TaDa it's Magic!

Predicting the Performance of Programs through Automated Doubling Experiments

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CodepaLOUsa 2021

Huh, what is this about?

Key Questions

Can a tool **automatically predict** a program's performance? Is it possible to automatically estimate the **worst-case time complexity** of a program?

Intended Audience

An **adventuresome** technology enthusiast who wants to explore how a new approach to **performance evaluation** can make their **programs faster**!

Let's learn how to predict a function's performance!

Why focus on Python programming?

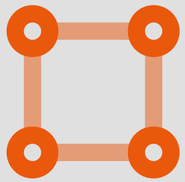
Prevalence of Python

Python is consistently ranked as one of the **top programming languages** for web development, data science, machine learning, and general programming

Importance of Performance

Programmers who create, say, **serverless functions** with AWS Lambda need to carefully **monitor** and **improve** the performance of these functions

Challenging about performance evaluation in Python?



Analytical Evaluation

- Algorithm
- Constructs
- Growth

Experimental Evaluation

- Program
- Benchmark
- Study

What are the trade-offs of these two approaches?

Analytical

- Provides a clear means by which to compare programs
- Does not depend on the hardware or software configuration
- Yet, often requires precise mathematical reasoning skills

Experimental

- Must generate inputs to the program subject to experiments
- Must repeatedly run a program and collect performance data
- Only generally accessible to programmers if good tools exist

Analysis characterizes an algorithm as, say, O(n)

Experiments run program to collect performance data

How to analytically evaluate a program's performance?

Commonly used growth functions

Study program's code constructs

"Fast" Order of Growth Functions

"Slow" Order of Growth Functions

Relationship between growth function and program's performance?

Slow growth functions → fast programs

Fast growth functions → slow programs

Analyzing the `add_digits` Function

```
def add_digits(digits: str) -> int:
    value = 0
    for digit in digits:
        value += int(digit)
    return value

sum_digits = add_digits("123")
print(sum_digits)
```

What is worst-case time complexity of `add_digits`?

Analyzing the `factorial` Function

```
def factorial(x: int) -> int:
    if x == 1:
        return 1
    else:
        return x*factorial(x-1)

factorial_value = factorial(3)
print(factorial_value)
```

What is worst-case time complexity of `factorial`?

Analyzing the `is_subset` Function

```
def is_subset(one: List, two: List) -> bool:
    for element_one in one:
        matched = False
        for element_two in two:
            if element_one == element_two:
                matched = True
                break
        if not matched:
            return False
    return True
```

What is worst-case time complexity of

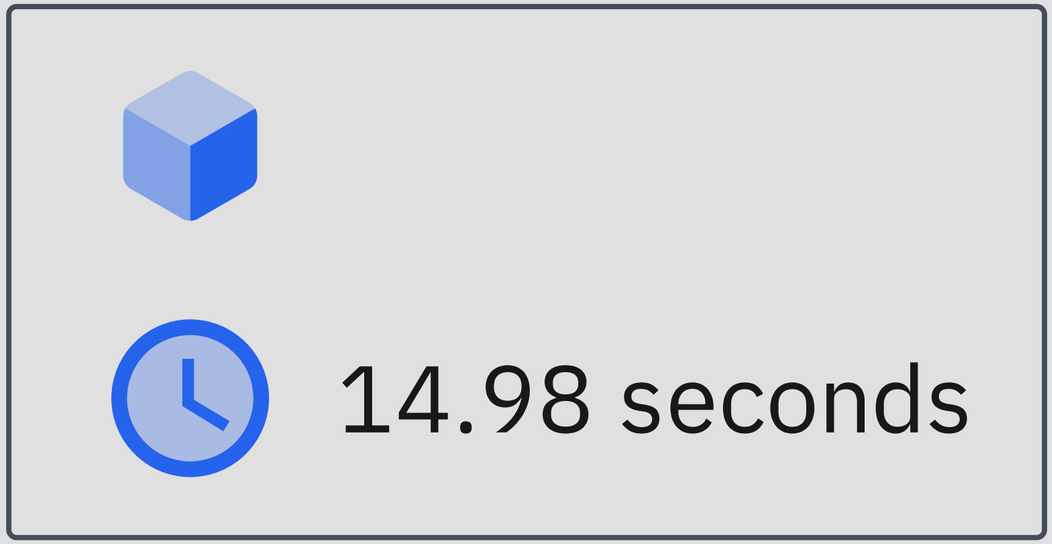
Run an experiment to get likely worst-case time complexity of program?

