Exceptions and file input/output

- try-raise-except-finally
- Exception
- control flow
- match - case
- file open/read/write
- sys.stdin, sys.stdout, sys.stderr
- context manager

Exceptions – Error handling and control flow

- Exceptions is a widespread technique to handle run-time **errors** / abnormal behaviour (e.g. in Python, Java, C++, JavaScript, C#)

- Exceptions can also be used as an **advanced control flow mechanism** (e.g. in Python, Java, JavaScript)

  - *Problem: How to perform a ”break” in a recursive function ?*

Built-in exceptions (class hierarchy)

```
BaseException
 +-- SystemExit
 +-- KeyboardInterrupt
 +-- GeneratorExit
 +-- Exception
      +-- StopIteration
      +-- StopAsyncIteration
      +-- ArithmeticError
      |    +-- FloatingPointError
      |    +-- OverflowError
      |    +-- ZeroDivisionError
      +-- AssertionError
      +-- AttributeError
      +-- BufferError
      +-- EOFError
      +-- ImportError
      |    +-- ModuleNotFoundError
      +-- LookupError
      |    +-- IndexError
      |    +-- KeyError
      +-- MemoryError
      +-- NameError
      |    +-- UnboundLocalError
      +-- TypeError
      +-- ValueError
      |    +-- UnicodeError
      |         +-- UnicodeDecodeError
      |         +-- UnicodeEncodeError
      |         +-- UnicodeTranslateError
      |
      +-- OSError
      |    +-- BlockingIOError
      |    +-- ChildProcessError
      |    +-- ConnectionError
      |    |    +-- BrokenPipeError
      |    |    +-- ConnectionAbortedError
      |    |    +-- ConnectionRefusedError
      |    |    +-- ConnectionResetError
      |    +-- FileExistsError
      |    +-- FileNotFoundError
      |    +-- InterruptedError
      |    +-- IsADirectoryError
      |    +-- NotADirectoryError
      |    +-- PermissionError
      |    +-- ProcessLookupError
      |    +-- TimeoutError
      +-- ReferenceError
      +-- RuntimeError
      |    +-- NotImplementedError
      |    +-- RecursionError
      +-- SyntaxError
      |    +-- IndentationError
      |         +-- TabError
      +-- SystemError
      +-- Warning
           +-- DeprecationWarning
           +-- PendingDeprecationWarning
           +-- RuntimeWarning
           +-- SyntaxWarning
           +-- UserWarning
           +-- FutureWarning
           +-- ImportWarning
           +-- UnicodeWarning
           +-- BytesWarning
           +-- ResourceWarning
```

docs.python.org/3/library/exceptions.html

Typical built-in exceptions

and unhandled behaviour

Python shell

```
> 7 / 0
| ZeroDivisionError: division by zero
> int('42x')
| ValueError: invalid literal for int() with base 10: '42x'
> x = y
| NameError: name 'y' is not defined
> L = [1] * 10_000_000_000
| MemoryError
> 2.5 ** 1000
| OverflowError: (34, 'Result too large')
> t = (3, 4)
> t[0] = 7
| TypeError: 'tuple' object does not support item assignment
> t[3]
| IndexError: tuple index out of range
> t.x
| AttributeError: 'tuple' object has no attribute 'x'
> x = {}
> x['foo']
| KeyError: 'foo'
> def f(x): f(x + 1)
> f(0)
| RecursionError: maximum recursion depth exceeded
> def f(): x = x + 1
> f()
| UnboundLocalError: local variable 'x' referenced before assignment
```

Catching exceptions – Fractions (I)

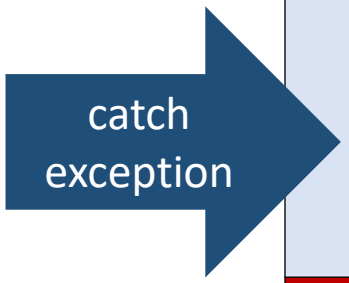
fraction1.py

```
while True:
    numerator = int(input('Numerator = '))
    denominator = int(input('Denominator = '))
    result = numerator / denominator
    print(f'{numerator} / {denominator} = {result}')
```

Python shell

```
Numerator = 10
Denominator = 3
10 / 3 = 3.3333333333333335
Numerator = 20
Denominator = 0
ZeroDivisionError: division by zero
```

