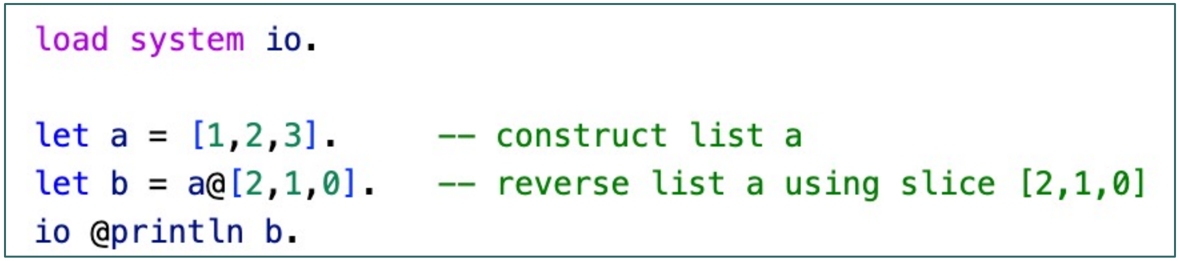
The Let Statement & Basic Pattern Matching

- Up till now we have used the let statement basically as an assignment statement into a single variable in the imperative fashion

  let <var> = <value>.



```
load system io.

let a = [1,2,3].      -- construct list a
let b = a@[2,1,0].    -- reverse list a using slice [2,1,0]
io @println b.
```

The Let Statement & Basic Pattern Matching

- However, the let statement is a pattern-match statement in Asteroid,

```
let <pattern> = <value>.
```

- where the pattern on the left side of the equal sign is matched against the value of the right side of the equal sign.
- **Simple patterns are expressions that consist purely of constructors and variables**

Pattern Matching – Foundations

- In programs values are represented by **constructors**,
  - 1
  - “Hello, World!”
  - [1,2,3]
  - (“Harry”, 32)
- Any structure that cannot be reduced any further consists purely of constructors and is the **minimal/canonical representation** of a value.
- The following are all representations of the value two:
  - 1+1; 3-1; 2*1; 2+0; 2
  - Only the last one is the canonical representation of the value two.
  - We say that 2 is a constructor for the value two.
  - In this case the constructor happens to be a constant.

Pattern Matching – Foundations

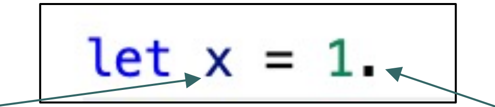
- Here is another example using lists
- The following are all representations of a list with the values one, two, and three
    - [1]+[2]+[3]; [1,2]+[3]; [1,2,3]+[]; [1,2,3]
- Again, only the last one is the canonical representation of the list
    - It represents the value of a list with integer values one, two, and three.

Pattern Matching – Foundations

- Constructors are interesting,
  - When they are part of an expression being evaluated, they represent values
  - Otherwise, they represent structure.
- We say this with the let statement,
  let <pattern> = <value>.
  - On the right of the = sign constructors represent values
  - On the left of the = sign constructors represent structure

Pattern Matching – Foundations

- When the pattern is just a single variable then the let statement looks like an assignment statement,

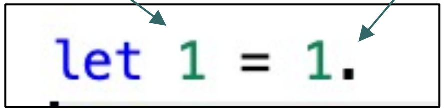


```
let x = 1.
```

Pattern

Value

- However, statements like,

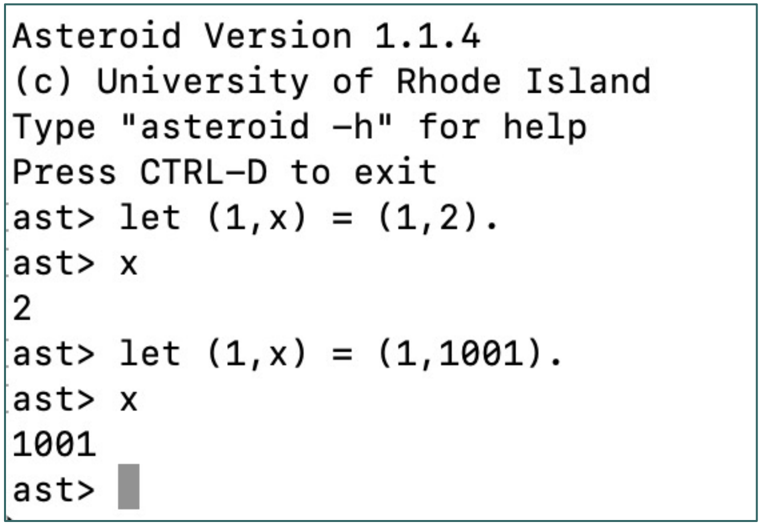


```
let 1 = 1.
```

- are completely legal,
  - the 1 on the left is a constructor viewed as pattern, the 1 on the right is a constructor viewed as a value.
  - highlighting the fact that the let statement is not equivalent to an assignment statement.

Pattern Matching – Foundations

- You can think of variables in a pattern as a “I don’t care” structure
- During a pattern match the variable will receive the structure that was actually matched during the pattern match



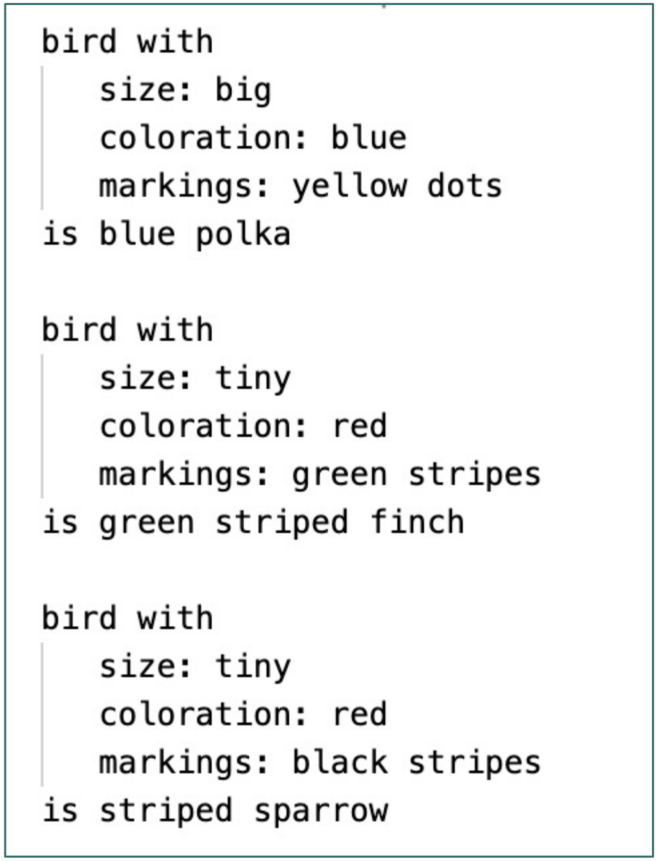
```
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
ast> let (1,x) = (1,2).
ast> x
2
ast> let (1,x) = (1,1001).
ast> x
1001
ast>
```

Pattern Matching – Foundations

- Patterns are all about structure
- For example,
  - a wildlife biologist might use pattern matching to identify a specific species of bird based on its size, coloration, and distinctive markings on its feathers – **structure**.
  - They would compare these characteristics to a known set of **patterns** for different bird species from a field guide and use this information to make an accurate identification.
- Observe, the structure of a value (unknown bird) is pattern-matched against a set of known patterns. If one of the patterns matches the value (bird) then we have a match (identification).

