System development life-cycle
Design

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From just programming to good programming.

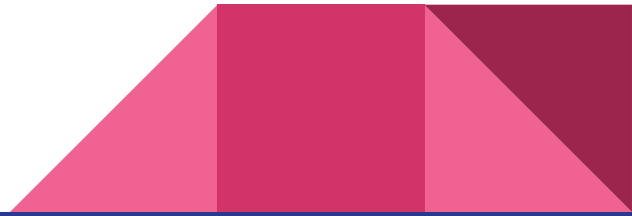
Analysis,
Design,
Tests,
Style.

Analysis to design

Same modeling tools used for analysis can describe the design.

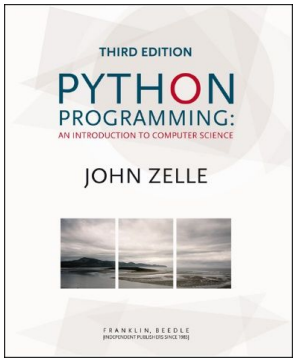
However, what design is good design?

- Computational efficiency
  - Time complexity $\mathcal{O}(n \log n)$
  - Space complexity
- Reliable solution
- Comprehensible code and program logic



Study in Design: Max of Three

- An algorithm to find the largest of three numbers.
- Taken from John Zelle's lectures:



Study in Design: Max of Three

```
def main():
    x_1, x_2, x_3 = eval(input("Please enter three values: "))

    # missing code sets max to the value of the largest

    print("The largest value is", max_val)
```

