Part I

Introduction to TensorFlow

Fundamentals

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Introduction to TensorFlow

- Main objectives:
  - Get to know the underlying concepts
  - Get to know the provided functionality

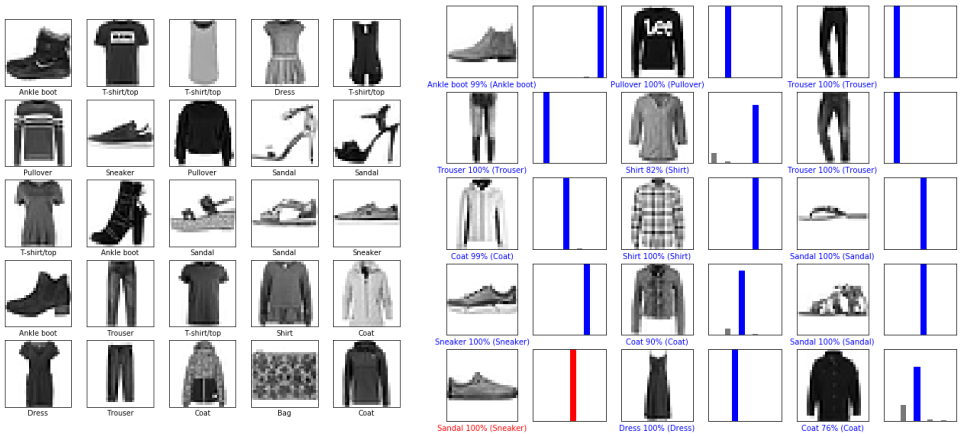
- Try it out **yourselves**!
  - Several notebooks
  - Programming assignments
  - Online resources