Pattern Matching – Foundations

- We can code that biologist example using pattern matching
- Assume we have a field guide with the following patterns

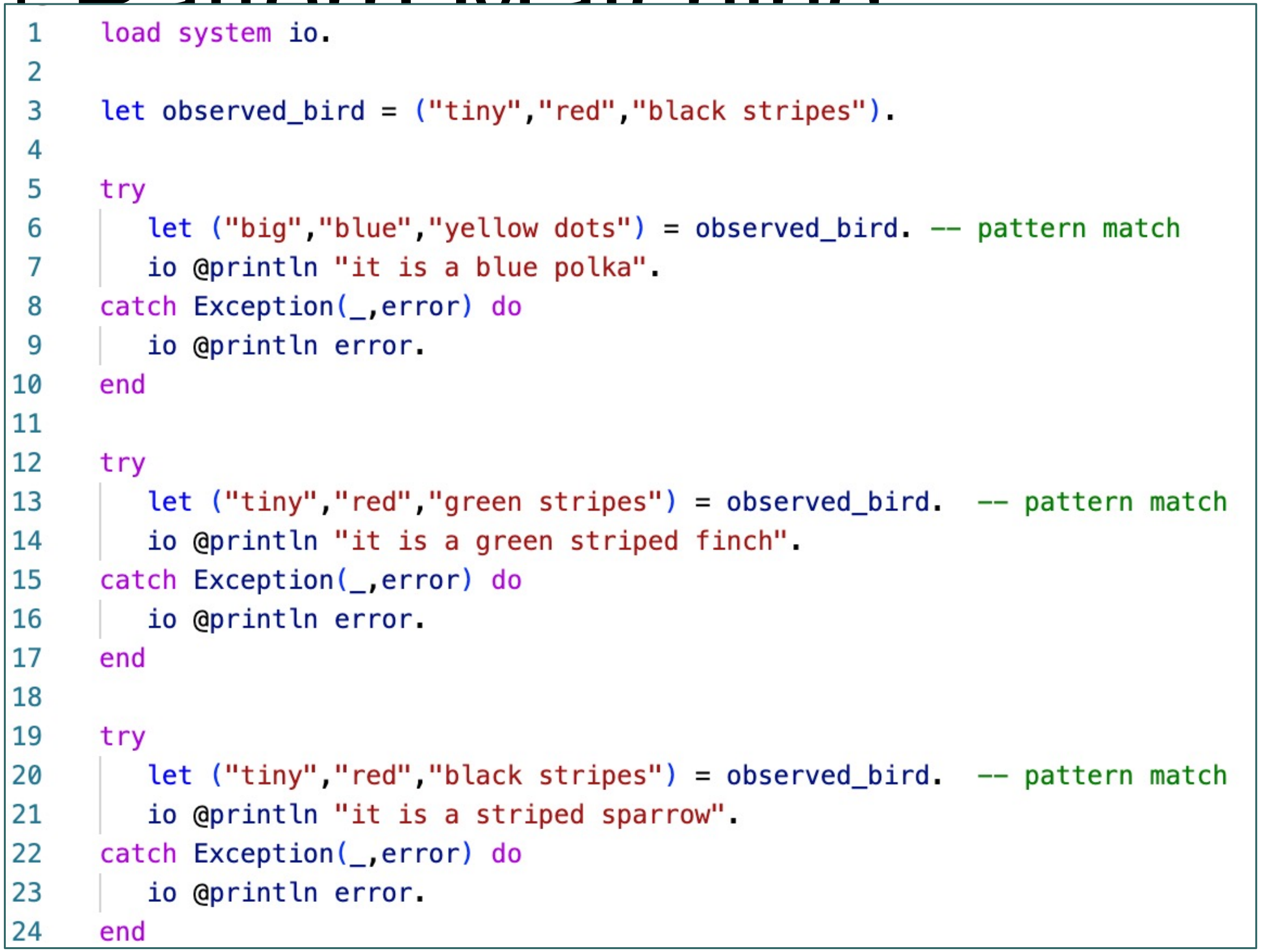


```
bird with
    size: big
    coloration: blue
    markings: yellow dots
is blue polka

bird with
    size: tiny
    coloration: red
    markings: green stripes
is green striped finch

bird with
    size: tiny
    coloration: red
    markings: black stripes
is striped sparrow
```

Pattern Matching – Foundations

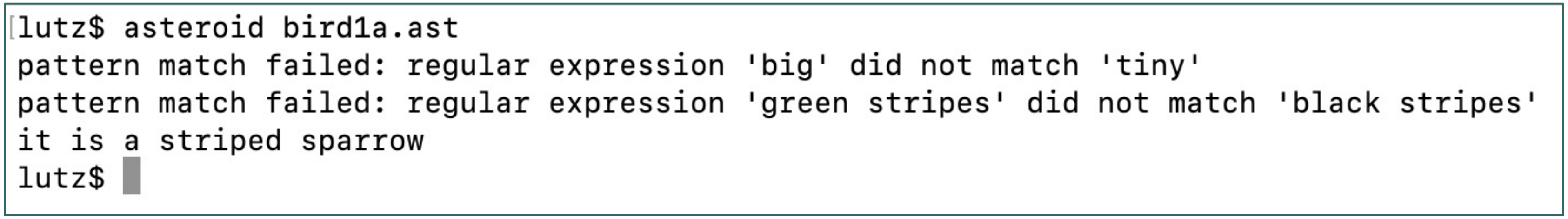
- We can solve this problem nicely with pattern matching in Asteroid,
  - We will encode the patterns as 3-tuples
  - We write a let statement for each pattern
  - When let statements fail they throw an exception, we will embed the let statements in a try-catch block so we can detect the pattern match failure

Pattern Matching



```
load system io.

let observed_bird = ("tiny","red","black stripes").

try
   let ("big","blue","yellow dots") = observed_bird. -- pattern match
   io @println "it is a blue polka".
catch Exception(_,error) do
   io @println error.
end

try
   let ("tiny","red","green stripes") = observed_bird.  -- pattern match
   io @println "it is a green striped finch".
catch Exception(_,error) do
   io @println error.
end

try
   let ("tiny","red","black stripes") = observed_bird.  -- pattern match
   io @println "it is a striped sparrow".
catch Exception(_,error) do
   io @println error.
end
```

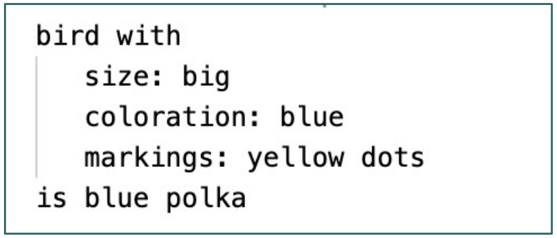
In004/bird1a.ast



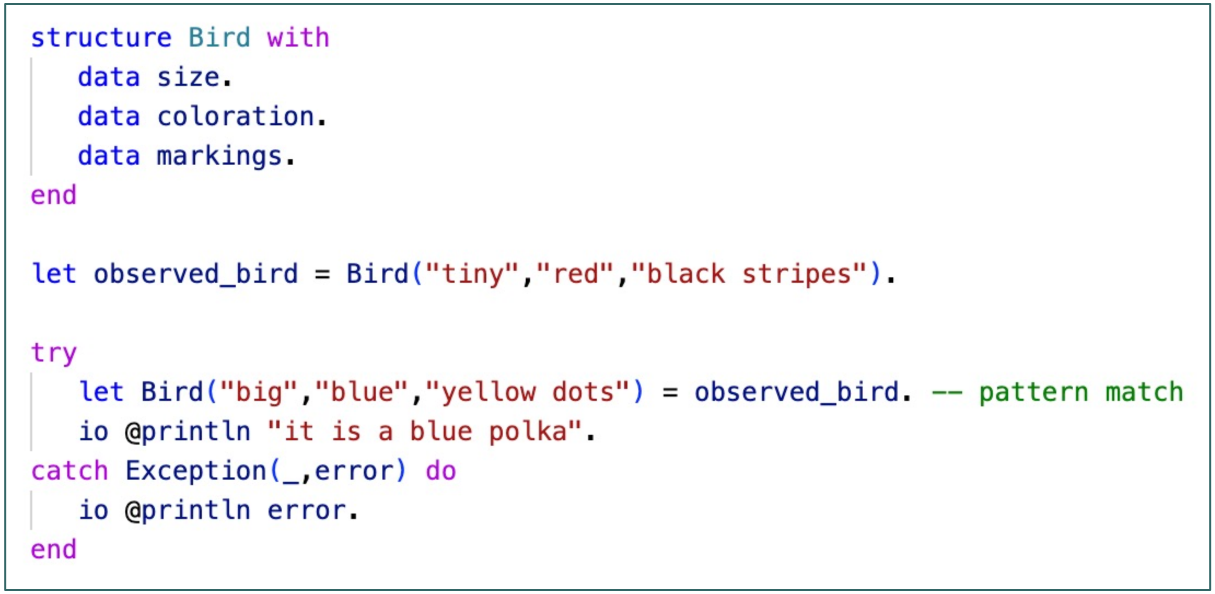
```
lutz$ asteroid bird1a.ast
pattern match failed: regular expression 'big' did not match 'tiny'
pattern match failed: regular expression 'green stripes' did not match 'black stripes'
it is a striped sparrow
lutz$
```

