Errors and Finite State Machines

Basic Programming in Python

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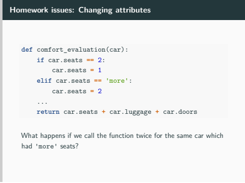
Quick homework issues

- Don't write your own sorting algorithms, just use what is their
- Don't remove all print statements – we do expect *some* output ;-)
- Try to structure your code using functions

Homework issues: Changing attributes

```python
def comfort_evaluation(car):
    if car.seats == 2:
        car.seats = 1
    elif car.seats == 'more':
        car.seats = 2
    ...
    return car.seats + car.luggage + car.doors
```

What happens if we call the function twice for the same car which had `'more'` seats?



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    ...
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```

What happens if we call the function twice for the same car which had `'more'` seats?

Don't change values if you just want to read them! Sometimes you want to use them somewhere else, or someone else wrote some code where it's still important to have `'more'`.

In this example on the first evaluation, `car.seats` would be set to 2, on the second it would then be set to 1!

Mutability

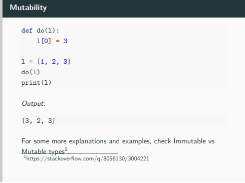
```python
def do(l):
    l[0] = 3


l = [1, 2, 3]
do(l)
print(l)
```

Output:

```
[3, 2, 3]
```

For some more explanations and examples, check Immutable vs Mutable types[1].

[1] https://stackoverflow.com/q/8056130/3004221



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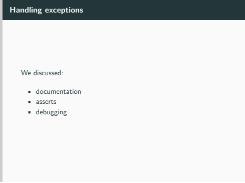
- Lists and objects are mutable, that means they can be modified inside functions unless you copy them.
- int, str, float, etc. are not mutable (immutable), they always stay what they were before the function call.

Handling exceptions

We discussed:

- documentation
- asserts
- debugging



Handling exceptions

We discussed:

- documentation
- asserts
- debugging

While most (maybe even all?) errors are called `Error`, you will find me calling them *exceptions*.

Correct would be to call `SyntaxErrors` errors and most other errors exceptions.

But since there is no clear distinction between the two, I try to use *exception* on all slides.

Expected exceptions

Sometimes exceptions are expected to happen. Be prepared!

```
number = None
while not number:
    value = input('Please enter a number > 0: ')
    number = float(value)
```

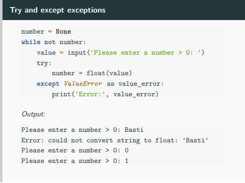
What if someone enters a name (and not a number)?

Try and except exceptions

```python
number = None
while not number:
    value = input('Please enter a number > 0: ')
    try:
        number = float(value)
    except ValueError as value_error:
        print('Error:', value_error)
```

Output:

```
Please enter a number > 0: Basti
Error: could not convert string to float: 'Basti'
Please enter a number > 0: 0
Please enter a number > 0: 1
```



Try and except exceptions

```
number = None
while not number:
    value = input('Please enter a number > 0: ')
    try:
        number = float(value)
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```

Output:

```
Please enter a number > 0: Basti
Error: could not convert string to float: 'Basti'
Please enter a number > 0: 0
Please enter a number > 0: 1
```

`try` runs code until an exception occurs. If that exception was expected, we can catch it with `except`.

Otherwise the program will crash, just as you have seen it many times with exceptions.

Multiple exceptions

Sometimes you want to except multiple exceptions.

There are three ways to do this:

- Excepting all exceptions at once
- Excepting all individually
- A combination thereof

Excepting multiple exceptions at once

```python
halogens = {9: 'F', 17: 'Cl',
            35: 'Br', 53: 'I',
            85: 'At'}
number = None
while number not in halogens.keys():
    try:
        number = int(input('Please enter an atomic number:
        print('You selected', halogens[number])
    except (ValueError, KeyError) as error:
        print('Sorry!', error)
```

Excepting multiple exceptions individually

```
halogens = {9: 'F', 17: 'Cl',
            35: 'Br', 53: 'I',
            85: 'At'}
number = None
while number not in halogens.keys():
    try:
        number = int(input('Please enter an atomic number:
        print('You selected', halogens[number])
    except ValueError as error:
        print('No number', error)
    except KeyError as error:
        print('Key not found', error)
```

To handle or not to handle?

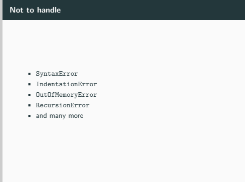
Which errors should be handled, which ones not?

To handle

- `KeyError`
- `ValueError`
- `ZeroDivisionError`
- `IndexError`
- and many more

Not to handle

- `SyntaxError`
- `IndentationError`
- `OutOfMemoryError`
- `RecursionError`
- and many more



Not to handle

- `SyntaxError`
- `IndentationError`
- `OutOfMemoryError`
- `RecursionError`
- and many more

You should never handle exceptions which occur because of the code syntax, nor should you handle exceptions which denote system limitations.

Rule of thumb: Handle only what you can handle with an algorithm.

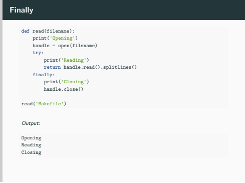
Finally

