Computational Structures in Data Science

Programming Paradigms

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Programming Paradigms

- **Paradigm** (Merriam Webster): a typical example or pattern of something; a model. Example: "there is a new paradigm for public art in this country"
- **Programming Paradigm** (Joe Turner, Clemson University): "A programming paradigm is a general approach, orientation, or philosophy of programming that can be used when implementing a program." You might call this a "style"

Why?

- Understanding the paradigm helps you understand the intent of the programmer
- Pick the right tool for the job!
  - Different problems require different solutions
- Most programs written today are multi-paradigm
  - They mix and match the style
- Problem solving technique

Examples of Paradigms

Example, three very different approaches to squaring list:

```
lst = []
for i in range(5):
        lst += [ i*i ]
```

```
map(lambda x: x*x, range(5))
```

```
[ x * x for x in range(5) ]
```

```
range(5).square_nums() # Only theoretically,
e.g assume `def square_nums(self)` exists.
```

Word of Warning

- There is no universally agreed upon taxonomy of human programming styles.
- One possible list:
  - Imperative
  - Functional
  - Array-based
  - Object-Oriented
  - Declarative
- These terms are a bit fluid, and as you'll see if you read more on wikipedia, there is substantial disagreement about these terms.

Programming Paradigms

Example, three very different approaches to squaring list:

Functional: `map(lambda x: x*x, [1, 2, 3])`

Array-based:

```
np.array([1,2,3]) * np.array([1,2,3])
np.array([1,2,3]) ** 2
```

Imperative:

```
def squares(nums):
    result = []
    for num in nums:
        result += [ num * num ]
    return result
```

The Imperative Programming Paradigm

- An imperative program provides a sequence of steps.
- Like following a recipe.
- Assignment is allowed (can set variables).
- Mutation is allowed (can change variables).
- Example (acronym):

```
def acronym_i(words):
    result = ''
    words = words.split(' ')
    for word in words:
        if len(word) > 4:
            result += word[0]
    return result
```

The Functional Programming Paradigm

- In functional programming, computation is thought of in terms of the evaluation of functions.
- No state (e.g. variable assignments).
- No mutation (e.g. changing variable values).
- No side effects when functions execute.

```
def acronym_f(words):
  return reduce(add,
         map(lambda w: w[0],
           filter(lambda w: len(w) > 3,
              words.split(' '))))
```

Imperative vs. Functional

- Can argue that functional is a subset of imperative.
- Functional programming is still a series of steps.
- "Just" need to avoid state and think of computation as functions.
- Functional Programs:
- More often fewer clear /correct ways to do something.
  - Programming feels more like solving puzzles.
  - Solutions can seem like magic (especially to imperative programmers).

Why do we push functional programming?

- Tend to be shorter.
- Tend to be easier to debug (no need to track variables / side effects).
- Tend to parallelize better (can split work on multiple computers).
  - Example: Each computer can do 1/8th of a "map" operation.
  - Reducing mutations makes computation easier to scale
  - Hugely prevalent in AI fields.
- Growing in popularity.
  - Explosion of ideas in new programming languages
  - "old" ideas are becoming new/popular

A Hybrid Approach

- Paradigms are not official rules. Just attempts to taxonomize approaches taken by humans.
- Code below is sorta functional, sorta imperative.
- Utilizes state for clarity. Many program this way. You might not.

```
def acronym_h(words):
    words = words.split(' ')
    long = filter(lambda w: len(w) > 4, words)
    letters = maps(lambda w: w[0], long)
    return ''.join(letters)
```

Discussion and Debate

- Which of these do you like best?

Imperative
Very small steps to reason about.
Seems "natural", but lots of code

```
def acronym_i(words):
  result = ''
  words = words.split(' ')
  for word in words:
    if len(word) > 4:
        result += word[0]
  return result
```

Functional: Less to keep track of. Fewer variables, lines

```
def acronym_f(words):
    return reduce(add,
            map(lambda w: w[0],
            filter(lambda w: len(w) > 3,
                    words.split(' '))))
```

Hybrid: Some functional, but uses variables, soom OOP!

```
def acronym_h(words):
  words = words.split(' ')
  long = filter(lambda w: len(w) > 3, words)
  letters = maps(lambda w: w[0], long)
  return ''.join(letters)
```

Array-Based Programming!

