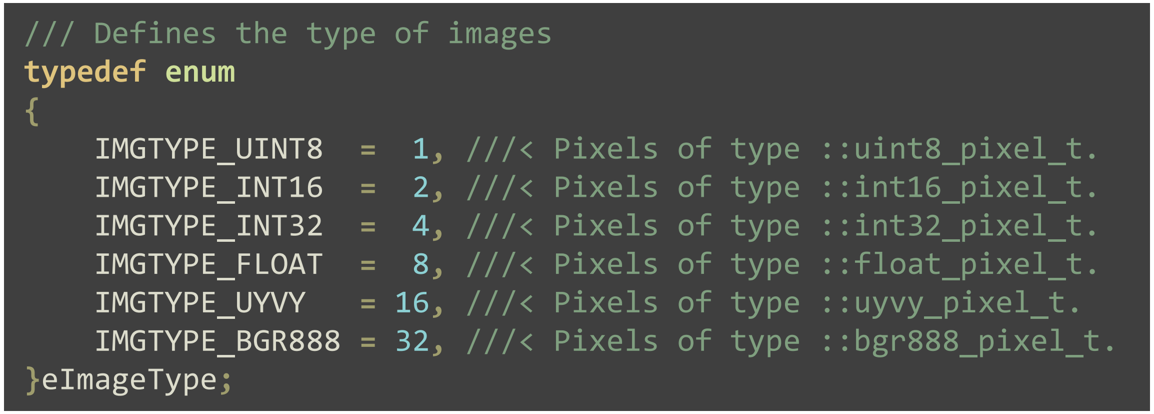
```
/// \brief Type definition of a uint8 pixel
///
/// 8 bits per pixel
typedef uint8_t uint8_pixel_t;
```

Memory allocation: $12 \times 1\ byte = 12\ bytes$

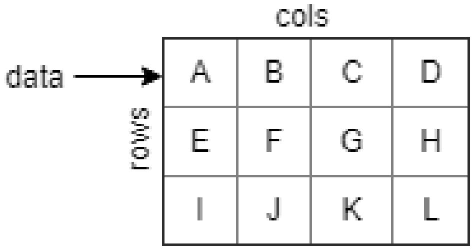


A	B	C	D	E	F	G	H	I	J	K	L

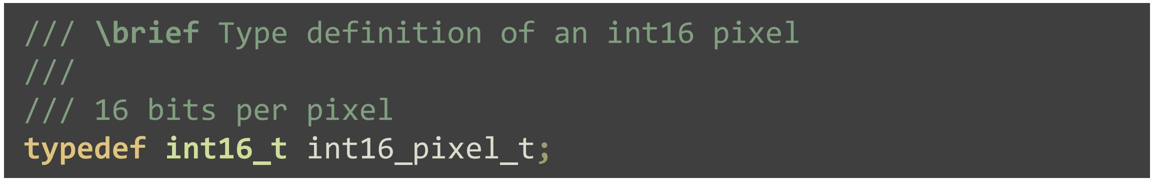
Image basics – eImageType



```
/// Defines the type of images
typedef enum
{
    IMGTYPE_UINT8  =  1, ///< Pixels of type ::uint8_pixel_t.
    IMGTYPE_INT16  =  2, ///< Pixels of type ::int16_pixel_t.
    IMGTYPE_INT32  =  4, ///< Pixels of type ::int32_pixel_t.
    IMGTYPE_FLOAT  =  8, ///< Pixels of type ::float_pixel_t.
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```

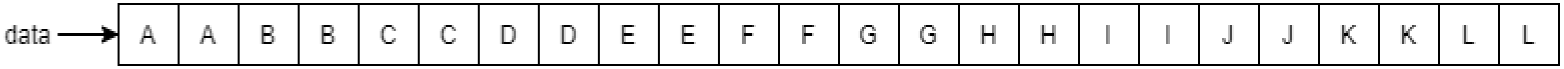


A	B	C	D
E	F	G	H
I	J	K	L



```
/// \brief Type definition of an int16 pixel
///
/// 16 bits per pixel
typedef int16_t int16_pixel_t;
```

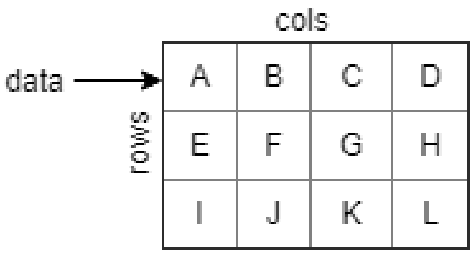
Memory allocation: $12 \times 2\ bytes = 24\ bytes$



A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	K	K	L	L

Image basics – eImageType

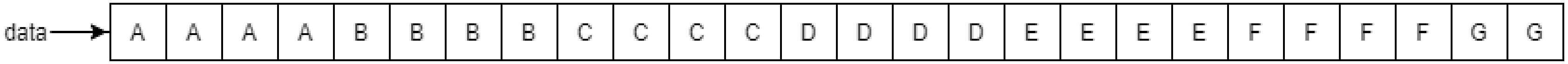
```
/// Defines the type of images
typedef enum
{
    IMGTYPE_UINT8  =  1, ///< Pixels of type ::uint8_pixel_t.
    IMGTYPE_INT16  =  2, ///< Pixels of type ::int16_pixel_t.
    IMGTYPE_INT32  =  4, ///< Pixels of type ::int32_pixel_t.
    IMGTYPE_FLOAT  =  8, ///< Pixels of type ::float_pixel_t.
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```



