合肥大學
HEFEI UNIVERSITY

Programming with Python

43. Klassen/Dunder: `__str__`, `__repr__`, und `__eq__`

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Dies ist ein Kurs über das Programmieren mit der Programmiersprache Python an der Universität Hefei (合肥大学).

Die Webseite mit dem Lehrmaterial dieses Kurses ist https://thomasweise.github.io/programmingWithPython (siehe auch den QR-Kode unten rechts). Dort können Sie das Kursbuch (in Englisch) und diese Slides finden. Das Repository mit den Beispielprogrammen in Python finden Sie unter https://github.com/thomasWeise/programmingWithPythonCode.

Outline

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- Das können wir auch mit den Dunder-Methoden machen.
- Das heist, das wir im Grunde alle der vorher genannten Funktionalitäten erzeugen, verändern, und anpassen können!

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- In Programm `str_vs_repr.py` vergleichen wir die beiden Funktionen.

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"""An example comparing `str` and `repr`."""

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the_int: int = 123  # An integer with value 123.
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l1: list[int] = [1, 2, 3]  # A list of integers.
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print(f"{l1 = }, but {l2 = }")  # str(list) uses repr for list elements.

# Get the date and time when this program was run.
right_now: datetime = datetime.now(tz=UTC)

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- Wir erstellen eine Variable `the_str` mit Wert `"123"`.
- Wenn wir `the_str` auf dem standard output stream (`stdout`) ausgeben, wenn wir also `print(str(the_str))` machen, dann taucht der Text `123` auf der Konsole auf.

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print(f"{repr(right_now) = }")
print(f"     right_now  =  {right_now!r}")
```

↓ `python3 str_vs_repr.py` ↓