- Not something we can easily demo in *native* Python.
- Treats arrays a "first class" objects – not just containers:
- Mathematical Operations correspond to "Pairwise" computations:
  - `np.array([1,2,3]) * np.array([1,2,3])`
  - `np.array([1,2,3]) + np.array([1,2,3]) == [2, 4, 6]` → `array([ True,  True,  True])`
  - **Note!** Even == is now an array operation. Good? Bad? Just different!
- Very common in data science, engineering!
  - Numpy, Pandas (Data 100), MATALAB, Julia, APL

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Object-Oriented Programming

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The Object-Oriented Programming Paradigm

- In object programming, we organize our thinking around objects, each containing its own data, and each with its own procedures that can be invoked.

- We've had plenty of practice here!
- OOP provides many tools!
- But also leaves many import questions open:
  - Should functions be mutable or immutable?
  - How much inheritance is the right amount?

Object-Oriented Programming

- There is a LOT more than what we see in C88C
  - Rich model for composing classes together
    - Python allows you to inherit from multiple classes at once
  - Can **easily** be overused.
  - Explored in depth in CS61B
- In Python "everything is an object"
  - You benefit from OOP ideas even when you don't realize.
  - Global functions like len() delegate to "magic" methods on objects, e.g. `__len__`

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Declarative Programming

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Declarative Programming

- In declarative programming, we express what we want, without specifying how. A program is simply a description of the result we want.
- Can be a very different thought process!
- Incredibly useful, but not necessarily best for all types of problems.

The Web: HTML

- Web pages are built with a language called HTML.
  - Programmers specific what content should be on the page, and where.
  - The browser lays out the content on each device in the right spot for each screen size, etc.
    - Developers don't have to specify what happens when someone changes the window size, or hits print, etc.
  - Tags, like "section", "p" (paragraph), "header" "time" describe the *type of content*

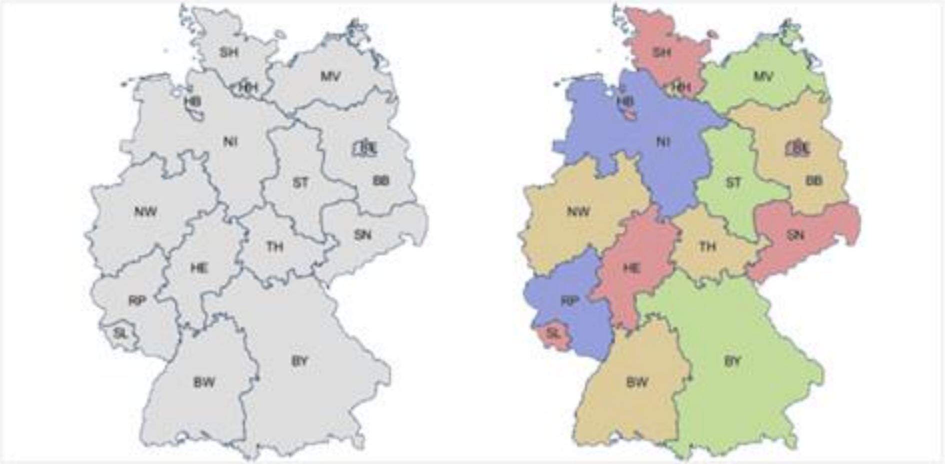
HTML Continued

- A partial section of the CS88 Website:

```
<div id="content" class="container">
    <div class="page-header">
    <h1><span class="content-title-brand">CS 
88</span>:
         Computational Structures in Data Science
    <div class="small">Fall 2023</div>
    <div class="small">Instructor: Michael Ball</div>
   </h1>
</div>
<section><h2>Announcements</h2>…
```

Declarative Programming

- In declarative programming, we express what we want, without specifying how. A program is simply a description of the result we want.
- Example: coloring a map of Germany using the Prolog language:



Prolog Example (From Bernardo Pires)

- Tell Prolog that colors exist:
  Tell Prolog that same colors can't touc

```
color(red).
color(green).
color(blue).
color(yellow).
```

```
neighbor(StateAColor, StateBColor) :- color(StateAColor),
    color(StateBColor),
    StateAColor \= StateBColor. /* \= is the not equal operator */
```

