Structures and All That

October 1, 2019

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We can get you prepared for the 31st century
With advanced programming and quad rendering
And Java plus plus plus scripting language
We offer advanced job placement assistance"

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- Whereas with "or" we would check which kind of data we would have and then use a computation specific to that data, with products we can directly project out data.
- Let's say that in Java that you have some person class with a first and last name represented as strings.
- It is easy to define a method that returns the person's full name by concatenating the first and last name.

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- We can represent a grid with one number in the same sense that we can simulate a 10x10 2D array with a 100 element array.

Structs Make Things Easier

Personally, I like doing things the easy way.

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def first_name(tup):
  return tup[0]
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- So Python gives classes (or named tuples) as a way to more easily define such structured data.

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- We will return to discussing lists in more detail later, since they are *extremely* important.
- But for now, remember that we wanted to avoid the inconveniences given by using other existing data types to represent some piece of compound data!

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(check-expect (distance-to-0 (point 0 5)) 5)
(check-expect (distance-to-0 (point 7 0)) 7)
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(define (distance-to-0 ap)
  (sqrt
    (+ (sqr (point-x ap))
       (sqr (point-y ap)))))
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  2. One selector per field, which extracts the value of the field from a structure instance; and
  3. One structure predicate, which, like ordinary predicates, distinguishes instances from all other kinds of values.

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2. The selectors per field are `(point-x point-val)` and `(point-y point-val)`. The general form of a selector for a specific field is `(struct-name-field-name val)`
3. A predicate for checking types is automatically created, for example: `(point? point-val)` and in general a predicate `struct?` is created.

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- **Sample Problem** Develop a structure type definition for a program that deals with bouncing balls,. The balls location is a single number, namely the distance of pixels from the top. Its constant speed is the number of pixels it moves per clock tick. Its velocity is the speed plus the direction in which it moves.

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- Let's first consider defining a 2D vector struct as follows: `(struct vector [delta-x delta-y])`
- Now, we can represent a ball as a point (which only has positive components) and a vector (which can have negative components): `(struct 2D-ball position vec)`

Other Representations

Our 2D Ball struct has nested occurrences of other structs. This is a natural thing, and even recursive descriptions of data are natural, i.e. linked lists and binary trees. But we can also consider using a *flat representation* for our 2D Ball, which doesn't nest structs.

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- Although valid, I think it's better to keep representations natural and just nest things, barring performance concerns.
- Let's talk about defining data definitions for structs. We must specify the form of the struct and the types of its field and provide an interpretation of what each of the fields represents. Here's how we do this for our point struct:

Other Representations

Our 2D Ball struct has nested occurrences of other structs. This is a natural thing, and even recursive descriptions of data are natural, i.e. linked lists and binary trees. But we can also consider using a *flat representation* for our 2D Ball, which doesn't nest structs.

- `(struct 2D-ball [x y delta-x delta-y]`
- Although valid, I think it's better to keep representations natural and just nest things, barring performance concerns.
- Let's talk about defining data definitions for structs. We must specify the form of the struct and the types of its field and provide an interpretation of what each of the fields represents. Here's how we do this for our point struct:

```
(define-struct point [x y])
; A Point is a structure:
;   (point Number Number)
; interpretation a point x pixels from left, y from top
```

-

Computing With Structures

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- Let us consider how to relate a struct description to a diagram that illustrates its “structure”.
- `(struct centry [name home office cell])`

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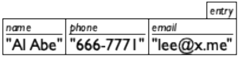

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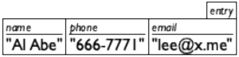

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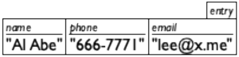

- In a sense, calling `(centry-name p1)` is unlocking a box in the struct, with a specific key that allows you to retrieve the underlying value. In general we can think of field access as a kind of "unboxing".
- Using a "key" to unlock the wrong box raises a runtime error `(centry-name (point 1 2))` $\hookrightarrow$ entry-name:expects a centry, given (point 42 5)

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- **Interpretation** - the action of explaining the meaning of something.
- **Denotation** - the object or concept to which a term refers, or the set of objects of which a predicate is true.