Introduction to TensorFlow

Examples

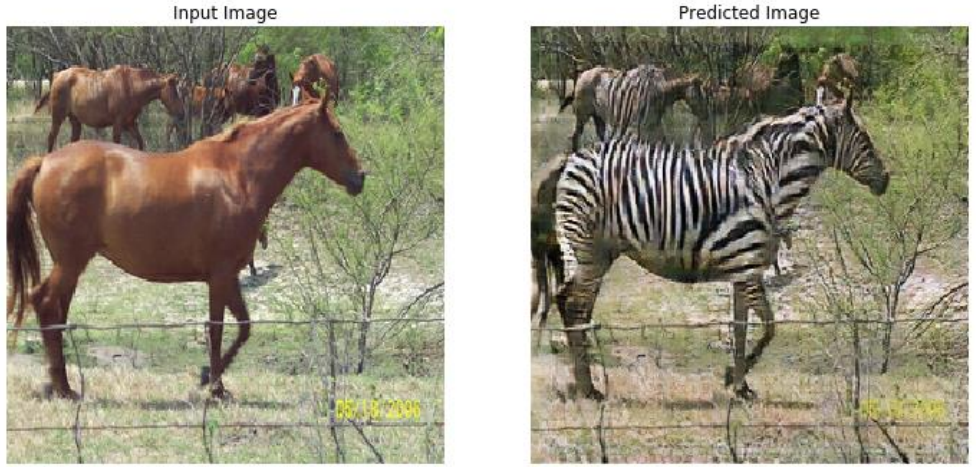
Image Classification

CNN



Unpaired Image Translation

Cycle GAN

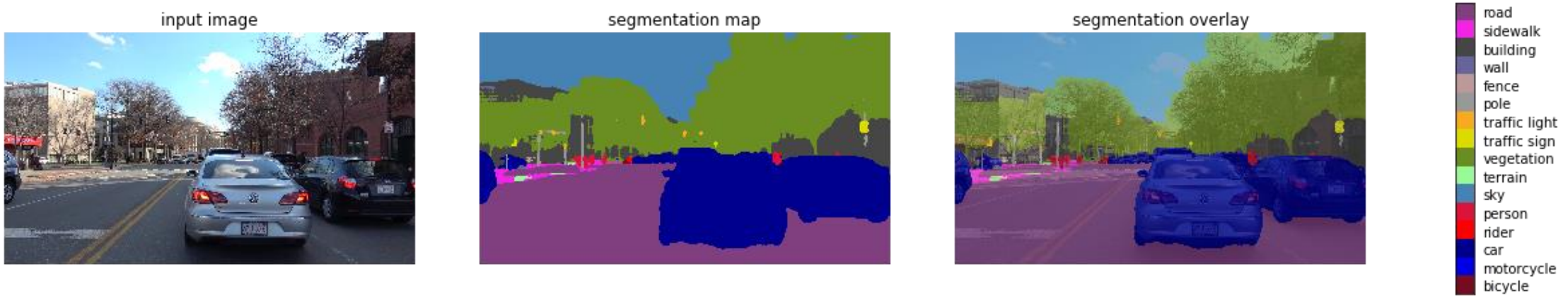


Introduction to TensorFlow

Examples

Image Segmentation

DeepLabv3+ & MobileNetV2 backbone



- … many more examples could be shown

  Natural Language Processing, Style Transfer, Object Detection/Tracking

- All shown examples are available to **you**, without any setup required!

Why TensorFlow?

- Framework for Deep Learning Models
- Fast prototyping for research
- **Not** just a research tool

  Robust model deployment in production on any platform

→ see https://www.tensorflow.org/about/case-studies

Agenda – Fundamentals

- Development Environments
- Scripting Language
- Automatic Differentiation
- TensorFlow Basics

Development Environments

Jupyter Notebook

- Web IDE with executable documents

Google Colab

- Jupyter notebook stored on Google Drive
- Free Access to GPUs / no setup / runs in the cloud
- Go to https://colab.research.google.com (15 GB of free GPU space)

PyCharm

- Provides advanced IDE features

Scripting language

- General purpose language
- Domain specific modules
- Has become the most popular language (for scientific programming)
- Language gets improved continuously

Python

Python as a Programming Language

- Intuitive Scripting Language
- Fully object oriented
- Interpreted language
- Duck typing
- A natural wrapper for C/C++ code
- Main wrapper for several DL frameworks
- Multiple development environments to choose from (PyCharm, Spyder)

Python

Python as an eco system

- Package manager (pip) and Package Index (PyPI)
- NumPy
- SciPy
- matplotlib
- Scikit-learn
- Pandas
- OpenCV-python
- …

Python Basics

Refresher – *see lecture slides for Python introduction*

- Built-in data types
  - floating point (*float*)
  - integer (*int*)
  - unsigned integer (*uint*)
  - string (*string*)
  - boolean (*bool*)

- Collections
  - *dictionary*
  - *tuple*
  - *list*
  - *set*

- There are no built-in arrays

  → NumPy provides n-d array support
  - Matrix operations implemented in C
  - Callable via python functions

Python Basics

A few remarks

- Python differentiates between
  - Iterables
    range, list, tuple – i.e. you can iterate over it
  - Iterators
    Agent that performs iteration, e.g. a *for*-loop provides you with an implicit iterator

- *With* context manager

```
with open('my_file.txt', 'r') as file_:
    for line in file_:
        print(line)
```

- Package imports

```
import tensorflow as tf
from tensorflow import keras
import numpy as np
```

Python Basics

Functions and Classes

- Functions

```
def my_func(a, b=0):

    c = a + b

    return c
```

- Classes

```
class MyClass(ParentClass):
    def __init__(self, value, purpose=None):
        super().__init__()  # call parent constructor

        self.value = value
        self.purpose = purpose

    def get_purpose(self):
        return self.purpose

    def store_something(self, x):
        self.value = x
```

Automatic Differentiation

Backpropagation

- Algorithm to train Deep Learning models
- How to calculate the gradient for each component?
  - (two-sided) finite differences

$$\frac{\partial}{\partial x_i} f(x_1, \ldots, x_N) = \lim_{h \to 0} \frac{f(x_1, \ldots, x_i + h, \ldots, x_N) - f(x_1, \ldots, x_i - h, \ldots, x_N)}{2h}$$

