On the Importance of Common Sense in Program Synthesis

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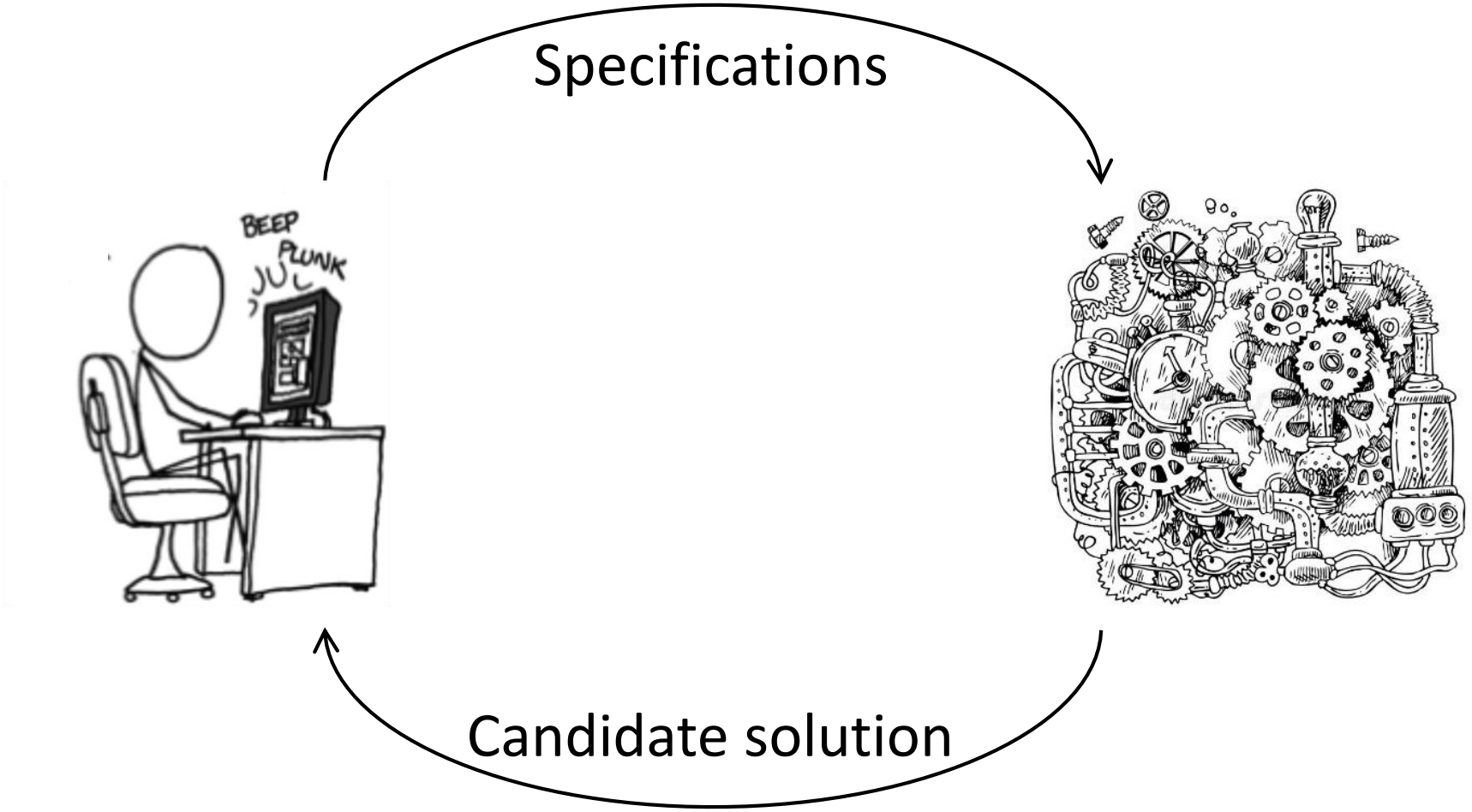
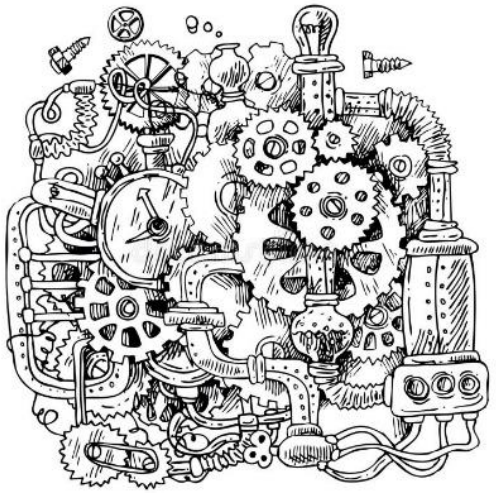
The research leading to these results has received funding from the European Union's - Seventh Framework Programme (FP7) under grant agreement n° 615688 – ERC- COG-PRIME.