Catching exceptions – Fractions (II)



fraction2.py

```
while True:
    numerator = int(input('Numerator = '))
    denominator = int(input('Denominator = '))
    try:
        result = numerator / denominator
    except ZeroDivisionError:
        print('cannot divide by zero')
        continue
    print(f'{numerator} / {denominator} = {result}')
```

Python shell

```
Numerator = 10
Denominator = 0
cannot divide by zero
Numerator = 20
Denominator = 3
20 / 3 = 6.666666666666667
Numerator = 42x
ValueError: invalid literal for int() with base 10: '42x'
```

Catching exceptions – Fractions (III)

catch exception

catch exception

fraction3.py

```
while True:
    try:
        numerator = int(input('Numerator = '))
        denominator = int(input('Denominator = '))
    except ValueError:
        print('input not a valid integer')
        continue
    try:
        result = numerator / denominator
    except ZeroDivisionError:
        print('cannot divide by zero')
        continue
    print(f'{numerator} / {denominator} = {result}')
```

Python shell

```
Numerator = 5
Denominator = 2x
input not a valid integer
Numerator = 5
Denominator = 2
5 / 2 = 2.5
```

fraction3.py

```python
while True:
    try:
        numerator = int(input('Numerator = '))
        denominator = int(input('Denominator = '))
    except ValueError:
        print('input not a valid integer')
        continue
    try:
        result = numerator / denominator
        print(f'{numerator} / {denominator} = {result}')
    except ZeroDivisionError:
        print('cannot divide by zero')
```

Python shell

```
| Numerator = 1000000000000000000000000000000000000000000000000000000000
  0000000000000000000000000000000000000000000000000000000000000000000000
  0000000000000000000000000000000000000000000000000000000000000000000000
  0000000000000000000000000000000000000000000000000000000000000000000000
  000000000000000000000000000000000000000000
| Denominator = 1
| OverflowError: integer division result too large for a float
```

exception not caught

Catching exceptions – Fractions (IV)

catch exceptions

fraction4.py

```
while True:
    try:
        numerator = int(input('Numerator = '))
        denominator = int(input('Denominator = '))
        result = numerator / denominator
        print(f'{numerator} / {denominator} = {result}')
    except ValueError:
        print('input not a valid integer')
    except ZeroDivisionError:
        print('cannot divide by zero')
```

Python shell

```
Numerator = 3
Denominator = 0
cannot divide by zero
Numerator = 3x
input not a valid integer
Numerator = 4
Denominator = 2
4 / 2 = 2.0
```

Keyboard interrupt (*Ctrl-c*)

- throws **`KeyboardInterrupt`** exception

infinite-loop1.py

```
print('starting infinite loop')

x = 0
while True:
    x = x + 1

print(f'done ({x = })')
input('type enter to exit')
```

Python shell

```
starting infinite loop
Traceback (most recent call last):
  File 'infinite-loop1.py', line 4, in <module>
    x = x + 1
KeyboardInterrupt
```

infinite-loop2.py

```
print('starting infinite loop')

try:
    x = 0
    while True:
        x = x + 1
except KeyboardInterrupt:
    pass

print(f'done ({x = })')
input('type enter to exit')
```

Python shell

```
starting infinite loop
done (x = 23890363)    Ctrl-c
type enter to exit
```

Keyboard interrupt (*Ctrl-c*)

- Be aware that you likely would like to leave the *Ctrl-c* generated **`KeyboardInterrupt`** exception unhandled, except when stated explicitly

read-int1.py

```
while True:
    try:
        x = int(input('An integer: '))
        break
    except ValueError:  # only ValueError
        continue

print('The value is:', x)
```

Python shell

```
An integer:                Ctrl-c
KeyboardInterrupt
```

read-int2.py

```
while True:
    try:
        x = int(input('An integer: '))
        break
    except:  # all exceptions
        continue

print('The value is:', x)
```