Pattern Matching – Foundations

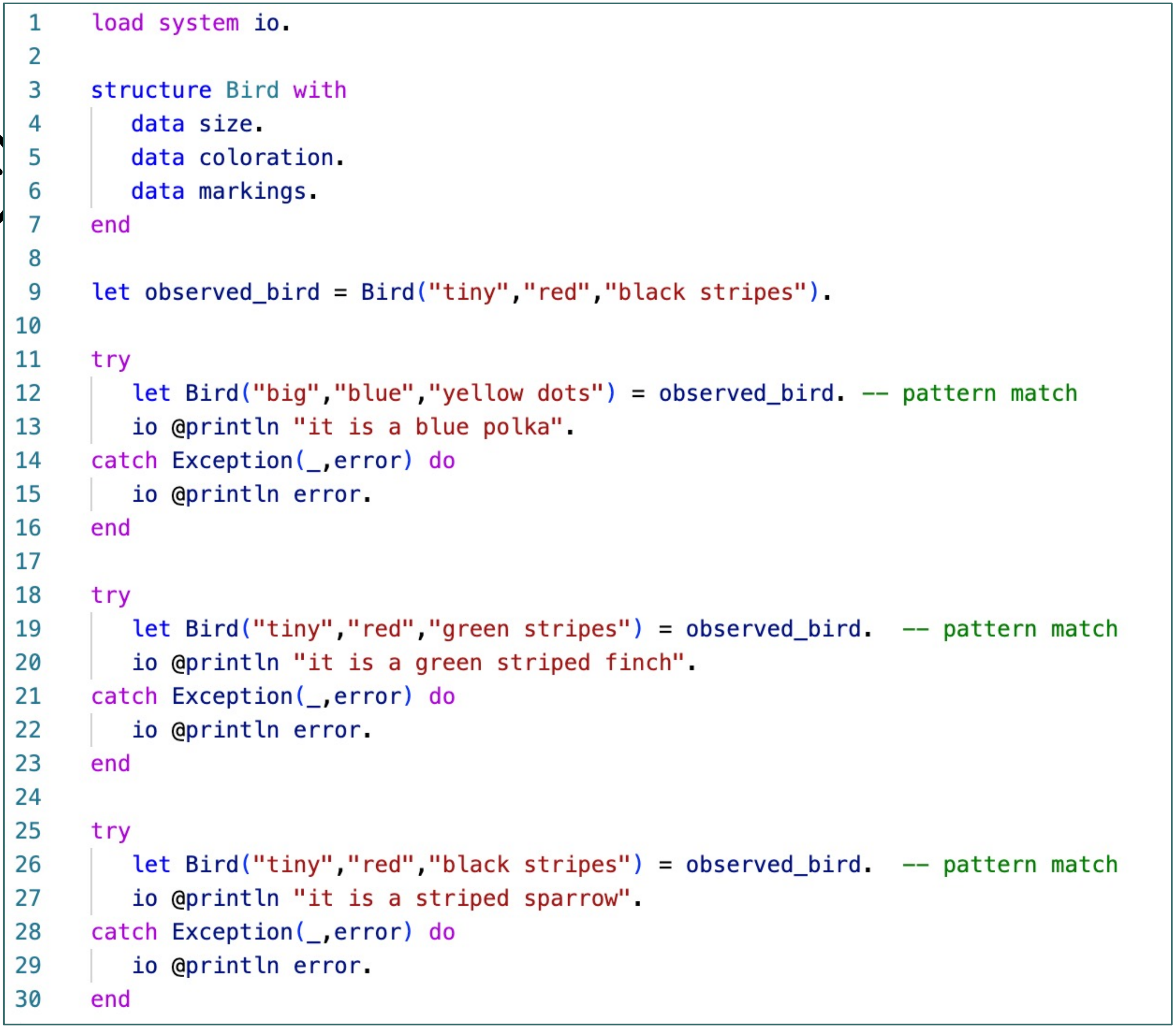
- It is nicer to represent the patterns as bird objects
- This way we stay closer to the original problem setting. E.g.,



```
bird with
    size: big
    coloration: blue
    markings: yellow dots
is blue polka
```

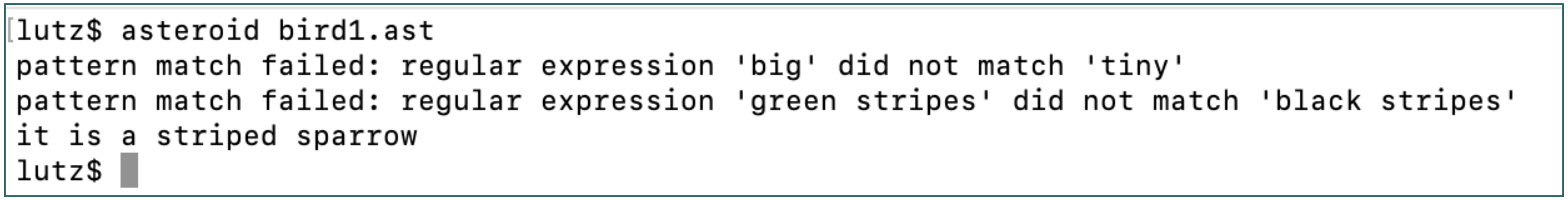


```
structure Bird with
    data size.
    data coloration.
    data markings.
end

let observed_bird = Bird("tiny","red","black stripes").

try
    let Bird("big","blue","yellow dots") = observed_bird. -- pattern match
    io @println "it is a blue polka".
catch Exception(_,error) do
    io @println error.
end
```



```
load system io.

structure Bird with
    data size.
    data coloration.
    data markings.
end

let observed_bird = Bird("tiny","red","black stripes").

try
    let Bird("big","blue","yellow dots") = observed_bird. -- pattern match
    io @println "it is a blue polka".
catch Exception(_,error) do
    io @println error.
end

try
    let Bird("tiny","red","green stripes") = observed_bird.  -- pattern match
    io @println "it is a green striped finch".
catch Exception(_,error) do
    io @println error.
end

try
    let Bird("tiny","red","black stripes") = observed_bird.  -- pattern match
    io @println "it is a striped sparrow".
catch Exception(_,error) do
    io @println error.
end
```