Program Synthesis



Programming by Example

$\mathcal{E} = \{\texttt{"abdfibfcfdebd"} \mapsto \texttt{"bd"}\}$



$p \;\; s.t. \; \forall (\iota, \omega) \in \mathcal{E}. [\![p]\!](\iota) = \omega$

Why examples?

- The process of writing code:
  1. Problem
  2. Intent
  3. Solution (which might have bugs, go to #1)
- Programmers use examples:
  1. To understand the problem
  2. To formulate intent
  3. To test the solution

9. Write a function that concatenates two lists.
[a,b,c], [1,2,3] → [a,b,c,1,2,3]
10. Write a function that combines two lists by alternatingly taking elements, e.g.
[a,b,c], [1,2,3] → [a,1,b,2,c,3].

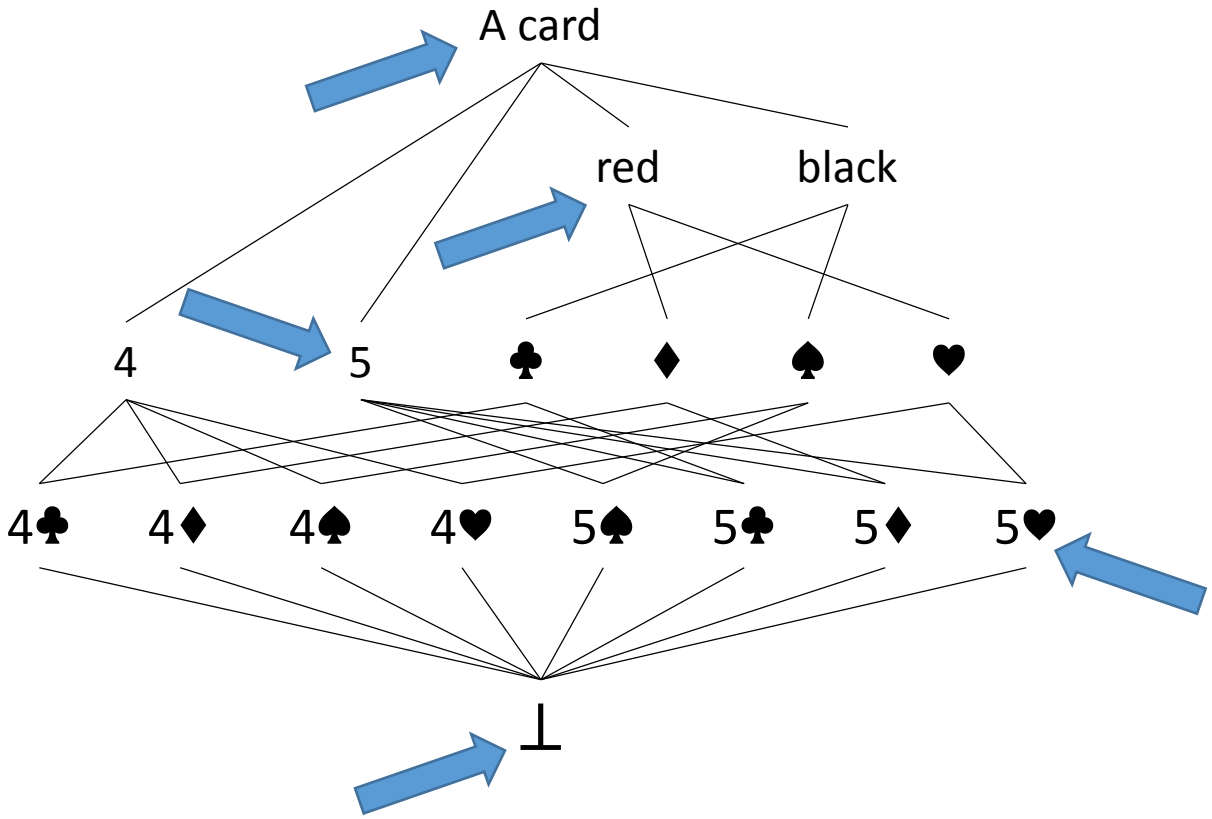
https://adriann.github.io/programming_problems.html