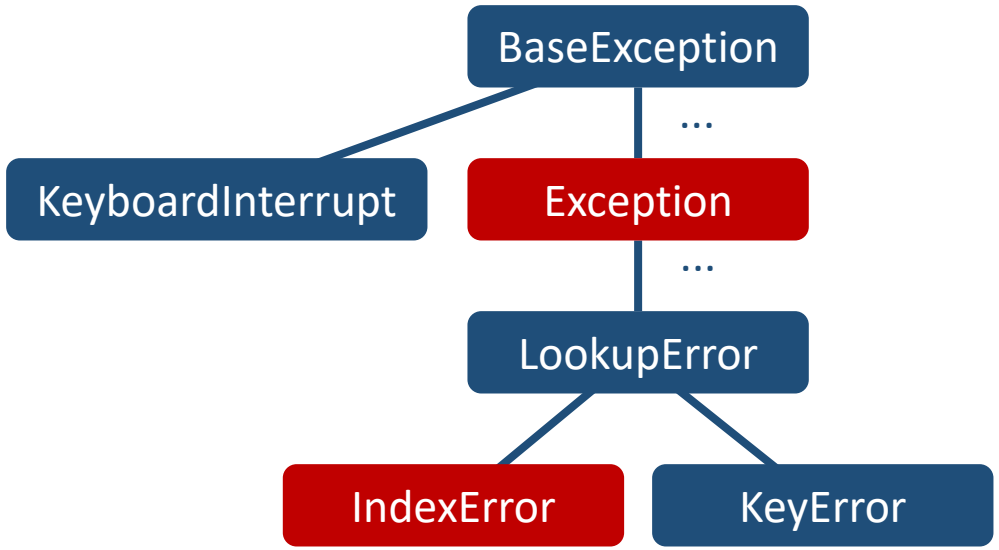
catches KeyboardInterrupt

Python shell

```
An integer:            Ctrl-c
An integer:            Ctrl-c
An integer:
```

- (left) `KeyboardInterrupt` is unhandled (right) it is handled (intentionally?)

Exception class hierarchy



except-twice1.py

```
try:
    L[4]
except IndexError:  # must be before Exception
    print('IndexError')
except Exception:
    print('Fall back exception handler')
```

except-twice2.py

```
try:
    L[4]
except Exception:  # and subclasses of Exception
    print('Fall back exception handler')
except IndexError:
    print('IndexError')  # unreachable
```

`try` statement syntax

arbitrary number of except cases

```
try:
    code
except ExceptionType1:
    code  # executed if raised exception instanceof
          # ExceptionType1 (or subclass of ExceptionType1)
except ExceptionType2:
    code  # executed if exception type matches and none of
          # the previous except statements matched
...
else:
    code  # only executed if no exception was raised
finally:
    code  # always executed independent of exceptions
          # typically used to clean up (like closing files)
```

`except` variations

```
except:                         # catch all exceptions
```

```
except ExceptionType:           # only catch exceptions of class ExceptionType
                                # or subclasses of ExceptionType

except (ExceptionType1, ExceptionType2, ..., ExceptionTypek):
                                # catch any of k classes (and subclasses)
                                # paranthesis cannot be omitted

except ExceptionType as e:
                                # catch exception and assign exception object to e
                                # e.args contains arguments to the raised exception
```

Raising exceptions

- An exception is raised (or trown) using one of the following (the first being an alias for the second):

```
raise ExceptionType
raise ExceptionType()
raise ExceptionType(args)
```

abstract.py

```
class A():
      def f(self):
          print('f')
          self.g()
      def g(self):
          raise NotImplementedError
class B(A):
      def g(self):
          print('g')
```

Python shell

```
> B().f()
| f
| g
> A().f()
| f
| NotImplementedError
```

User exceptions

- New exception types are created using class inheritance from an existing exception type (possibly defining __init__)

tree-search.py

```
class SolutionFound(Exception):  # new exception
    pass

def recursive_tree_search(x, tree):
    if isinstance(tree, tuple):
        for child in tree:
            recursive_tree_search(x, child)
    elif x == tree:
        raise SolutionFound  # found x in tree

def tree_search(x, tree):
    try:
        recursive_tree_search(x, tree)
    except SolutionFound:
        print('found', x)
    else:
        print('search for', x, 'unsuccessful')
```

Python shell

```
> tree_search(8, ((3,2),5,(7,(4,6))))
| search for 8 unsuccessful
> tree_search(7, ((3,2),5,(7,(4,6))))
| found 7
```

PEP8 on exceptions

- For all try/except clauses, limit the try clause to the absolute minimum amount of code necessary
- The class naming convention applies (CapWords)
- Use the suffix "Error" on your exception names
  (if the exception actually is an error)
- A bare `except:` clause will catch `SystemExit` and `KeyboardInterrupt` exceptions, making it harder to interrupt a program with Control-C, and can disguise other problems.
  If you want to catch all exceptions that signal program errors, use `except Exception:`

www.python.org/dev/peps/pep-0008/

3 ways to read lines from a file

Steps

1. Open file using `open`
2. Read lines from file using
   a) `for line in filehandler:`
   b) `filehandler.readlines`
   c) `filehandler.readline`
3. Close file using `close`

