Conceptual Mutation Testing for Student Programming Misconceptions

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BROWN

CRA
Computing Research Association

Understanding CS Problems

Understanding CS Problems

Q. median

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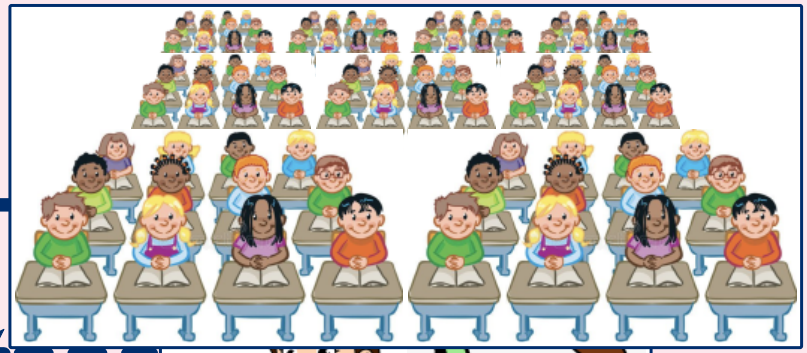
feedback?

Understanding CS Problems

Q. median



feedback?

Understanding CS Problems

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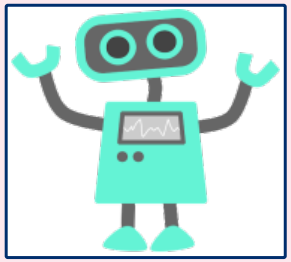

Understanding CS Problems

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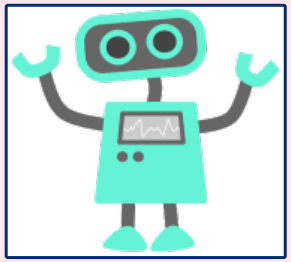
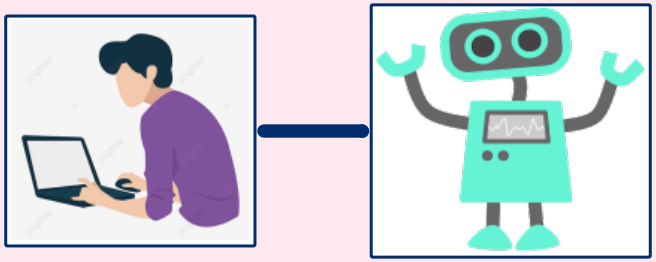


How to communicate?



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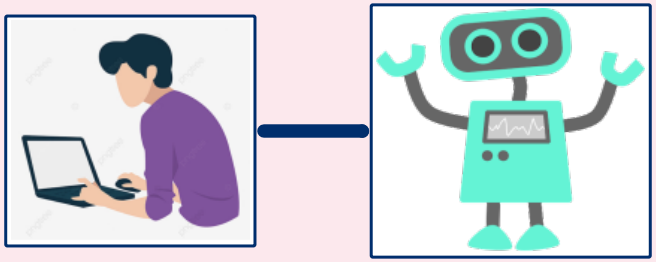
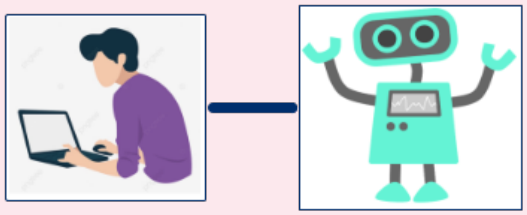


Test Cases

Q. median



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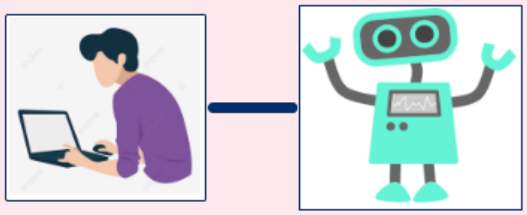
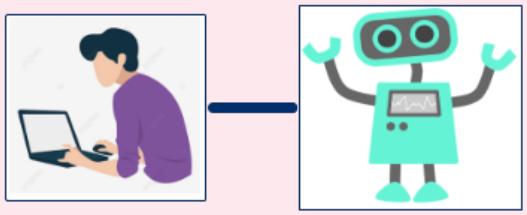


```
median [1] is 1
median [1, 2, 3] is 3
median [3, 3, 3] is 3
```

Q. median



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median [1] is 1
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median [3, 3, 3] is 3
```

What's wrong with these tests?

View File median-tests.arr + Begin