A	B	C	D
E	F	G	H
I	J	K	L

```
/// \brief Type definition of an int32 pixel
///
/// 32 bits per pixel
typedef int32_t int32_pixel_t;
```

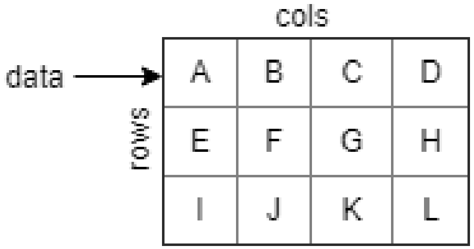
Memory allocation: $12 \times 4\ bytes = 48\ bytes$



A	A	A	A	B	B	B	B	C	C	C	C	D	D	D	D	E	E	E	E	F	F	F	F	G	G

Image basics – eImageType

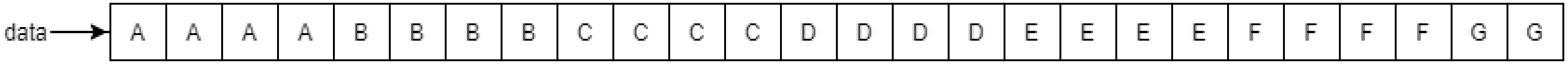
```
/// Defines the type of images
typedef enum
{
    IMGTYPE_UINT8  =  1, ///< Pixels of type ::uint8_pixel_t.
    IMGTYPE_INT16  =  2, ///< Pixels of type ::int16_pixel_t.
    IMGTYPE_INT32  =  4, ///< Pixels of type ::int32_pixel_t.
    IMGTYPE_FLOAT  =  8, ///< Pixels of type ::float_pixel_t.
    IMGTYPE_UYVY   = 16, ///< Pixels of type ::uyvy_pixel_t.
    IMGTYPE_BGR888 = 32, ///< Pixels of type ::bgr888_pixel_t.
}eImageType;
```



A	B	C	D
E	F	G	H
I	J	K	L

```
/// \brief Type definition of a float pixel
///
/// 32 bits per pixel
typedef float float_pixel_t;
```

Memory allocation: $12 \times 4\ bytes = 48\ bytes$



A	A	A	A	B	B	B	B	C	C	C	C	D	D	D	D	E	E	E	E	F	F	F	F	G	G

Image basics – Creating images

```
// Create an image
image_t *src = newUint8Image(4, 3);

// Use src in an image processing pipeline
// ...

// Cleanup
deleteUint8Image(src);
```

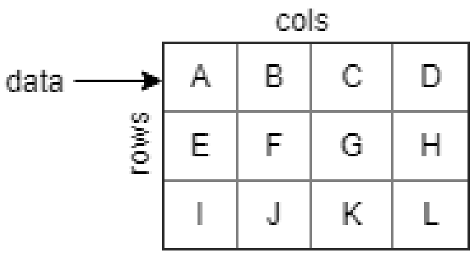
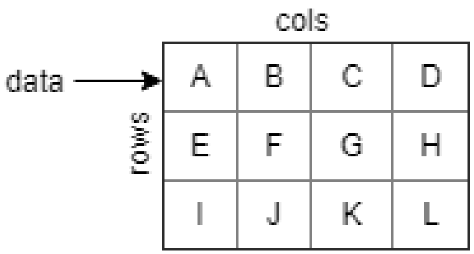