`open ('filename.txt')` assumes the file to be in the same folder as your Python program, but you can also provide a full path `open('c:/Users/gerth/Documents/filename.txt')`

try to open file for reading

filename

filehandle

iterate over lines in file

close file when done

reading-file1.py

```
f = open('reading-file1.py')
for line in f:
    print('> ', line, end='')
f.close()
```

read all lines into a list of strings

reading-file2.py

```
f = open('reading-file2.py')
lines = f.readlines()
f.close()
for line in lines:
    print('> ', line, end='')
```

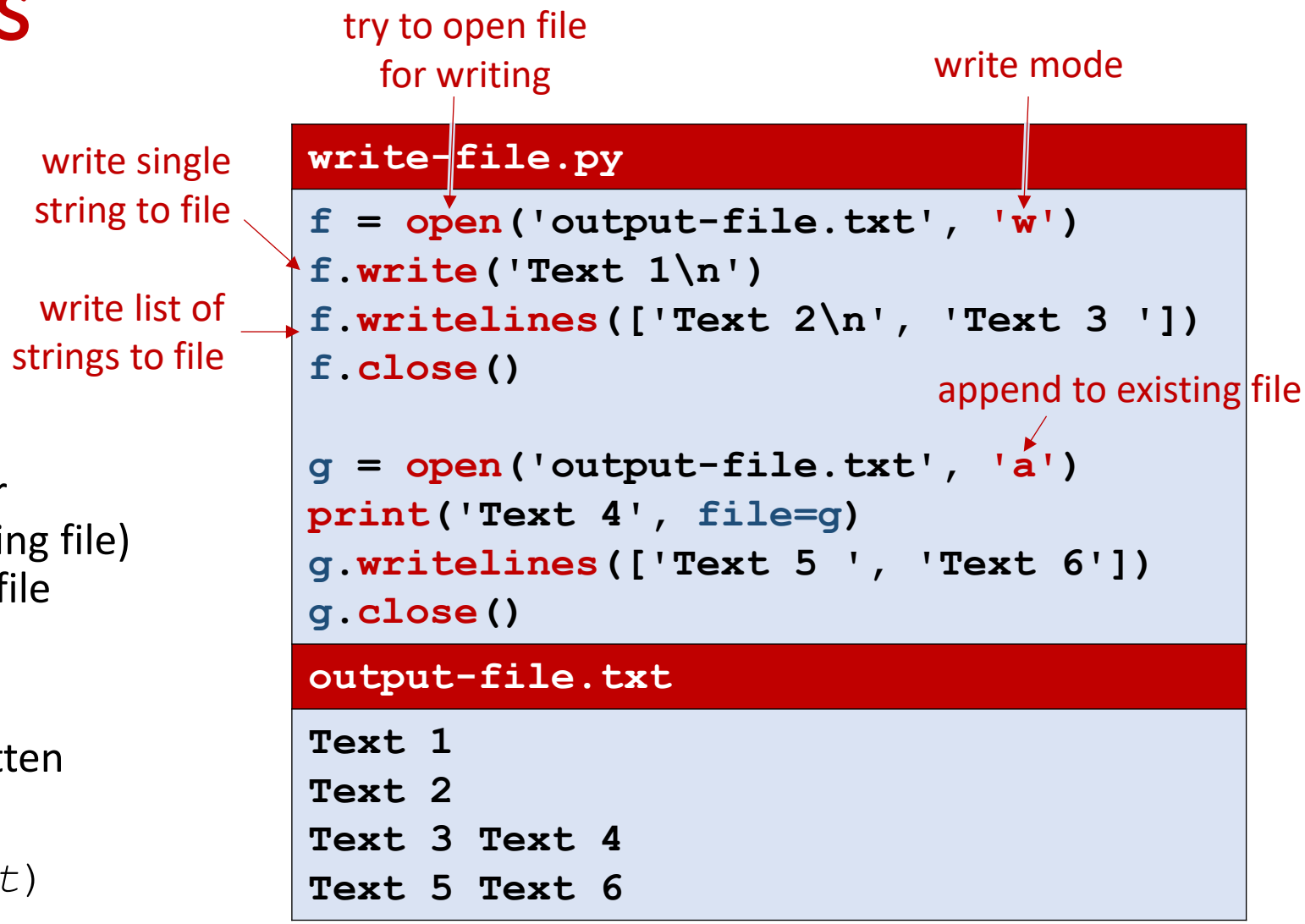
read single line (terminated by '\n')

reading-file3.py

```
f = open('reading-file3.py')
line = f.readline()
while line != '':
    print('> ', line, end='')
    line = f.readline()
f.close()
```