```
123
123
123
'123'
l1 = [1, 2, 3], but l2 = ['1', '2', '3']
 str(right_now) = '2025-10-30 00:38:35.961734+00:00'
     right_now  =  2025-10-30 00:38:35.961734+00:00
repr(right_now) = 'datetime.datetime(2025, 10, 30, 0, 38, 35, 961734,
   ↪ tzinfo=datetime.timezone.utc)'
     right_now  =  datetime.datetime(2025, 10, 30, 0, 38, 35, 961734,
        ↪ tzinfo=datetime.timezone.utc)
```

Beispiel: `str` und `repr`

- Das erwarten wir so auch, denn das ist sowohl die kompakteste Variante, den Wert darzustellen, als auch alle Information, die man braucht, um ihn neu zu erzeugen.
- Wir erstellen eine Variable `the_str` mit Wert `"123"`.
- Wenn wir `the_str` auf dem standard output stream (`stdout`) ausgeben, wenn wir also `print(str(the_str))` machen, dann taucht der Text `123` auf der Konsole auf.
- Drucken wir dagegen `repr(the_str)` aus, dann erscheint `'123'`.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
print(the_int)  # This is identical to `print(str(the_int))`
print(repr(the_int))  # Prints the same as above.

the_string: str = "123"  # A string, with value "123".
print(the_string)  # This is identical to `print(str(the_string))`.
print(repr(the_string))  # Notice the added `'` around the string.

l1: list[int] = [1, 2, 3]  # A list of integers.
l2: list[str] = ["1", "2", "3"]  # A list of strings.
print(f"{l1 = }, but {l2 = }")  # str(list) uses repr for list elements.

# Get the date and time when this program was run.
right_now: datetime = datetime.now(tz=UTC)

# Print the human-readable, concise string representation for users who
# want to know that the object means but do not necessarily need to know
# its detailed content.
print(f" {str(right_now) = }")
print(f"     right_now  =  {right_now!s}")

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# values of all attributes of `right_now`.
print(f"{repr(right_now) = }")
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Beispiel: `str` und `repr`

- Wir erstellen eine Variable `the_str` mit Wert `"123"`.
- Wenn wir `the_str` auf dem standard output stream (`stdout`) ausgeben, wenn wir also `print(str(the_str))` machen, dann taucht der Text `123` auf der Konsole auf.
- Drucken wir dagegen `repr(the_str)` aus, dann erscheint `'123'`.
- Beachten Sie die einzelnen Anführungszeichen an beiden Enden?

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
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Beispiel: `str` und `repr`

- Wir erstellen eine Variable `the_str` mit Wert `"123"`.
- Wenn wir `the_str` auf dem standard output stream (`stdout`) ausgeben, wenn wir also `print(str(the_str))` machen, dann taucht der Text `123` auf der Konsole auf.
- Drucken wir dagegen `repr(the_str)` aus, dann erscheint `'123'`.
- Beachten Sie die einzelnen Anführungszeichen an beiden Enden?
- Diese sind notwendig.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
print(the_int)  # This is identical to `print(str(the_int))`
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print(the_string)  # This is identical to `print(str(the_string))`.
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l1: list[int] = [1, 2, 3]  # A list of integers.
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# Get the date and time when this program was run.
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Beispiel: `str` und `repr`

- Wenn wir `the_str` auf dem standard output stream (`stdout`) ausgeben, wenn wir also `print(str(the_str))` machen, dann taucht der Text `123` auf der Konsole auf.
- Drucken wir dagegen `repr(the_str)` aus, dann erscheint `'123'`.
- Beachten Sie die einzelnen Anführungszeichen an beiden Enden?
- Diese sind notwendig.
- Ohne sie wären `repr(the_str)` und `repr(the_int)` gleich.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
print(the_int)  # This is identical to `print(str(the_int))`
print(repr(the_int))  # Prints the same as above.

the_string: str = "123"  # A string, with value "123".
print(the_string)  # This is identical to `print(str(the_string))`.
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l1: list[int] = [1, 2, 3]  # A list of integers.
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print(f"{l1 = }, but {l2 = }")  # str(list) uses repr for list elements.

# Get the date and time when this program was run.
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Beispiel: `str` und `repr`

- Drucken wir dagegen `repr(the_str)` aus, dann erscheint `'123'`.
- Beachten Sie die einzelnen Anführungszeichen an beiden Enden?
- Diese sind notwendig.
- Ohne sie wären `repr(the_str)` und `repr(the_int)` gleich.
- Wir könnten nicht unterscheiden, ob ein String oder eine Ganzzahl ausgegeben wurde.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
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Beispiel: `str` und `repr`

- Beachten Sie die einzelnen Anführungszeichen an beiden Enden?
- Diese sind notwendig.
- Ohne sie wären `repr(the_str)` und `repr(the_int)` gleich.
- Wir könnten nicht unterscheiden, ob ein String oder eine Ganzzahl ausgegeben wurde.
- Das spielt natürlich nur eine Rolle, wenn wir uns für die innere Arbeitsweise unseres Programms interessieren.

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from datetime import UTC, datetime

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Beispiel: `str` und `repr`

- Diese sind notwendig.
- Ohne sie wären `repr(the_str)` und `repr(the_int)` gleich.
- Wir könnten nicht unterscheiden, ob ein String oder eine Ganzzahl ausgegeben wurde.
- Das spielt natürlich nur eine Rolle, wenn wir uns für die innere Arbeitsweise unseres Programms interessieren.
- Und genau dafür existiert `repr`.

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

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Beispiel: `str` und `repr`

- Ohne sie wären `repr(the_str)` und `repr(the_int)` gleich.
- Wir könnten nicht unterscheiden, ob ein String oder eine Ganzzahl ausgegeben wurde.
- Das spielt natürlich nur eine Rolle, wenn wir uns für die innere Arbeitsweise unseres Programms interessieren.
- Und genau dafür existiert `repr`.
- Nun erstellen wir zwei Kollektionen.

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

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Beispiel: `str` und `repr`

- Wir könnten nicht unterscheiden, ob ein String oder eine Ganzzahl ausgegeben wurde.
- Das spielt natürlich nur eine Rolle, wenn wir uns für die innere Arbeitsweise unseres Programms interessieren.
- Und genau dafür existiert `repr`.
- Nun erstellen wir zwei Kollektionen.
- Zuerst erzeugen wir die Liste `l1`, die die drei Ganzzahlen `1`, `2` und `3` beinhaltet.

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
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Beispiel: `str` und `repr`

- Das spielt natürlich nur eine Rolle, wenn wir uns für die innere Arbeitsweise unseres Programms interessieren.
- Und genau dafür existiert `repr`.
- Nun erstellen wir zwei Kollektionen.
- Zuerst erzeugen wir die Liste `l1`, die die drei Ganzzahlen `1`, `2` und `3` beinhaltet.
- Dann erstellen wir die List `l2`, die drei Strings, nämlich `"1"`, `"2"` und `"3"`.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
print(the_int)  # This is identical to `print(str(the_int))`
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Beispiel: `str` und `repr`

- Und genau dafür existiert `repr`.
- Nun erstellen wir zwei Kollektionen.
- Zuerst erzeugen wir die Liste `l1`, die die drei Ganzzahlen `1`, `2` und `3` beinhaltet.
- Dann erstellen wir die List `l2`, die drei Strings, nämllich `"1"`, `"2"` und `"3"`.
- Dann wenden wir geben wir beide Listen aus wobei intern `str(l1)` und `str(l2)` werden.

```python
"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
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l1: list[int] = [1, 2, 3]  # A list of integers.
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print(f"{l1 = }, but {l2 = }")  # str(list) uses repr for list elements.

# Get the date and time when this program was run.
right_now: datetime = datetime.now(tz=UTC)

# Print the human-readable, concise string representation for users who
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print(f" {str(right_now) = }")
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↓ `python3 str_vs_repr.py` ↓

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```

Beispiel: `str` und `repr`

- Nun erstellen wir zwei Kollektionen.
- Zuerst erzeugen wir die Liste `l1`, die die drei Ganzzahlen `1`, `2` und `3` beinhaltet.
- Dann erstellen wir die List `l2`, die drei Strings, nämlich `"1"`, `"2"` und `"3"`.
- Dann wenden wir geben wir beide Listen aus wobei intern `str(l1)` und `str(l2)` werden.
- Das Ergebnis von `print(f"{l1 = }, but {l2 = }")` ist `l1 = [1, 2, 3],` `but l2 = ['1', '2', '3']`.

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- Beachten Sie wieder die einzelnen Anführungszeichen um die String-Elemente von `l2`.

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- Beachten Sie wieder die einzelnen Anführungszeichen um die String-Elemente von `l2`.
- Wenn die textuelle Repräsentation der Standard-Kollektionstypen bon Python mit `str` oder `repr` erzeugt wird, dann weden die Elemente der Kollektionen immer `repr` zu Stringskonvertiert, nie mit `str`[6].