```
include my-gdrive("median-code.arr")
# DO NOT CHANGE ANYTHING ABOVE THIS LINE

check:
  median([list: 1]) is 1
  median([list: 1, 2, 3]) is 3
  median([list: 3, 3, 3, 3]) is 3


end
```

View File median-tests.arr + Begin Implementation Run Stop

```
1  include my-gdrive("median-code.arr")
2  # DO NOT CHANGE ANYTHING ABOVE THIS LINE
3
4  check:
5    median([list: 1]) is 1
6    median([list: 1, 2, 3]) is 3
7    median([list: 3, 3, 3, 3]) is 3
8
9
10 end
```

median-tests.arr

INCORRECT CONSEQUENTLY, THOROUGHNESS IS UNKNOWN

These tests do not match the behavior described by the assignment:

definitions://:5:2-5:30

```
6  median([list: 1, 2, 3]) is 3
```

View File median-tests.arr + Begin

```
include my-gdrive("median-code.arr")
# DO NOT CHANGE ANYTHING ABOVE THIS LINE

check:
  median([list: 1]) is 1
  median([list: 1, 2, 3]) is 2
  median([list: 3, 3, 3, 3]) is 3

  #Shows that Median is not Mean
  median([list: 1, 1, 3]) is 1

  # Shows that Median is not Mode
  median([list: 1, 1, 3, 4, 4]) is 3
end
```

View File median-tests.arr + Begin Implementation Run Stop

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median-tests.arr

VALID

These tests are valid and consistent with the assignment handout. They caught 2 of 4 sample buggy programs. Add more test cases to improve this test suite's thoroughness.

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median-tests.arr

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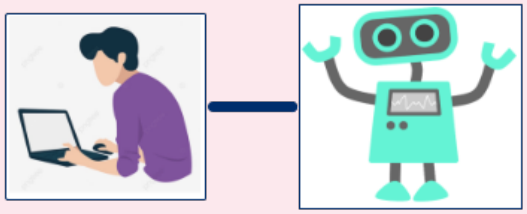

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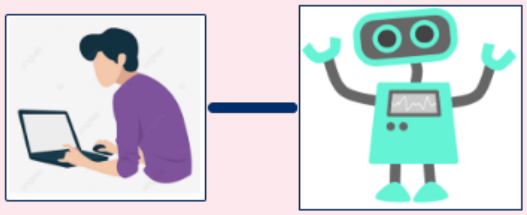


Tests must distinguish:

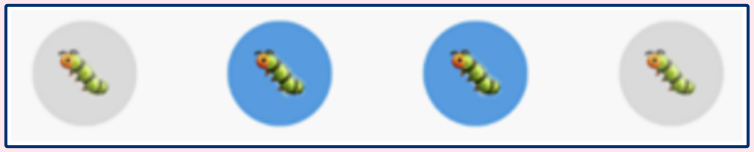
`median` vs. `mean`
`mode`
`middle ...`

Valid & Thorough

How to check thoroughess?

Buggy solutions

(mutation testing)



RQ. How to design buggies?

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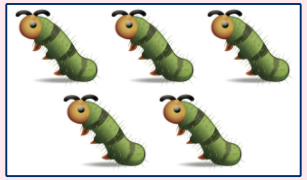
Need to discover misconceptions

Prior Work:

Expert-Driven

Today, a recipe:

Buggies from Data



1. Design problem

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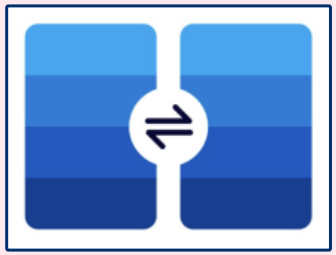
Running example:

Doc Diff