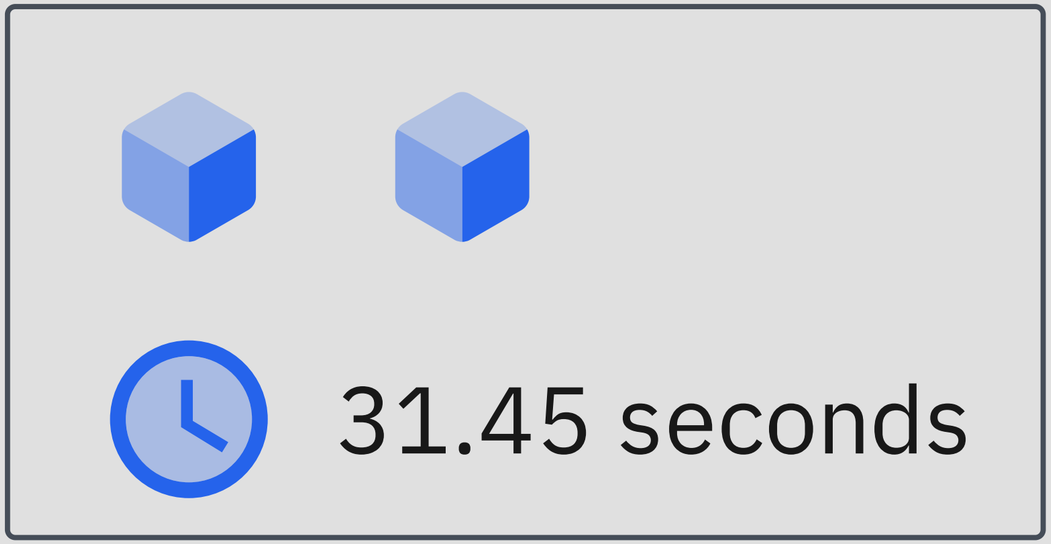
Bespoke auto-doubling experiment tool

TaDa auto-doubling for a Python function

Doubling Experiment: Linear

Double the size of the program's input



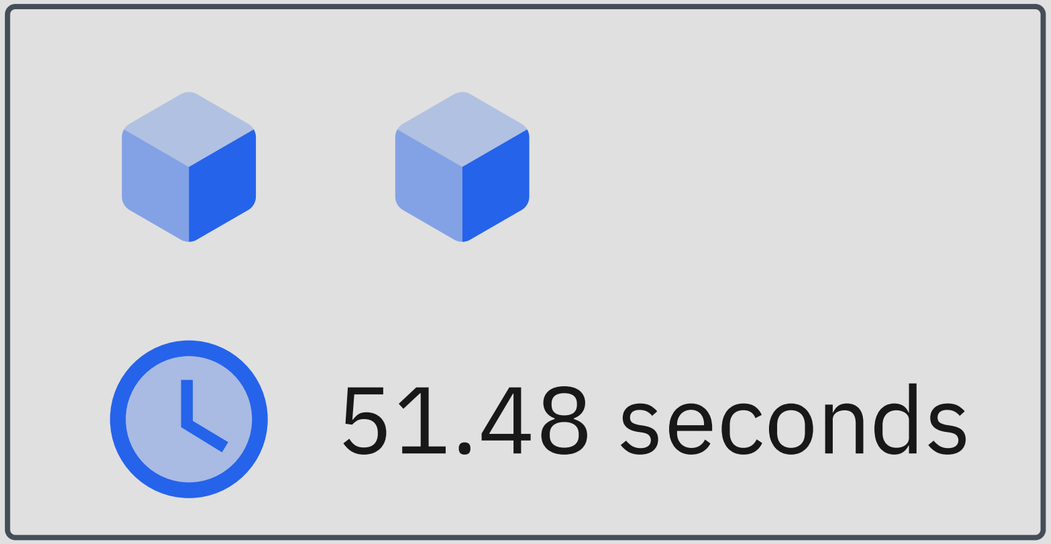


Doubling ratio is approximately 2

Likely worst-case time complexity is O(n)

Doubling Experiment: Quadratic

Double the size of the program's input

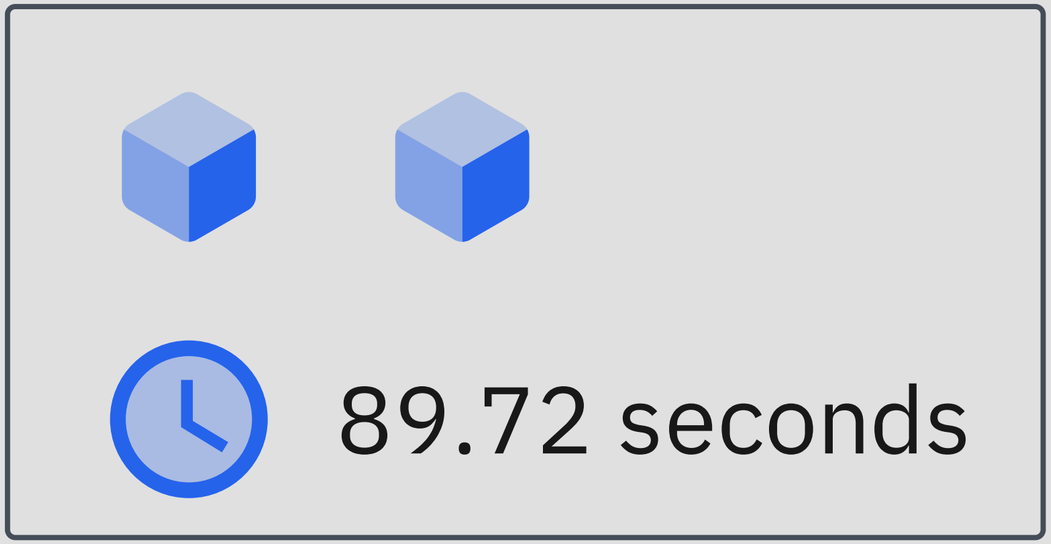


Doubling ratio is approximately 4

Likely worst-case time complexity is O(n^2)