  - symbolic differentiation

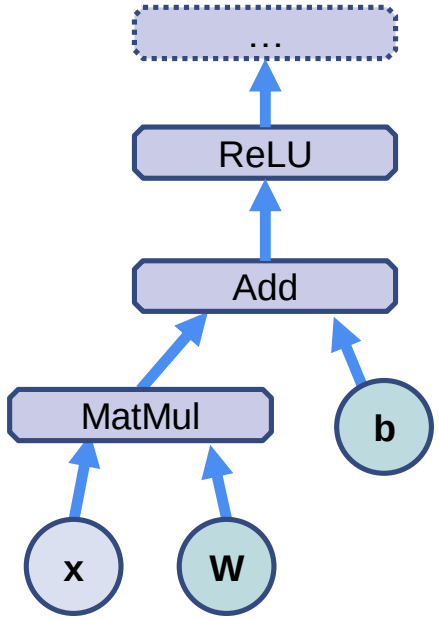
$$f(x) = \frac{1}{e^{-x} + 1} \rightarrow \frac{df(x)}{dx} = \frac{e^{-x}}{(e^{-x} + 1)^2} = f(x)(1 - f(x)$$

  - automatic differentiation:

    numerically stable and efficient

Automatic Differentiation

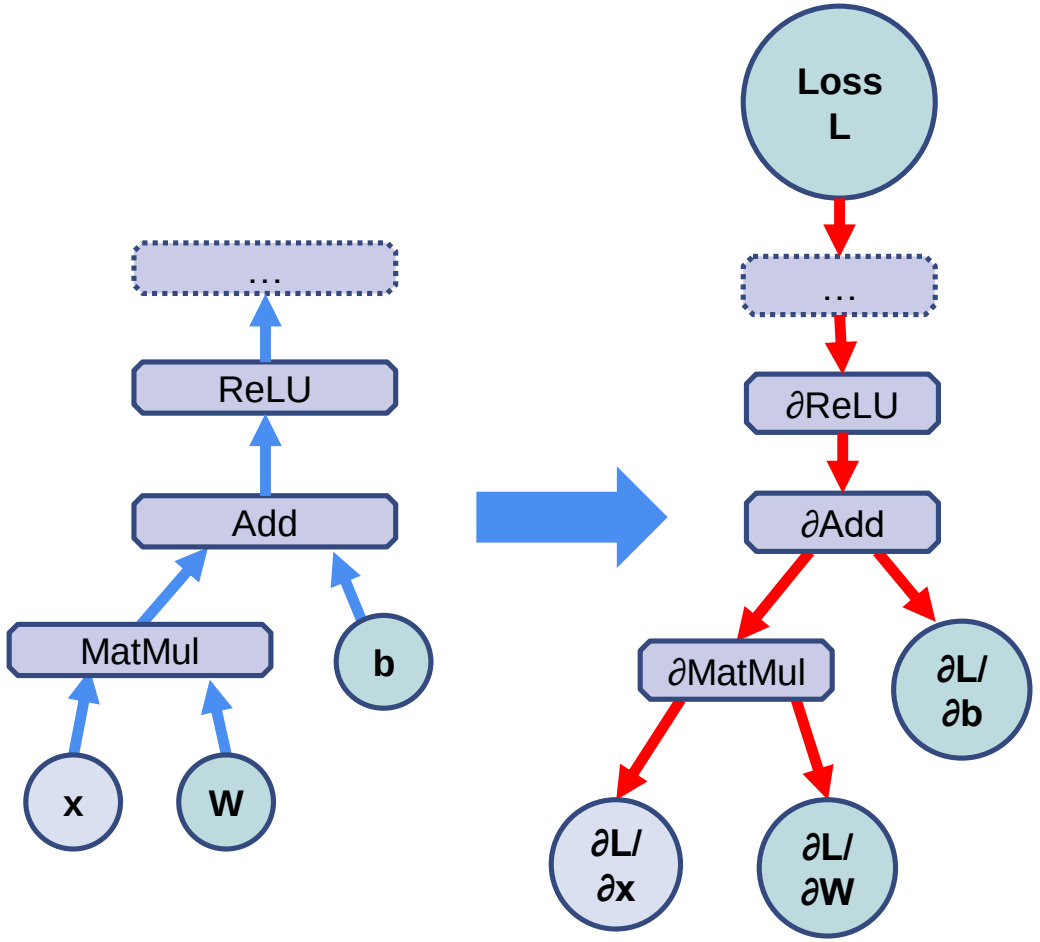
- **Main idea:** Computations are represented as graphs
  - Nodes are the operations (ops)
  - Edges are the data tensors (multidimensional arrays)
- Low-level programming model
- Automatic Differentiation
  - Assembling a computation graph
  - Applying backprop updates
  - Enables complex architectures / No derivatives calculated by hand