```
docdiff ['a'] ['A'] is 1
```

```
docdiff ['one', 'two'] ['one'] is 1/2
```

```
docdiff ['hello'] ['world] is 0
```

2. Collect invalid tests

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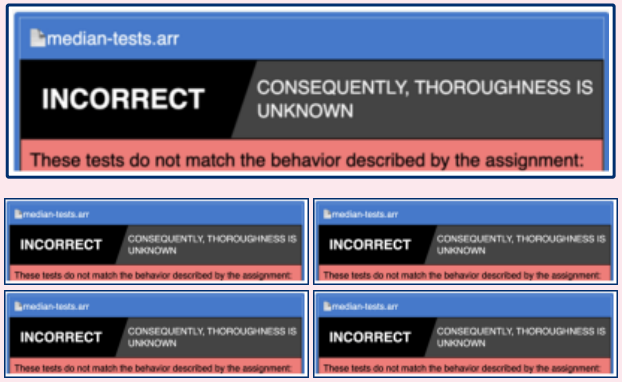
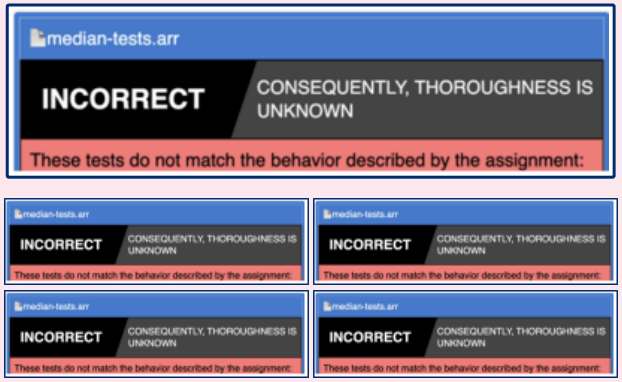


2. Collect invalid tests

Doc Diff ==> 1,500 invalids in ~1 week



3. Cluster tests by feature vector

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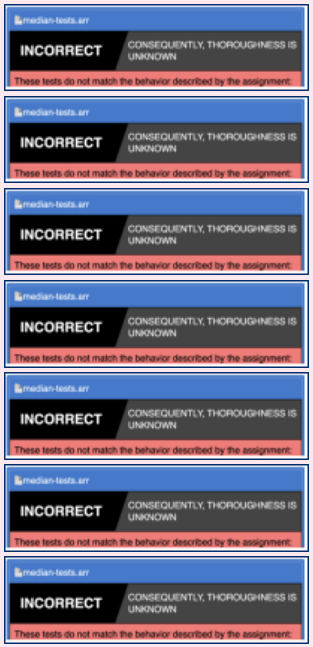

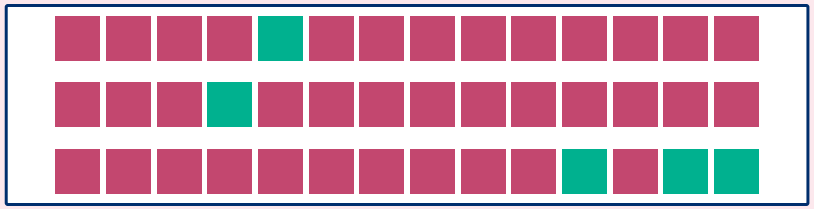

Feature vectors <== problem characteristics

