Module 17: Neural Networks and Deep Learning: Part Three: Convolutional Neural Networks

Learning outcomes:

1. Describe the structure and function of convolutional and pooling layers in CNNs.
2. Implement a CNN for image classification using a provided data set.
3. Modify CNN architecture or preprocessing steps to improve model performance.
4. Evaluate CNN performance using accuracy metrics and visual inspection of outputs.
5. Interpret when CNNs are appropriate for solving business problems.

Convolutional neural networks (CNNs)

CNNs are a class of deep learning models designed to work with grid-like data such as images, audio spectrograms or sensor readings. Inspired by the human visual cortex, CNNs process data in layers that detect increasingly complex features – from edges and textures to full objects.

Core building blocks of CNNs

- **Convolutions:** apply small, learnable filters to extract local patterns such as edges or shapes.
- **Pooling layers:** downsample feature maps to reduce size and highlight key features.
- **Activation functions:** introduce non-linearity (commonly, ReLU).
- **Fully connected layers:** combine features for classification or regression outputs.

Why CNNs?

- **Efficiency:** weight-sharing reduces the number of parameters compared with fully connected networks.
- **Performance:** capture spatial hierarchies of features, improving accuracy in vision tasks.
- **Versatility:** extend beyond images to audio, time series, medical scans and more.

Training and evaluation

1. **Training workflow:**
    - Load and preprocess data (normalisation, augmentation).
    - Define architecture (convolution → pooling → dense).
    - Optimise with stochastic gradient descent (SGD) or Adam to minimise loss.
2. **Evaluation tools:**
    - Accuracy is a measure of overall model performance.
    - A confusion matrix is a tool for identifying which classes are confused.
    - Per-class accuracy is a measure of strengths and weaknesses across categories.
    - Visual inspection of misclassified samples is a method for revealing model limitations.

Applications and business context

CNNs power a wide range of real-world systems:

- **Healthcare:** analysing X-rays and MRI scans
- **Manufacturing:** detecting product defects on assembly lines
- **Retail:** automated product categorisation and visual search
- **Transportation:** vision systems for self-driving cars
- **Finance:** detecting fraudulent activity in image-like transaction patterns

Tip: CNNs are the most effective when the data has spatial or grid-like structure. For purely tabular or sequential data, other models (e.g. gradient boosting, RNNs, transformers) may be more appropriate.