Automatic Differentiation

Reverse Mode Automatic Differentiation

- Forward pass
  - Edge values are generated (data tensors)
  - Values are recorded to a **tape**
- Backward Pass
  - Chain rule is applied step by step
  - Intermediate results are used in the next step



Notebook - AutoDiff

Automatic Differentiation

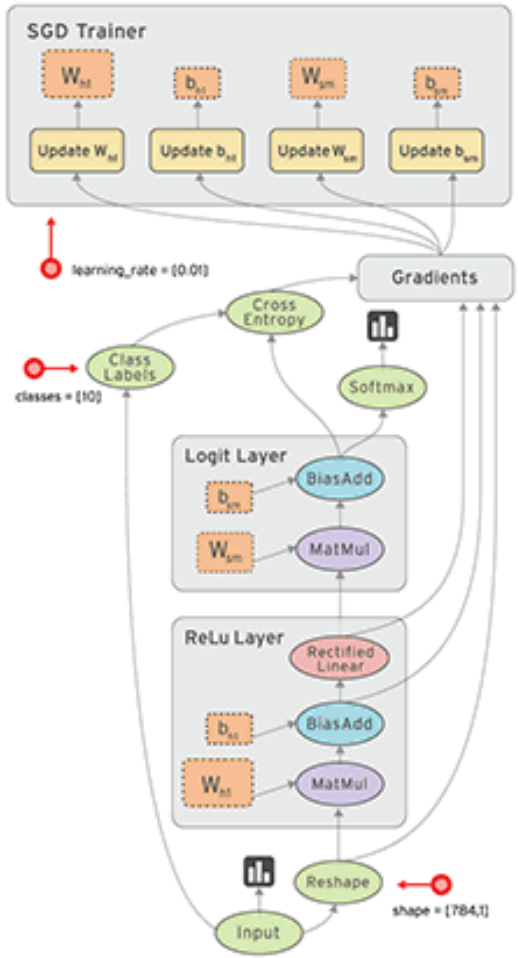
- Environment basics: Jupyter Notebook / Google Colab
- Underlying concept used for backpropagation
- Calculating losses for computational graphs
- Using Autograd

→ **see intro_nb_autodiff.ipynb**

TensorFlow Basics

Data flow graphs

- **TensorFlow** provides the API for generation of such graphs
- Typical program consisted of 2 phases (TF 1.0):
  - Construction phase: assembling a graph (model)
  - Execution phase: pushing data through the graph
- Computations defined as a Directed Acyclic Graph (DAG)
  - Graph is defined in high-level language
  - Graph is compiled and optimized



TensorFlow Basics

Data flow graphs are also

- “slow” because of overhead
- difficult to debug
- not “pythonic”

Solution: Eager Execution

- Evaluate operations immediately (PyTorch, TF2.0)
- No separate graph construction and execution