Image basics – Creating images

```
// Create an image
image_t *src = newFloatImage(4, 3);

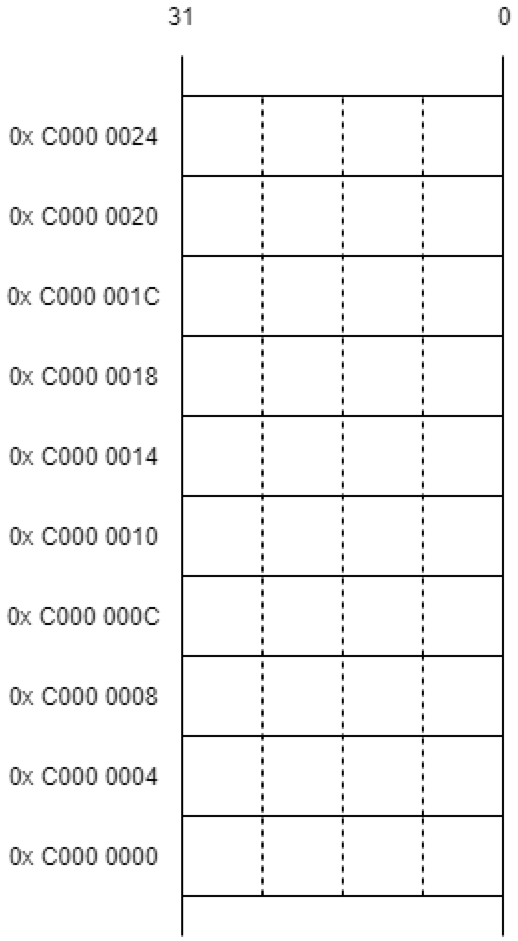
// Use src in an image processing pipeline
// ...

// Cleanup
deleteFloatImage(src);
```



A	B	C	D
E	F	G	H
I	J	K	L

Image basics – Pointers



```
int a = 0;
```

- ‘a’ is a variable, but what is a variable?

  name of a storage area

- What does the type of a variable tell?

  size and layout in memory

- How can we get the memory address of a variable?

  by using the reference operator: &

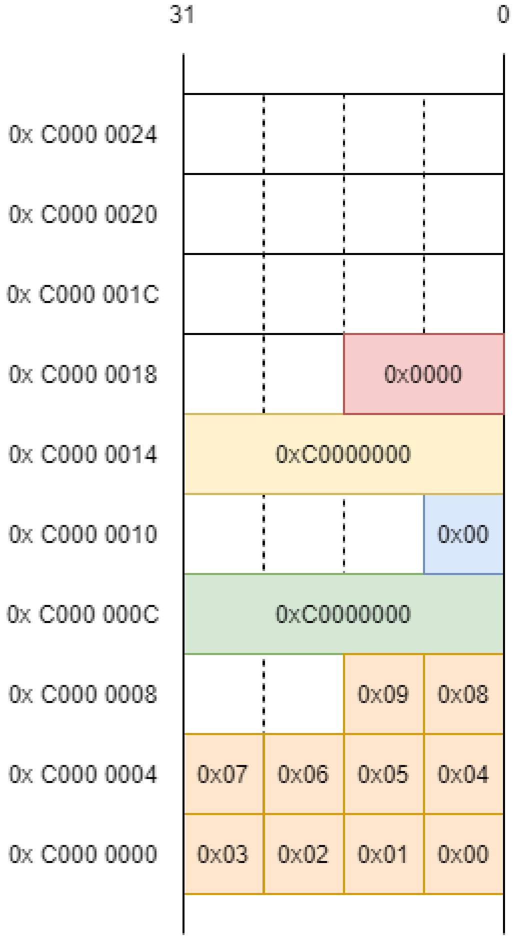
  ```
  int *p1 = &a;
  ```

- Why is this incorrect?

  ```
  char *p2 = &a;
  ```

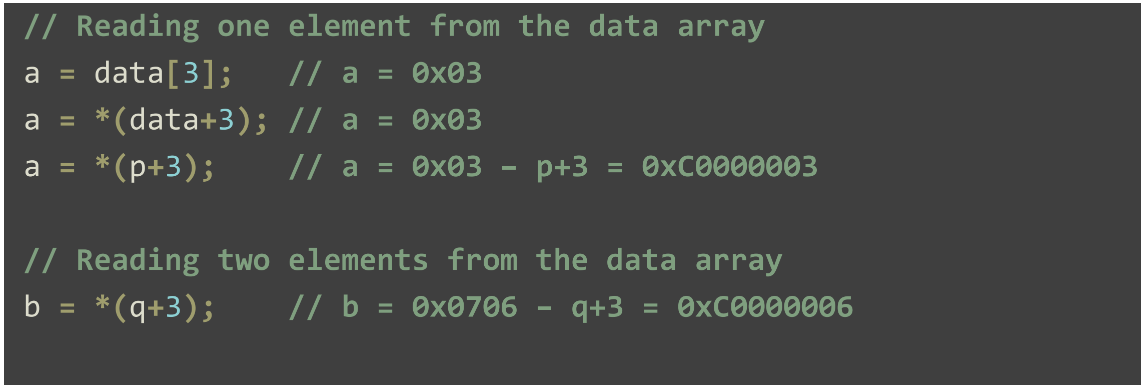
  The base-type of the pointer is different from the base-type of the variable

