

Extracted from:

Programming Elixir ≥ 1.6

Functional |> Concurrent |> Pragmatic |> Fun

This PDF file contains pages extracted from *Programming Elixir ≥ 1.6*, published by the Pragmatic Bookshelf. For more information or to purchase a paperback or PDF copy, please visit <http://www.pragprog.com>.

Note: This extract contains some colored text (particularly in code listing). This is available only in online versions of the books. The printed versions are black and white. Pagination might vary between the online and printed versions; the content is otherwise identical.

Copyright © 2018 The Pragmatic Programmers, LLC.

All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form, or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior consent of the publisher.

The Pragmatic Bookshelf

Raleigh, North Carolina

Programming Elixir ≥ 1.6

Functional

|> Concurrent

|> Pragmatic

|> Fun

Dave Thomas

Foreword by

José Valim,

Creator of Elixir



Programming Elixir \geq 1.6

Functional |> Concurrent |> Pragmatic |> Fun

Dave Thomas

The Pragmatic Bookshelf

Raleigh, North Carolina



Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and The Pragmatic Programmers, LLC was aware of a trademark claim, the designations have been printed in initial capital letters or in all capitals. The Pragmatic Starter Kit, The Pragmatic Programmer, Pragmatic Programming, Pragmatic Bookshelf, PragProg and the linking *g* device are trademarks of The Pragmatic Programmers, LLC.

Every precaution was taken in the preparation of this book. However, the publisher assumes no responsibility for errors or omissions, or for damages that may result from the use of information (including program listings) contained herein.

Our Pragmatic books, screencasts, and audio books can help you and your team create better software and have more fun. Visit us at <https://pragprog.com>.

The team that produced this book includes:

Publisher: Andy Hunt

VP of Operations: Janet Furlow

Managing Editor: Brian MacDonald

Supervising Editor: Jacquelyn Carter

Copy Editor: Candace Cunningham

Indexing: Potomac Indexing, LLC

Layout: Gilson Graphics

For sales, volume licensing, and support, please contact support@pragprog.com.

For international rights, please contact rights@pragprog.com.

Copyright © 2018 The Pragmatic Programmers, LLC.

All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form, or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior consent of the publisher.

Printed in the United States of America.

ISBN-13: 978-1-68050-299-2

Encoded using the finest acid-free high-entropy binary digits.

Book version: P1.0—May 2018

In this chapter, you'll see:

- The recursive structure of lists
- Traversing and building lists
- Accumulators
- Implementing map and reduce

CHAPTER 7

Lists and Recursion

When we program with lists in conventional languages, we treat them as things to be iterated—it seems natural to loop over them. So why do we have a chapter on *lists and recursion*? Because if you look at the problem in the right way, recursion is a perfect tool for processing lists.

Heads and Tails

Earlier we said a list may either be empty or consist of a head and a tail. The head contains a value and the tail is itself a list. This is a recursive definition.

We'll represent the empty list like this: `[]`.

Let's imagine we could represent the split between the head and the tail using a pipe character: `|`. The single-element list we normally write as `[3]` can be written as the value 3 joined to the empty list:

```
[ 3 | [] ]
```

(I've highlighted the inner list.)

When we see the pipe character, we say that what's on the left is the head of a list and what's on the right is the tail.

Let's look at the list `[2, 3]`. The head is 2, and the tail is the single-element list containing 3. And we know what that list looks like—it is our previous example. So we could write `[2,3]` as

```
[ 2 | [ 3 | [] ] ]
```

At this point, part of your brain is telling you to go read today's XKCD—this list stuff can't be useful. Ignore that small voice, just for a second. We're about to do something magical. But before we do, let's add one more term, making

our list `[1, 2, 3]`. This is the head `1` followed by the list `[2, 3]`, which is what we derived a moment ago:

```
[ 1 | [ 2 | [ 3 | [] ] ] ]
```

This is valid Elixir syntax. Type it into IEx.

```
iex> [ 1 | [ 2 | [ 3 | [] ] ] ]
[1, 2, 3]
```

And here's the magic. When we discussed pattern matching, we said the pattern could be a list, and the values in that list would be assigned from the right-hand side.

```
iex> [a, b, c] = [ 1, 2, 3 ]
[1, 2, 3]
iex> a
1
iex> b
2
iex> c
3
```

We can also use the pipe character in the pattern. What's to the left of it matches the head value of the list, and what's to the right matches the tail.

```
iex> [ head | tail ] = [ 1, 2, 3 ]
[1, 2, 3]
iex> head
1
iex> tail
[2, 3]
```

Using Head and Tail to Process a List

Now we can split a list into its head and its tail, and we can construct a list from a value and a list, which become the head and tail of that new list.