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Beispiel: `str` und `repr`

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- Andernfalls könnten wir nicht zwischen `l1` und `l2` in der Ausgabe unterscheiden.
- Ein anderes gutes Beispiel für den Unterschied zwischen `str` und `repr` ist Python's Klasse `datetime`.

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- Wir diskutieren diese Klasse hier nicht im Detail.

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- Andernfalls könnten wir nicht zwischen `l1` und `l2` in der Ausgabe unterscheiden.
- Ein anderes gutes Beispiel für den Unterschied zwischen `str` und `repr` ist Python's Klasse `datetime`.
- Wir diskutieren diese Klasse hier nicht im Detail.
- Es reicht zu wissen, dass Instanzen dieser Klasse eine Kombination aus Datum und Uhrzeit darstellen.

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- Im Programm importieren wir erst die Klasse `datetime` aus dem Modul mit dem selben Namen.

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- Wir diskutieren diese Klasse hier nicht im Detail.
- Es reicht zu wissen, dass Instanzen dieser Klasse eine Kombination aus Datum und Uhrzeit darstellen.
- Im Programm importieren wir erst die Klasse `datetime` aus dem Modul mit dem selben Namen.
- Wir erstellen eine Variable `right_now`, die das Ergebnis der Funktion `datetime.now` zugewiesen bekommt, die ein Objekt zurückliefert, in dem das aktuelle Datum und die aktuelle Uhrzeit gespeichert sind.

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- Wenn wir das Ergebnis der Funktion `str` auf ein Objekt `o` in einem f-String ausgeben wollen, dann benutzen wir die Format-Spezifikation `!s`, schreiben also `f"{o!s}"`.

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print(f"{l1 = }, but {l2 = }")  # str(list) uses repr for list elements.

# Get the date and time when this program was run.
right_now: datetime = datetime.now(tz=UTC)

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↓ `python3 str_vs_repr.py` ↓

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```

Beispiel: `str` und `repr`

- Wir erstellen eine Variable `right_now`, die das Ergebnis der Funktion `datetime.now` zugewiesen bekommt, die ein Objekt zurückliefert, in dem das aktuelle Datum und die aktuelle Uhrzeit gespeichert sind.
- Wenn wir das Ergebnis der Funktion `str` auf ein Objekt `o` in einem f-String ausgeben wollen, dann benutzen wir die Format-Spezifikation `!s`, schreiben also `f"{o!s}"`.
- Wir sehen, dass die String-Repräsentation von einem `datetime`-Objekt ein einfacher, leicht lesbarer Datums- und Uhrzeit-String ist.

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- Wir könnten die Ausgabe von `repr` direkt in die Python-Konsole kopieren!

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Beispiel: `str` und `repr`

- Das Ergebnis der Funktion `repr` für ein Objekt `o` in einem f-String wird mit der Format-Spezifikation `!r` abgefragt, also durch `f"{o!r}"`.
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- Wir könnten die Ausgabe von `repr` direkt in die Python-Konsole kopieren!
- Das würde ein `datetime`-Objekt mit genau den selben Daten wie `right_now` erzeugen.

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

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Beispiel: `str` und `repr`

- Machen wir das mit einem `datetime`-Objekt, dann bekommen wir tatsächlich die Information, die wir brauchen, um das Objekt wieder zu erzeugen.
- Wir könnten die Ausgabe von `repr` direkt in die Python-Konsole kopieren!
- Das würde ein `datetime`-Objekt mit genau den selben Daten wie `right_now` erzeugen.
- Das würde auch mit den String-Repräsentationen der beiden Listen `l1` und `l2` oben funktionieren.

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"""An example comparing `str` and `repr`."""

from datetime import UTC, datetime

the_int: int = 123  # An integer with value 123.
print(the_int)  # This is identical to `print(str(the_int))`
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Strings und Gleichheit

Beispiel: `Point` und Gleichheit

- Gehen wir noch ein paar Schritte zurück zu einem Beispiel, das wir selbst erstellt haben.

```python
"""A simple class for points."""

from math import isfinite, sqrt
from typing import Final


class Point:
    """
    A class for representing a point in the two-dimensional plane.

    >>> p = Point(1, 2.5)
    >>> p.x
    1
    >>> p.y
    2.5

    >>> try:
    ...     Point(1, 1e308 * 1e308)
    ... except ValueError as ve:
    ...     print(ve)
    x=1 and y=inf must both be finite.
    """

    def __init__(self, x: int | float, y: int | float) -> None:
        """
        The constructor: Create a point and set its coordinates.

        :param x: the x-coordinate of the point
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        """
        if not (isfinite(x) and isfinite(y)):
            raise ValueError(f"x={x} and y={y} must both be finite.")
        #: the x-coordinate of the point
        self.x: Final[int | float] = x
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    def distance(self, p: "Point") -> float:
        """
        Get the distance to another point.

        :param p: the other point
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        >>> Point(1, 1).distance(Point(4, 4))
        4.242640687119285
        """
        return sqrt((self.x - p.x) ** 2 + (self.y - p.y) ** 2)
```

Beispiel: `Point` und Gleichheit

- Gehen wir noch ein paar Schritte zurück zu einem Beispiel, das wir selbst erstellt haben.
- Wir erinnern uns an die Klasse `Point`, mit der wir Punkte in der zweidimensionalen Euklidischen Ebene dargestellt haben.