Doubling Experiment: Cubic

Double the size of the program's input



Doubling ratio is approximately 8

Likely worst-case time complexity is O(n^3)

What are challenges with running automated doubling experiments?

- Automatically generate inputs to the function
- Determine when to stop running experiments
- Establish a statistical confidence in the prediction

TaDa Runs a Doubling Experiment

Input is a Python function and configuration options

Output is a data table and a performance prediction

See `Tada-Project/tada` for details

Analyzing the `insertion_sort` Function

```
def insertion_sort(lst: list[int]) -> list[int]:
    for i in range(1, len(lst)):
        value = lst[i]
        pos = i
        while pos > 0 and value < lst[pos - 1]:
            lst[pos] = lst[pos - 1]
            pos -= 1
        lst[pos] = value
    return lst
```

Can TaDa predict worst-case of `insertion_sort`?

Analyzing the `bubble_sort` Function

```
def bubble_sort(lst: list[int]) -> list[int]:
    for num in range(len(lst) - 1, 0, -1):
        for i in range(num):
            if lst[i] > lst[i + 1]:
                temp = lst[i]
                lst[i] = lst[i + 1]
                lst[i + 1] = temp
    return lst
```

Can TaDa predict worst-case of `bubble_sort`?

How to automatically generate function inputs during experiments?

- Hypothesis: Property-based testing tool
- JSON Schema: Describe format of input

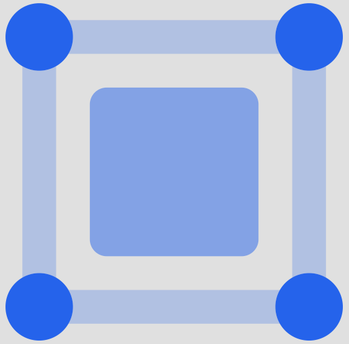
Hypothesis and JSON Schema for Data

```
[{
  "type": "array",
  "items": {
    "type": "integer"
  },
  "uniqueItems": true,
  "maxItems": 0,
  "minItems": 0
}]
```

Describe structure to support automated data generation

TaDa's Automated Analysis of Insertion Sort

insertion_sort: O(n) linear or O(nlogn) linearithmic			
Size	Mean	Median	Ratio
25	3.644364811706543e-06	3.498709533691405e-06	0
50	6.535123836263021e-06	6.483351989746092e-06	1.793213405878218
100	1.2902192108154296e-05	1.2540842590332028e-05	1.9742842571032526
200	2.5023900944010416e-05	2.4608139038085928e-05	1.9395077002608803
400	5.2639685791015 6e-05	5.3515207031250005e-05	2.2084473840729952
800	0.00011801120257161459	0.0001125137929687 5	2.1354094829925283

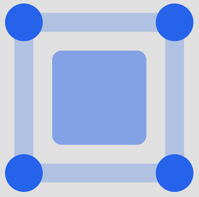


- Interpreting TaDa's output:
  - Ran multiple threads for multiple input sizes
  - Doubled the input size and recorded time
  - Used ratio to correctly predict worst-case

TaDa's Comparison of Sorting Functions

bubble_sort: O(n^2) quadratic			
Size	Mean	Median	Ratio
25	2.8776128824869792e-05	2.8462072509765 62e-05	0
50	0.00010703222574869792	0.00010308191601562499	3.7194796562140504
100	0.0004109644687825521	0.0003943741044921 8743	3.8396330255474633
200	0.0015730586140625	0.0015326660937500002	3.8277241308051635
400	0.00632440301875	0.0062295721562 49999	4.020449690947576
800	0.02929213468333 3335	0.028519337000000006	4.631604690038055

At the greatest common size 800:
Mean: insertion_sort is 99.60% faster than bubble_sort
Median: insertion_sort is 99.61% faster than bubble_sort



Correct worst-case predictions and empirical insights

Performance Evaluation

TaDa tool bridges the experimental and analytical!

Analytical study of performance is challenging

Experimental study requires data and tooling

TaDa runs doubling experiments and predicts

Tool Development with Python

TaDa makes it easy to run doubling experiments!

See `Tada-Project/tada` for details

`https://www.gregorykapfhammer.com/`

`gkapfham/codepalousa2021-presentation-tada`