So why talk about lists after we talk about modules and functions? Because lists and recursive functions go together like fish and chips. Let's look at finding the length of a list.

- The length of an empty list is 0.
- The length of a list is 1 plus the length of that list's tail.

How IEx Displays Lists

In [Chapter 11, *Strings and Binaries*, on page ?](#), you'll see that Elixir has two representations for strings. One is the familiar sequence of characters in consecutive memory locations. Literals written with double quotes use this form.

The second form, using single quotes, represents a string as a list of integer codepoints. So the string 'cat' is the three codepoints: 99, 97, and 116.

This is a headache for IEx. When it sees a list like [99,97,116] it doesn't know if it is supposed to be the string 'cat' or a list of three numbers. So it uses a heuristic. If all the values in a list represent printable characters, it displays the list as a string; otherwise it displays a list of integers.

```
iex> [99, 97, 116]
'cat'
iex> [99, 97, 116, 0] # '0' is nonprintable
[99, 97, 116, 0]
```

In [Chapter 11, *Strings and Binaries*, on page ?](#), we'll cover how to bypass this behavior. In the meantime, don't be surprised if a string pops up when you were expecting a list.

Writing the list-length algorithm in Elixir is easy:

`lists/mylist.exs`

```
defmodule MyList do
  def len([], do: 0)
  def len([head|tail], do: 1 + len(tail))
end
```

The only tricky part is the definition of the function's second variant:

```
def len([ head | tail ]) ...
```

This is a pattern match for any nonempty list. When it does match, the variable `head` will hold the value of the first element of the list, and `tail` will hold the rest of the list. (And remember that every list is terminated by an empty list, so the tail can be `[]`.)

Let's see this at work with the list [11, 12, 13, 14, 15]. At each step, we take off the head and add 1 to the length of the tail:

```
len([11,12,13,14,15])
= 1 + len([12,13,14,15])
= 1 + 1 + len([13,14,15])
= 1 + 1 + 1 + len([14,15])
= 1 + 1 + 1 + 1 + len([15])
= 1 + 1 + 1 + 1 + 1 + len([])
= 1 + 1 + 1 + 1 + 1 + 0
= 5
```

Let's try our code to see if theory works in practice:

```
iex> c "mylist.exs"
...mylist.exs:3: variable head is unused
[MyList]
iex> MyList.len([])
0
iex> MyList.len([11,12,13,14,15])
5
```

It works, but we have a compilation warning—we never used the variable `head` in the body of our function. We can fix that, and make our code more explicit, using the special variable `_` (underscore), which acts as a placeholder. We can also use an underscore in front of any variable name to turn off the warning if that variable isn't used. I sometimes like to do this to document the unused parameter.

```
lists/mylist1.exs
defmodule MyList do
  def len([]), do: 0
  def len([_head | tail]), do: 1 + len(tail)
end
```

When we compile, the warning is gone. (However, if you compile the second version of `MyList`, you may get a warning about “redefining module `MyList`.” This is just Elixir being cautious.)

```
iex> c "mylist1.exs"
[MyList]
iex> MyList.len([1,2,3,4,5])
5
iex> MyList.len(["cat", "dog"])
2
```

Using Head and Tail to Build a List

Let's get more ambitious. Let's write a function that takes a list of numbers and returns a new list containing the square of each. We don't show it, but these definitions are also inside the `MyList` module.

```
lists/mylist1.exs
def square([]), do: []
def square([head | tail]), do: [head*head | square(tail)]
```

There's a lot going on here. First, look at the parameter patterns for the two definitions of `square`. The first matches an empty list and the second matches all other lists.