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- Diese Klasse war ziemlich nützlich, als wir Klassen für verschiedene Formen implementiert haben.
- Damals haben wir schon die Dunder-Methode `__init__` kennengelernt.
- Spielen wir mit der Klasse etwas mehr.

```python
"""Examples for using our class :class:`Point` without dunder."""

from point import Point

p1: Point = Point(3, 5)  # Create a first point.
p2: Point = Point(7, 8)  # Create a second, different point.
p3: Point = Point(3, 5)  # Create a third point, which equals the first.

print(f" {str(p1) = }")  # should be a short string representation of p1
print(f"      p1  =  {p1!s}")  # (almost) the same as the above
print(f"{repr(p1) = }")  # should be a representation for programmers
print(f"      p1  =  {p1!r}")  # (almost) the same as the above

print(f"{(p1 is p2) = }")  # False, p1 and p2 are different objects
print(f"{(p1 is p3) = }")  # False, p1 and p3 are different objects
print(f"{(p1 == p2) = }")  # False, because without dunder `==` = `is`
print(f"{(p1 == p3) = }")  # False, but should ideally be True
print(f"{(p1 != p2) = }")  # True, because without dunder `==` = `is`
print(f"{(p1 != p3) = }")  # True, but should ideally be False

print(f"{(p1 == 5) = }")  # comparison with the integer 5 yields False
```

↓ `python3 point_user_2.py` ↓

```
 str(p1) = '<point.Point object at 0x7f179bb8dbb0>'
      p1  =  <point.Point object at 0x7f179bb8dbb0>
repr(p1) = '<point.Point object at 0x7f179bb8dbb0>'
      p1  =  <point.Point object at 0x7f179bb8dbb0>
(p1 is p2) = False
(p1 is p3) = False
(p1 == p2) = False
(p1 == p3) = False
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Beispiel: `Point` und Gleichheit

- Wir erinnern uns an die Klasse `Point`, mit der wir Punkte in der zweidimensionalen Euklidischen Ebene dargestellt haben.
- Diese Klasse war ziemlich nützlich, als wir Klassen für verschiedene Formen implementiert haben.
- Damals haben wir schon die Dunder-Methode `__init__` kennengelernt.
- Spielen wir mit der Klasse etwas mehr.
- Im Programm `point_user_2.py` erstellen wir drei Instanzen dieser Klasse.

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- Die drei Objekte sind alle verschiedene Instanzen von `Point`, also erwarten wir das genau so.

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print(f"{(p1 == p2) = }")  # False, because without dunder `==` = `is`
print(f"{(p1 == p3) = }")  # False, but should ideally be True
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print(f"{(p1 == 5) = }")  # comparison with the integer 5 yields False
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↓ python3 point_user_2.py ↓

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 str(p1) = '<point.Point object at 0x7f179bb8dbb0>'
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Beispiel: `Point` und Gleichheit

- In Einheit 16 hatten wir den Unterschied zwischen der Gleichheit und der Identität von Objekten diskutiert.
- Alle drei Variablen `p1`, `p2` und `p3` zeigen auf verschiedene Objekte.
- Während `p1 is p1` offensichtlich `True` ist, müssen `p1 is p2` und `p1 is p3` offensichtlich `False` sein.
- Die drei Objekte sind alle verschiedene Instanzen von `Point`, also erwarten wir das genau so.
- Es ist aber ärgerlich, dass `p1 == p3` auch `False` ergibt.

```python
"""Examples for using our class :class:`Point` without dunder."""

from point import Point

p1: Point = Point(3, 5)  # Create a first point.
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- Es ist aber ärgerlich, dass `p1 == p3` auch `False` ergibt.
- `p1 == p2` soll `False` sein, weil diese beiden Punkte unterschiedlich sind.

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Beispiel: `Point` und Gleichheit

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Beispiel: `Point` und Gleichheit

- `p1 == p2` soll `False` sein, weil diese beiden Punkte unterschiedlich sind.
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Beispiel: `Point` und Gleichheit

- Die beiden Punkte `p1` und `p3` haben aber die selben Koordinaten.
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Beispiel: `Point` und Gleichheit

- Sie sollten als gleich betrachtet werden.
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- Der Grund dafür ist das Python nicht wissen kann, wann und warum Instanzen unserer eigenen Klasse als gleich betrachtet werden sollen.
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- Diese Methode bekommt ein beliebiges Objekt `other` als Parameter und soll `True` bei Gleichheit zurückliefern und `False` sonst.
- Genau wie `str(o)` `o.__str__()` aufruft, so ruft der `a == b`-Operator `a.__eq__(b)` auf, wenn `a` `__eq__` implementiert.

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Beispiel: `Point` und Gleichheit

- Zum Schluss vergleichen wir noch, ob `p1` das selbe wie die Ganzzahl `5` ist.
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- Wie gesagt prüft der Standard-Gleichheits-Operator nur auf Identität.

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- Das sollte offensichtlich `False` ergeben.
- Und das tut es auch.
- Weil die beiden Objekte `p1` und `5` nicht identisch sind.
- Wie gesagt prüft der Standard-Gleichheits-Operator nur auf Identität.
- Falls wir `__eq__` selbst implementieren, dann muss die Methode `False` zurückliefern, wenn sie `5` als Argument bekommt (anstatt abzustürzen oder eine Ausnahme auszulösen. . .).