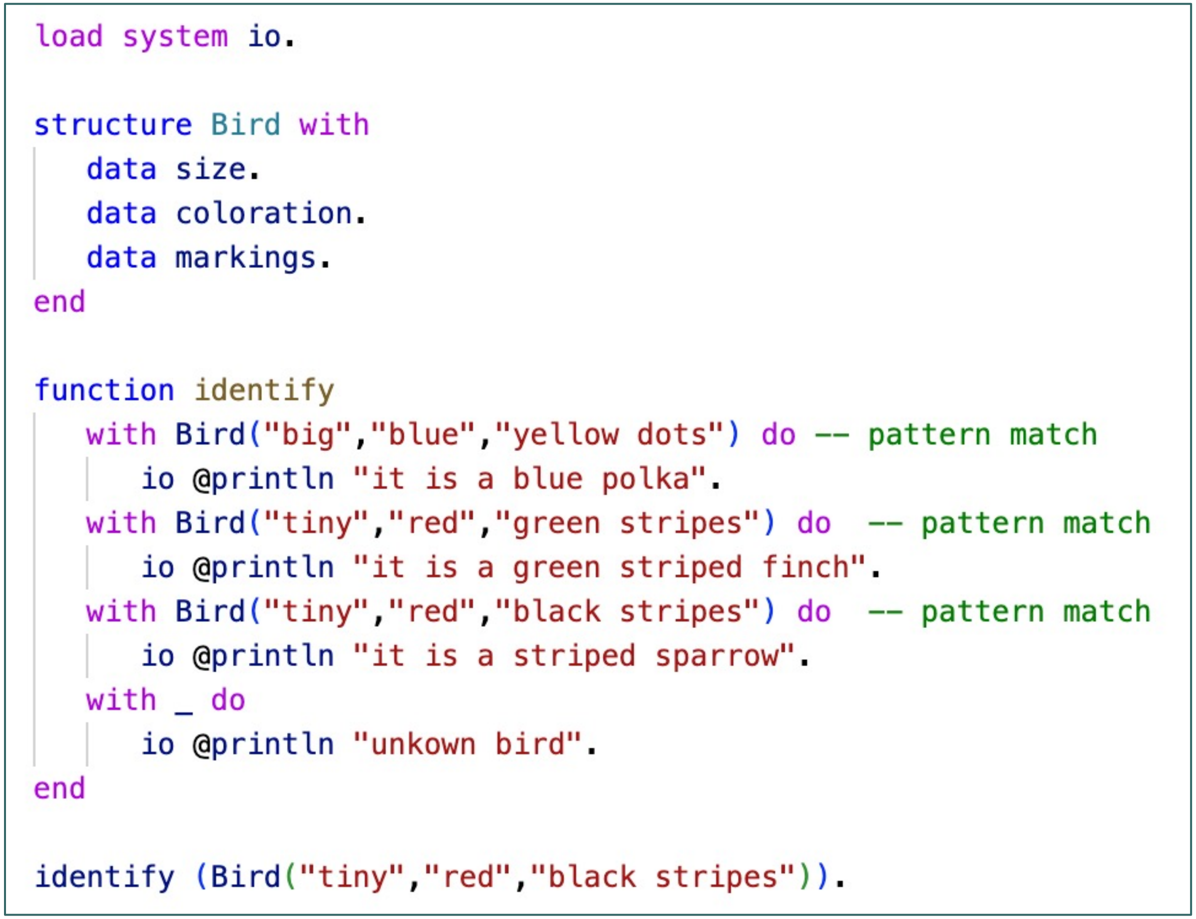
ln004/bird1b.ast



```
lutz$ asteroid bird1.ast
pattern match failed: regular expression 'big' did not match 'tiny'
pattern match failed: regular expression 'green stripes' did not match 'black stripes'
it is a striped sparrow
lutz$ 
```

Pattern Matching – Foundations

- Here is a much more elegant solution using pattern matching in functions

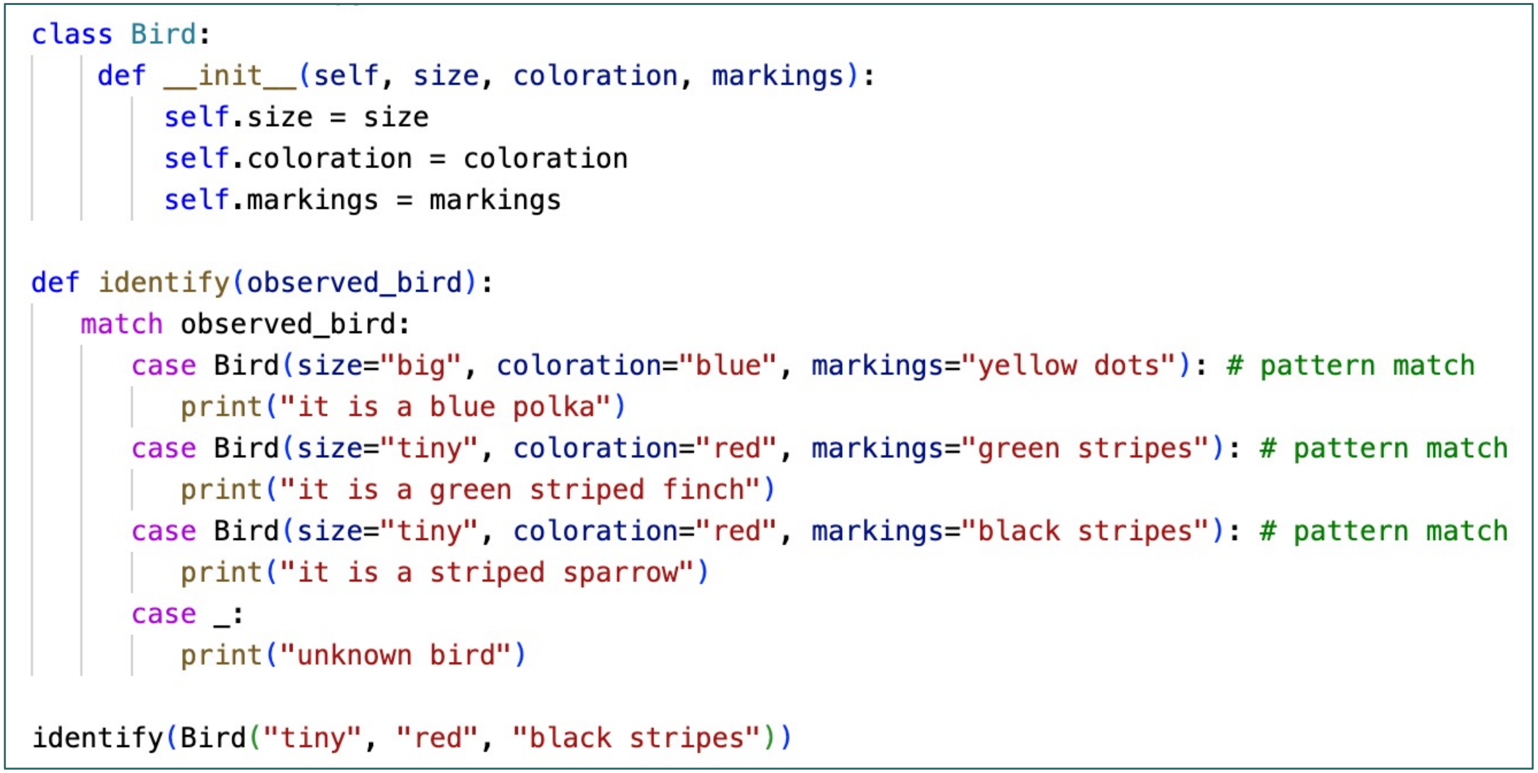


```
load system io.

structure Bird with
   data size.
   data coloration.
   data markings.
end

function identify
   with Bird("big","blue","yellow dots") do -- pattern match
      io @println "it is a blue polka".
   with Bird("tiny","red","green stripes") do  -- pattern match
      io @println "it is a green striped finch".
   with Bird("tiny","red","black stripes") do  -- pattern match
      io @println "it is a striped sparrow".
   with _ do
      io @println "unkown bird".
end

identify (Bird("tiny","red","black stripes")).
```