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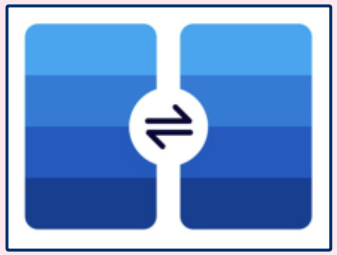

- Case-insensitive
- Words may repeat
- Diff may be a fraction

... [14 in total]

5. Sort clusters

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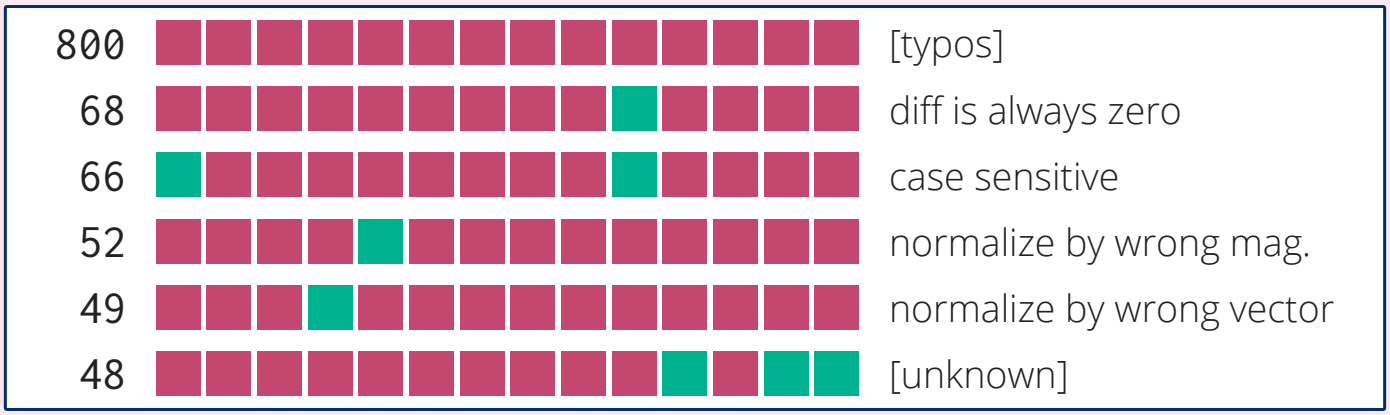
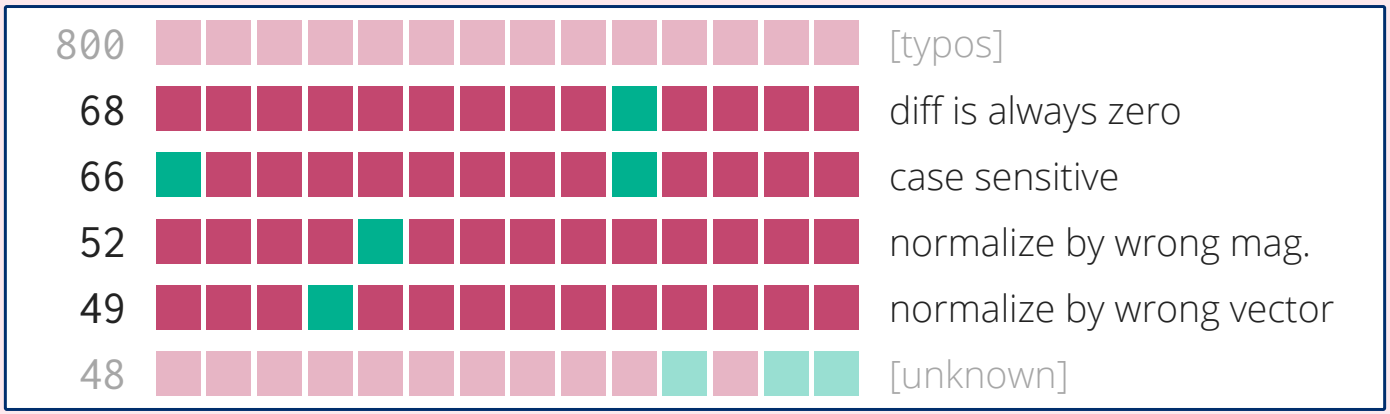
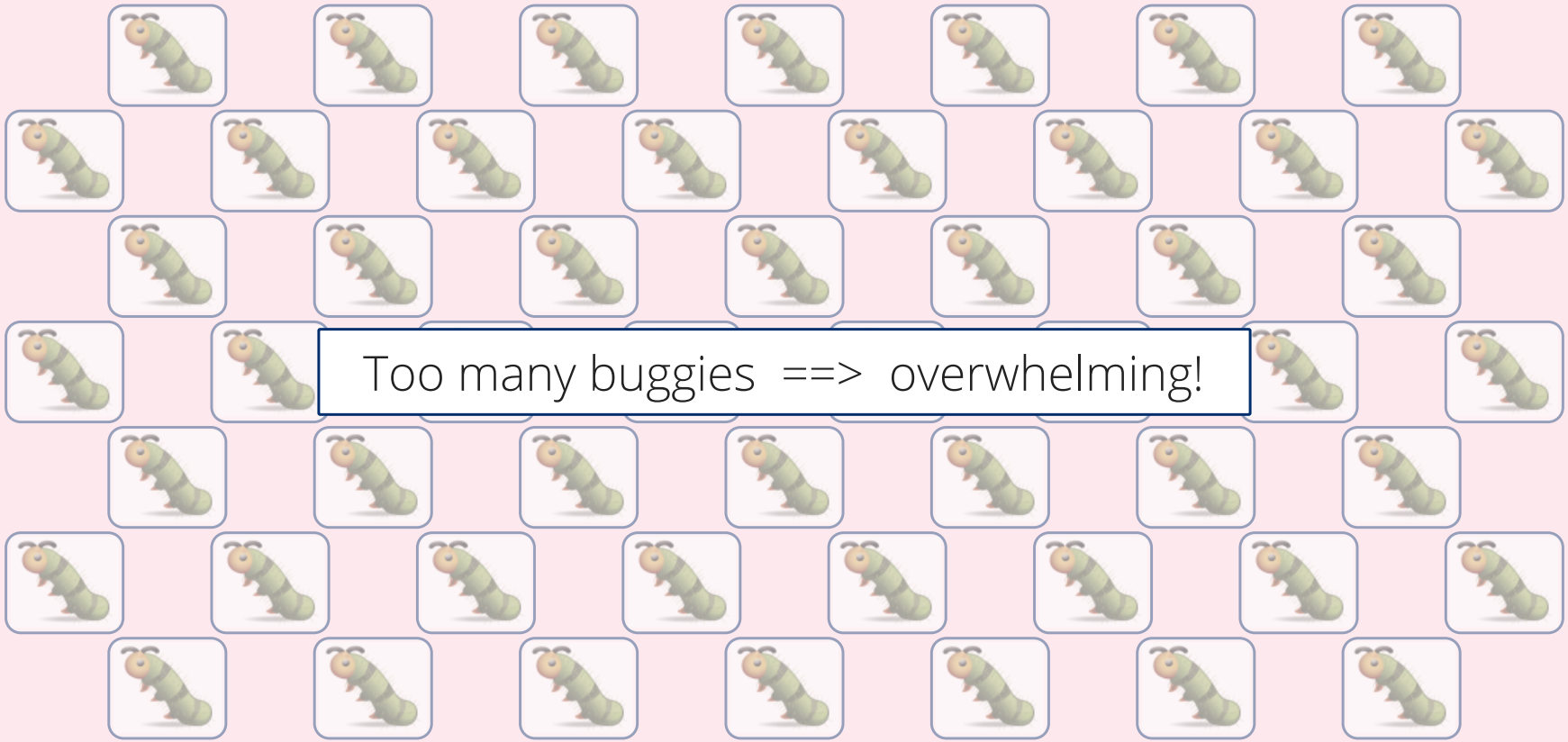


5. Sort clusters

6. Make buggies




Too many buggies ==> overwhelming!

6. Make buggies

* Focus on 1-2
* Favor narrow characteristics
* Maximize subproblem coverage

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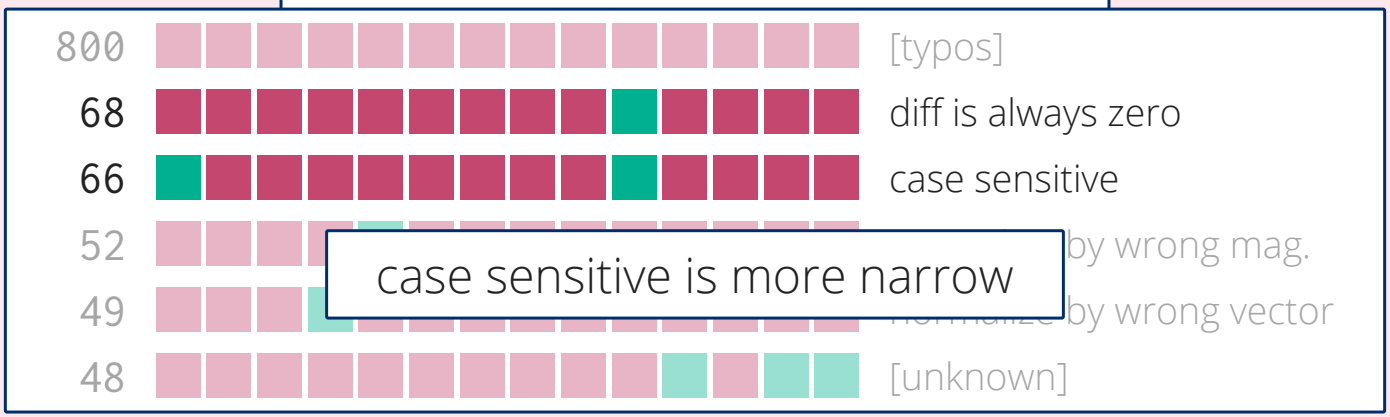