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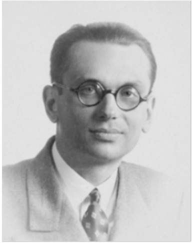
- My definition - A formal language that has a computable semantics specifying the denotation of a “sentence” written in the language. This denotation can be given by compilation into some other formal language, or by a direct interpretation.

Some Important People



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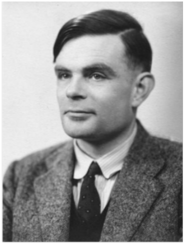

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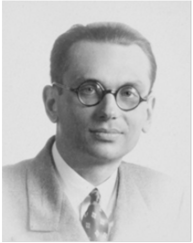

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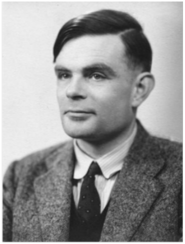

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Natural Interpretations?

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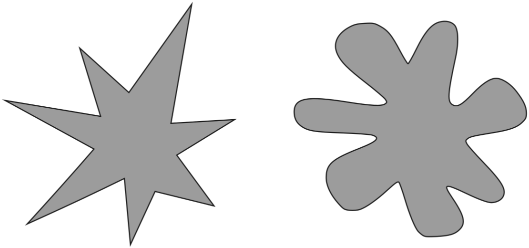

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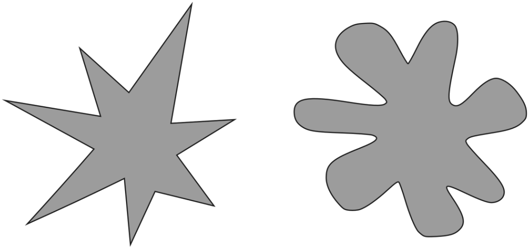

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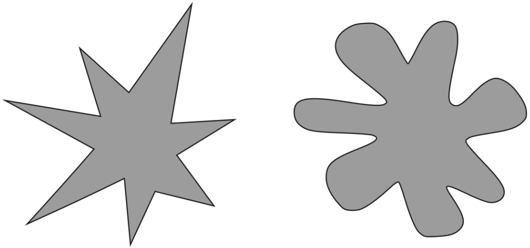

- Which of these shapes is named Bouba and which Kiki?
- This is likely due to some physical attributes of sound, but our strong preference for naming the round one Bouba and the sharp one Kiki shows that humans have **innate preferences** about the *naming* and *representation of things*.

Interpreting Structure

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- Interestingly, we can give 2 interpretations, depending on if the ball is moving vertically (interpretation 1) or horizontally (interpretation 2)

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```
; A Ball-2d is a structure:
;    (ball Point Vel)
; interpretation a 2-dimensional position and velocity

(define-struct vel [deltax deltay])
; A Vel is a structure:
;    (vel Number Number)
; interpretation (make-vel dx dy) means a velocity of
; dx pixels [per tick] along the horizontal and
; dy pixels [per tick] along the vertical direction
```

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- The T just communicates that we are defining linked lists that work over any type (*parametric polymorphism* otherwise known as *generics* in Java)

Structs and Program Design

Now we need to consider designing programs using structs.

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```
(define MTS (empty-scene 100 100))
(define DOT (circle 3 "solid" "red"))

; A Point represents the state of the world.

; Point -> Point
(define (main p0)
  (big-bang p0
    [on-tick x+]
    [on-mouse reset-dot]
    [to-draw scene+dot]))
```

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- Testing this is uninteresting, so let's consider if we were asked to define the `x+` function, which takes in a Point and returns a new Point with an x-coordinate that is 3 units further to the right of the old point.