In004/bird2.ast

Pattern Matching – Foundations

- Here is a solution using pattern matching in Python

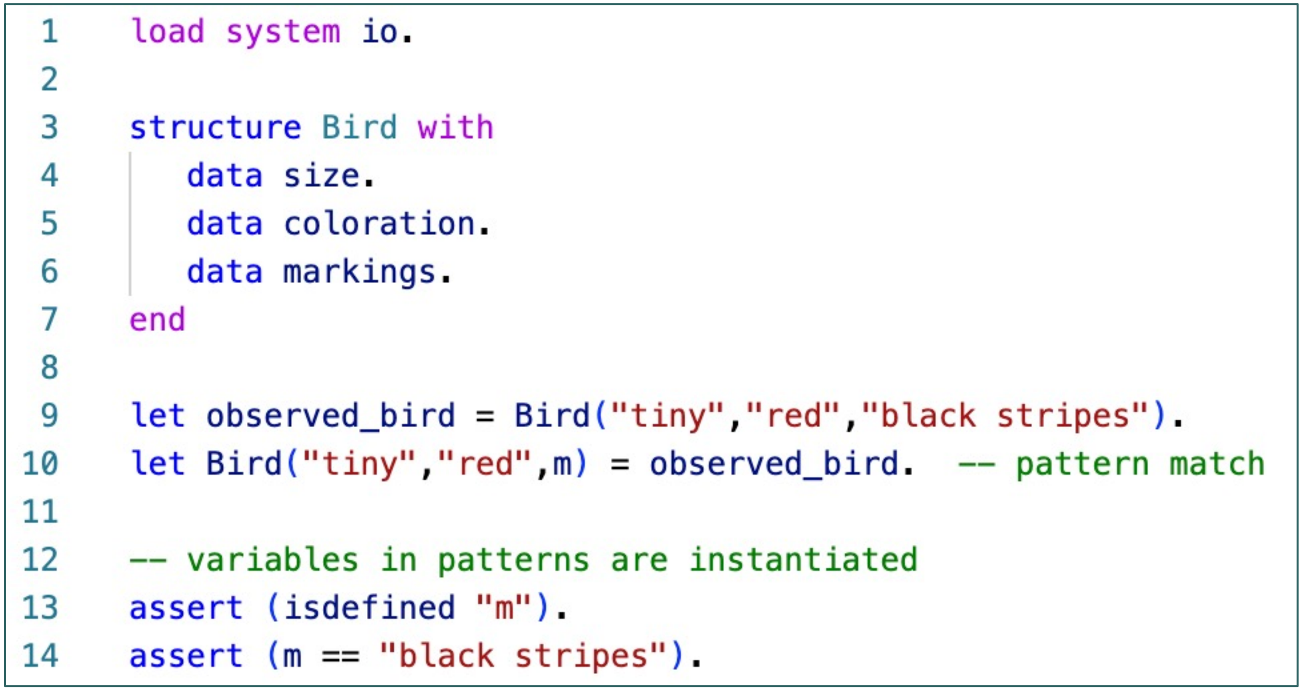


```python
class Bird:
    def __init__(self, size, coloration, markings):
        self.size = size
        self.coloration = coloration
        self.markings = markings

def identify(observed_bird):
    match observed_bird:
        case Bird(size="big", coloration="blue", markings="yellow dots"): # pattern match
            print("it is a blue polka")
        case Bird(size="tiny", coloration="red", markings="green stripes"): # pattern match
            print("it is a green striped finch")
        case Bird(size="tiny", coloration="red", markings="black stripes"): # pattern match
            print("it is a striped sparrow")
        case _:
            print("unknown bird")

identify(Bird("tiny", "red", "black stripes"))
```

ln004/bird2.py

Pattern Matching – Foundations

- Variables allow for partial matches
- Variables in patterns are instantiated in the current environment

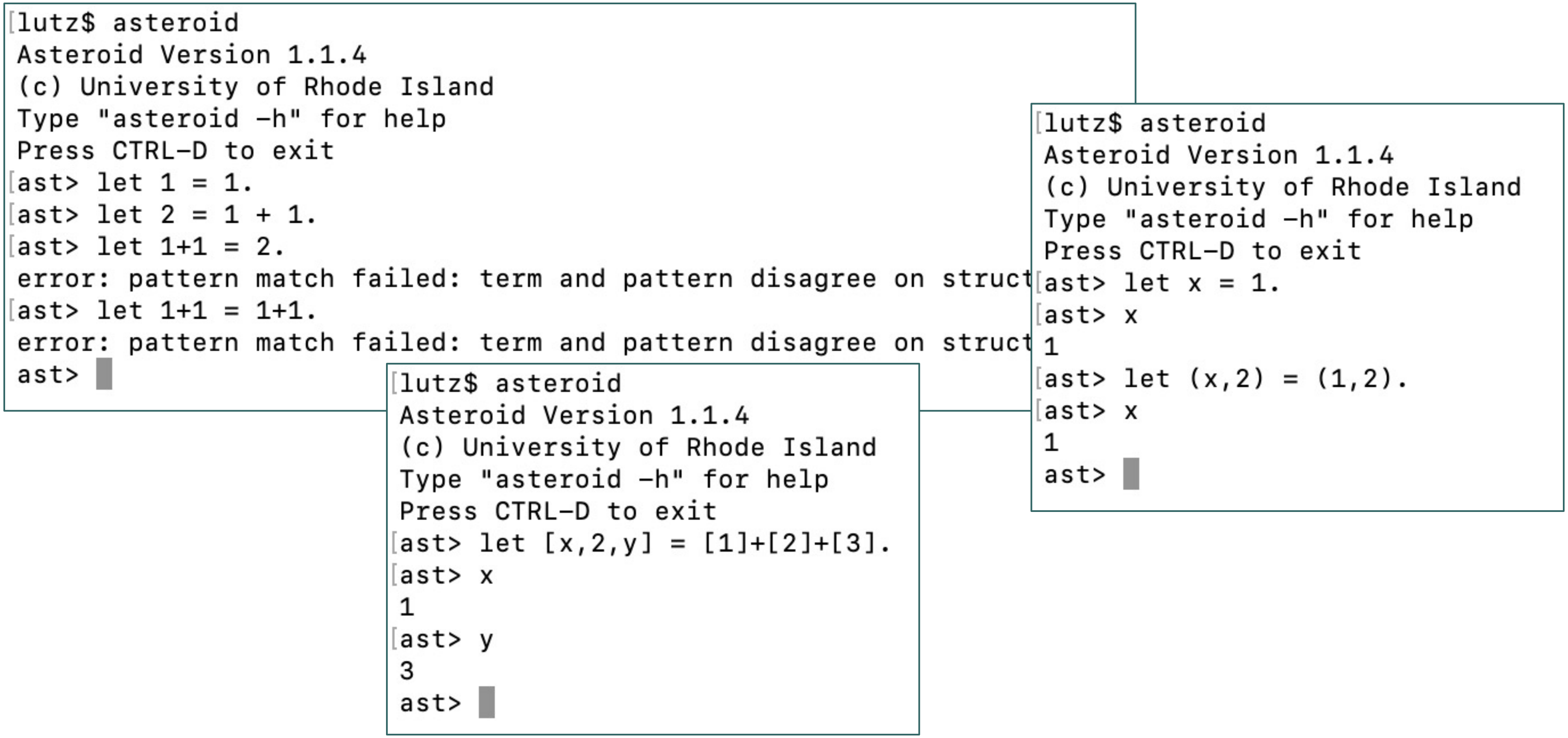


```
load system io.

structure Bird with
   data size.
   data coloration.
   data markings.
end

let observed_bird = Bird("tiny","red","black stripes").
let Bird("tiny","red",m) = observed_bird.  -- pattern match

-- variables in patterns are instantiated
assert (isdefined "m").
assert (m == "black stripes").
```