Image basics – Pointers



	31			0
0x C000 0024				
0x C000 0020				
0x C000 001C				
0x C000 0018			0x0000	
0x C000 0014	0xC0000000			
0x C000 0010				0x00
0x C000 000C	0xC0000000			
0x C000 0008			0x09	0x08
0x C000 0004	0x07	0x06	0x05	0x04
0x C000 0000	0x03	0x02	0x01	0x00

```
uint8_t data[10] = {0,1,2,3,4,5,6,7,8,9};
uint8_t *p = data; // alternative: &data[0]
uint8_t a = 0;
uint16_t *q = (uint16_t *)data;
uint16_t b = 0;
```



```
// Reading one element from the data array
a = data[3];    // a = 0x03
a = *(data+3); // a = 0x03
a = *(p+3);     // a = 0x03 – p+3 = 0xC0000003

// Reading two elements from the data array
b = *(q+3);     // b = 0x0706 – q+3 = 0xC0000006
```

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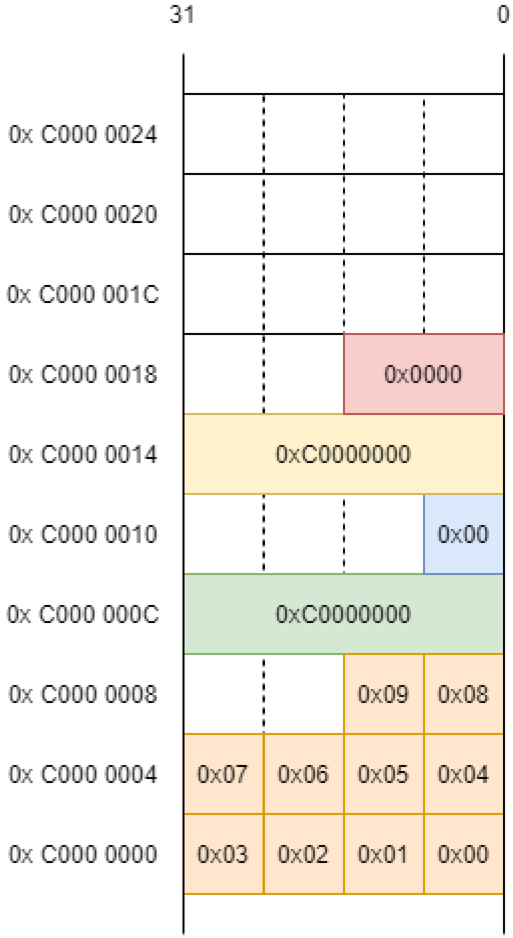
Image basics – Pointers



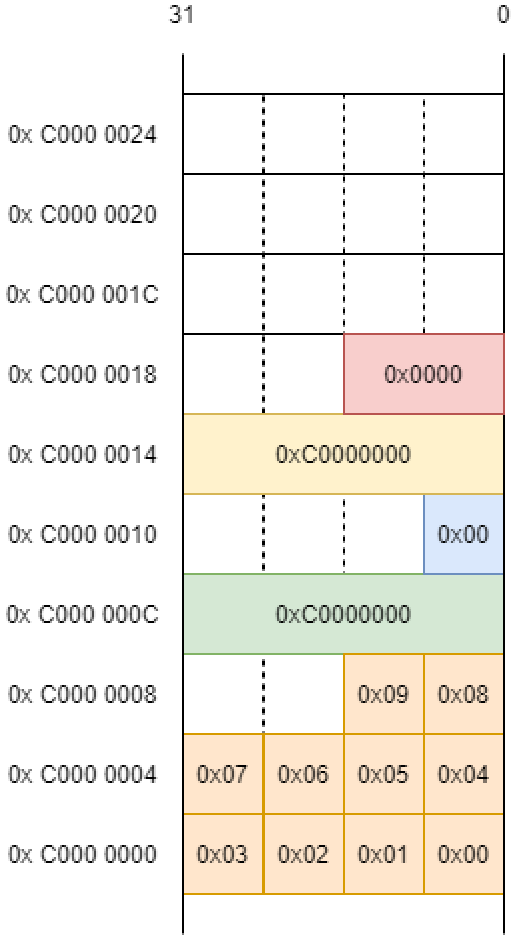
	31			0
0x C000 0024				
0x C000 0020				
0x C000 001C				
0x C000 0018			0x0000	
0x C000 0014	0xC0000000			
0x C000 0010				0x00
0x C000 000C	0xC0000000			
0x C000 0008			0x09	0x08
0x C000 0004	0x07	0x06	0x05	0x04
0x C000 0000	0x03	0x02	0x01	0x00

```
uint8_t data[10] = {0,1,2,3,4,5,6,7,8,9};
uint8_t *p = data; // alternative: &data[0]
uint8_t a = 0;
uint16_t *q = (uint16_t *)data;
uint16_t b = 0;
```

```
// Writing one element to the data array
p = data + 1; // p = 0xC000 0001
p++;          // p = 0xC000 0002
*p = 0;       // data = {0,1,0,3,4,5,6,7,8,9}

// Writing two elements to the data array
q = (uint16_t *)data + 1; // q = 0xC000 0002
q++;                      // q = 0xC000 0004
*q = 0;                   // data = {0,1,2,3,0,0,6,7,8,9}
```

