Images

- Another way of viewing a single variable that is a function of two independent variables is to display it as a 2D image.
- The Z, or height, values of the function is encoded by an intensity value or colour.
- The human visual system is highly proficient at interpreting this form of display if the data represents intensity.
- However, the visual system can have difficulty if the data represents some other quantity such as height.
- Images in standard formats such as gif, tiff, and jpeg are stored so that each pixel value lies in the range \([0, 255]\).

Why 0-255

- The range \([0, 255]\) is chosen so that each pixel can be represented by 8 bits (one byte).
  - 0: Black
  - 128: Grey
  - 255: White
- Colour images will typically consist of three 2D arrays in the range \([0, 255]\) for each of the red, green, and blue channels.
- When you read an image into Matlab, Matlab stores the image as a matrix of numbers - each number lies in the range \([0, 255]\).
- To save memory, Matlab uses the type uint8 (an unsigned 8 bit integer which can represent the values \([0, 255]\) only) to represent the numbers in the image matrix.

An Example

```matlab
>> picci = imread('shape1.jpg');
>> whos
Name        Size         Bytes  Class
picci     149x148        22052  uint8 array
>> imagesc(Z);      % Rescale values in array Z to the full range of the current colour map, displaying the contents of the array as an image.
>> axis image;      % Like axis equal - displays the image with the correct aspect ratio.
```
Mathematical Operations on unit8 Data

- Matlab does not allow mathematical operations such as multiplication on data of type uint8 because numerical overflow is very likely.
- If you want perform a mathematical operation to an image, you need to cast it into an array of doubles. For example:
  ```matlab
  >> picci = double(picci); % Cast from uint8 to double.
  >> whos
  Name        Size         Bytes  Class
  picci     149x148       176416  double array
  ```
- Note that the memory used is now 8 times larger. A uint8 uses 8 bits, a double uses 64 bits.
- Note that Matlab's syntax for casting differs from most other languages. For example in Java, C, or C++ you would write:
  ```java
  picci = (double)picci;
  ```

Colour

- Colour is a very interesting quantity in that it is not absolute - it is just a perception that lives in our heads.
- Colour is a function of the dominant wavelength of the light.
- Photometrically, colour is on a linear scale from about 400nm up to 700nm.

Colour wheels

- Perceptually, colour is very different - it is perceived to be a cyclic quantity, not a linear one.
- Colour is often described in terms of the "colour wheel":
  ![Colour Wheel](image)
- Note that red and violet are next to each other and not at distant ends of the spectrum.

Colour Spaces

- There are two main models for representing colour:
  1. The RGB (Red-Green-Blue) model.
  2. The HSV (Hue-Saturation-Value) or HSI (Hue-Saturation-Intensity) model.
**RGB**

- **RGB** represents colour in terms of 3 independent axes - one in each of the primary colours: red, green, and blue.

**An additive model**

- The RGB colour model is an *additive* model.
- The colours present in the light are added to form new colours.

- Red + Green = Yellow
- Red + Blue = Magenta
- Blue + Green = Cyan

**Greyscale**

- The greyscale spectrum lies on the line joining the black and white vertices.

<table>
<thead>
<tr>
<th>0.0 Red + 0.0 Green + 0.0 Blue</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 Red + 0.5 Green + 0.5 Blue</td>
<td>Grey</td>
</tr>
<tr>
<td>1.0 Red + 1.0 Green + 1.0 Blue</td>
<td>White</td>
</tr>
</tbody>
</table>

- The RGB model is used for colour monitors and video cameras.
- The RGB model is the standard representation for colour, although this is starting to change.

**HSV or HSI**

- The HSI model is a perceptual model of colour space.
- Think of it as a 3D elliptical blob:
  - The central vertical axis – the greyscale, with intensity (brightness) varying from 0 (black) at the bottom to 1 (white) at the top.
  - The angle around the "equator" – the hue value (red, orange, yellow, green, blue, indigo, violet, and back to red again).
  - The axis radially outwards from the central vertical axis – the saturation (purity – how little the colour is diluted by white light) of the colour.
The HSV model

- At the perimeter (with saturation 1), we have "solid" colours.
- As we move inwards, we obtain the "pastel" colours.
- At the central axis (with saturation 0), we have no colour - just a grey value.
- Specifying a colour in terms of hue, saturation, and intensity is much easier and more intuitive than working in RGB.
- However, graphics systems prefer colour specified in terms of RGB because hardware is built around this model.
- The conversion between HSV and RGB is quite complicated.
- Matlab provides conversion functions for you:

```matlab
>> rgb2hsv                  % Convert from RGB to HSV.
>> hsv2rgb                  % Convert from HSV to RGB.
```

Variation comparison of HSI

- Hues
- Saturation
- Intensity

Colour maps

- A colour map is simply a table of colours specified in terms of red, green, and blue components.
- The contents of the colour table is arbitrary.
- A colour map allows you to map a single number into a colour.
- For example, when you display an image, the value of each pixel is used as an index into the colour map.
- If a pixel has a value of 55, the colour that the pixel is displayed as will simply be whatever is in the corresponding entry of the colour table.

Colour Maps in Matlab

- Matlab provides a number of colour maps and functions for generating colour maps:

```matlab
>> colormap(gray)         % The gray colour map is a 64 x 3 array of RGB values giving a greyscale.
>> colormap(hot)          % The hot colour map is a set of RGB values providing a set of temperature colours: black-red-yellow-white.
>> gray(8)                % Make a grey colour map with 8 entries.
ans =
    0         0         0 % Black
    0.1429    0.1429    0.1429 % Dark grey
    0.2857    0.2857    0.2857
    0.4286    0.4286    0.4286
    0.5714    0.5714    0.5714 % Light grey
    0.7143    0.7143    0.7143
    0.8571    0.8571    0.8571
    1.0000    1.0000    1.0000 % White
```

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Colour Map in Matlab

```matlab
>> hot(8)               % Make a hot colour map
% with 8 entries.
ans =
0.3333        0        0  % Dark red
0.6667        0        0
1.0000        0        0  % Red
1.0000  0.3333        0
1.0000  0.6667        0
1.0000  1.0000        0  % Yellow
1.0000  1.0000  0.5000
1.0000  1.0000  1.0000  % White
```

- Note that the `imagesc` function rescales image values to the full range of the current colour map so that all the pixel values get fully "spread" across the colour map.
- The function `image` uses the pixel values directly to lookup colour values from the colour map.
- Type `help graph3d` at the Matlab command prompt for a full list of the colour maps that Matlab provides.

Hue for cyclic data

- We said earlier that perceptually colour is cyclic.
- Actually, it is just the hue component that is cyclic.
- The saturation and intensity axes are perceived as linear.
- Therefore, if you have a property that is cyclic, then the most appropriate way to represent it is with hue.

Greyscale not suitable for cyclic data

- If you try to represent something cyclic via a greyscale, you get a nasty discontinuity at the wrap-around point.

<table>
<thead>
<tr>
<th>Red</th>
<th>Grey</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Variations in intensity or saturation level should be used to indicate the level of some quantity that changes along a linear scale.

Colour for region classification

- Note also that we tend to view different colours (hues) as indicating different classifications of regions.
- The classic example is on maps:
Use colour wisely

• If you were to look at the same map which only displayed altitude above sea level as a grey value, then your perception of the map would be very different.

• Depending on the context, the presence of different colours (hues) can be either be an aid, or a distraction, in the visualisation of data.