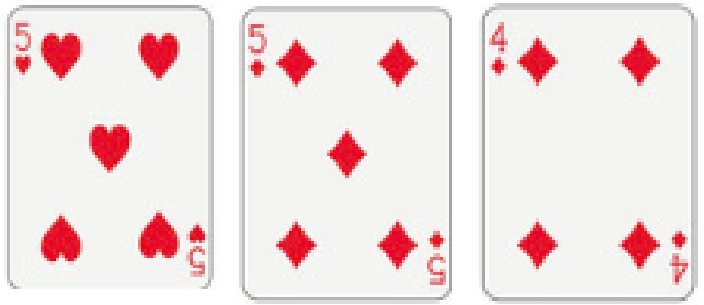
ML has used this since the 70s

- Version Spaces [Mitchell ‘77]
  - Generalize using a set of “concepts” that are ranked for generality

Version Spaces and Concept Learning

- Generalize the set of cards you're shown





ML has used this since the 70s

- Version Spaces [Mitchell ‘77]
  - Generalize using a set of “concepts” that are ranked for generality
- ML mimicking how humans generalize from multiple examples
  - Given n examples, remember what they have in common
  - If updating with example n+1, see what it has in common with the list for n examples
- (Under a specific set of circumstances, we would call this ⊔)

Bias, our savior

An unbiased language: one that can describe any subset of concrete examples.

Bias in ML

- A ML algorithm is *biased* by its language of classifiers.
- This is not a bad thing!
  - Bias is what gives us generalization to examples we haven't seen
- Desirable biases:
  - Domain knowledge on samples ("samples are English letters, it doesn't matter what we decide for Klingon")
  - Domain knowledge on use of the result ("will flag suspicious transactions for human review, ok to have false positives on one parameter")

Bias in synthesis

- Synthesis (often powered by ML) is biased by the *search space* and the *search algorithm*
- Search space: possible programs
  - We can't represent what we can't represent
  - In combination with the algorithm, programs "mask" each other
- Search algorithm: will lead to overfitting
  - Input: "a**bd**fibfcfde**bd**fde**bd**ihgfkjfde**bd**"
  - Output: "bd"
  - Resulting program: `input.takeRight(2)`

Common sense vs. bias

- Human common sense is (supposedly) able to give us *unbiased* learning that can generalize past existing examples.

- Let's try it out:
  - $f(1,1) = 1$
  - $f(1,2) = 2$
  - $f(3,0) = 3$

Three examples is a very small number to generalize from (if you're a computer)! Well done!

Generalize better with multiple biases?

- One way to try to be less biased is to have multiple competing biases
- Example: let's look for $f(x, y, z)$: $bool$ where
  - $f(2.3,5.7,4.0) = f(1.0,1.0,1.0) = f(2.0,3.0,2.5) = true$
  - $f(2.0,2.0,2.1) = false$

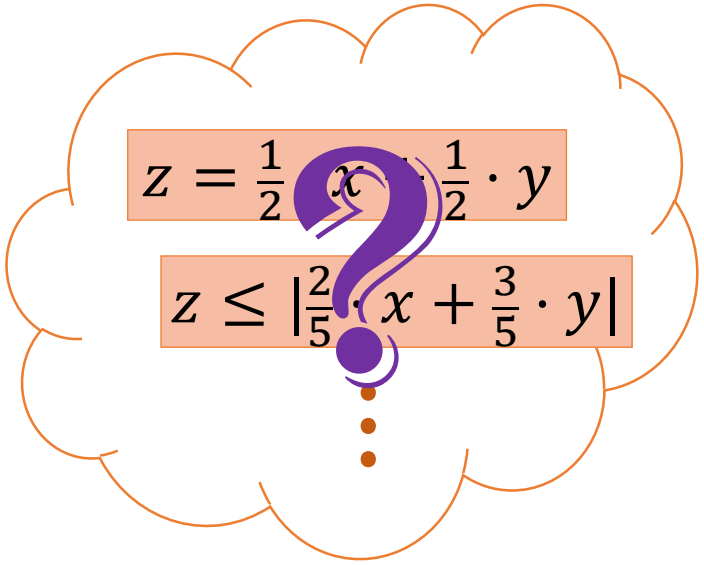
$z = a \cdot x + b \cdot y$ ⋯⋯▸ $z = \frac{1}{2} \cdot x + \frac{1}{2} \cdot y$