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Beispiel: `Point` mit Dunder Methoden

- Um die vorhin genannten Probleme alle zu lösen, implementieren wir die drei Dunder-Methoden `__str__`, `__repr__` und `__eq__` in unserer `Point`-Klasse in Datei `point_with_dunder.py`.

```python
"""A class for points, with string and equals dunder methods."""

from math import isfinite
from types import NotImplementedType
from typing import Final


class Point:
    """A class for representing a point in the two-dimensional plane."""

    def __init__(self, x: int | float, y: int | float) -> None:
        """
        The constructor: Create a point and set its coordinates.

        :param x: the x-coordinate of the point
        :param y: the y-coordinate of the point
        """
        if not (isfinite(x) and isfinite(y)):
            raise ValueError(f"x={x} and y={y} must both be finite.")
        #: the x-coordinate of the point
        self.x: Final[int | float] = x
        #: the y-coordinate of the point
        self.y: Final[int | float] = y

    def __repr__(self) -> str:
        """
        Get a representation of this object useful for programmers.

        :return: `"Point(x, y)"`

        >>> repr(Point(2, 4))
        'Point(2, 4)'
        """
        return f"Point({self.x}, {self.y})"

    def __str__(self) -> str:
        """
        Get a concise string representation useful for end users.

        :return: `"(x,y)"`

        >>> str(Point(2, 4))
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    def __eq__(self, other) -> bool | NotImplementedType:
        """
        Check whether this point is equal to another object.

        :param other: the other object
        :return: `True` if and only if `other` is also a `Point` and has
            the same coordinates; `NotImplemented` if it is not a point

        >>> Point(1, 2) == Point(2, 3)
        False
        >>> Point(1, 2) == Point(1, 2)
        True
        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
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Beispiel: `Point` mit Dunder Methode

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- Die kurze String-Repräsentation, die `__str__` liefert, beinhaltet einfach die Punkt-Koordinaten, mit Komma getrennt, in Klammern.

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    """A class for representing a point in the two-dimensional plane."""

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    def __eq__(self, other) -> bool | NotImplementedType:
        """
        Check whether this point is equal to another object.

        :param other: the other object
        :return: `True` if and only if `other` is also a `Point` and has
            the same coordinates; `NotImplemented` if it is not a point

        >>> Point(1, 2) == Point(2, 3)
        False
        >>> Point(1, 2) == Point(1, 2)
        True
        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methode

- Um die vorhin genannten Probleme alle zu lösen, implementieren wir die drei Dunder-Methoden `__str__`, `__repr__` und `__eq__` in unserer `Point`-Klasse in Datei `point_with_dunder.py`.
- Die kurze String-Repräsentation, die `__str__` liefert, beinhaltet einfach die Punkt-Koordinaten, mit Komma getrennt, in Klammern.
- Das liefert alle Informationen auf einen Blick, aber es könnte mit der String-Repräsentation eines Tupels verwechselt werden.

```python
    """A class for representing a point in the two-dimensional plane."""

    def __init__(self, x: int | float, y: int | float) -> None:
        """
        The constructor: Create a point and set its coordinates.

        :param x: the x-coordinate of the point
        :param y: the y-coordinate of the point
        """
        if not (isfinite(x) and isfinite(y)):
            raise ValueError(f"x={x} and y={y} must both be finite.")
        #: the x-coordinate of the point
        self.x: Final[int | float] = x
        #: the y-coordinate of the point
        self.y: Final[int | float] = y

    def __repr__(self) -> str:
        """
        Get a representation of this object useful for programmers.

        :return: `"Point(x, y)"`

        >>> repr(Point(2, 4))
        'Point(2, 4)'
        """
        return f"Point({self.x}, {self.y})"

    def __str__(self) -> str:
        """
        Get a concise string representation useful for end users.

        :return: `"(x,y)"`

        >>> str(Point(2, 4))
        '(2,4)'
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Beispiel: `Point` mit Dunder Methode

- Um die vorhin genannten Probleme alle zu lösen, implementieren wir die drei Dunder-Methoden `__str__`, `__repr__` und `__eq__` in unserer `Point`-Klasse in Datei `point_with_dunder.py`.
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Beispiel: `Point` mit Dunder Methode

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- Die Dunder-Methode `__eq__` prüft erst, ob das andere Objekt eine Instanz von `Point` ist.

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Beispiel: `Point` mit Dunder Methode

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        >>> Point(1, 2) == Point(2, 3)
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        >>> Point(1, 2) == Point(1, 2)
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        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methode

- Das liefert alle Informationen auf einen Blick, aber es könnte mit der String-Repräsentation eines Tupels verwechselt werden.
- Deshalb wird `__repr__` einen String der Form `"Point(x, y)"` liefern.
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        """
        Get a concise string representation useful for end users.

        :return: `"(x,y)"`

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        '(2,4)'
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        :param other: the other object
        :return: `True` if and only if `other` is also a `Point` and has
            the same coordinates; `NotImplemented` if it is not a point

        >>> Point(1, 2) == Point(2, 3)
        False
        >>> Point(1, 2) == Point(1, 2)
        True
        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methoden

- Deshalb wird `__repr__` einen String der Form `"Point(x, y)"` liefern.
- Die Dunder-Methode `__eq__` prüft erst, ob das andere Objekt eine Instanz von `Point` ist.
- Wenn ja, dann liefert sie `True` genau dann wenn die `x`- und `y`-Koordinate des Punkts `other` die gleichen sind wie die des Punkts `self`.
- Andernfalls liefert sie die Konstante `NotImplemented` zurück.

