Lecture 3: Advanced object-oriented programming

- Programming paradigms
- The motivation for OOP
- Advanced concepts: `__special__` methods, class attributes, class methods, static methods
- Inheritance: class hierarchies, abstract classes and methods

Who am I?

- 2021: BA Computational Linguistics and Comparative Linguistics
- 2024 (🤞): MA Computational Linguistics and Neuroinformatics
- Text simplification research @ UZH
- Teaching @ UZH & ZB
- Previously: web development @ Idiotikon (Swiss German dictionary)

andreas@cl.uzh.ch

Learning objectives

By the end of this lecture, you should:

- Understand the characteristics and advantages of OOP
- Be able to design and implement your own classes
- Understand what inheritance is and what problems it solves
- Understand the concepts of *class attributes/methods*, *parent/child classes*, *abstract classes/methods*, and know their syntax in Python
- Be able to understand and extend existing class hierarchies
- Be able to design and implement your own class hierarchies

Refer to the OOP cheat sheet on OLAT! We will expect you to understand these concepts at the midterm exam.

Quiz: OOP basics

pwa.klicker.uzh.ch/join/asaeub

Programming paradigms

- Most problems can be solved in many different *ways*
- A programming paradigm is a *way of programming*
- Programming paradigms are often used to characterize different programming languages

Example using functional programming

In [ ]:

```
def simulate_years(balance: float, interest_rate: float, num_years: int) -> float:
    for _ in range(num_years):
        balance = balance * (1 + interest_rate)
    return balance
```

Example using functional programming

In [ ]:
```
def simulate_years(balance: float, interest_rate: float, num_years: int) -> float:
    for _ in range(num_years):
        balance = balance * (1 + interest_rate)
    return balance
```

In [ ]:
```
my_balance = 1000.00
my_interest_rate = 0.01

print("My current balance is: ", my_balance)
my_balance = simulate_years(my_balance, my_interest_rate, 10)
print("After 10 years, my balance will be: ", my_balance)
my_balance = simulate_years(my_balance, my_interest_rate, 10)
print("After 10 more years, my balance will be: ", my_balance)
```

Example using object-oriented programming

In [ ]:

```
class BankAccount:
    def __init__(self, balance: float, interest_rate: float):
        self.balance = balance
        self._interest_rate = interest_rate

    def simulate_years(self, num_years: int) -> None:
        for _ in range(num_years):
            self.balance = self.balance * (1 + self._interest_rate)
```

Example using object-oriented programming

In [ ]:
```python
class BankAccount:
    def __init__(self, balance: float, interest_rate: float):
        self.balance = balance
        self._interest_rate = interest_rate

    def simulate_years(self, num_years: int) -> None:
        for _ in range(num_years):
            self.balance = self.balance * (1 + self._interest_rate)
```

In [ ]:
```python
my_account = BankAccount(1000.00, 0.01)
print("My current balance is: ", my_account.balance)
my_account.simulate_years(10)
print("After 10 years, my balance will be: ", my_account.balance)
my_account.simulate_years(10)
print("After 10 more years, my balance will be: ", my_account.balance)
```

Features of object-oriented programming

Encapsulation:

- State is handled inside the object
- State can be hidden from the user

Mutability:

- The object's state can be modified

Interface:

- The methods tell us what we can do with the object

Inheritance:

- Sharing code between classes with similar functionality

Features of functional programming

Pure functions:

- Functions don't have side-effects (same input → same output)

