#18: Specifications

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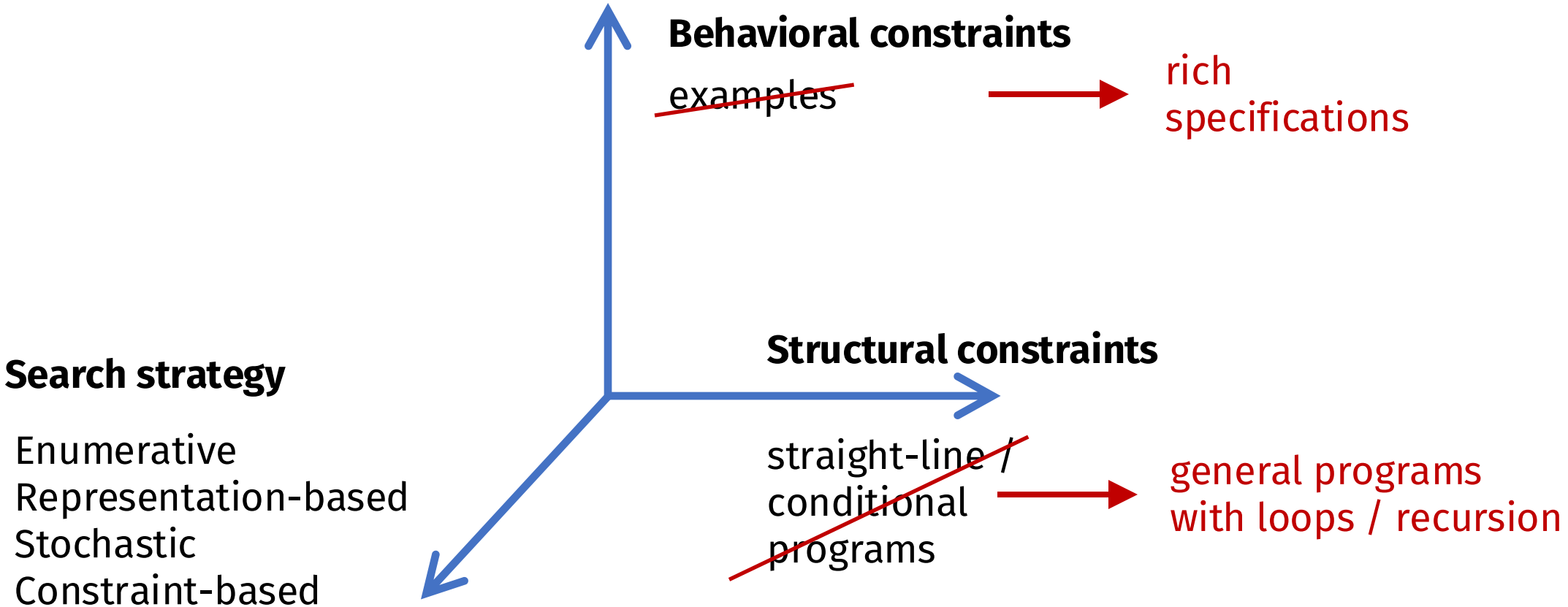
EECS 700: Introduction to Program Synthesis

Logistics

- Project proposal coming up this weekend
- Brahma paper assignment released

3-axes of synthesis



Examples of rich specifications

- Reference implementation
- Assertions
- Tests
- Pre- and post-condition
- Fancy types

Reference Implementation

Easy to compute the result, but hard to compute it efficiently or under structural constraints

```
bit[W] AES_round (bit[W] in, bit[W] rkey)
{
  ... // Transcribe NIST standard
}
bit[W] AES_round_sk (bit[W] in, bit[W] rkey) implements AES_round {
  ... // Sketch for table lookup
}
```

Assertions

Hard to compute the result, but easy to check its properties

```
split_seconds (int totsec) {
  int h := ?;
  int m := ?;
  int s := ?;
  assert totsec == h*3600 + m*60 + s;
  assert 0 <= h && 0 <= m < 60 && 0 <= s < 60;
}
```

Tests

Hard to specify results as inputs/outputs, but can assert postconditions about state of the program

```
post = Post.create(author: 'author', slug: 'hello-world', title: 'Hello World')
updated = update_post('author', 'hello-world', author: 'dummy',
                      title: 'Foo Bar', slug: 'foobar')

assert { updated.id == post.id }          # the returned post should be same
assert { updated.author == "author" }     # the author field should not be updated
assert { updated.title == "Foo Bar" }     # the title should be updated
assert { updated.slug == 'hello-world' }
```

Pre-/post-conditions

Hard to compute the result; need correctness guarantees

```
sort (int[] in, int n) returns (int[] out)
  requires          n ≥ 0
  ensures           ∀i j.0 ≤ i < j < n ⇒ out[i] ≤ out[j]
                    ∀i .0 ≤ i < n ⇒ ∃j.0 ≤ j < n ∧ in[i] = out[j]
{
  ?
}
```

Refinement types

Same as pre-/post-conditions but logic goes inside the types

```
data RBT a where
  Empty :: RBT a
  Node  :: x: a ->
    black: Bool ->
    left:  { RBT {a | _v < x} | !black ==> isBlack _v } ->
    right: { RBT {a | x < _v} | (!black ==> isBlack _v) &&
                  (blackHeight _v == blackHeight left)} ->
    RBT a

insert :: x: a -> t: RBT a -> {RBT a | elems _v == elems t + [x]}
insert = ?
```

binary search tree

red nodes have black children

same number of black nodes on every path to leaves

Why go beyond examples?

- Might need too many
  - **Example:** Myth needs 12 for insert_sorted, 24 for list_n_th
  - Examples contain *too little* information
  - Successful tools use domain-specific ranking
- Output difficult to construct
  - **Example:** AES cypher, RBT
  - Examples also contain *too much* information (concrete outputs)
- Need strong guarantees
  - **Example:** AES cypher
- Reasoning about non-functional properties
  - **Example:** security protocols

Why is this hard?

```
gcd (int a, int b) returns (int c)
  requires a > 0 ∧ b > 0
  ensures  a % c = 0 ∧ b % c = 0
           ∀d . c < d  ⇒  a % d ≠ 0  ∨  b % d ≠ 0
{
  int x , y := a, b;
  while (x != y) {
    if (x > y) x := ?;
    else y := ?;
}}
```

infinitely many inputs

cannot validate by testing

infinitely many paths!

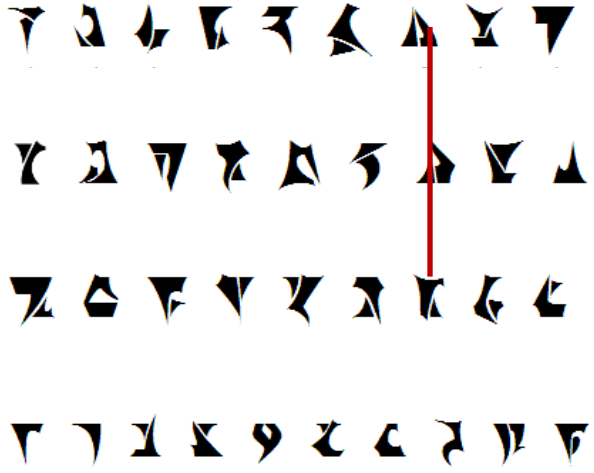
hard to generate constraints

Why is this hard?

Synthesis from examples

validation was easy!

Synthesis from specifications



SEE IF YOU CAN FIND ANY KLINGON FRUIT!

validation is hard!
(and search is still hard)

Upcoming lectures