3 ways to write lines to a file

- Opening file:
  `open(`*`filename`*`, `*`mode`*`)`
  where *mode* is a string, either `'w'` for opening a new (or truncating an existing file) and `'a'` for appending to an existing file
- Write single string:
  `filehandle``.write(`*`string`*`)`
  Returns the number of characters written
- Write list of strings strings:
  `filehandle``.writeline(`*`list`*`)`
- Newlines (`'\n'`) must be written explicitly
- `print` can take an optional `file` argument



Exceptions while dealing with files

- When dealing with files one should be prepared to handle errors / raised exceptions, e.g. `FileNotFoundError`

reading-file4.py

```
try:
    f = open('reading-file4.py')
except FileNotFoundError:
    print('Could not open file')
else:
    try:
        for line in f:
            print('> ', line, end='')
    finally:
        f.close()
```

Opening files using `with` (recommended way)

- The Python keyword `with` allows to create a *context manager* for handling files
- Filehandle will automatically be closed, also when exceptions occur
- Under the hood: filehandles returned by `open` support `__enter__` and `__exit__` methods

f = result of calling `__enter__()` on result of `open` expression, which is the file handle

reading-file5.py

```
with open('reading-file5.py') as f:
    for line in f:
        print('> ', line, end='')
```

docs.python.org/3/library/stdtypes.html#typecontextmanager

Does a file exist?

- Module `os.path` contains a method `isfile` to check if a file exists

checking-files.py

```
import os.path

filename = input('Filename: ')
if os.path.isfile(filename):
    print('file exists')
else:
    print('file does not exist')
```

docs.python.org/3/library/os.path.html

module `sys`

- Module `sys` contains the three standard file handles
  - `sys.stdin` (used by the `input` function)
  - `sys.stdout` (used by the `print` function)
  - `sys.stderr` (error output from the Python interpreter)

sys-test.py

```
import sys
sys.stdout.write('Input an integer: ')
x = int(sys.stdin.readline())
sys.stdout.write(f'{x} square is {x ** 2}')
```

Python shell

```
Input an integer: 10
10 square is 100
```

docs.python.org/3/library/sys.html

print(..., file=*output file*)

sys-print-file.py

```
import sys
def complicated_function(file):
    print('Hello world', file=file)  # print to file or STDOUT
while True:
    file_name = input('Output file (empty for STDOUT): ')

    if file_name == '':
        file = sys.stdout
        break
    else:
        try:
            file = open(file_name, 'w')
            break
        except Exception:
            pass
complicated_function(file)
if file != sys.stdout:
    file.close()
```

Input performance

- Reading 10.000.000 short lines

`input()`	2.2 sec
`sys.stdin.readlines()`	0.65 sec
`sys.stdin.readline()`	0.65 sec
`readline()` alias	0.50 sec
`for line in sys.stdin:`	0.39 sec
`sys.stdin.read()`	0.18 sec
`sys.stdin.read().split('\n')`	0.53 sec

- Note: Time difference up to a factor 10

input_performance.py

```
from time import time
import sys
n = 10_000_000
data = 'numbers.txt'
def test_input():
    for i in range(n):
        line = input()
def test_stdin_readline():
    for i in range(n):
        line = sys.stdin.readline()
def test_stdin_readline():
    readline = sys.stdin.readline
    for i in range(n):
        line = readline()
def test_stdin_readlines():
    lines = sys.stdin.readlines()
def test_stdin_read():
    text = sys.stdin.read()
def test_for():
    for line in sys.stdin:
        pass
def create_test_input():
    with open(data, 'w') as file:
        for i in range(n):
            print(i, file=file)
create_test_input()
for _ in range(5):
    for name, value in list(vars().items()):
        if name.startswith('test_'):
            with open(data) as file:
                original_stdin = sys.stdin
                sys.stdin = file
                start = time()
                value()
                end = time()
                sys.stdin = original_stdin
            print(f'{name} {end - start:.2} sec')
```