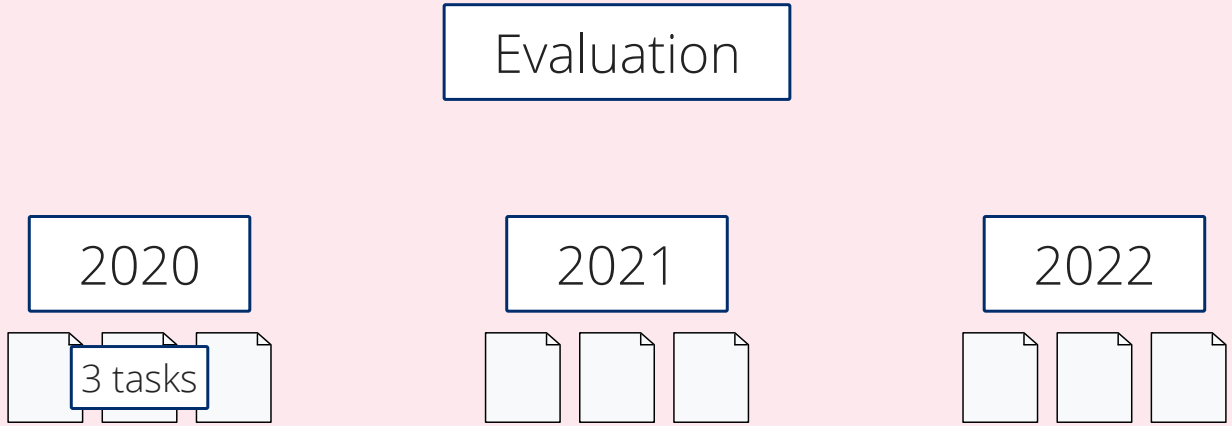
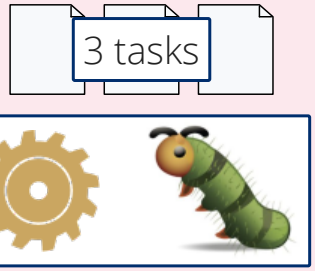


case sensitive is more narrow


Evaluation
2020
3 tasks
2021
2022

Evaluation

2020

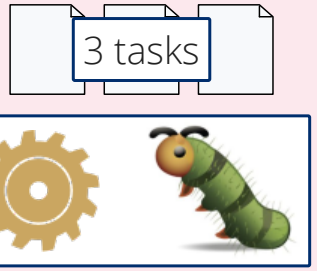


2021

2022

Evaluation

2020



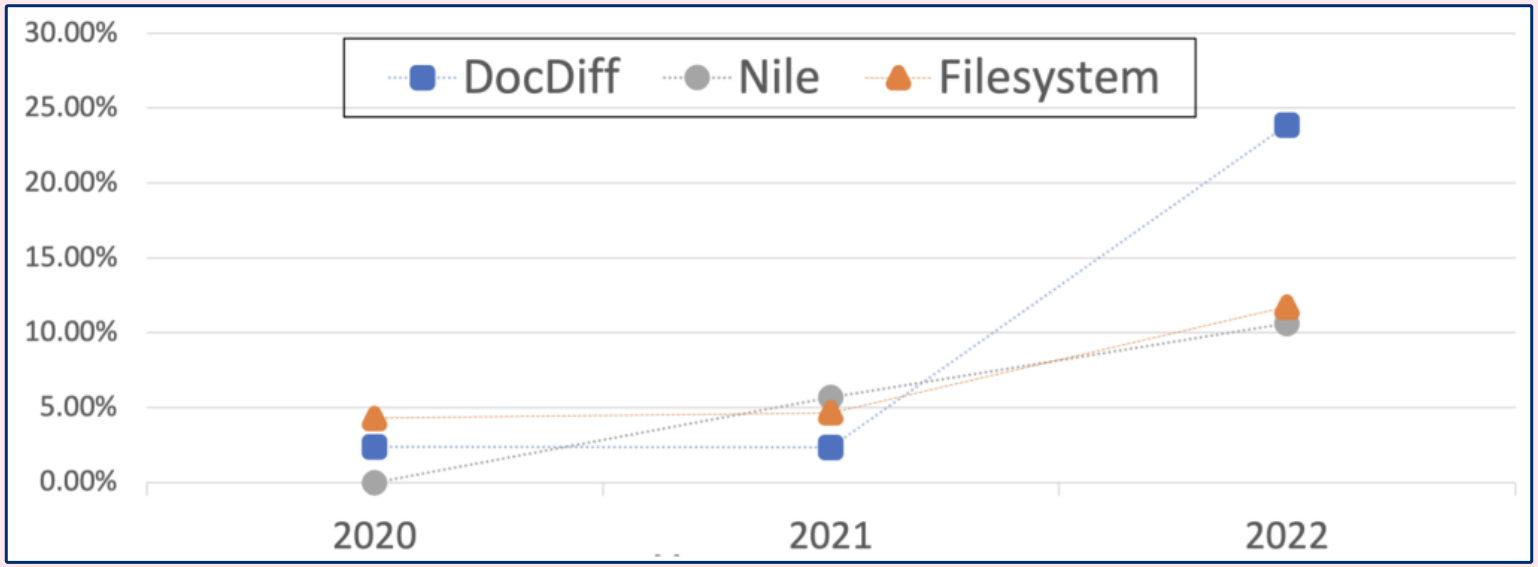
2021

2022

2020, 2021 ==> test
2022 ==> deploy

% explainable invalid tests

explainable = 1- or 2-



old buggies | old buggies | new buggies

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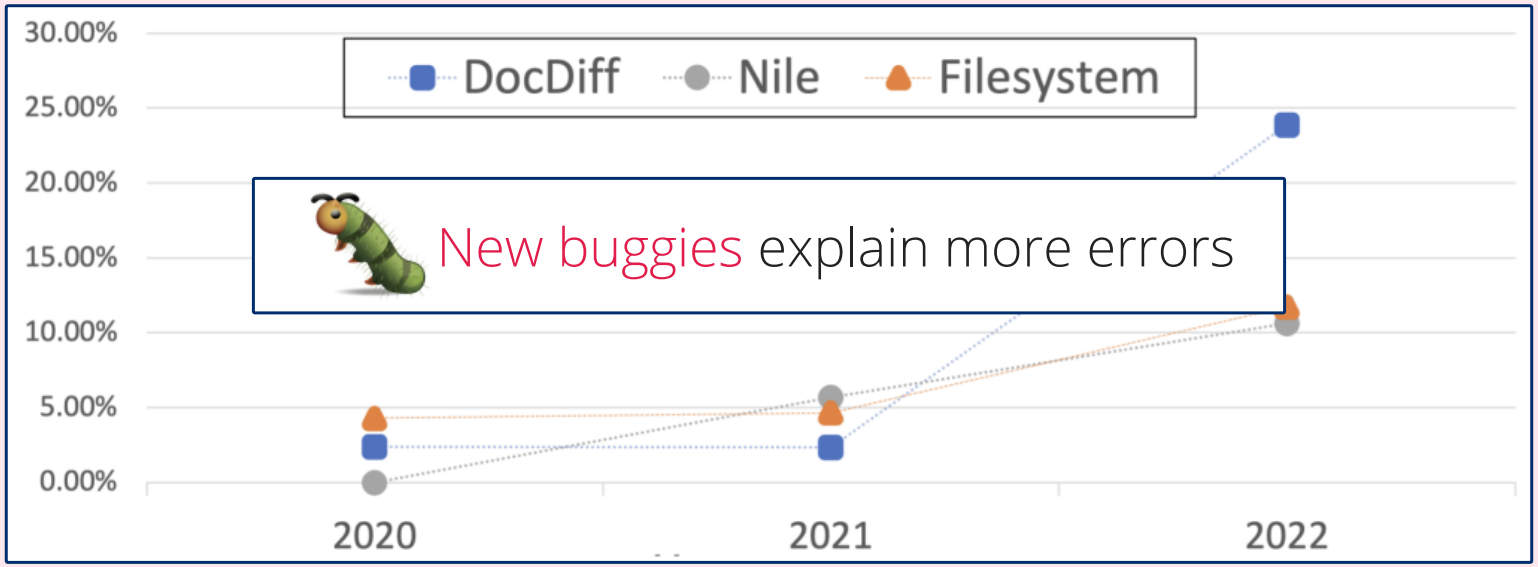


old buggies | old buggies | new buggies

High Effect Sizes for 2022