In004/bird3.ast

Basic Patterns

- Something a bit more CS related

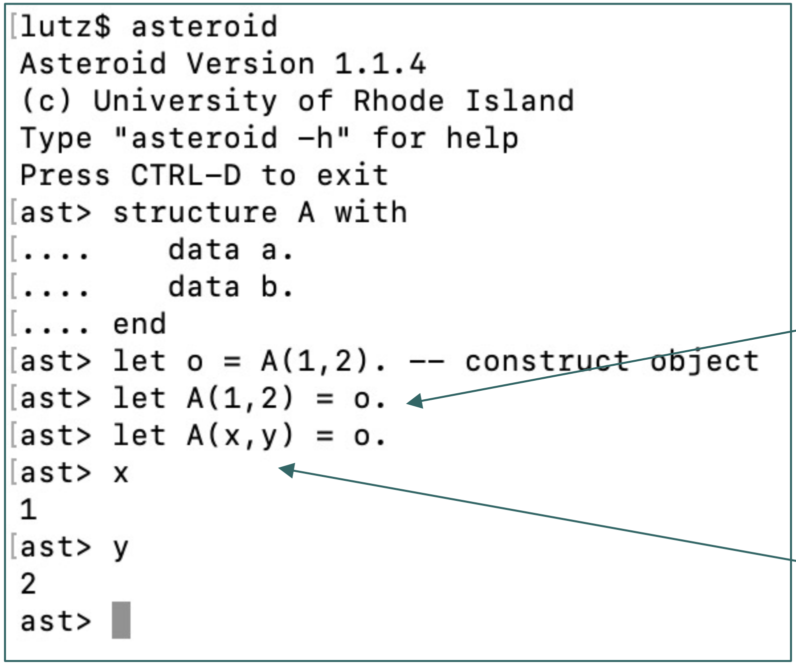


```
[lutz$ asteroid
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
[ast> let 1 = 1.
[ast> let 2 = 1 + 1.
[ast> let 1+1 = 2.
error: pattern match failed: term and pattern disagree on struct
[ast> let 1+1 = 1+1.
error: pattern match failed: term and pattern disagree on struct
ast>
```

```
[lutz$ asteroid
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
[ast> let [x,2,y] = [1]+[2]+[3].
[ast> x
1
[ast> y
3
ast>
```

```
[lutz$ asteroid
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
[ast> let x = 1.
[ast> x
1
[ast> let (x,2) = (1,2).
[ast> x
1
ast>
```

Basic Patterns



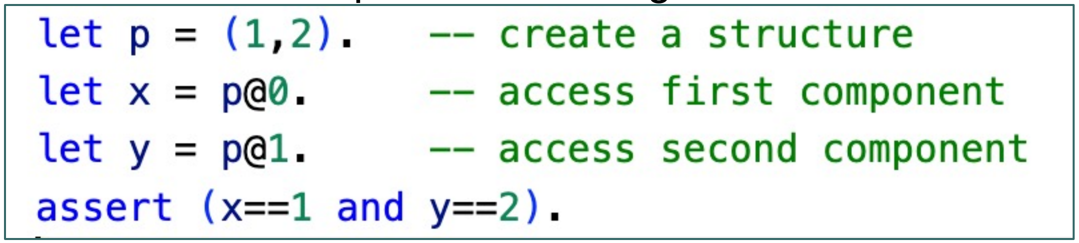
```
[lutz$ asteroid
 Asteroid Version 1.1.4
 (c) University of Rhode Island
 Type "asteroid -h" for help
 Press CTRL-D to exit
[ast> structure A with
[....     data a.
[....     data b.
[.... end
[ast> let o = A(1,2). -- construct object
[ast> let A(1,2) = o.
[ast> let A(x,y) = o.
[ast> x
 1
[ast> y
 2
 ast> 
```

- The idea of constructors on the right representing values and, on the left, representing structure/patterns also works for objects!
- The expression A(1,2) on the left side is a constructor for the object considered as a pattern
- We can insert variables into the constructor, A(x,y), for easy access to the components of the object o
  - **destructuring**

Destructuring

- The idea of destructuring is fundamental to pattern matching
- It makes access to substructures much more readable (and efficient).

Without structural pattern matching

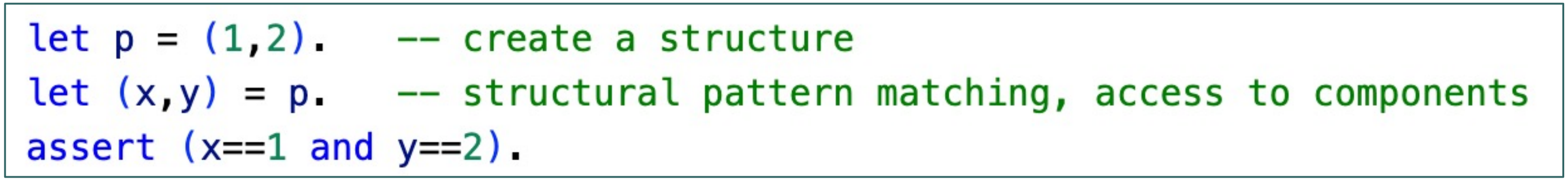


```
let p = (1,2).    -- create a structure
let x = p@0.      -- access first component
let y = p@1.      -- access second component
assert (x==1 and y==2).
```

In004/destruct1.ast

With structural pattern matching

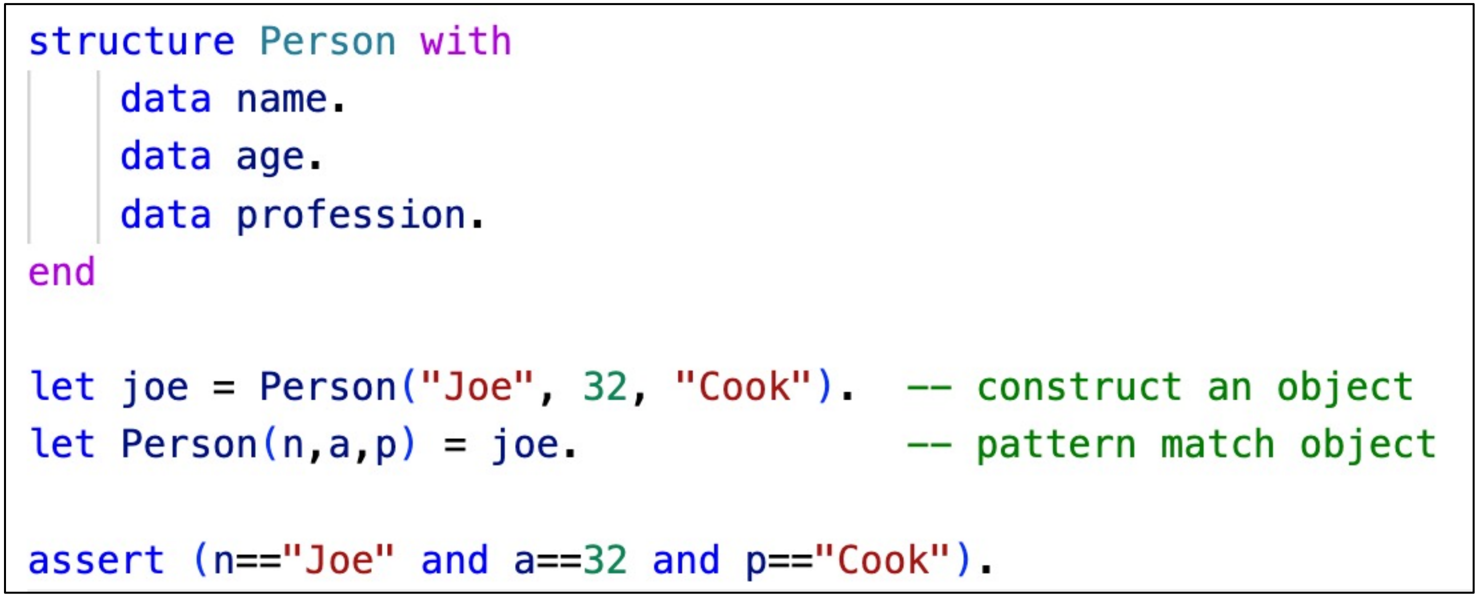
In004/destruct2.ast



```
let p = (1,2).    -- create a structure
let (x,y) = p.    -- structural pattern matching, access to components
assert (x==1 and y==2).
```