Strategy 1: Compare Each to All

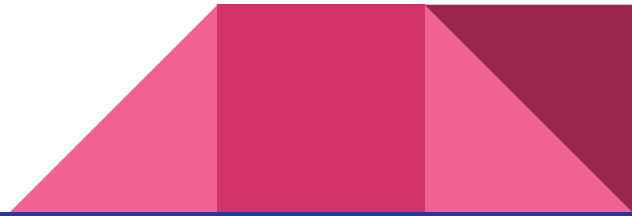
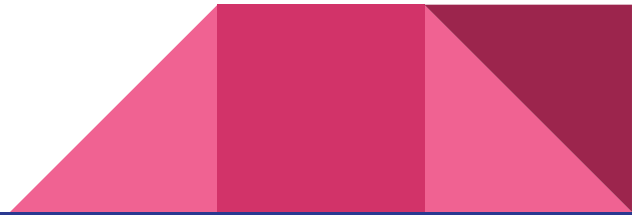
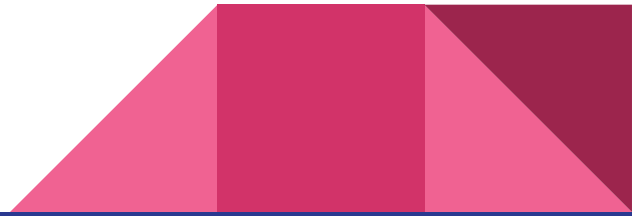
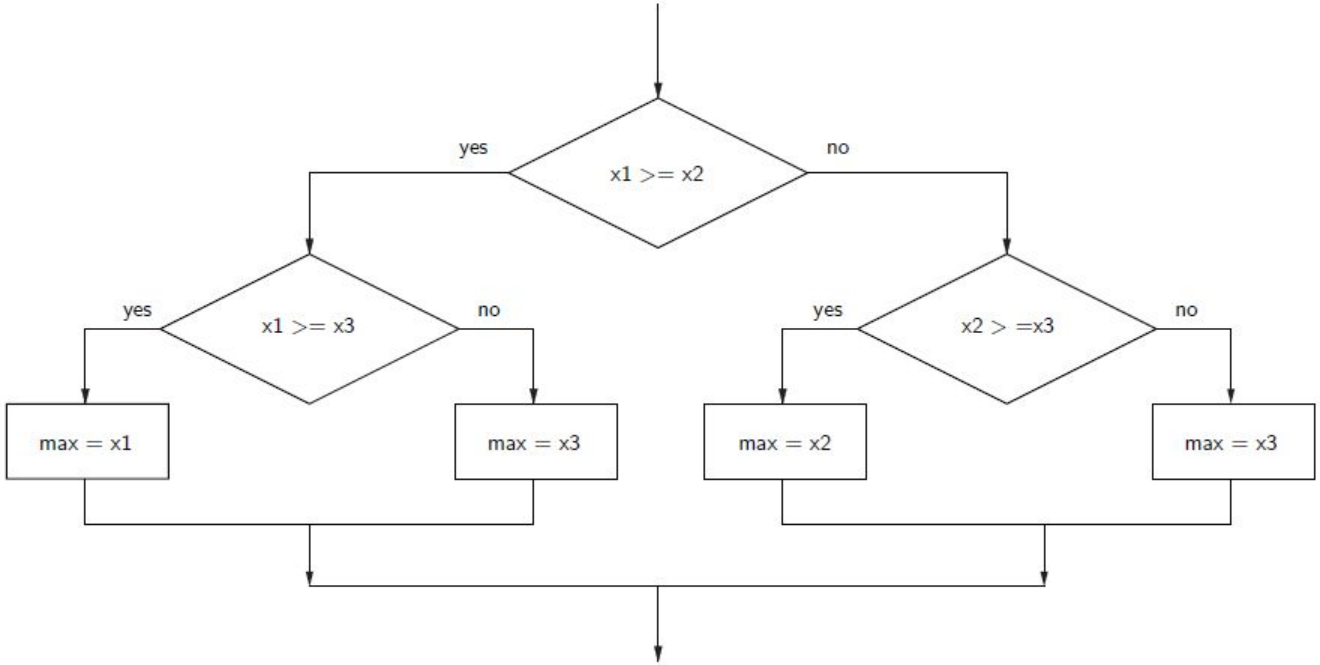
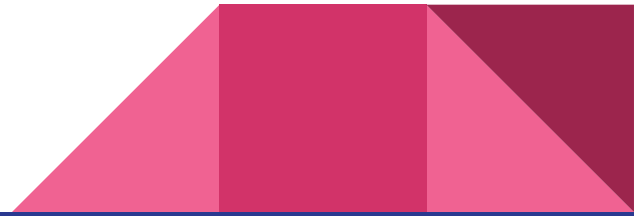
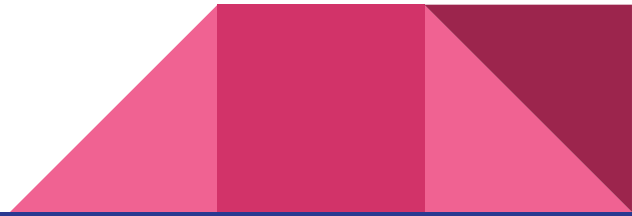
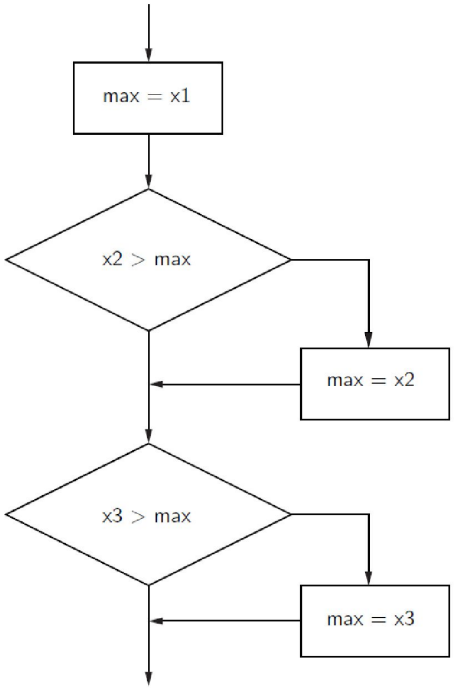
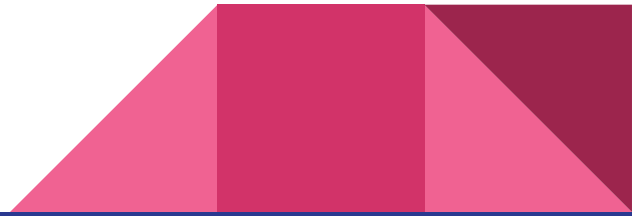
- This looks like a three-way decision, where we need to execute *one* of the following:

```
max_val = x_1
max_val = x_2
max_val = x_3
```

- All we need to do now is preface each one of these with the right condition!

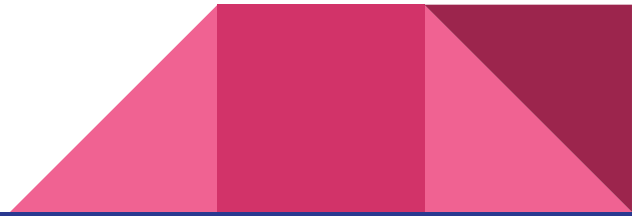
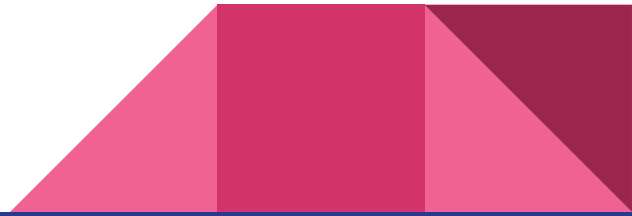
Strategy 1: Compare Each to All