Image basics – Pointers



```
uint8_t data[10] = {0,1,2,3,4,5,6,7,8,9};
uint8_t *p = data; // alternative: &data[0]
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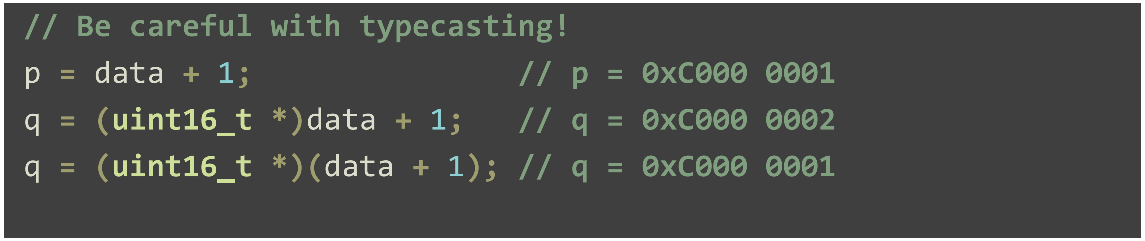
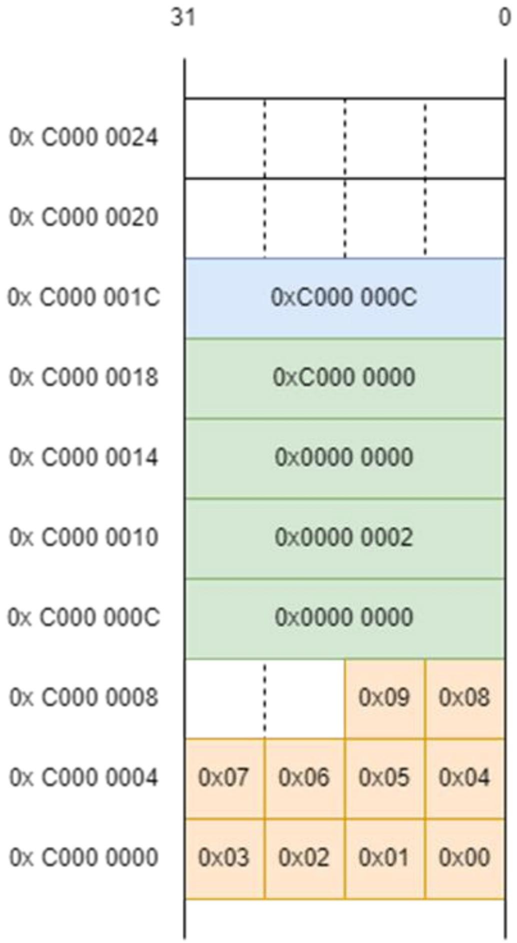
uint16_t b = 0;
```



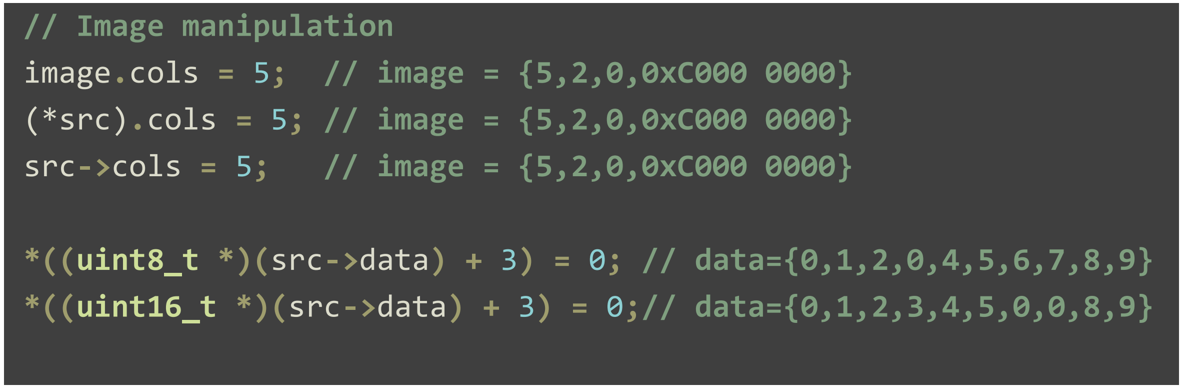
```
// Be careful with typecasting!
p = data + 1;                // p = 0xC000 0001
q = (uint16_t *)data + 1;    // q = 0xC000 0002
q = (uint16_t *)(data + 1); // q = 0xC000 0001
```