```python
def read(filename):
    print('Opening')
    handle = open(filename)
    try:
        print('Reading')
        return handle.read().splitlines()
    finally:
        print('Closing')
        handle.close()

read('Makefile')
```

Output:

```
Opening
Reading
Closing
```



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read('Makefile')
```

Output:

```
Opening
Reading
Closing
```

Statements inside a finally block will always be executed, regardless of exceptions before or not.

It even works after returns!

It is most commonly used to ensure files and other connections are closed.

But beware: `with` is almost always better!

Finally

Exception:

```python
try:
    a = int('abc')
except ValueError:
    a = -1
finally:
    print('Finally!')
print(a)
```

Output:

```
Finally!
-1
```

No exception:

```python
try:
    a = int('1')
except ValueError:
    a = -1
finally:
    print('Finally!')
print(a)
```

Output:

```
Finally!
1
```

Raising your own exceptions

```python
class CarException(Exception): pass

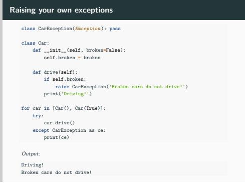
class Car:
    def __init__(self, broken=False):
        self.broken = broken

    def drive(self):
        if self.broken:
            raise CarException('Broken cars do not drive!')
        print('Driving!')

for car in [Car(), Car(True)]:
    try:
        car.drive()
    except CarException as ce:
        print(ce)
```

Output:

```
Driving!
Broken cars do not drive!
```



Raising your own exceptions

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for car in [Car(), Car(True)]:
    try:
        car.drive()
    except CarException as ce:
        print(ce)
```

Output:

```
Driving!
Broken cars do not drive!
```

`class CarException(Exception)` means that the class `CarException` *inherits* all properties the class `Exception` has. We won't discuss inheritance in more details. But it is important so that you can `raise` exceptions.

The string in the exception you raise should be meaningful: It's the error message other people will see.

Use cases for exception handling

When writing your own programs, you will mostly have to deal with exceptions when facing user input.

But there are other situations: Reading files, downloading data, program interruptions, . . .

Combining strings and numbers

A common pattern we used so far:

```python
wheels = 4
description = 'My car has ' + wheels + ' wheels.'
print(description)
```

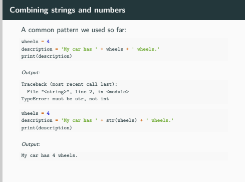
Output:

```
Traceback (most recent call last):
  File "<string>", line 2, in <module>
TypeError: must be str, not int
```

```python
wheels = 4
description = 'My car has ' + str(wheels) + ' wheels.'
print(description)
```

Output:

```
My car has 4 wheels.
```



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```

```
wheels = 4
description = 'My car has ' + str(wheels) + ' wheels.'
print(description)
```

Output:

```
My car has 4 wheels.
```

Casting things to strings manually is very tedious. There's a better way!

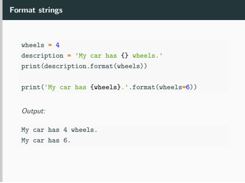
Format strings

```
wheels = 4
description = 'My car has {} wheels.'
print(description.format(wheels))

print('My car has {wheels}.'.format(wheels=6))
```

Output:

```
My car has 4 wheels.
My car has 6.
```



Format strings

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description = 'My car has {} wheels.'
print(description.format(wheels))

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```

Output:

```
My car has 4 wheels.
My car has 6.
```

The `{}` are delimiters. Here they just serve as placeholders, but we can do much more with them. Notice the `wheels` in the second case? It allows to name an argument.

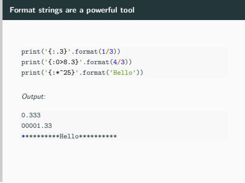
Consider: `'I am at ({x}, {y})'.format(y=2, x=5)`.

Format strings are a powerful tool

```
print('{:.3}'.format(1/3))
print('{:0>8.3}'.format(4/3))
print('{:*^25}'.format('Hello'))
```

Output:

```
0.333
00001.33
**********Hello**********
```



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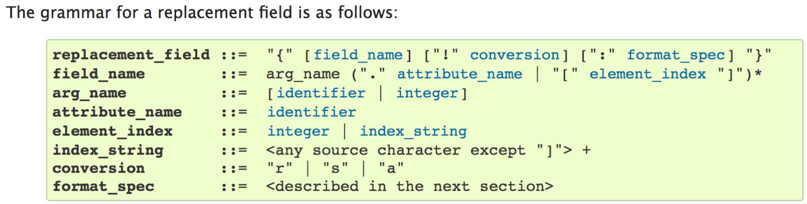
Output:

```
0.333
00001.33
**********Hello**********
```

The : means: now comes a format rule! The format rules then follow a special syntax. The examples here go as follows:

- .3 Format with 3 decimal places ("After decimal separator, use up to 3 digits").
- 0>8.3 Pad with 0s (put zeros to fill the width), align right (>), make it 8 characters long (at least), and have 3 after the decimal separator. Note that 8 is the *total* length, so there will be $8 - 3 - 1$ characters (or more if needed) left of the ..
- *^25 Pad with *s, align centered (^), make it 25 wide.

Format specifications


The grammar for a replacement field is as follows:

```
replacement_field ::=  "{" [field_name] ["!" conversion] [":" format_spec] "}"
field_name        ::=  arg_name ("." attribute_name | "[" element_index "]")*
arg_name          ::=  [identifier | integer]
attribute_name    ::=  identifier
element_index     ::=  integer | index_string
index_string      ::=  <any source character except "]"> +
conversion        ::=  "r" | "s" | "a"
format_spec       ::=  <described in the next section>
```

Figure 1:
https://docs.python.org/3.6/library/string.html#format-string-syntax

Format specifications

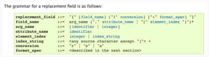


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Figure 1:
https://docs.python.org/3.6/library/string.html#format-string-syntax

Now you can create output which looks like you want without having to weirdly concatenate strings and check spaces, etc.

There is much more inside the documentation, we will take a look at some of it now.

Paradigm shift

We have now learned a huge set of tools in Python:

Variables, functions, classes, numbers, strings, error handling, documentation, lists, dictionaries, sets, tuples, some built-in functions, lambdas, list comprehensions, mathematical operations, directory structures, imports, naming and code conventions, input and output, loops, if and else, . . .

If you want to go into more details about all those things, I recommend the Python Tutorial[2]. It covers what we did and sometimes a little bit more.

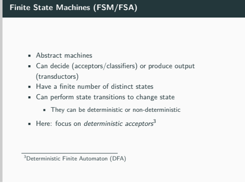
For the rest of the course, we will mostly focus on applications.

[2] https://docs.python.org/3/tutorial/

Finite State Machines (FSM/FSA)

- Abstract machines
- Can decide (acceptors/classifiers) or produce output (transductors)
- Have a finite number of distinct states
- Can perform state transitions to change state
  - They can be deterministic or non-deterministic
- Here: focus on *deterministic acceptors*[3]

[3] Deterministic Finite Automaton (DFA)



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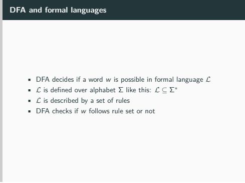
[3]Deterministic Finite Automaton (DFA)

- Sometimes called *Finite State Automaton* (FSA)
- The formal things now will be a little bit boring for people following the Computer Science D class by Prof. Chimani or the Computational Linguistics class by Dr. phil. Gregoromichelaki, but we will make some more practical considerations.
- You can already guess: This is a cool link to other subjects!

DFA and formal languages

- DFA decides if a word w is possible in formal language $\mathcal{L}$
- $\mathcal{L}$ is defined over alphabet Σ like this: $\mathcal{L} \subseteq \Sigma^*$
- $\mathcal{L}$ is described by a set of rules
- DFA checks if w follows rule set or not



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- Σ can be something like $\{a, b\}$
- Σ^* is then the set of all possible combinations of a and b and the empty set $\emptyset$
- Examples are: $aaababb$, a, $\emptyset$, $bbbb$, ab, $\ldots$

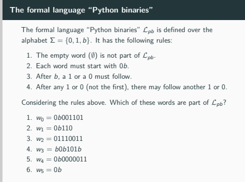
The formal language “Python binaries”

The formal language “Python binaries” $\mathcal{L}_{pb}$ is defined over the alphabet $\Sigma = \{0, 1, b\}$. It has the following rules:

1. The empty word ($\emptyset$) is not part of $\mathcal{L}_{pb}$.
2. Each word must start with $0b$.
3. After b, a 1 or a 0 must follow.
4. After any 1 or 0 (not the first), there may follow another 1 or 0.