> *A special value which should be returned by the binary special methods [...] to indicate that the operation is not implemented with respect to the other type...*
>
> *Note: When a binary (or in-place) method returns `NotImplemented` the interpreter will try the reflected operation on the other type (or some other fallback, depending on the operator). If all attempts return `NotImplemented`, the interpreter will raise an appropriate exception. Incorrectly returning `NotImplemented` will result in a misleading error message or the `NotImplemented` value being returned to Python code.*
>
> — [8], 2001

Beispiel: `Point` mit Dunder Methode

- Die Dunder-Methode `__eq__` prüft erst, ob das andere Objekt eine Instanz von `Point` ist.
- Wenn ja, dann liefert sie `True` genau dann wenn die `x`- und `y`-Koordinate des Punkts `other` die gleichen sind wie die des Punkts `self`.
- Andernfalls liefert sie die Konstante `NotImplemented` zurück.
- In dem wir `NotImplemented` bei `other`-Objekten, die keine Instanzen von `Point` sind, zurückliefern, dann verweisen wir einfach auf das Standardverhalten des Operators `==`.

```python
    """A class for representing a point in the two-dimensional plane."""

    def __init__(self, x: int | float, y: int | float) -> None:
        """
        The constructor: Create a point and set its coordinates.

        :param x: the x-coordinate of the point
        :param y: the y-coordinate of the point
        """
        if not (isfinite(x) and isfinite(y)):
            raise ValueError(f"x={x} and y={y} must both be finite.")
        #: the x-coordinate of the point
        self.x: Final[int | float] = x
        #: the y-coordinate of the point
        self.y: Final[int | float] = y

    def __repr__(self) -> str:
        """
        Get a representation of this object useful for programmers.

        :return: `"Point(x, y)"`

        >>> repr(Point(2, 4))
        'Point(2, 4)'
        """
        return f"Point({self.x}, {self.y})"

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        """
        Get a concise string representation useful for end users.

        :return: `"(x,y)"`

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        """
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        """
        Check whether this point is equal to another object.

        :param other: the other object
        :return: `True` if and only if `other` is also a `Point` and has
            the same coordinates; `NotImplemented` if it is not a point

        >>> Point(1, 2) == Point(2, 3)
        False
        >>> Point(1, 2) == Point(1, 2)
        True
        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methode

- Wenn ja, dann liefert sie `True` genau dann wenn die `x`- und `y`-Koordinate des Punkts `other` die gleichen sind wie die des Punkts `self`.
- Andernfalls liefert sie die Konstante `NotImplemented` zurück.
- In dem wir `NotImplemented` bei `other`-Objekten, die keine Instanzen von `Point` sind, zurückliefern, dann verweisen wir einfach auf das Standardverhalten des Operators `==`.
- Wenn `other` keine Instanz von `Point`, dann gibt es keine Möglichkeit, auf Gleichheit zu vergleichen.

```python
    """A class for representing a point in the two-dimensional plane."""

    def __init__(self, x: int | float, y: int | float) -> None:
        """
        The constructor: Create a point and set its coordinates.

        :param x: the x-coordinate of the point
        :param y: the y-coordinate of the point
        """
        if not (isfinite(x) and isfinite(y)):
            raise ValueError(f"x={x} and y={y} must both be finite.")
        #: the x-coordinate of the point
        self.x: Final[int | float] = x
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        >>> Point(1, 2) == Point(2, 3)
        False
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        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methode

- Andernfalls liefert sie die Konstante `NotImplemented` zurück.
- In dem wir `NotImplemented` bei `other`-Objekten, die keine Instanzen von `Point` sind, zurückliefern, dann verweisen wir einfach auf das Standardverhalten des Operators `==`.
- Wenn `other` keine Instanz von `Point`, dann gibt es keine Möglichkeit, auf Gleichheit zu vergleichen.
- Wir könnten in diesem Fall einfach `False` zurückliefern, was auch OK wäre.

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    """A class for representing a point in the two-dimensional plane."""

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Beispiel: `Point` mit Dunder Methode

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- `NotImplemented` zu liefern gibt uns das gleiche Ergebnis wenn wir mit Objekten eines anderen Typs vergleichen wie z. B. `5`.

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Beispiel: `Point` mit Dunder Methode

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- `NotImplemented` zu liefern gibt uns das gleiche Ergebnis wenn wir mit Objekten eines anderen Typs vergleichen wie z. B. `5`.
- Es ermöglicht aber anderen Programmieren, eine neue Klasse zu schreiben, die einen Gleichheitsvergleich mit unseren `Point`-Instanzen implementiert.

```python
    """A class for representing a point in the two-dimensional plane."""

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Beispiel: `Point` mit Dunder Methode

- Wir könnten in diesem Fall einfach `False` zurückliefern, was auch OK wäre.
- `NotImplemented` zu liefern gibt uns das gleiche Ergebnis wenn wir mit Objekten eines anderen Typs vergleichen wie z. B. `5`.
- Es ermöglicht aber anderen Programmieren, eine neue Klasse zu schreiben, die einen Gleichheitsvergleich mit unseren `Point`-Instanzen implementiert.
- Wenn wir `__eq__` implementieren, dann ist der richtige Type Hint für den Rückgabewert `bool | NotImplementedType`.