Image basics – Pointers



	31			0
0x C000 0024				
0x C000 0020				
0x C000 001C	0xC000 000C			
0x C000 0018	0xC000 0000			
0x C000 0014	0x0000 0000			
0x C000 0010	0x0000 0002			
0x C000 000C	0x0000 0000			
0x C000 0008			0x09	0x08
0x C000 0004	0x07	0x06	0x05	0x04
0x C000 0000	0x03	0x02	0x01	0x00

```
uint8_t data[10] = {0,1,2,3,4,5,6,7,8,9};
image_t image = {0,2,IMGTYPE_UINT8,data};
image_t *src = &image;
```



```
// Image manipulation
image.cols = 5;  // image = {5,2,0,0xC000 0000}
(*src).cols = 5; // image = {5,2,0,0xC000 0000}
src->cols = 5;   // image = {5,2,0,0xC000 0000}

*((uint8_t *)(src->data) + 3) = 0; // data={0,1,2,0,4,5,6,7,8,9}
*((uint16_t *)(src->data) + 3) = 0;// data={0,1,2,3,4,5,0,0,8,9}
```

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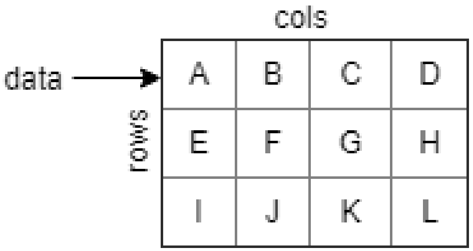
Image basics – Accessing pixels

Use convenience functions for accessing pixels



A	B	C	D
E	F	G	H
I	J	K	L

```
inline void setUint8Pixel(const image_t *img, const int32_t c, const int32_t r, const uint8_pixel_t value)
{
    *((uint8_pixel_t *)(img->data) + (r * img->cols + c)) = value;
}
```

Explicit type cast to pixel type

Calculating the offset

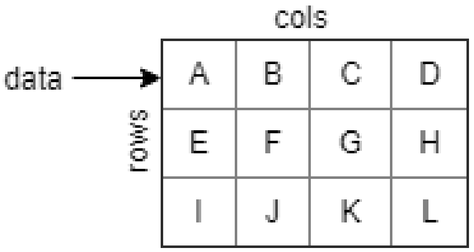
```
inline uint8_pixel_t getUint8Pixel(const image_t *img, const int32_t c, const int32_t r)
{
    return (*((uint8_pixel_t *)(img->data) + (r * img->cols + c)));
}
```

Explicit type cast to pixel type

Calculating the offset

Image basics – Accessing pixels

Use convenience functions for accessing pixels



A	B	C	D
E	F	G	H
I	J	K	L

```
inline void setFloatPixel(const image_t *img, const int32_t c, const int32_t r, const float_pixel_t value)
{
    *((float_pixel_t *)(img->data) + (r * img->cols + c)) = value;
}
```

Explicit type cast to pixel type

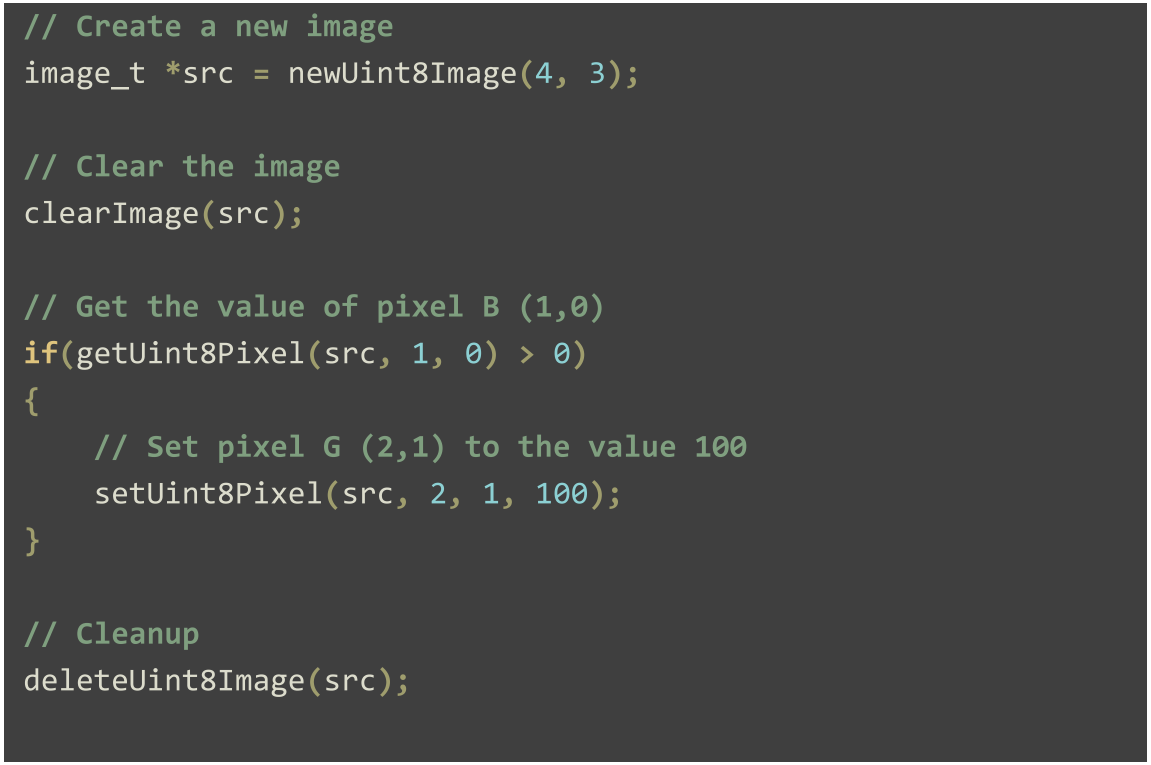
Calculating the offset

```
inline float_pixel_t getFloatPixel(const image_t *img, const int32_t c, const int32_t r)
{
    return (*((float_pixel_t *)(img->data) + (r * img->cols + c)));
}
```