- Let's look at the case where x_1 is the largest.
- ```
  if x_1 >= x_2 >= x_3:
      max_val = x_1
  ```
- Is this syntactically correct?
  - Many languages would not allow this *compound condition*
  - Python does allow it, though. It's equivalent to x_1 ≥ x_2 ≥ x_3.


  ```

Strategy 1: Compare Each to All

- Whenever you write a decision, there are two crucial questions:
  1. When the condition is true, is executing the body of the decision the right action to take?
     - x_1 is at least as large as x_2 and x_3, so assigning max_val to x_1 is OK.
     - Always pay attention to borderline values!
  2. Are we certain that this condition is true in all cases where x_1 is the max?
     - Suppose the values are 5, 2, and 4.
     - Clearly, x_1 is the largest, but does x_1 ≥ x_2 ≥ x_3 hold?
     - We don't really care about the relative ordering of x_2 and x_3, so we can make two separate tests: x_1 >= x_2 *and* x_1 >= x_3.



Strategy 1: Compare Each to All

We can separate these conditions with *and*!

```
if x_1 >= x_2 and x_1 >= x_3:
    max_val = x_1
elif x_2 >= x_1 and x_2 >= x_3:
    max_val = x_2
else:
    max_val = x_3
```

We're comparing each possible value against all the others to determine which one is largest.

Strategy 1: Compare Each to All

- What would happen if we were trying to find the max of five values?
- We would need four Boolean expressions, each consisting of four conditions *and*ed together.
- Yuck!



Strategy 2: Decision Tree

- We can avoid the redundant tests of the previous algorithm using a *decision tree* approach.
- Suppose we start with `x_1 >= x_2`. This knocks either `x_1` or `x_2` out.
- If the condition is true, we need to see which is larger, `x_1` or `x_3`.

Strategy 2: Decision Tree

```
if x_1 >= x_2:
   if x_1 >= x_3:
      max_val = x_1
   else:
      max_val = x_3
else:
   if x_2 >= x_3:
      max_val = x_2
   else
      max_val = x_3
```

Strategy 2: Decision Tree



Strategy 2: Decision Tree

- This approach makes exactly two comparisons, regardless of the ordering of the original three variables.
- However, this approach is more complicated than the first. To find the max of four values you'd need `if-else`s nested three levels deep with eight assignment statements!



Strategy 3: Sequential Processing

- You could probably look at three numbers and just *know* which is the largest. But what if you were given a list of a hundred numbers?
- One strategy is to scan through the list looking for a big number. When one is found, mark it, and continue looking. If you find a larger value, mark it, erase the previous mark, and continue looking.



Strategy 3: Sequential Processing



Strategy 3: Sequential Processing

- This idea can easily be translated into Python.

```
max_val = x_1
if x_2 > max_val:
    max_val = x_2
if x_3 > max_val:
    max_val = x_3
```

Strategy 3: Sequential Programming

- This process is repetitive and lends itself to using a loop.
- We prompt the user for a number, we compare it to our current max, if it is larger, we update the max value, repeat.



Strategy 3: Sequential Programming

```
# program: maxn.py
#   Finds the maximum of a series of numbers

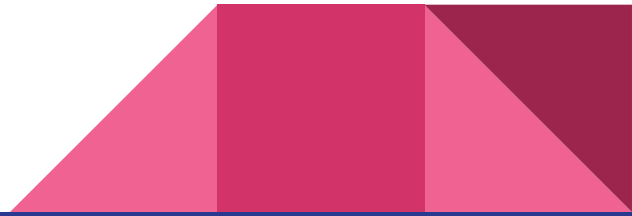
def main():
    n = int(input("How many numbers are there? "))

    # Set max to be the first value
    max_val = float(input("Enter a number >> "))

    # Now compare the n-1 successive values
    for i in range(n-1):
        x = float(input("Enter a number >> "))
        if x > max_val:
            max_val = x
    print("The largest value is", max_val)
```



Strategy 4: Use Python

- Python has a built-in function called `max` that returns the largest of its parameters.

- ```
  def main():
      x_1, x_2, x_3 = eval(input("Please enter three values: "))
      print("The largest value is", max(x_1, x_2, x_3))
  ```


  ```

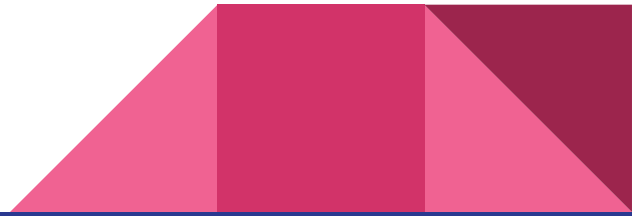
Some Lessons

- Don’t reinvent the wheel.
- Generality is good.
- Be the computer (try to solve it yourself).
- There’s usually more than one way to solve a problem.
  - Decide which suits best your need and don’t get stuck with the first one.
- Keep it simple and stupid (KISS).