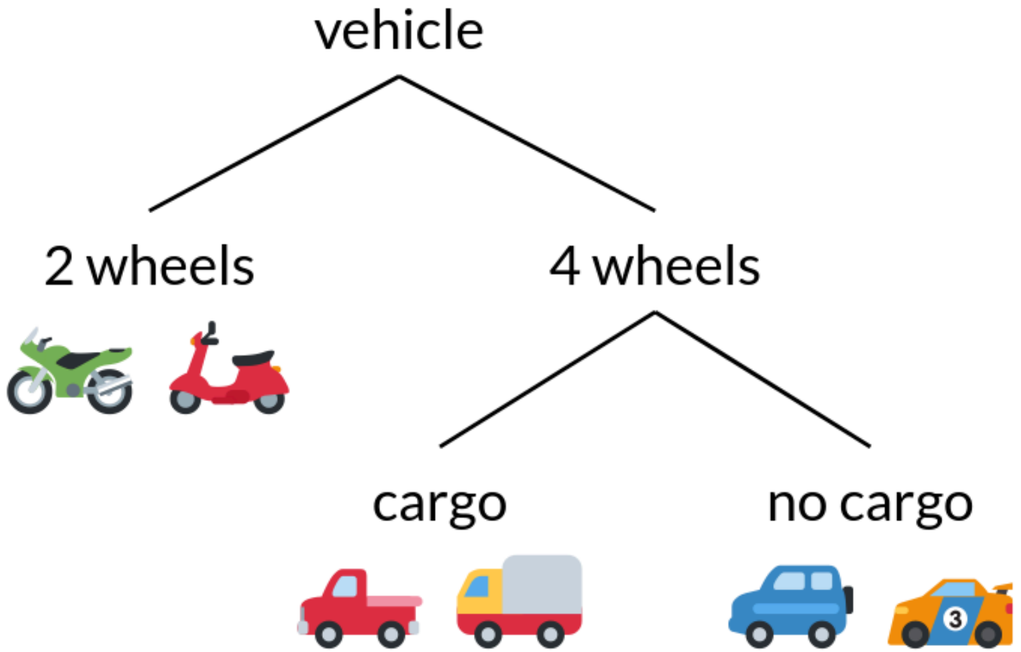
Immutability:

- Objects cannot be modified
- To modify state, create new objects and discard the old ones

Composition:

- Splitting functions into small, independent units (great for unit tests!)
- Maximizing reusability of functions

The intuition behind OOP



Two types of classes

Classes that **store data** (in attributes):

- a corpus
- a dictionary
- a chat conversation
- ...

Classes that **do things** (with methods):

- a tokenizer
- a search engine
- a machine translation system
- ...

(plus: classes that do both)

Example implementation: Word-by-word translation

In [ ]:

```
dictionary = {
    "hello": "hallo",
    "world": "Welt",
}

def translate(sentence: str, dictionary: dict):
    tokens = sentence.split()
    translation = " ".join(dictionary.get(token, token) for token in tokens)
    return translation

print(translate("hello world !", dictionary))
```

We will design two classes:

- `WordByWordTranslator`: can translate text from one language to another
- `ParallelDataset`: can store parallel texts in two languages (e.g., for training or evaluation)

We will design two classes:

- `WordByWordTranslator`: can translate text from one language to another
- `ParallelDataset`: can store parallel texts in two languages (e.g., for training or evaluation)

We will get to know the following concepts along the way:

- Encapsulation, public interfaces
- `__special__` methods
- Class methods
- Class attributes
- Properties

`ParallelDataset` class

In [ ]:

```python
from typing import Sequence, Iterator

class ParallelDataset:
    def __init__(self, source: Sequence[str], target: Sequence[str]):
        self._source = source
        self._target = target

    def get_parallel_item(self, index: int) -> tuple[str, str]:
        return self._source[index], self._target[index]
```

Encapsulation

- The **underlying data structure** is hidden from the user.
- The user interacts with the object through a **public interface**.
- Methods and attributes starting with an underscore `_` are considered **private**.
- Private methods and attributes *should* not be accessed from outside the class (but nothing prevents you from doing so).

Encapsulation

- The **underlying data structure** is hidden from the user.
- The user interacts with the object through a **public interface**.
- Methods and attributes starting with an underscore `_` are considered **private**.
- Private methods and attributes *should* not be accessed from outside the class (but nothing prevents you from doing so).