Second, look at the body of the second definition:

```
def square([ head | tail ]), do: [ head*head | square(tail) ]
```

When we match a nonempty list, we return a new list whose head is the square of the original list's head and whose tail is a list of squares of the tail. This is the recursive step.

Let's try it:

```
iex> c "mylist1.exs"
[MyList]
iex> MyList.square []           # this calls the 1st definition
[]
iex> MyList.square [4,5,6]     # and this calls the 2nd
[16, 25, 36]
```

Let's do something similar—a function that adds 1 to every element in the list:

```
lists/mylist1.exs
def add_1([], _), do: []
def add_1([ head | tail ], _), do: [ head+1 | add_1(tail) ]
```

And call it:

```
iex> c "mylist1.exs"
[MyList]
iex> MyList.add_1 [1000]
[1001]
iex> MyList.add_1 [4,6,8]
[5, 7, 9]
```

Creating a Map Function

With both `square` and `add_1`, all the work is done in the second function definition. And that definition looks about the same for each—it returns a new list whose head is the result of either squaring or incrementing the head of its argument and whose tail is the result of calling itself recursively on the tail of the argument. Let's generalize this. We'll define a function called `map` that takes a list and a function and returns a new list containing the result of applying that function to each element in the original.

```
lists/mylist1.exs
def map([], _func), do: []
def map([ head | tail ], func), do: [ func.(head) | map(tail, func) ]
```

The `map` function is pretty much identical to the `square` and `add_1` functions. It returns an empty list if passed an empty list; otherwise it returns a list where the head is the result of calling the passed-in function and the tail is a recursive call to itself. Note that in the case of an empty list, we use `_func` as

the second parameter. The underscore prevents Elixir from warning us about an unused variable.

To call this function, pass in a list and a function (defined using `fn`):

```
iex> c "mylist1.exs"
[MyList]
iex> MyList.map [1,2,3,4], fn (n) -> n*n end
[1, 4, 9, 16]
```

A function is just a built-in type, defined between `fn` and the `end`. Here we pass a function as the second argument (`func`) to `map`. This is invoked inside `map` using `func.(head)`, which squares the value in `head`, using the result to build the new list.

We can call `map` with a different function:

```
iex> MyList.map [1,2,3,4], fn (n) -> n+1 end
[2, 3, 4, 5]
```

And another:

```
iex> MyList.map [1,2,3,4], fn (n) -> n > 2 end
[false, false, true, true]
```

And we can do the same using the `&` shortcut notation:

```
iex> MyList.map [1,2,3,4], &(&1 + 1)
[2, 3, 4, 5]
iex> MyList.map [1,2,3,4], &(&1 > 2)
[false, false, true, true]
```

Reducing a List to a Single Value

The `map/2` function we just wrote abstracts the idea of applying a function to each element of a list independently.

But what if we want to apply that function across the elements? How could we create an abstraction that would let us sum a list, or find the product of its elements, or find the largest element?

The `sum` function reduces a collection to a single value. Other functions need to do something similar—return the greatest/least value, the product of the elements, a string containing a concatenation of elements, and so on. How can we write a general-purpose function that reduces a collection to a value?

We know it has to take a collection. We also know we need to pass in some initial value (just like our `sum/1` function passed a 0 as an initial value to its

helper). Additionally, we need to pass in a function that takes the current value of the reduction along with the next element of the collection, and returns the next value of the reduction. So, it looks like our reduce function will be called with three arguments:

```
reduce(collection, initial_value, fun)
```

Now let's think about the recursive design:

- `reduce([], value, _fun) → value`
- `reduce([head | tail], value, fun) → reduce(tail, fun.(head, value), fun)`

`reduce` applies the function to the list's head and the current value, and passes the result as the new current value when reducing the list's tail.

Here's our code for `reduce`. See how closely it follows the design:

```
lists/reduce.exs
defmodule MyList do
  def reduce([], value, _) do
    value
  end
  def reduce([head | tail], value, func) do
    reduce(tail, func.(head, value), func)
  end
end
```

And, again, we can use the shorthand notation to pass in the function:

```
iex> c "reduce.exs"
[MyList]
iex> MyList.reduce([1,2,3,4,5], 0, &(&1 + &2))
15
iex> MyList.reduce([1,2,3,4,5], 1, &(&1 * &2))
120
```

Your Turn

► [Exercise: ListsAndRecursion-1](#)

Write a `mapsum` function that takes a list and a function. It applies the function to each element of the list and then sums the result, so

```
iex> MyList.mapsum [1, 2, 3], &(&1 * &1)
14
```

► [Exercise: ListsAndRecursion-2](#)

Write a `max(list)` that returns the element with the maximum value in the list. (This is slightly trickier than it sounds.)