Destructuring

- Here is another example using structures and objects



```
structure Person with
    data name.
    data age.
    data profession.
end

let joe = Person("Joe", 32, "Cook").  -- construct an object
let Person(n,a,p) = joe.              -- pattern match object

assert (n=="Joe" and a==32 and p=="Cook").
```

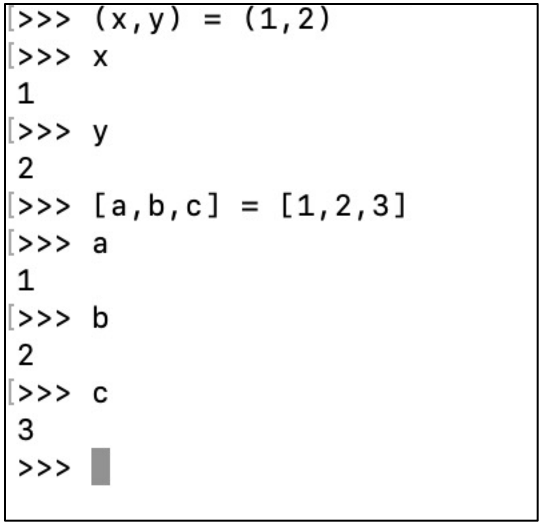
ln004/destruct3.ast

Basic Pattern Matching Summary

- The let statement
  let <pattern> = value .
- On the right side of equal sign constructors represent values
  - Operators/functions are allowed
- On the left side constructors represent structure
  - Operators/functions are **not** allowed
  - Constructors must minimally represent structure
- Variables are allowed in patterns for partial matches/destructuring
- Pattern matching is part of a programming paradigm called **declarative programming**
  - We will look at this more carefully when we examine control structures in Asteroid.

Pattern Matching in Python

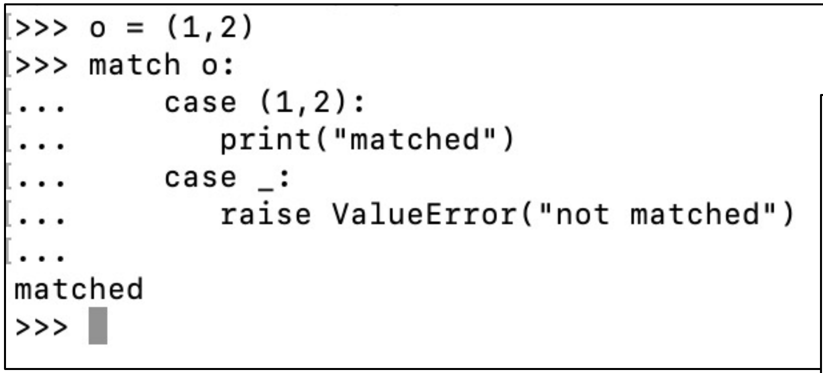
- Limited pattern matching available with the assignment statement
  - Called **destructuring** assignment



```
[>>> (x,y) = (1,2)
[>>> x
1
[>>> y
2
[>>> [a,b,c] = [1,2,3]
[>>> a
1
[>>> b
2
[>>> c
3
>>> 
```

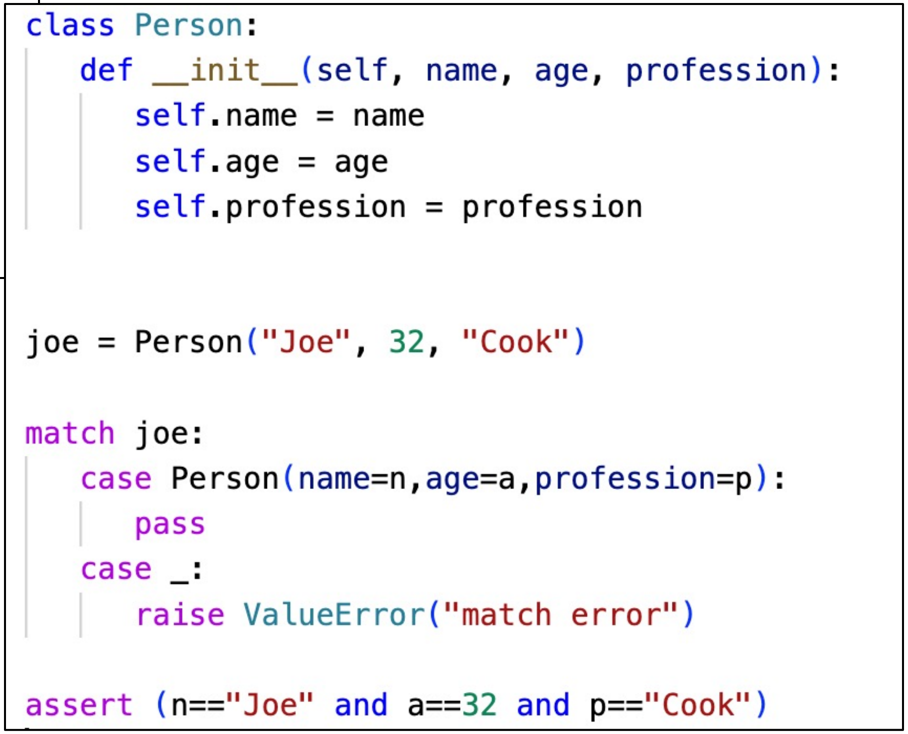
Pattern Matching in Python

- The match statement as of 3.10 provides a bit more functionality



```
[>>> o = (1,2)
[>>> match o:
[...     case (1,2):
[...         print("matched")
[...     case _:
[...         raise ValueError("not matched")
[...
matched
>>> 
```

ln004/destruct3.py



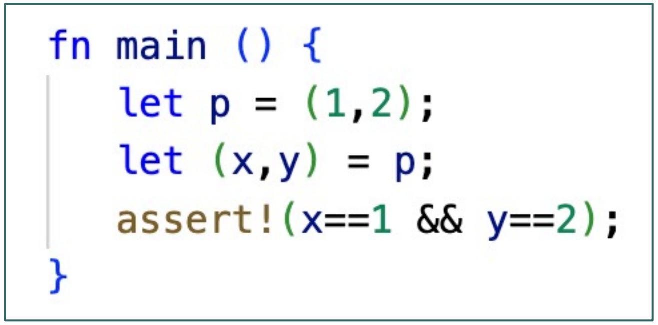
```python
class Person:
    def __init__(self, name, age, profession):
        self.name = name
        self.age = age
        self.profession = profession


joe = Person("Joe", 32, "Cook")

match joe:
    case Person(name=n,age=a,profession=p):
        pass
    case _:
        raise ValueError("match error")

assert (n=="Joe" and a==32 and p=="Cook")
```