In [ ]:
```
dataset_de_en = ParallelDataset(
    ["hello world !", "this is a test"],
    ["hallo Welt !", "das ist ein Test"],
)
dataset_de_en.get_parallel_item(0)
```

Special methods

Special methods define how objects implement certain operations and functionalities which are built into Python's syntax, for example:

- `__init__()`: called when an object is **constructed** using `ClassName()`
- `__str__()`: called when an object is **converted to a string** using `str(obj)`
- `__lt__(other)`: called when an object is compared using `<` (less-than operator)
- `__gte__(other)`: called when an object is compared using `>=` (**greater-than-or-equal operator**)
- `__getitem__(index)`: called when an object is **indexed** using `obj[index]`
- `__iter__()`: called when an object is converted to an iterator (e.g. by using it in a `for` loop)

In [ ]:

```
class ParallelDataset:
    def __init__(self, source: Sequence[str], target: Sequence[str]):
        self._source = source
        self._target = target

    def __getitem__(self, index: int) -> tuple[str, str]:
        # Enables indexing with []
        return self._source[index], self._target[index]

    def __len__(self) -> int:
        # Enables len()
        return len(self._source)

    def __iter__(self) -> Iterator[tuple[str, str]]:
        # Enables iteration in for loops
        for i in range(len(self)):
            yield self[i]
```

In [ ]:

```
dataset_de_en = ParallelDataset(
    ["hello world !", "this is a test"],
    ["hallo Welt !", "das ist ein Test"],
)

print(dataset_de_en[0])
print(len(dataset_de_en))
for source, target in dataset_de_en:
    print(source, target)
```

Class methods and static methods

Instance method	`class MyClass:`
	`    def my_method(self):`
	`        ...`
		`my_obj.my_method()`

Class method	`class MyClass:`
	`    @classmethod`
	`    def my_method(cls):`
	`        ...`
		`MyClass.my_method()`
		`my_obj.my_method()`

Static method	`class MyClass:`
	`    @staticmethod`
	`    def my_method():`
	`        ...`
		`MyClass.my_method()`
		`my_obj.my_method()`

(from the OOP cheat sheet on OLAT)

Class methods are often used as an "alternative constructor":

In [ ]:

```
class ParallelDataset:
    def __init__(self, source: Sequence[str], target: Sequence[str]):
        self._source = source
        self._target = target

    @classmethod
    def load(cls, source_filename: str, target_filename: str) -> "ParallelDataset":
        with open(source_filename) as f:
            source = [line.strip() for line in f]
        with open(target_filename) as f:
            target = [line.strip() for line in f]
        return cls(source, target)

    def __getitem__(self, index: int) -> tuple[str, str]:
        # Enables indexing with []
        return self._source[index], self._target[index]

    def __len__(self) -> int:
        # Enables len()
        return len(self._source)

    def __iter__(self) -> Iterator[tuple[str, str]]:
        # Enables iteration in for loops
        for i in range(len(self)):
            yield self[i]
```

In [ ]:

```
dataset = ParallelDataset.load("translation/test.src", "translation/test.trg")

list(dataset)
```

Quiz: encapsulation

pwa.klicker.uzh.ch/join/asaeub

`WordByWordTranslator` class

In [ ]:

```python
import sacrebleu

class WordByWordTranslator:
    def __init__(self, dictionary: dict[str, str]):
        self._dictionary = dictionary

    def translate(self, text: str) -> str:
        tokens = text.split()
        translation = " ".join(self._dictionary.get(token, token) for token in tokens)
        return translation

    def evaluate(self, dataset: ParallelDataset) -> float:
        translations = [self.translate(source) for source, _ in dataset]
        targets = [target for _, target in dataset]
        return sacrebleu.corpus_bleu(translations, [targets]).score

    @classmethod
    def load(cls, filename: str) -> "WordByWordTranslator":
        with open(filename) as f:
            dictionary = dict(line.strip().split("\t") for line in f)
        return cls(dictionary)
```

In [ ]:
```
translator = WordByWordTranslator.load("translation/en-de.tsv")
translator.translate("this is a test")
```

In [ ]:
```
translator.evaluate(dataset)
```

Classes can wrap very different implementations into a common public interface.

`GoogleTranslator` class

In [ ]:

```python
import googletrans

class GoogleTranslator:
    def __init__(self, source_lang: str, target_lang: str):
        self.source_lang = source_lang
        self.target_lang = target_lang
        self._translator = googletrans.Translator()

    def translate(self, text: str) -> str:
        translation = self._translator.translate(
            text, src=self.source_lang, dest=self.target_lang
        )
        return translation.text

    def evaluate(self, dataset: ParallelDataset) -> float:
        translations = [self.translate(source) for source, _ in dataset]
        targets = [target for _, target in dataset]
        return sacrebleu.corpus_bleu(translations, [targets]).score
```

In [ ]:

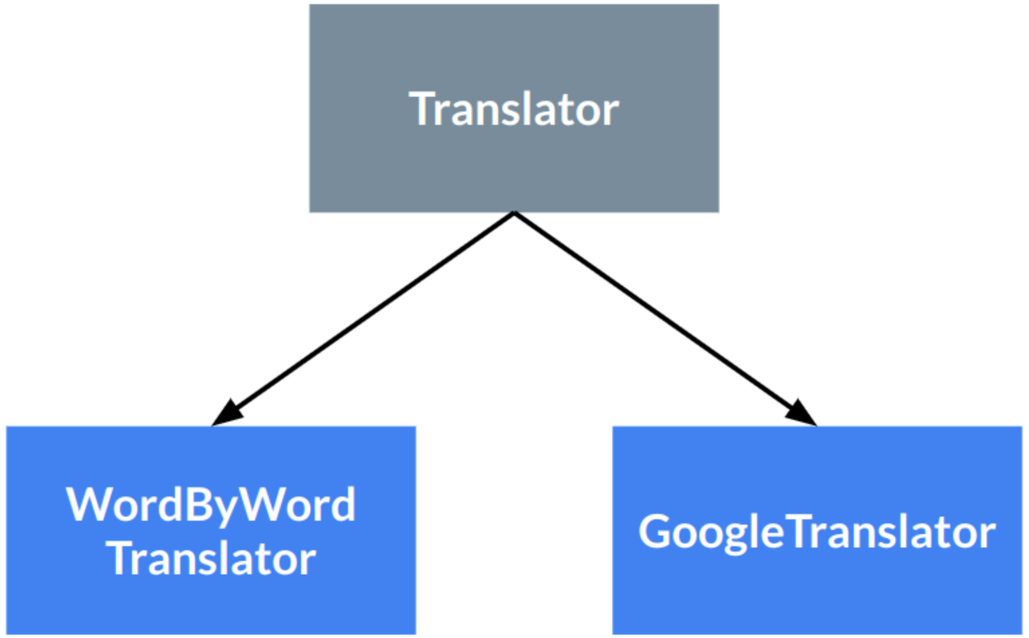
```
translator1 = WordByWordTranslator.load("translation/en-de.tsv")
translator2 = GoogleTranslator("en", "de")

print(translator1.translate("this is a test"))
print(translator2.translate("this is a test"))

print(translator1.evaluate(dataset))
print(translator2.evaluate(dataset))
```

Inheritance

- **Inheritance** allows us to share code and interfaces between similar classes.
- **Child classes** inherit all methods and attributes from their **parent class**.



Superclass / parent class	`class Parent:`
	`    def my_method(self):`
	`        ...`

Subclass / child class	**`class Child(Parent):`** `    pass`

`super()`	`class Child(Parent):`
	`    def my_method(self):`
	`        **super().my_method()**`
	`        ...`

(from the OOP cheat sheet on OLAT)

Parent class

In [ ]:

```
class Translator:
    def __init__(self, source_lang: str, target_lang: str):
        self.source_lang = source_lang
        self.target_lang = target_lang

    def evaluate(self, dataset: ParallelDataset) -> float:
        translations = [self.translate(source) for source, _ in dataset]
        targets = [target for _, target in dataset]
        return sacrebleu.corpus_bleu(translations, [targets]).score
```

Child classes

In [ ]:

```python
import re

class WordByWordTranslator(Translator):
    def __init__(self, dictionary: dict[str, str], source_lang: str, target_lang: str):
        super().__init__(source_lang, target_lang)
        self._dictionary = dictionary

    def translate(self, text: str) -> str:
        tokens = text.split()
        translation = " ".join(self._dictionary.get(token, token) for token in tokens)
        return translation

    @classmethod
    def load(cls, filename: str) -> "WordByWordTranslator":
        source_lang, target_lang = re.search(r"([a-z]+)-([a-z]+).tsv", filename).groups()
        with open(filename) as f:
            dictionary = dict(line.strip().split("\t") for line in f)
        return cls(dictionary, source_lang, target_lang)
```