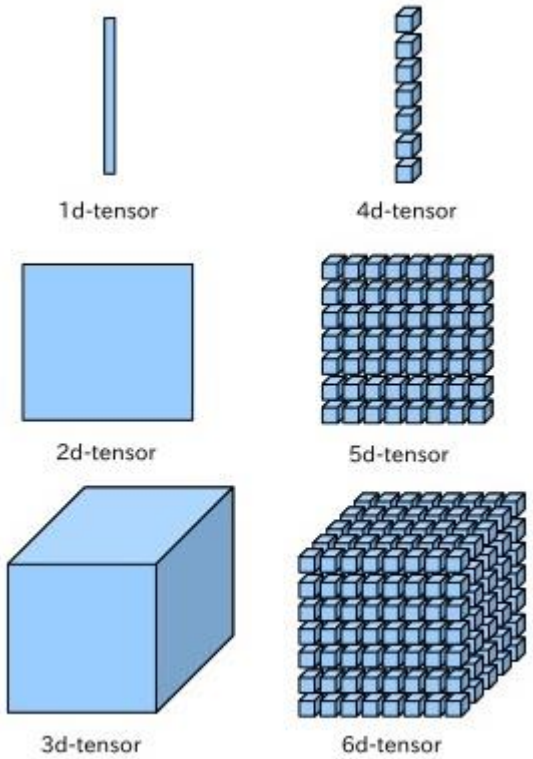
TensorFlow Basics

Tensors

- A tensor may be represented as multidimensional array (n-d array)
- Tensors are basis independent and can be formulated as multilinear map of two vector spaces *V** and *V*:

$$f : \underbrace{V^* \times \cdots V^*}_{p \text{ copies}} \times \underbrace{V \times \cdots V}_{q \text{ copies}} \to \mathbb{R}$$

- For fixed basis, tensors representation as n-d array is sufficient

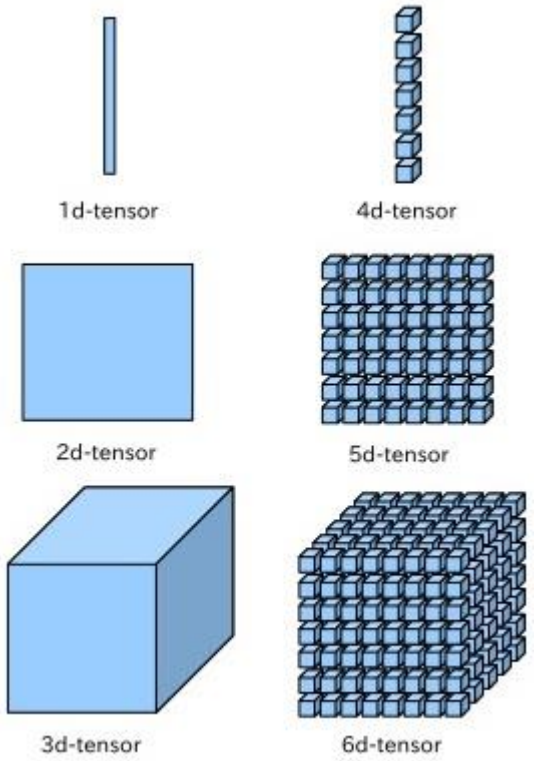


source: https://blog.knoldus.com/

TensorFlow Basics

TensorFlow Tensor

- Basic data structure
- Only one data type per tensor!
- *tf.variable* supports similar syntax to NumPy
- Identical data types to NumPy, i.e. *tf.float32 == np.float32*
- **NumPy Compatibility** – seamless conversion / call *a.numpy()*
- Rank of a tensor:
  - Scalar rank 0 (0th-order tensor)
  - Vector rank 1
  - Matrix rank 2
  - Tensor rank >=3
  - **Rank: order of the tensor == NumPy *ndim***



source: https://blog.knoldus.com/

TensorFlow Basics

What is TensorFlow?