$z \geq |a \cdot x - b \cdot y|$ ⋯⋯▸ No consistent a, b

$z \leq |a \cdot x - b \cdot y|$ ⋯⋯▸ $z \leq |\frac{2}{5} \cdot x + \frac{3}{5} \cdot y|$

Generalize better with multiple biases

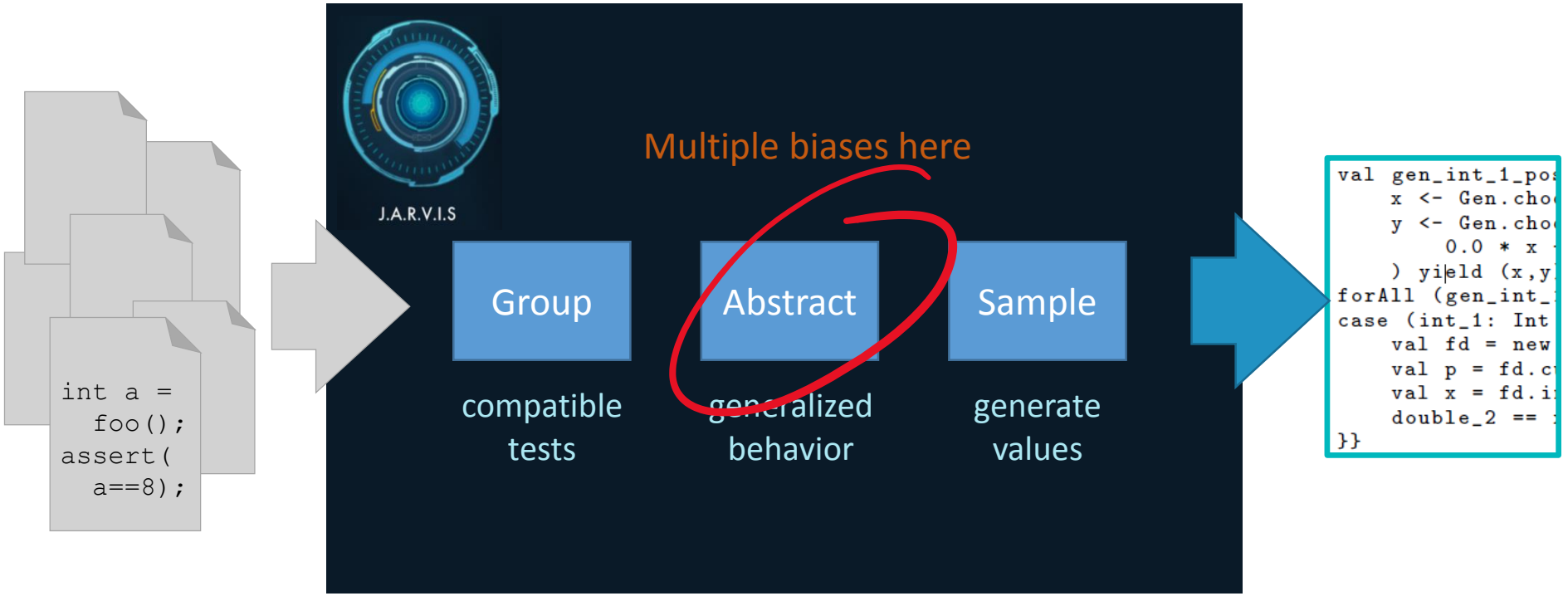
- What do you do when there's more than one answer?
- We can rank them and pick the highest rank
- Ranking is domain specific
  - Human-directed intervention in a less-biased system



What happens when we change domains?

- Will our ranking still fit?