```python
    """A class for representing a point in the two-dimensional plane."""

    def __init__(self, x: int | float, y: int | float) -> None:
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        The constructor: Create a point and set its coordinates.

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        :param other: the other object
        :return: `True` if and only if `other` is also a `Point` and has
            the same coordinates; `NotImplemented` if it is not a point

        >>> Point(1, 2) == Point(2, 3)
        False
        >>> Point(1, 2) == Point(1, 2)
        True
        """
        return (other.x == self.x) and (other.y == self.y) \
            if isinstance(other, Point) else NotImplemented
```

Beispiel: `Point` mit Dunder Methoden benutzen

- Wir benutzen nun unsere neue Klasse `Point` genauso wie wir die alte in Program `point_user_2.py` verwendet haben.

```python
"""Examples for using our class :class:`Point` without dunder."""

from point import Point

p1: Point = Point(3, 5)  # Create a first point.
p2: Point = Point(7, 8)  # Create a second, different point.
p3: Point = Point(3, 5)  # Create a third point, which equals the first.

print(f"{str(p1) = }")  # should be a short string representation of p1
print(f"     p1  =  {p1!s}")  # (almost) the same as the above
print(f"{repr(p1) = }")  # should be a representation for programmers
print(f"     p1  =  {p1!r}")  # (almost) the same as the above

print(f"{(p1 is p2) = }")  # False, p1 and p2 are different objects
print(f"{(p1 is p3) = }")  # False, p1 and p3 are different objects
print(f"{(p1 == p2) = }")  # False, because without dunder `==` = `is`
print(f"{(p1 == p3) = }")  # False, but should ideally be True
print(f"{(p1 != p2) = }")  # True, because without dunder `==` = `is`
print(f"{(p1 != p3) = }")  # True, but should ideally be False

print(f"{(p1 == 5) = }")  # comparison with the integer 5 yields False
```

↓ `python3 point_user_2.py` ↓

```
 str(p1) = '<point.Point object at 0x7f179bb8dbb0>'
     p1  =  <point.Point object at 0x7f179bb8dbb0>
repr(p1) = '<point.Point object at 0x7f179bb8dbb0>'
     p1  =  <point.Point object at 0x7f179bb8dbb0>
(p1 is p2) = False
(p1 is p3) = False
(p1 == p2) = False
(p1 == p3) = False
(p1 != p2) = True
(p1 != p3) = True
(p1 == 5) = False
```

Beispiel: `Point` mit Dunder Methoden benutzen

- Wir benutzen nun unsere neue Klasse `Point` genauso wie wir die alte in Program `point_user_2.py` verwendet haben.
- Das tun wir in dem neuen Programm `point_with_dunder_user.py`.

```python
"""Examples for using our class :class:`Point` with dunder methods."""

from point_with_dunder import Point

p1: Point = Point(3, 5)  # Create a first point.
p2: Point = Point(7, 8)  # Create a second, different point.
p3: Point = Point(3, 5)  # Create a third point, which equals the first.

print(f" {str(p1) = }")  # a short string representation of p1
print(f"     p1  =  {p1!s}")  # (almost) the same as the above
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print(f"{(p1 is p2) = }")  # False, p1 and p2 are different objects
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print(f"{(p1 == p2) = }")  # False, calls our `__eq__` method
print(f"{(p1 == p3) = }")  # True, as it should be, because of `__eq__`
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print(f"{(p1 != p3) = }")  # False, as it should be

print(f"{(p1 == 5) = }")  # comparison with the integer 5 yields False
```

↓ `python3 point_with_dunder_user.py` ↓

```
 str(p1) = '(3,5)'
     p1  =  (3,5)
repr(p1) = 'Point(3, 5)'
     p1  =  Point(3, 5)
(p1 is p2) = False
(p1 is p3) = False
(p1 == p2) = False
(p1 == p3) = True
(p1 != p2) = True
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(p1 == 5) = False
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- Wir benutzen nun unsere neue Klasse `Point` genauso wie wir die alte in Program `point_user_2.py` verwendet haben.
- Das tun wir in dem neuen Programm `point_with_dunder_user.py`.
- Die Ausgabe dieses Programms passt viel besser zu dem, was wir uns vorstellen.

```python
"""Examples for using our class :class:`Point` with dunder methods."""

from point_with_dunder import Point

p1: Point = Point(3, 5)  # Create a first point.
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 str(p1) = '(3,5)'
     p1  =  (3,5)
repr(p1) = 'Point(3, 5)'
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- Wir benutzen nun unsere neue Klasse `Point` genauso wie wir die alte in Program `point_user_2.py` verwendet haben.
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- Die Funktion `str` liefert uns nun kurzen aber informativen Output für Instanzen der Klasse `Point`.

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"""Examples for using our class :class:`Point` with dunder methods."""

from point_with_dunder import Point

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 str(p1) = '(3,5)'
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- Das tun wir in dem neuen Programm `point_with_dunder_user.py`.
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- Der `repr`-Operator gibt uns Text, den wir im Prinzip in den Python-Interpreter kopieren könnten und mit dem wir so das gleiche Objekt nochmal erstellen könnten.

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"""Examples for using our class :class:`Point` with dunder methods."""

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- Die Gleicheits- und Ungleichheits-Operatoren zeigen ebenfalls viel vernünftigeres Verhalten und sehen, wenn zwei Punkte die selben Koordinaten haben.

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- Sie funktionieren auch richtig wenn das andere Objekt kein Punkt ist.