Performance of scanning a file

- Python can efficiently scan through quite big files

File	Size	Time
Atom_chem_shift.csv	≈ 750 MB	≈ 8 sec
cano.txt	≈ 3.7 MB	≈ 0.1 sec

The first search finds all lines related to ThrB12-DKP-insulin (Entry ID 6203) in a chemical database available from www.bmrb.wisc.edu

The second search finds all occurrences of “Germany” in Conan Doyle's complete Sherlock Holmes available at sherlock-holm.es

file-scanning.py

```
from time import time

for filename, query in [
        ('Atom_chem_shift.csv', ',6203,'),
        ('cano.txt', 'Germany')
    ]:
    count = 0
    matches = []
    start = time()
    with open(filename) as f:
        for i, line in enumerate(f, start=1):
            count += 1
            if query in line:
                matches.append((i, line))
    end = time()

    for i, line in matches:
        print(i, ':', line, end='')
    print('Duration:', end - start)
    print(len(matches), 'of', count, 'lines match')
```

Python shell

```
...
3057752 : 195,,2,2,30,30,THR,HB,H,1,4.22,0.02,,1,,,,,,,,,,,,,,,,,,,,228896,6203,2
3057753 : 196,,2,2,30,30,THR,HG21,H,1,1.18,0.02,,1,,,,,,,,,,,,,,,,,,,,228896,6203,2
3057754 : 197,,2,2,30,30,THR,HG22,H,1,1.18,0.02,,1,,,,,,,,,,,,,,,,,,,,228896,6203,2
3057755 : 198,,2,2,30,30,THR,HG23,H,1,1.18,0.02,,1,,,,,,,,,,,,,,,,,,,,228896,6203,2
Duration: 7.760039329528809
329 of 9758361 lines match
57557 :      "Well, then, to the West, or to England, or to Germany, where father
66515 :      kind master. He wanted me to go with his wife to Germany yesterday,
66642 :      of business in Germany in the past and my name is probably familiar
73273 :      associates with Germany. This he placed in his instrument cupboard.
Duration: 0.07700657844543457
4 of 76764 lines match
```

sudoku.py

```
class Sudoku:
  def __init__(self, puzzle):
    self.puzzle = puzzle

  def solve(self):
    def find_free():
      for i in range(9):
        for j in range(9):
          if self.puzzle[i][j] == 0:
            return (i, j)
      return None

    def unused(i, j):
      i_, j_ = i // 3 * 3, j // 3 * 3
      cells  = {(i, k) for k in range(9)}
      cells |= {(k, j) for k in range(9)}
      cells |= {(i, j) for i in range(i_, i_ + 3)
                       for j in range(j_, j_ + 3)}
      return set(range(1, 10)) - {self.puzzle[i][j] for i, j in cells}

    class SolutionFound(Exception):
      pass

    def recursive_solve():
      cell = find_free()
      if not cell:
        raise SolutionFound
      i, j = cell
      for value in unused(i, j):
        self.puzzle[i][j] = value
        recursive_solve()
      self.puzzle[i][j] = 0

    try:
      recursive_solve()
    except SolutionFound:
      pass
```

sudoku.py (*continued*)

```
  def print(self):
    for i, row in enumerate(self.puzzle):
      cells = [f' {c} ' if c else ' . ' for c in row]
      print('|'.join([''.join(cells[j:j+3]) for j in (0,3,6)]))
      if i in (2, 5):
        print('---------+---------+---------')

with open('sudoku.txt') as f:
    A = Sudoku([[int(x) for x in line.strip()] for line in f])

A.solve()
A.print()
```

sudoku.txt

```
517600034
289004000
346205090
602000010
038006047
000000000
090000078
703400560
000000000
```

Python shell

```
|  5  1  7 | 6  9  8 | 2  3  4
|  2  8  9 | 1  3  4 | 7  5  6
|  3  4  6 | 2  7  5 | 8  9  1
| ---------+---------+---------
|  6  7  2 | 8  4  9 | 3  1  5
|  1  3  8 | 5  2  6 | 9  4  7
|  9  5  4 | 7  1  3 | 6  8  2
| ---------+---------+---------
|  4  9  5 | 3  6  2 | 1  7  8
|  7  2  3 | 4  8  1 | 5  6  9
|  8  6  1 | 9  5  7 | 4  2  3
```