JARVIS, a test synthesizer [VMCAI18]



What happens when we change domains?

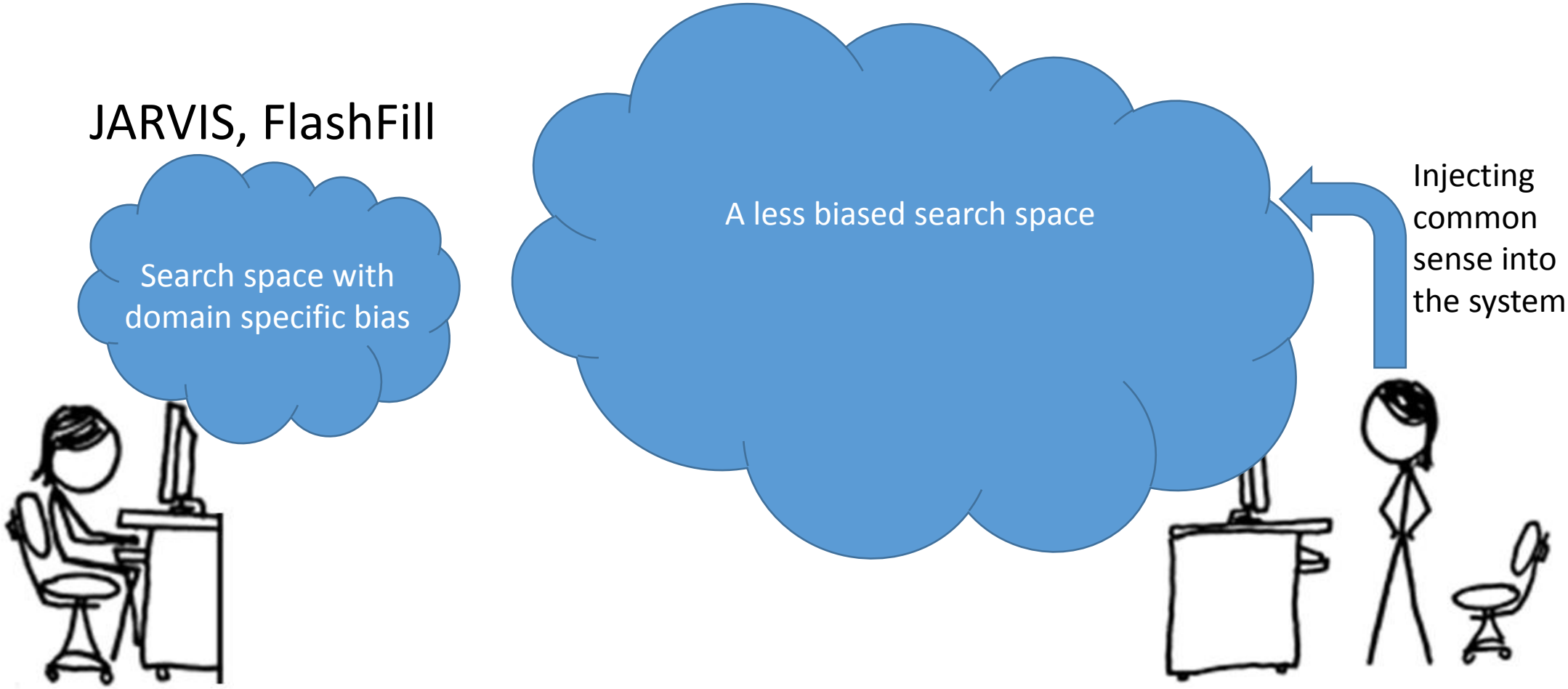
- Will our ranking still fit?
- JARVIS ranking of numerical domains is well suited to testing numerical libraries
- When we wanted something different (e.g. geometry) required re-doing the ranking to fit new domain

- What could we have done differently?

What could we have done differently?

- We suggested the user might occasionally help JARVIS out.
- Why not? The user can bring a moment of common sense to the mix:
  - Choose between generalizations
  - Manually generalize the result more
- While the synthesizer still does the brunt of the work

But for any more we want to involve a human



Test Driven Development (Nature's PBE)

- An iterative process
  - introducing a failing test
  - writing the minimal amount of code to make that test pass

Let’s program a calculator!