Explicit type cast to pixel type

Calculating the offset

Image basics – Accessing pixels

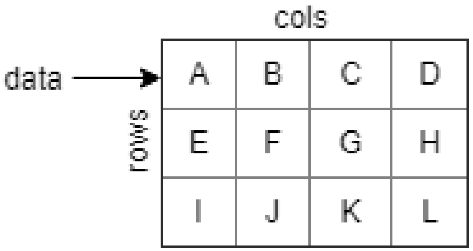


```
// Create a new image
image_t *src = newUint8Image(4, 3);

// Clear the image
clearImage(src);

// Get the value of pixel B (1,0)
if(getUint8Pixel(src, 1, 0) > 0)
{
    // Set pixel G (2,1) to the value 100
    setUint8Pixel(src, 2, 1, 100);
}

// Cleanup
deleteUint8Image(src);
```



A	B	C	D
E	F	G	H
I	J	K	L

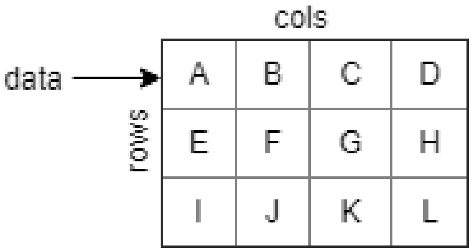
Image basics – Accessing pixels

```
// Create a new image
image_t *src = newFloatImage(4, 3);

// Clear the image
clearImage(src);

// Get the value of pixel B (1,0)
if(getFloatPixel(src, 1, 0) > 0.0f)
{
    // Set pixel G (2,1) to the value 100
    setFloatPixel(src, 2, 1, 100);
}

// Cleanup
deleteFloatImage(src);
```



A	B	C	D
E	F	G	H
I	J	K	L

Anatomy of a project

Target projects

- *For running the image processing pipeline on the microcontroller*

Apps

- *For running the image processing pipeline on the PC (uses OpenCV)*
- *For visualizing images from a target and displaying additional information, e.g. a histogram (uses OpenCV)*

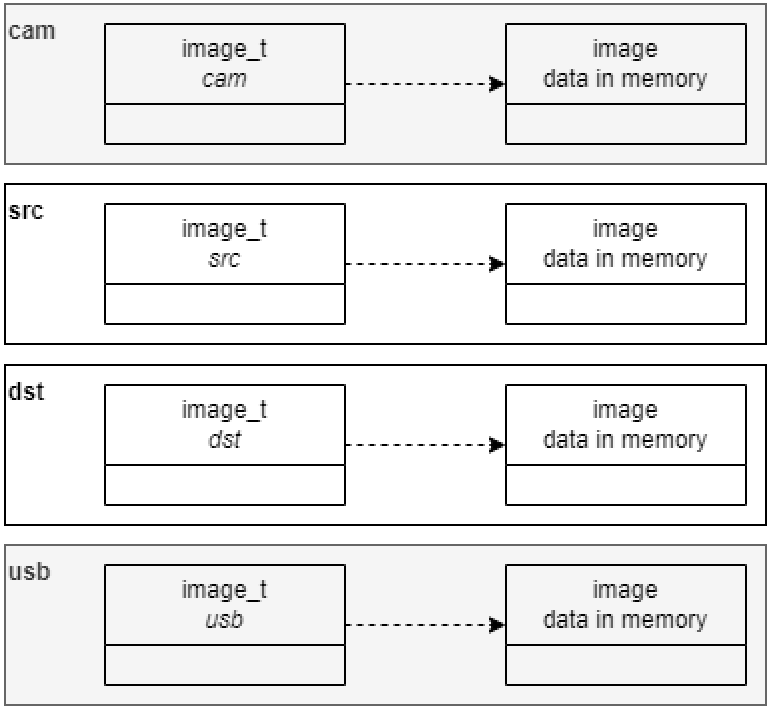
- *For unit testing the individual image processing operators (uses Unity)*