Design process (bottom-up)

- Express the algorithm as a series of smaller problems.
- Develop an interface for each of the small problems.
- Detail the algorithm by expressing it in terms of its interfaces with the smaller problems.
- Repeat the process for each smaller problem.

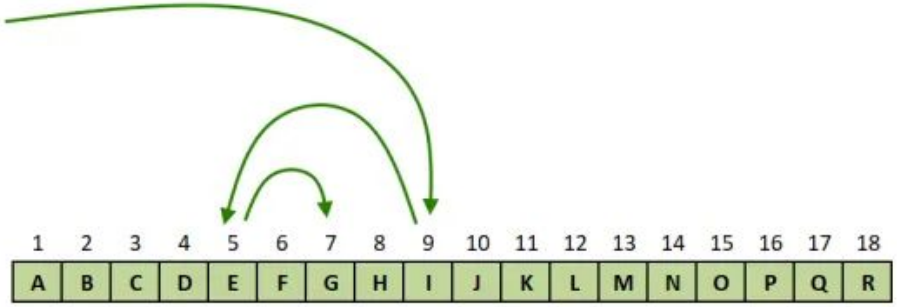


Favourite (toy) problems

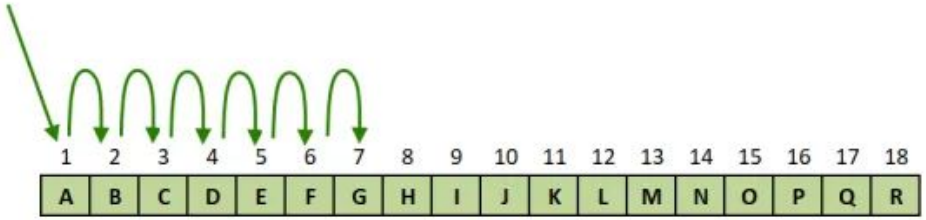
- Search
- Sorting

(in practice often already implemented by someone)

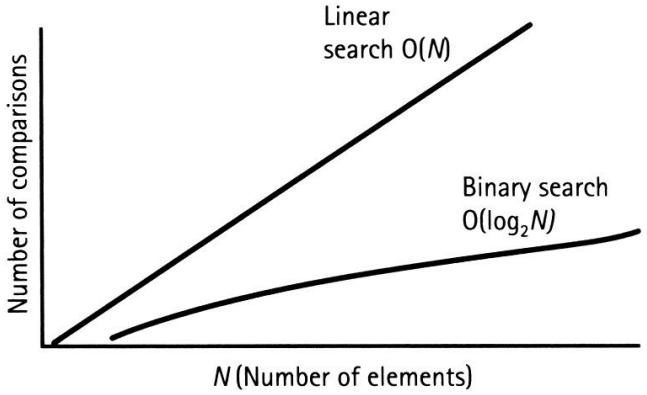
Search: linear vs binary search



Binary Search - Find 'G' in sorted list A-R



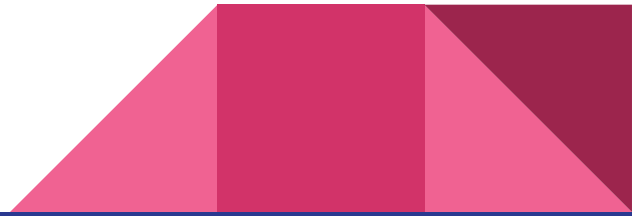
Linear Search - Find 'G' in sorted list A-R



https://algorithms.tutorialhorizon.com/linear-search-vs-binary-search/
https://towardsdatascience.com/a-guide-to-linear-search-and-binary-search-on-arrays-data-structures-algorithms-2c23a74af28a

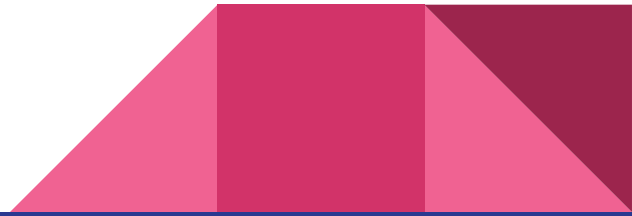
Exercise

- Implement a linear and binary search algorithm in Python
- It should have as an input a sorted list of numbers (e.g. [1, 5, 9]) and it tries to identify the numbers location or return that the number is not in the list
- IMPLEMENT the search, do not just use `in` or similar Python shortcuts ;)



Sort

- Search is most effective on sorted data (can use assumptions) thus sorting is an important tool
- Similar as search, can have many implementations



Sorting

- Sorting algorithm demonstrations
- Should be chosen based on the data and data structures (e.g., binary trees)