Considering the rules above. Which of these words are part of $\mathcal{L}_{pb}$?

1. $w_0 = 0b001101$
2. $w_1 = 0b110$
3. $w_2 = 01110011$
4. $w_3 = b0b101b$
5. $w_4 = 0b0000011$
6. $w_5 = 0b$



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2. $w_1 = 0b110$
3. $w_2 = 01110011$
4. $w_3 = b0b101b$
5. $w_4 = 0b0000011$
6. $w_5 = 0b$

Valid: w_0, w_1, w_4.

Invalid: w_2 (no b), w_3 (too many b), w_5 (no 0 or 1 after b).

DFA for "Python binaries"

A DFA $\mathcal{A}$ is a quintuple[4]:

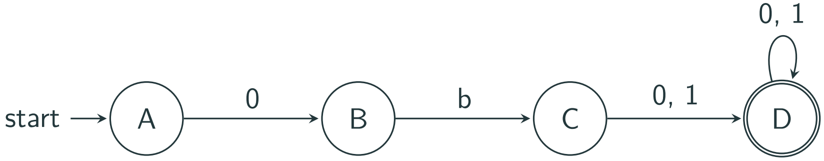
$$\mathcal{A} = (\Sigma, S, S_0 \in S, \delta : S \times \Sigma \to S, G \subseteq S)$$

with:

- Σ: the input alphabet, here $\Sigma = \{0, 1, b\}$
- S: the set of states, we discuss this on the next slide
- $S_0 \in S$: the start state, also next slide
- δ: the transition function which describes when to move where
- G: the set of goal states, if these are reached, the DFA accepts

[4] No worries, it's not that hard!

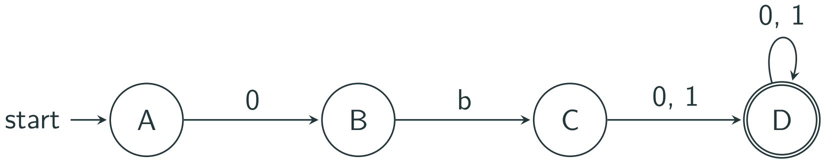
Drawing a DFA as a directed graph



We can now identify our states easily:

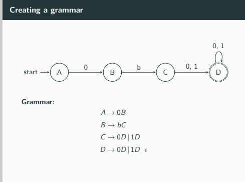
- $S = \{A, B, C, D\}$
- $S_0 = A$
- $G = \{D\}$

Creating a grammar



Grammar:

$$\begin{aligned} A &\to 0B \\ B &\to bC \\ C &\to 0D \mid 1D \\ D &\to 0D \mid 1D \mid \epsilon \end{aligned}$$



Creating a grammar

$$\begin{tikzcd}
\text{start} \arrow[r] & A \arrow[r, "0"] & B \arrow[r, "b"] & C \arrow[r, "0, 1"] & D \arrow[loop above, "0, 1"]
\end{tikzcd}$$

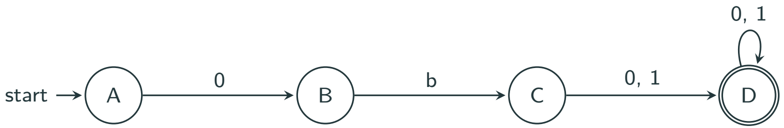
Grammar:

$$A \to 0B$$
$$B \to bC$$
$$C \to 0D \,|\, 1D$$
$$D \to 0D \,|\, 1D \,|\, \epsilon$$

A $|$ denotes an `or`, ϵ means no input. Rules can either be of the form $S \to \sigma \in \Sigma \times S$, $S \to \sigma \in \Sigma$, or $S \to \epsilon$. The last two rules, which don't have new states defined, are called "terminal" rule.

There are also many algorithms to convert between grammars, diagrams, rules, etc.; the problems we discuss are usually easily solved by "looking closely".

Writing a transition function



Grammar:

$$A \to 0B$$
$$B \to bC$$
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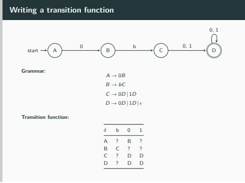
$$D \to 0D \mid 1D \mid \epsilon$$

Transition function:

δ	b	0	1
A	?	B	?
B	C	?	?
C	?	D	D
D	?	D	D



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$$A \rightarrow 0B$$
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Transition function:

δ	b	0	1
A	?	B	?
B	C	?	?
C	?	D	D
D	?	D	D

You can read the transfer function like this:

Given a state (first column) and an input (first row), the state changes to the state which is defined if we take state and input as coordinates. For example, given state B and input 0, the next state would be C. State A and input b result in state B. And so on. Formally each cell defines a rule of the form $S \times \Sigma \rightarrow S$, e.g. $B \times b \rightarrow C$ and $C \times 0 \rightarrow D$.

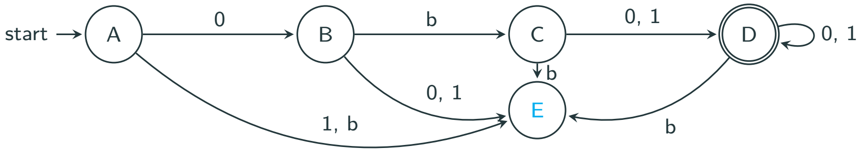
What about the question marks?

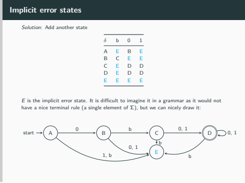
Implicit error states

Solution: Add another state

δ	b	0	1
A	E	B	E
B	C	E	E
C	E	D	D
D	E	D	D
E	E	E	E

E is the implicit error state. It is difficult to imagine it in a grammar as it would not have a nice terminal rule (a single element of Σ), but we can nicely draw it:





Implicit error states

Solution: Add another state

δ	b	0	1
A	E	B	E
B	C	E	E
C	E	D	D
D	E	D	D
E	E	E	E

E is the implicit error state. It is difficult to imagine it in a grammar as it would not have a nice terminal rule (a single element of Σ), but we can nicely draw it:

$$\begin{tikzcd}
\text{start} \arrow[r] & A \arrow[r, "0"] \arrow[rrd, bend right, "{1, b}"'] & B \arrow[r, "b"] \arrow[rd, bend right, "{0, 1}"] & C \arrow[r, "{0, 1}"] \arrow[d, "b"] & D \arrow[loop right, "{0, 1}"] \arrow[ld, bend left, "b"] \\
 & & & E &
\end{tikzcd}$$

The implicit error state is useful when we program our FSA.

To find out what leads to error state, imagine all possible inputs for each state: Those which are not “legal” according to the grammar rules lead to the error state (sometimes called “trap”).

Implementing δ

δ	b	0	1
A	E	B	E
B	C	E	E
C	E	D	D
D	E	D	D
E	E	E	E