Test code:

```
@Test
public void calculatorEmptyString() {
    Calculator c = new Calculator();
    int res = c.evaluate("");

}
```

System code:

```
public class Calculator {
 public int evaluate(String expr) {
    return -1;
 }
}
```

Failing test

Test code:

```
@Test
public void calculatorEmptyString() {
    Calculator c = new Calculator();
    int res = c.evaluate("");
    Assert.assertEquals(res, 0);
}
```

```
java.lang.AssertionError:
Expected :0
Actual   :-1
  <Click to see difference>
<1 internal calls>
    at org.junit.Assert.failNotEquals(Assert.java:743) <3 in
    at CalculatorTests.calculatorEmptyString(CalculatorTests
```

System code:

```
public class Calculator {
 public int evaluate(String expr) {
    return -1;
 }
}
```

Fix the code to match

Test code:

```
@Test
public void calculatorEmptyString() {
    Calculator c = new Calculator();
    int res = c.evaluate("");
    Assert.assertEquals(res, 0);
}
```

System code:

```
public class Calculator {
 public int evaluate(String expr) {
    return 0;
 }
}
```

Test Driven Development (Nature's PBE)

- An iterative process
  - introducing a failing test
  - writing the minimal amount of code to make that test pass
- This is just what we do in PBE:
  1. Differentiating input-output example (failed test)
  2. Find next program that matches (make all tests pass)
- So what's the difference? The lack of common sense.

TDD vs. PBE

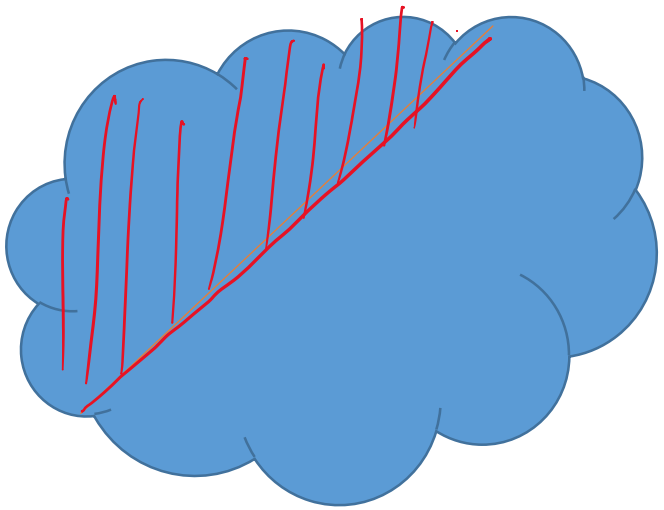
- Test 1: isPrime(5) == true
  - TDD: return true;
  - PBE: return true;
- Test 2: isPrime(4) == false
  - TDD: return x % 2 == 1
  - PBE: return x == 5

The less bias in our search space, the more the result will lean toward an overfitted result

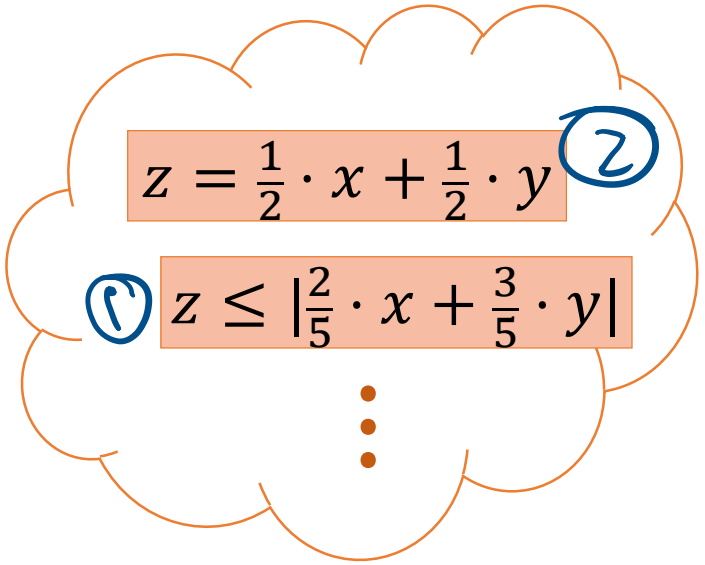
We need bias (even though we don't like it)