Anatomy of a target project

Mandatory

Optional

Mandatory



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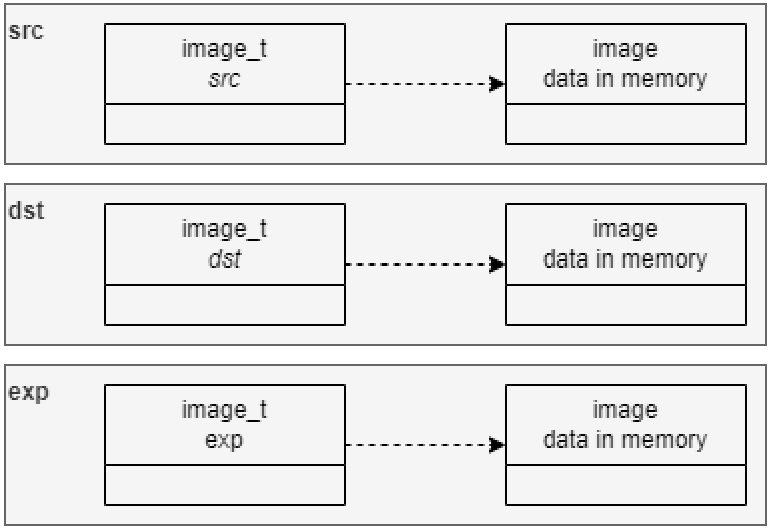
Anatomy of the unit test app project

Mandatory

Mandatory

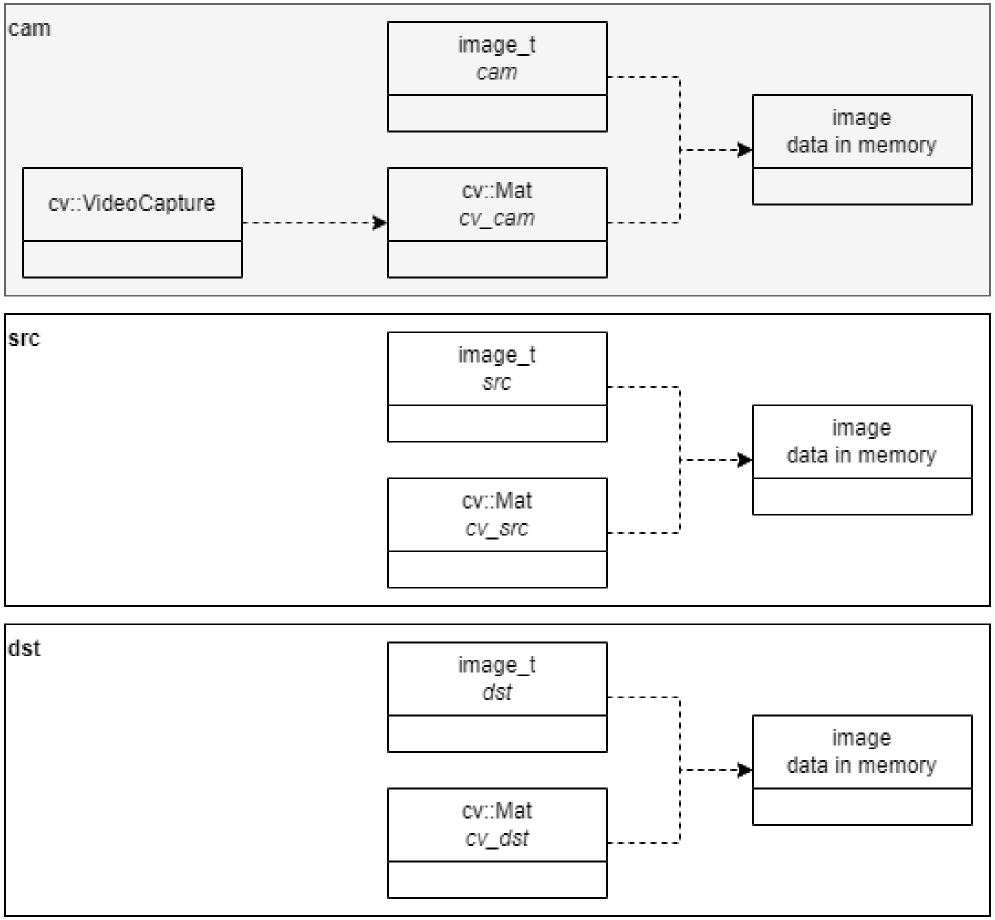
Mandatory



Anatomy of an app project

Mandatory

Optional



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EVD1 – Assignment

Study guide

Week 1

4 Change and run the example project

5 Run OpenCV Webcam app

6 Unit testing