`match – case` (since Python 3.10)

- Assume we want to do different things depending on the value of an expression (different *cases*)
- Can be done using `if`, but also using `match – case`, that is also evaluated top-down

match-case.py

```
x = 7

if x == 1:
    print('x is one')
elif x == 2:
    print('x is two')
elif x == 3 or x == 4 or x == 5:
    print('x is three, four or five')
else:
    print(x, 'is not in the range 1-5')
```

Python shell

```
7 is not in the range 1-5
```

match-case.py

```
x = 7

match x:  # match expression
    case 1:
        print('x is one')
    case 2:
        print('x is two')
    case 3 | 4 | 5:  # match any of the cases
        print('x is three, four or five')
    case value:  # else, value = variable name
        print(value, 'is not in the range 1-5')
```

Python shell

```
7 is not in the range 1-5
```

match – case

Can match…

- simple values
- named variable values
- guards (`if`)
- sequences of values
- dictionaries
- builtin types
- user defined classes
- nested structures of the above

match-case.py

```
class Color:
    RED   = 'ff0000'
    GREEN = '00ff00'
    BLUE  = '0000ff'

class Point:
    __match_args__ = ('x', 'y')

    def __init__(self, x, y):
        self.x = x
        self.y = y

    def __repr__(self):
        return f'Point({self.x}, {self.y})'
```

match-case.py

```
def f(x):
  match x:
    case 42:
        return 'the integer 42'
    case 1 | 2 | 3 | 4 | 5:
        return 'integer in range(1, 6)'
    case (1, 2):
        return 'sequence containing the elements 1 and 2'
    case [x, 2]:
        return 'sequence of length 2, last=2, first=' + str(x)
    case (x, y) if x + y == 7:  # guard
        return 'sequence with two values with sum 7'
    case [0, 1, *x]:  # x is list of remaining elements in sequence
        return 'sequence starting with 0 and 1, and tail ' + str(x)
    case {'a': 7, 'b': x}:
        return 'dictionary "a" -> 7, "b" -> ' + str(x)
    case (('a' | 'b'), ('c' | 'd')):
        return 'tuple length 2, first "a" or "b", last "c" or "d"'
    case (('x' | 'y') as fst, ('x' | 'y') as snd):
        return '(fst, snd), where fst=' + str(fst) + ', snd=' + str(snd)
    case float(value):  # test on builtin type
        return 'a float ' + str(value)
    case Color.RED:  # class or object attribute
        return 'the color red'
    case Point(x=7, y=value):  # Point object with attributes x and y
        return 'a Point object with x=7, and y=' + str(value)
    case Point(x, y):  # requires __match_args__ in class Point
        return 'a point Point(' + str(x) + ', ' + str(y) + ')'
    case e:  # ⚠ using the wildcard _ would not bind to a variable
        return 'cannot match ' + repr(e)
```

Python shell (match-case.py *continued*)

```
> for x in [42, 1, [1, 2], [7, 2], range(3, 5), (3, (5, 7)), (0, 1, 2, 3, 4, 5), {'a':7, 'b':42, 'c':1},
            ('b', 'c'), ('y', 'x'), 3.14, 'ff0000', Point(7, 42), Point(3, 5), 'abc']:
      print('f(' + repr(x) + ') = ' + repr(f(x)))
| f(42) = 'the integer 42'
| f(1) = 'integer in range(1, 6)'
| f([1, 2]) = 'sequence containing the elements 1 and 2'
| f([7, 2]) = 'sequence of length 2, last=2, first=7'
| f(range(3, 5)) = 'sequence with two values with sum 7'
| f((3, (5, 7))) = 'a triplet (3, (5, 7))'
| f((0, 1, 2, 3, 4, 5)) = 'sequence starting with 0 and 1, and tail [2, 3, 4, 5]'
| f({'a': 7, 'b': 42, 'c': 1}) = 'dictionary "a" -> 7, "b" -> 42'
| f(('b', 'c')) = 'tuple length 2, first "a" or "b", last "c" or "d"'
| f(('y', 'x')) = '(fst, snd), where fst=y, snd=x'
| f(3.14) = 'a float 3.14'
| f('ff0000') = 'the color red'
| f(Point(7, 42)) = 'a Point object with x=7, and y=42'
| f(Point(3, 5)) = 'a point Point(3, 5)'
| f('abc') = "cannot match 'abc'"
```