C++ backend with functionality callable by Python frontend

+ Automatic Differentiation

+ Data Flow Graphs

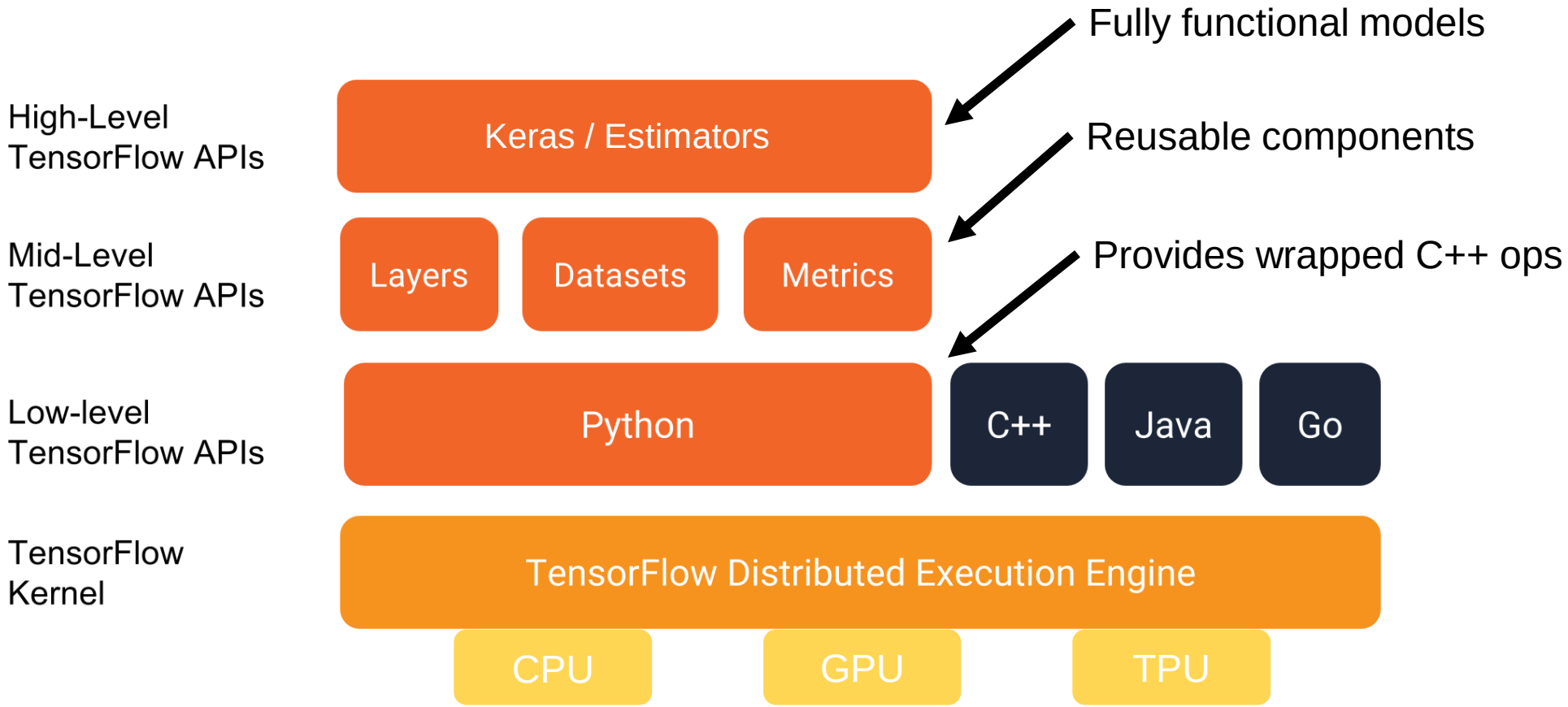
+ DL functionality (Optimizers, Losses, Layers, …)

+ Utilities (I/O, data pipeline, …)

+ Portability / Distribution (CPU, GPU, TPU)

TensorFlow Basics

Underlying Structure



Notebook – Machine Learning

Machine Learning example using TensorFlow

- Syntax examples: NumPy vs TensorFlow
- Automatic Differentiation with TensorFlow
- Linear and Polynomial Regression in TensorFlow

→ **see intro_nb_ml.ipynb**

TensorFlow API

- TensorFlow website provides you with rich information
- API can be easily navigated and is searchable
- Head over to https://www.tensorflow.org/api_docs/python/tf