- The human can create bias for us

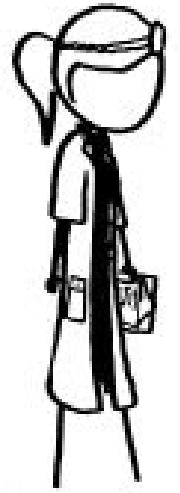
Rule out parts of the search space



Rank candidates



Bring domain knowledge to a generic synthesizer



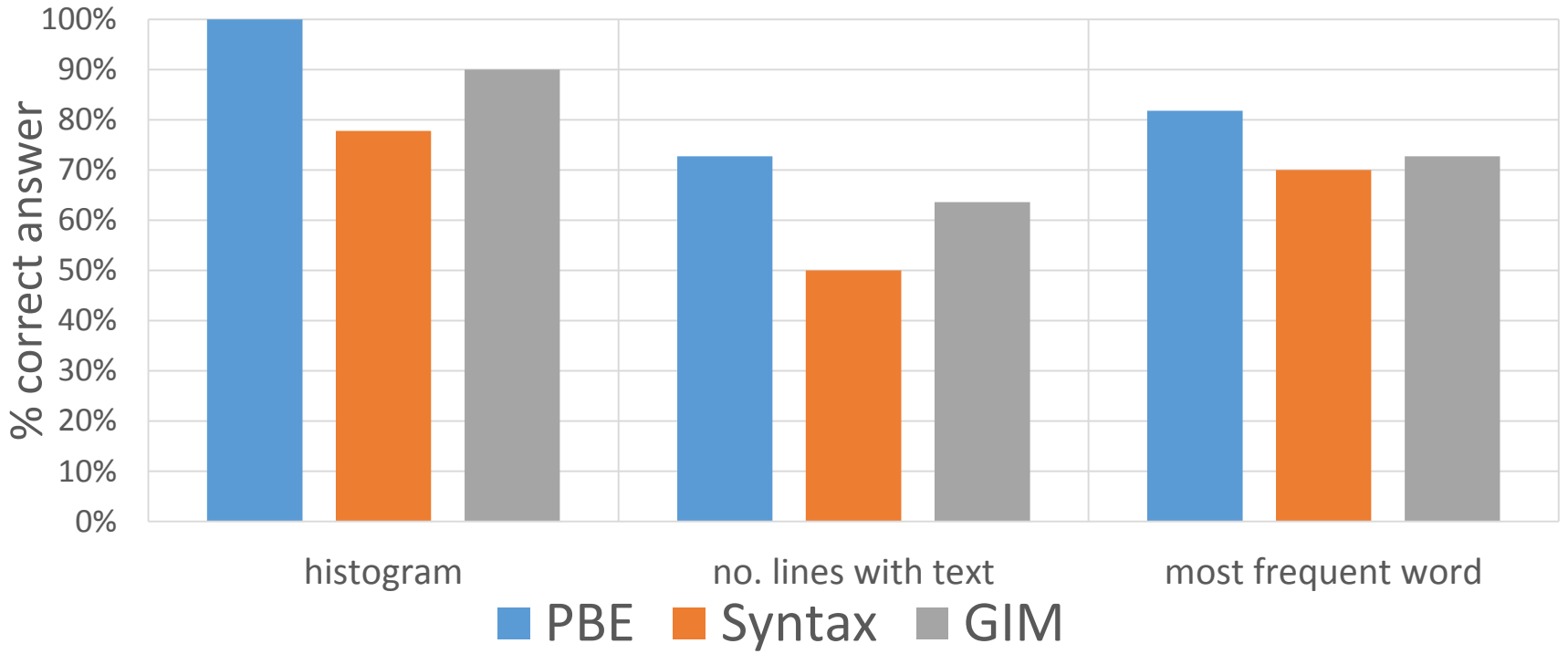
Demo time!

Inversion of control

- Current program synthesis: user repeatedly queries the synthesizer
- Inversion of control:
  - the synthesizer uses the human in order to get the best result
  - ask the best questions
  - give the best feedback tools

Help the user (help us)

- Because the user isn't perfect, either



Extreme programming, the computer aided version

- PBE is (kind of) like TDD
- More generally, programming with a synthesizer is like pair programming

- This is our ideal
  - The machine brings the knowledge
  - The human brings the common sense