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- To take inventory we project out the x and y fields from our point, as usual:

```
(define (x+ p) (... (point-x p) ... (point-y p) ...)
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- If we had more fields than y, we simply are projecting out the old field as an argument when creating the new struct value.
- This adds a lot of boilerplate code...

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- `point-set-x` is known as a *functional setter*, similar to a more traditional setter in languages like Java.
- However, defining an update operation on a complicated structure can get very complicated, and we can get around this uses *lenses* (we may discuss this later in the course).

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```
(check-expect
  (reset-dot (point 10 20) 29 31 "button-down")
  (point 29 31))
(check-expect
  (reset-dot (point 10 20) 29 31 "button-up")
  (point 10 20))
```

-

Events Creating Structs (cont.)

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- The takeaway here is that our skeletons can end up being more complicated than the actual final version.
- This is especially true when we consider skeletoning out code for which a parameter is a struct.

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- For some of the classes you see in Java, skeletoning out code in such a manner is infeasible...

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- We will return to this point later in the course.

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- The idea that a function signature can tell you about the behavior of the function is an extremely powerful idea.

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- If this is the domain of some function, we restricted ourselves to needing to handle three values.

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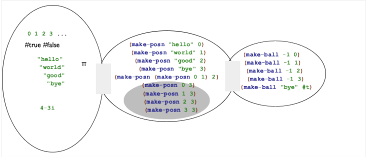
- 

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- This might mean creating a function `(define (make-point x y) ...)` that checks that both `x` and `y` actually receive integers before calling the `point` constructor. More on this later.

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- For intervals, use the end points (if they are included) and at least one interior point.
- For itemizations, deal with each part separately
- For data definitions for structures, follow the natural language description; that is, use the constructor and pick an example from the data collection named for each field.

Back to the Drawing Board

As usual, introducing structs necessitates that we change our design process so that we have clear instructions on how to deal with structs as the input and output to/of functions. We will illustrate the changes with the following problem:

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- **Sample Problem** Design a function that computes the distance of objects in a 3-dimensional space to the origin.
- The first step to our design process has a bigger change than was typical for previous revisions to our design process.

Step 1 and Structs

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- (1) When a problem calls for the representation of pieces of information that belong together or describe a natural whole, you need a structure type definition. It requires as many fields as there are relevant properties. An instance of this structure type corresponds to the whole, and the values in the fields correspond to its attributes.

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- (1) A data definition for a structure type introduces a name for the collection of instances that are legitimate. Furthermore, it must describe which kind of data goes with which field. Use only names of built-in data collections or previously defined data definitions.
- (1) In the end, we (and others) must be able to use the data definition to create sample structure instances. Otherwise, something is wrong with our data definition. To ensure that we can create instances, our data definitions should come with data examples.

Add Steps 2 and 3

Here's how we apply our step 1 changes to our sample problem:

```
(define-struct r3 [x y z])
; An R3 is a structure:
;   (make-r3 Number Number Number)

(define ex1 (make-r3 1 2 13))
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- (3) Your functional examples should use the examples generated by step (1):

  ```
  (check/expect (r3-distance ex1) (sqrt 174))
  (check/expect (r3-distance ex2) (sqrt 10))
  ```

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- (5) Use the selector expressions from the template when you define the function. Delete unneeded selections.
- (6) As usual, except that your tests are based on examples from step (1) and other examples.

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- Let's come up with a data interpretation. Let's assume the ufo descends 2-dimensionally with random jumps to the left or right.

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- Continue to think about other kinds of games and what kind of state we need

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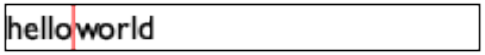
- 

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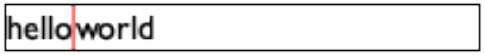
- 

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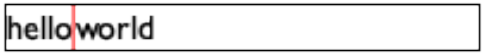
- 

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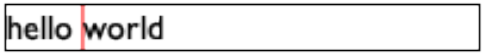
- 

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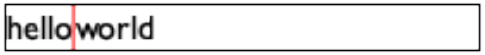
- 

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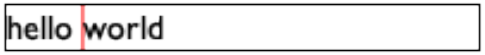
- 

- Here is a start to our data interpretation:

```
(define-struct editor [pre post])
; An Editor is a structure:
;   (make-editor String String)
; interpretation (make-editor s t) describes an editor
; whose visible text is (string-append s t) with
; the cursor displayed between s and t
```