```python
"""Examples for using our class :class:`Point` with dunder methods."""

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- Mit `__str__`, `__repr__`, `__eq__` und `__ne__` haben wir bereits vier Methoden berührt, die wir bereits sehr oft verwendet haben – wenn auch indirekt.

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- Wir haben nun unsere Reise in das Reich der so genannten *Dunder*-Methoden begonnen.
- Diese Methoden kontrollieren viel von dem Verhalten der Operatoren und Konstrukte der Sprache Python.
- Mit `__str__`, `__repr__`, `__eq__` und `__ne__` haben wir bereits vier Methoden berührt, die wir bereits sehr oft verwendet haben – wenn auch indirekt.
- Welche anderen Abenteuer erwarten uns so tief im Getriebe der Python-Machine?

谢谢您们！

Thank you!

Vielen Dank!

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Glossary (in English) I

Bash is a the shell used under Ubuntu Linux, i.e., the program that „runs" in the terminal and interprets your commands, allowing you to start and interact with other programs[5,23,37]. Learn more at https://www.gnu.org/software/bash.

f-string let you include the results of expressions in strings[7,10–12,22,28]. They can contain expressions (in curly braces) like `f"a{6-1}b"` that are then transformed to text via (string) interpolation, which turns the string to `"a5b"`. F-strings are delimited by `f"..."`.

Git is a distributed Version Control Systems (VCS) which allows multiple users to work on the same code while preserving the history of the code changes[27,31]. Learn more at https://git-scm.com.

GitHub is a website where software projects can be hosted and managed via the Git VCS[25,31]. Learn more at https://github.com.

IT information technology

Linux is the leading open source operating system, i.e., a free alternative for Microsoft Windows[1,13,26,30,34]. We recommend using it for this course, for software development, and for research. Learn more at https://www.linux.org. Its variant Ubuntu is particularly easy to use and install.

Microsoft Windows is a commercial proprietary operating system[4]. It is widely spread, but we recommend using a Linux variant such as Ubuntu for software development and for our course. Learn more at https://www.microsoft.com/windows.

Mypy is a static type checking tool for Python[20] that makes use of type hints. Learn more at https://github.com/python/mypy and in[36].

Python The Python programming language[15,19,21,36], i.e., what you will learn about in our book[36]. Learn more at https://python.org.

Glossary (in English) II

stderr The *standard error stream* is one of the three pre-defined streams of a console process (together with the standard input stream (`stdin`) and the `stdout`)[17]. It is the text stream to which the process writes information about errors and exceptions. If an uncaught `Exception` is raised in Python and the program terminates, then this information is written to standard error stream (`stderr`). If you run a program in a terminal, then the text that a process writes to its `stderr` appears in the console.

stdin The *standard input stream* is one of the three pre-defined streams of a console process (together with the `stdout` and the `stderr`)[17]. It is the text stream from which the process reads its input text, if any. The Python instruction `input` reads from this stream. If you run a program in a terminal, then the text that you type into the terminal while the process is running appears in this stream.

stdout The *standard output stream* is one of the three pre-defined streams of a console process (together with the `stdin` and the `stderr`)[17]. It is the text stream to which the process writes its normal output. The `print` instruction of Python writes text to this stream. If you run a program in a terminal, then the text that a process writes to its `stdout` appears in the console.

(string) interpolation In Python, string interpolation is the process where all the expressions in an f-string are evaluated and the final string is constructed. An example for string interpolation is turning `f"Rounded {1.234:.2f}"` to `"Rounded 1.23"`.

terminal A terminal is a text-based window where you can enter commands and execute them[1,9]. Knowing what a terminal is and how to use it is very essential in any programming- or system administration-related task. If you want to open a terminal under Microsoft Windows, you can Druck auf ⊞+R, dann Schreiben von `cmd`, dann Druck auf ↲. Under Ubuntu Linux, Ctrl+Alt+T opens a terminal, which then runs a Bash shell inside.

type hint are annotations that help programmers and static code analysis tools such as Mypy to better understand what type a variable or function parameter is supposed to be[18,33]. Python is a dynamically typed programming language where you do not need to specify the type of, e.g., a variable. This creates problems for code analysis, both automated as well as manual: For example, it may not always be clear whether a variable or function parameter should be an integer or floating point number. The annotations allow us to explicitly state which type is expected. They are *ignored* during the program execution. They are a basically a piece of documentation.

Glossary (in English) III

Ubuntu is a variant of the open source operating system Linux[9,14]. We recommend that you use this operating system to follow this class, for software development, and for research. Learn more at `https://ubuntu.com`. If you are in China, you can download it from `https://mirrors.ustc.edu.cn/ubuntu-releases`.

VCS A *Version Control System* is a software which allows you to manage and preserve the historical development of your program code[31]. A distributed VCS allows multiple users to work on the same code and upload their changes to the server, which then preserves the change history. The most popular distributed VCS is Git.