Matchup	Problem	95% CI	p value
2022 vs 2020	DocDiff	[-0.75, -0.57]	1.35E-29
	Nile	[-0.55, -0.26]	9.07E-14
	FileSys	[-0.35, -0.21]	2.35E-10
2022 vs 2021	DocDiff	[-0.70, -0.51]	6.87E-29
	Nile	[-0.27, -0.07]	1.82E-3
	FileSys	[-0.33, -0.19]	2.32E-9
2021 vs 2020	DocDiff	[-0.07, 0.08]	4.60E-1
	Nile	[-0.39, -0.13]	1.15E-17
	FileSys	[-0.06, 0.03]	2.52E-1

Weeks of Data > Years of Tuning

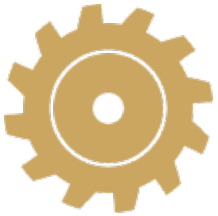
Promising approach for new problems

II

Recipe to uncover misconceptions

semi-automatic

II



Recipe to uncover misconceptions

semi-automatic

Data ==> better teaching

What's next? Hinting

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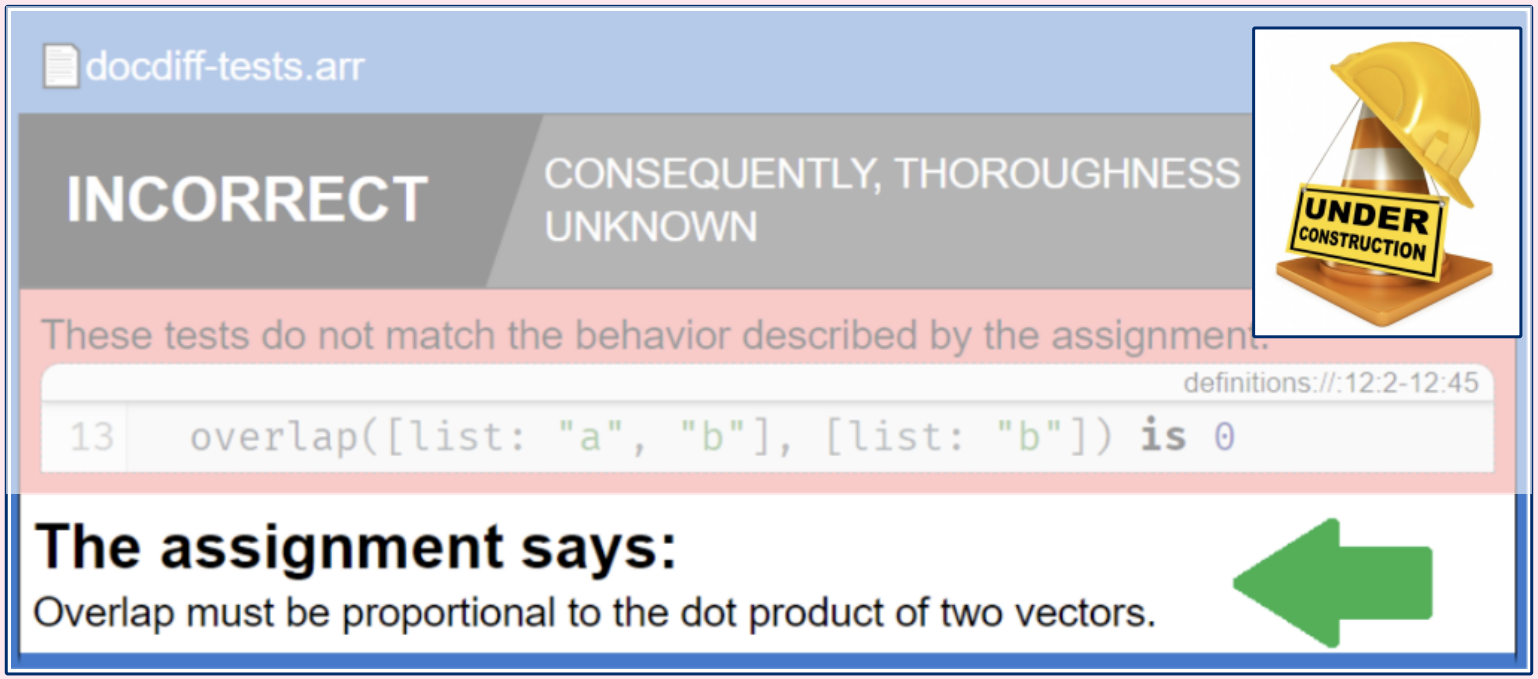

Deep Goal:

Rigorous methods for CS Ed research

THE UNIVERSITY OF UTAH

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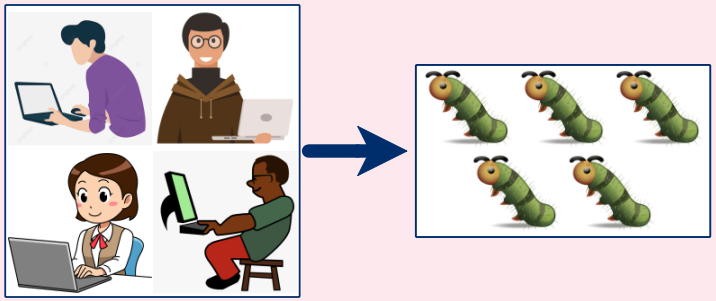
Let's talk!

1. design problem
2. identify characteristics
3. collect invalid tests
4. cluster by feature vector
5. analyze top clusters
6. select buggies



Future

Data collection is a bottleneck

~1 semester ramp-up

+70% typos! How to reduce?

D4 / Data Druid

Table 8 Our 2022 chaffs gave 1-m/2-m outcomes significantly more often than prior chaffs. The 2021 vs. 2020 results are similar except for Nile, which used D4 in 2021.

Matchup	Assignment	p value	Z score	Effect Size [95% CI] (Cohen's D)
2022 vs 2020	DocDiff	1.35E-29	-11.24	0.66 [-0.75, -0.57]
	Nile	9.07E-14	-7.36	-0.41 [-0.55, -0.26]
	Filesystem	2.35E-10	-6.22	-0.28 [-0.35, -0.21]
2022 vs 2021	DocDiff	6.87E-29	-11.09	-0.61 [-0.70, -0.51]
	Nile	1.82E-03	-2.91	-0.17 [-0.27, -0.07]
	Filesystem	2.32E-09	-5.86	-0.26 [-0.33, -0.19]
2021 vs 2020	DocDiff	4.60E-01	0.1	0 [-0.07, 0.08]
	Nile	1.15E-17	-8.48	-0.26 [-0.39, -0.13]
	Filesystem	2.52E-01	-0.67	-0.02 [-0.06, 0.03]