```python
def delta(state, letter):
    states, inputs = ['A', 'B', 'C', 'D', 'E'], ['b', '0', '1']
    transition = [
        ['E', 'B', 'E'],
        ['C', 'E', 'E'],
        ['E', 'D', 'D'],
        ['E', 'D', 'D'],
        ['E', 'E', 'E']
    ]
    return transition[states.index(state)][inputs.index(letter)]

print('A x b -> {}'.format(delta('A', 'b')))
print('A x 0 -> {}'.format(delta('A', '0')))
print('C x 1 -> {}'.format(delta('C', '1')))
```

Output:

```
A x b -> E
A x 0 -> B
C x 1 -> D
```

Implementing a DFA

File: binary.py

```
def delta(state, letter):
    states, inputs = ['A', 'B', 'C', 'D', 'E'], ['b', '0', '1']
    transition = [
        ['E', 'B', 'E'],
        ['C', 'E', 'E'],
        ['E', 'D', 'D'],
        ['E', 'D', 'D'],
        ['E', 'E', 'E']
    ]
    return transition[states.index(state)][inputs.index(letter)]

def fsa(word):
    state = 'A'
    for letter in word:
        state = delta(state, letter)
    return state == 'D'

if __name__ == '__main__':
    for b in ['0b01', '011', '0b1101']:
        print('{} {}'.format(b, fsa(b)))
```

Output:

```
0b01 True
011 False
0b1101 True
```

Checking our examples

```python
import binary  # The file from last slide

for b in ['0b001101', '0b110', '01110011',
          'b0b101b', '0b0000011', '0b']:
    print('{} {}'.format(b, binary.fsa(b)))
```

Output:

```
0b001101 True
0b110 True
01110011 False
b0b101b False
0b0000011 True
0b False
```

Where do we find DFA?

Where do you think do we find DFA?

Where do we find DFA?

- coin vending machines
- programming (remember the string format syntax?)
- cars (e.g. wiper motors)
- process descriptions
- ...

Your ninth homework

- Coffee machines are also some automaton. Help us to decide which “recipes” work best for our coffee!