► *Exercise: ListsAndRecursion-3*

An Elixir single-quoted string is actually a list of individual character codes. Write a `caesar(list, n)` function that adds `n` to each list element, wrapping if the addition results in a character greater than `z`.

```
iex> MyList.caesar('ryvkve', 13)
?????? :)
```

More Complex List Patterns

Not every list problem can be easily solved by processing one element at a time. Fortunately, the join operator, `|`, supports multiple values to its left. Thus, you could write

```
iex> [ 1, 2, 3 | [ 4, 5, 6 ] ]
[1, 2, 3, 4, 5, 6]
```

The same thing works in patterns, so you can match multiple individual elements as the head. For example, this program swaps pairs of values in a list:

`lists/swap.exs`

```
defmodule Swapper do
  def swap([], do: [])
  def swap([ a, b | tail ], do: [ b, a | swap(tail) ])
  def swap([_]), do: raise "Can't swap a list with an odd number of elements"
end
```

We can play with it in IEx:

```
iex> c "swap.exs"
[Swapper]
iex> Swapper.swap [1,2,3,4,5,6]
[2, 1, 4, 3, 6, 5]
iex> Swapper.swap [1,2,3,4,5,6,7]
** (RuntimeError) Can't swap a list with an odd number of elements
```

The third definition of `swap` matches a list with a single element. This will happen if we get to the end of the recursion and have only one element left. Given that we take two values off the list on each cycle, the initial list must have had an odd number of elements.

Lists of Lists

Let's imagine we had recorded temperatures and rainfall at a number of weather stations. Each reading looks like this:

```
[ timestamp, location_id, temperature, rainfall ]
```

Our code is passed a list containing a number of these readings, and we want to report on the conditions for one particular location, number 27.

lists/weather.exs

```
defmodule WeatherHistory do

  def for_location_27([], do: [])
  def for_location_27([ [time, 27, temp, rain ] | tail]) do
    [ [time, 27, temp, rain] | for_location_27(tail) ]
  end
  def for_location_27([ _ | tail]), do: for_location_27(tail)

end
```

This is a standard *recurse until the list is empty* stanza. But look at our function definition's second clause. Where we'd normally match into a variable called head, here the pattern is

```
for_location_27([ [ time, 27, temp, rain ] | tail])
```

For this to match, the head of the list must itself be a four-element list, and the second element of this sublist must be 27. This function will execute only for entries from the desired location. But when we do this kind of filtering, we also have to remember to deal with the case when our function doesn't match. That's what the third line does. We could have written

```
for_location_27([ [ time, _, temp, rain ] | tail])
```

but in reality we don't care *what* is in the head at this point.

In the same module we define some simple test data:

lists/weather.exs

```
def test_data do
  [
    [1366225622, 26, 15, 0.125],
    [1366225622, 27, 15, 0.45],
    [1366225622, 28, 21, 0.25],
    [1366229222, 26, 19, 0.081],
    [1366229222, 27, 17, 0.468],
    [1366229222, 28, 15, 0.60],
    [1366232822, 26, 22, 0.095],
    [1366232822, 27, 21, 0.05],
    [1366232822, 28, 24, 0.03],
    [1366236422, 26, 17, 0.025]
  ]
end
```

We can use that to play with our function in IEx. To make this easier, I'm using the import function. This adds the functions in WeatherHistory to our local

name scope. After calling `import` we don't have to put the module name in front of every function call.

```
iex> c "weather.exs"
[WeatherHistory]
iex> import WeatherHistory
WeatherHistory
iex> for_location_27(test_data)
[[1366225622, 27, 15, 0.45], [1366229222, 27, 17, 0.468],
 [1366232822, 27, 21, 0.05]]
```

Our function is specific to a particular location, which is pretty limiting. We'd like to be able to pass in the location as a parameter. We can use pattern matching for this.

lists/weather2.exs

```
defmodule WeatherHistory do
  def for_location([], _target_loc), do: []
  ➤ def for_location([ [time, target_loc, temp, rain] | tail], target_loc) do
    [ [time, target_loc, temp, rain] | for_location(tail, target_loc) ]
  end
  def for_location([ _ | tail], target_loc), do: for_location(tail, target_loc)
end
```

Now the second function fires only when the location extracted from the list head equals the target location passed as a parameter.