Tell Prolog all the borders:

```
germany(SH, MV, HH, HB, NI, ST, BE, BB, SN, NW, HE, TH, RP, SL, BW, BY) :-
neighbor(SH, NI), neighbor(SH, HH), neighbor(SH, MV),
neighbor(HH, NI),
neighbor(MV, NI), neighbor(MV, BB),
neighbor(NI, HB), neighbor(NI, BB), neighbor(NI, ST), neighbor(NI, TH),
neighbor(NI, HE), neighbor(NI, NW),
neighbor(ST, BB), neighbor(ST, SN), neighbor(ST, TH),
neighbor(BB, BE), neighbor(BB, SN),
neighbor(NW, HE), neighbor(NW, RP),
neighbor(SN, TH), neighbor(SN, BY),
neighbor(RP, SL), neighbor(RP, HE), neighbor(RP, BW),
neighbor(HE, BW), neighbor(HE, TH), neighbor(HE, BY),
neighbor(TH, BY),
neighbor(BW, BY).
```

Ask Prolog for answer:

```
?- germany(SH, MV, HH, HB, NI, ST, BE, BB, SN, NW, HE, TH, RP, SL, BW, BY).
```

Declarative Programming → Results

- Result is a list of states and color pairs

BB = BW, **BW** = HB, **HB** = NW, **NW** = SH, **SH** = SL, **SL** = TH, **TH** = red,
BE = NI, **NI** = RP, **RP** = SN, **SN** = green,
BY = yellow,
HE = HH, **HH** = MV, **MV** = ST, **ST** = blue

Declarative Programming

- Each declarative language has only a limited number of tasks for which you can specify "what", and not "how", e.g.
- Prolog: Logic.
- SQL: Queries from a database.
- Pandas and `datascience` modules: Data manipulation operations like aggregation, filtering, joining, etc.
  - Very common operations in Data 8 and Data 100.
  - While the syntax of Pandas is odd, the ideas will build upon Data 8.

Declarative Programming In Data 8

- `cones.group('Flavor')`
  - `datascience` module figures out the grouping
- `table.where(label, conditions)`
- Can combine these simpler expressions together for more complex questions

Declarative or Object-Oriented?

- Both!
- Tables (in Data 8, Pandas, etc) are Python objects
  - There is a `class Table` with a `def columns(self)` method
- However, the *interface* is *often* declarative.
  - You describe what the output should look like

Why SQL?

- SQL is a declarative programming language for accessing and modifying data in a relational database.
- It is an entirely new way of thinking ("new" in 1970, and new to you now!) that specifies what should happen, but not how it should happen.
- Python is a multi-paradigm language, but we haven't yet tried declarative programming.

What is SQL?

- A declarative language
  - Described what to compute
  - Query processor (interpreter) chooses which of many equivalent query plans to execute to perform the SQL statements
- ANSI and ISO standard, but many variants
  - CS88's SQL will work on nearly all relational databases—databases that use tables.

What is SQL?

- SELECT statement creates a new table, either from scratch or by projecting a table
- INSERT adds to a table, UPDATE changes data.
- CREATE TABLE statement gives a global name to a table
- Lots of other statements
  - ANALYZE, DELETE, EXPLAIN, …

SQL: Describe The Shape of the result!

```
# An example of creating a Table from a list of rows.
Table(["Flavor","Color","Price"]).with_rows([
    ('strawberry','pink', 3.55),
    ('chocolate','light brown', 4.75),
    ('chocolate','dark brown', 5.25),
    ('strawberry','pink',5.25),
    ('bubblegum','pink',4.75)])
```

Flavor	Color	Price
strawberry	pink	3.55
chocolate	light brown	4.75
chocolate	dark brown	5.25
strawberry	pink	5.25
bubblegum	pink	4.75

What if I want a table with just a few rows?

- Here the `where()` in Python is using the datascience module.

```
cones.where(cones["Price"] > 5)
```

ID	Flavor	Color	Price
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

SQL:

```
sqlite> select * from cones where Price > 5;
ID|Flavor|Color|Price
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
6|chocolate|dark brown|5.25
```

```
sqlite> select * from cones where Flavor = "chocolate";
ID|Flavor|Color|Price
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
6|chocolate|dark brown|5.25
```

Summary

- Paradigms are styles, guidelines for how to approach a program
- Each is equally capable, but some are suited best to particular tasks.
- Declarative programming gets us to think about the what rather than the how.
- Almost no programs are purely single-paradigm