In [ ]:
```python
class GoogleTranslator(Translator):
    def __init__(self, source_lang: str, target_lang: str):
        super().__init__(source_lang, target_lang)
        self._translator = googletrans.Translator()

    def translate(self, text: str) -> str:
        translation = self._translator.translate(
            text, src=self.source_lang, dest=self.target_lang
        )
        return translation.text
```

In [ ]:
```python
translator1 = WordByWordTranslator.load("translation/en-de.tsv")
translator2 = GoogleTranslator("en", "de")

print(translator1.translate("this is a test"))
print(translator2.translate("this is a test"))
```

In [ ]:
```python
print(translator1.evaluate(dataset))
print(translator2.evaluate(dataset))
```

Abstract classes

- Prevent the user from instantiating a parent class
- Force all subclasses to implement certain methods

Abstract class
Abstract method
	`from abc import ABC, abstractmethod`
	
	`class AbstractParent(ABC):`
	`  @abstractmethod`
	`  def my_abstract_method(self):`
	`  pass`

(from the OOP cheat sheet on OLAT)

In [ ]:

```python
from abc import ABC, abstractmethod

class Translator(ABC):
    def __init__(self, source_lang: str, target_lang: str):
        self.source_lang = source_lang
        self.target_lang = target_lang

    @abstractmethod
    def translate(self, text: str) -> str:
        pass

    def evaluate(self, dataset: ParallelDataset) -> float:
        translations = [self.translate(source) for source, _ in dataset]
        targets = [target for _, target in dataset]
        return sacrebleu.corpus_bleu(translations, [targets]).score
```

In [ ]:
```
translator = Translator("en", "de")
```

In [ ]:
```
translator = Translator("en", "de")
```

In [ ]:
```
class IncompleteTranslator(Translator):
    pass

translator = IncompleteTranslator("en", "de")
```

Quiz: inheritance

pwa.klicker.uzh.ch/join/asaeub

Class attributes

- Shared between all instances of a class
- Can be overridden in child classes

Instance attribute	`class MyClass:`
	`  def __init__(self):`
	`  **self.my_attribute = ...`**
		`my_obj.my_attribute`

Class attribute	`class MyClass:` `  **my_attribute = ...`**	`MyClass.my_attribute` `my_obj.my_attribute`

(from the OOP cheat sheet on OLAT)

Class attributes are often used to store class-specific constants:

In [ ]:
```
class Translator(ABC):
    requires_network = False
    ...

class WordByWordTranslator(Translator):
    ...

class GoogleTranslator(Translator):
    requires_network = True
    ...
```

Class attributes are often used to store class-specific constants:

In [ ]:
```
class Translator(ABC):
    requires_network = False
    ...

class WordByWordTranslator(Translator):
    ...

class GoogleTranslator(Translator):
    requires_network = True
    ...
```

In [ ]:
```
WordByWordTranslator.requires_network
```

In [ ]:
```
GoogleTranslator.requires_network
```

In [ ]:
```
translator = GoogleTranslator()
translator.requires_network
```

Complete example

- Find the complete implementation on OLAT (`translation_example.zip`).
- Install dependencies using `pip install -r requirements.txt`.
- Next week, we will use this code to create our own Python package.

A final note on OOP

- OOP can make your code more **readable, maintainable, and extensible**, but it can also make it more **complex and difficult to test**.
- Different programming paradigms lend themselves to different types of problems.
- Use the exercises to practice writing classes and get an intuition for when OOP makes sense and when it doesn't.

Take-home messages

- **Encapsulation** allows us to hide the implementation details of a class from the user.
- A leading underscore `_` indicates that an attribute or method is **"private"** and should not be accessed from outside the class.
- **Special methods** like `__len__` and `__iter__` allow us to implement built-in Python operators and functionalities for our own classes.
- Different types of methods and attributes:
    - **Instance methods** vs. **class methods** vs. **static methods**
    - **Instance attributes** vs. **class attributes**
- **Inheritance** allows us to share code and interfaces between similar classes.
    - **Child classes** inherit all methods and attributes from their **parent class**.
    - `super()` is used to call the parent class's methods.
    - **Abstract classes** cannot be instantiated and require their child classes to implement certain methods.

Refer to the OOP cheat sheet on OLAT for an overview with examples!

Exercise 2

⚠️ This will be the first **graded exercise**! ⚠️

It will count 20% towards your exercise grade.