But we can improve on this. Our filter doesn't care about the other three fields in the head—it just needs the location. But we do need the value of the head itself to create the output list. Fortunately, Elixir pattern matching is recursive and we can match patterns inside patterns.

lists/weather3.exs

```
defmodule WeatherHistory do
  def for_location([], _target_loc), do: []
  ➤ def for_location([ head = [_, target_loc, _, _] | tail], target_loc) do
    [ head | for_location(tail, target_loc) ]
  end
  def for_location([ _ | tail], target_loc), do: for_location(tail, target_loc)
end
```

The key change here is this line:

```
def for_location([ head = [_, target_loc, _, _] | tail], target_loc)
```

Compare that with the previous version:

```
def for_location([ [ time, target_loc, temp, rain ] | tail], target_loc)
```

In the new version, we use placeholders for the fields we don't care about. But we also match the entire four-element array into the parameter head. It's as if we said, "Match the head of the list where the second element is matched to target_loc and then match that whole head with the variable head." We've extracted an individual component of the sublist as well as the entire sublist.

In the original body of for_location, we generated our result list using the individual fields:

```
def for_location([ [ time, target_loc, temp, rain ] | tail], target_loc)
  [ [ time, target_loc, temp, rain ] | for_location(tail, target_loc) ]
end
```

In the new version, we can just use the head, making it a lot clearer:

```
def for_location([ head = [_, target_loc, _, _ ] | tail], target_loc) do
  [ head | for_location(tail, target_loc) ]
end
```

Your Turn

► *Exercise: ListsAndRecursion-4*

Write a function `MyList.span(from, to)` that returns a list of the numbers from from up to to.

The List Module in Action

The List module provides a set of functions that operate on lists.

```
#
# Concatenate lists
#
iex> [1,2,3] ++ [4,5,6]
[1, 2, 3, 4, 5, 6]
#
# Flatten
#
iex> List.flatten([[[1], 2], [[[3]]]])
[1, 2, 3]
#
# Folding (like reduce, but can choose direction)
#
iex> List.foldl([1,2,3], "", fn value, acc -> "#{value}({acc})" end)
"3(2(1()))"
iex> List.foldr([1,2,3], "", fn value, acc -> "#{value}({acc})" end)
"1(2(3()))"
```

```

#
# Updating in the middle (not a cheap operation)
#
iex> list = [ 1, 2, 3 ]
[ 1, 2, 3 ]
iex> List.replace_at(list, 2, "buckle my shoe")
[1, 2, "buckle my shoe"]
#
# Accessing tuples within lists
#
iex> kw = [{:name, "Dave"}, {:likes, "Programming"}, {:where, "Dallas", "TX"}]
[{:name, "Dave"}, {:likes, "Programming"}, {:where, "Dallas", "TX"}]
iex> List.keyfind(kw, "Dallas", 1)
{:where, "Dallas", "TX"}
iex> List.keyfind(kw, "TX", 2)
{:where, "Dallas", "TX"}
iex> List.keyfind(kw, "TX", 1)
nil
iex> List.keyfind(kw, "TX", 1, "No city called TX")
"No city called TX"
iex> kw = List.keydelete(kw, "TX", 2)
[name: "Dave", likes: "Programming"]
iex> kw = List.keyreplace(kw, :name, 0, {:first_name, "Dave"})
[first_name: "Dave", likes: "Programming"]

```

Get Friendly with Lists

Lists are the natural data structure to use when you have a stream of values to handle. You'll use them to parse data, handle collections of values, and record the results of a series of function calls. It's worth spending a while getting comfortable with them.

Next we'll look at the various dictionary types, including maps. These let us organize data into collections of key/value pairs.