https://peps.python.org/pep-0636/

Pattern Matching in Rust

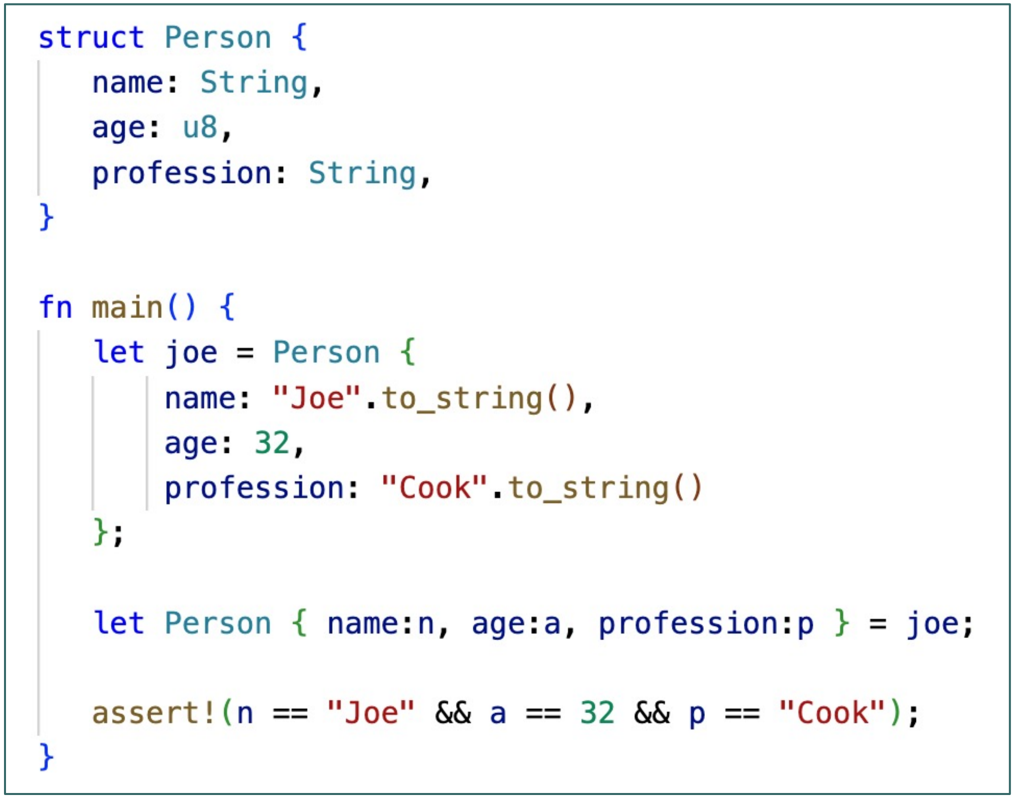
- Rust also supports pattern matching

ln004/destruct2.prs



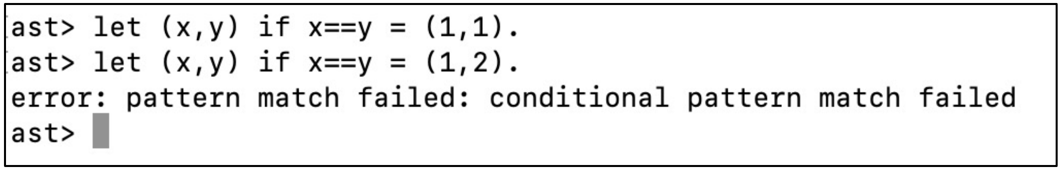
```
fn main () {
    let p = (1,2);
    let (x,y) = p;
    assert!(x==1 && y==2);
}
```

ln004/destruct3.rs

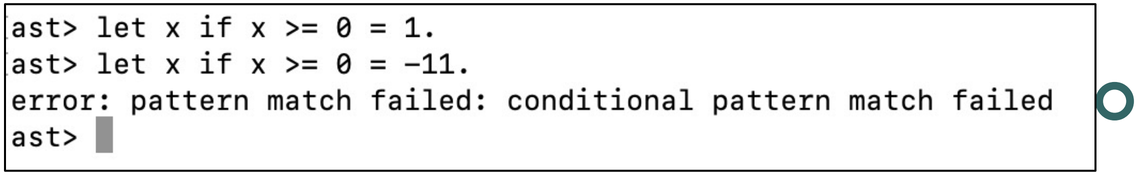


```
struct Person {
    name: String,
    age: u8,
    profession: String,
}

fn main() {
    let joe = Person {
        name: "Joe".to_string(),
        age: 32,
        profession: "Cook".to_string()
    };

    let Person { name:n, age:a, profession:p } = joe;

    assert!(n == "Joe" && a == 32 && p == "Cook");
}
```

Conditional Pattern Matching



```
ast> let (x,y) if x==y = (1,1).
ast> let (x,y) if x==y = (1,2).
error: pattern match failed: conditional pattern match failed
ast> 
```



```
ast> let x if x >= 0 = 1.
ast> let x if x >= 0 = -11.
error: pattern match failed: conditional pattern match failed
ast> 
```

- Only assign a pair if the two component values are the same
- Only assign positive values to x

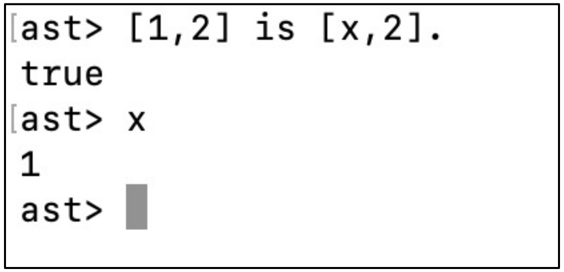
The is Predicate

Note: a predicate is a function/operator that always returns true or false. No other return value is permitted.

- The is predicate is of the form

  <value> is <pattern>

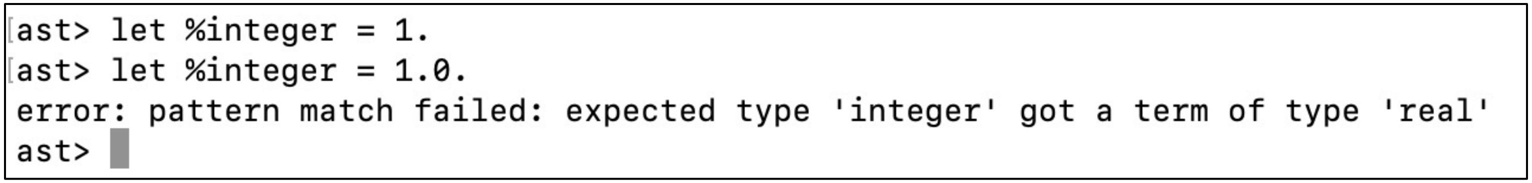
  and returns true if the value matches the pattern otherwise it will return false
- The is predicate allows us to do pattern matching is expressions



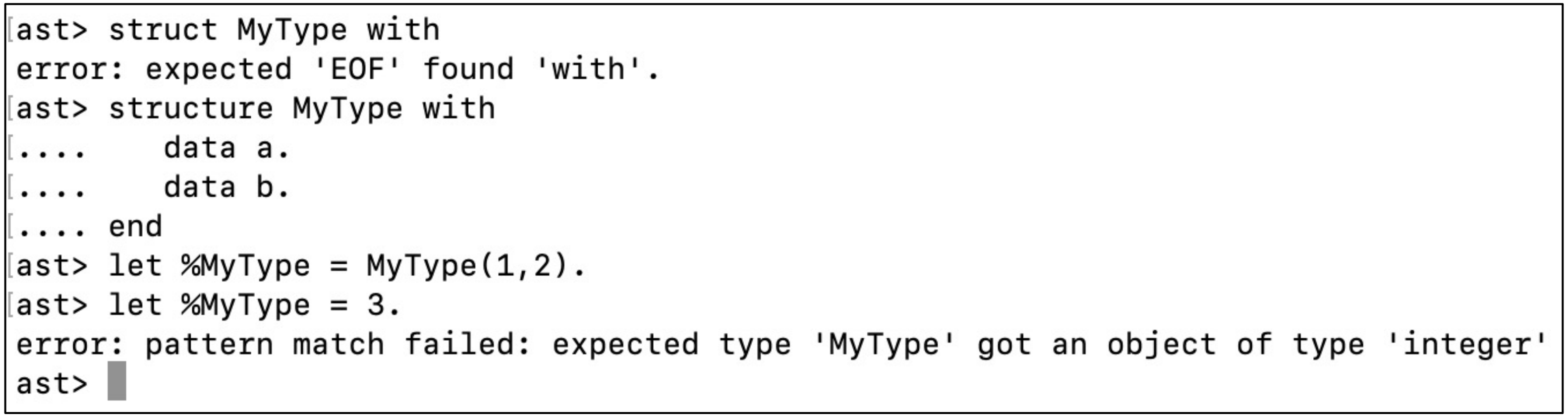
```
[ast> [1,2] is [x,2].
 true
[ast> x
 1
 ast> 
```

Type Patterns

- Type patterns are patterns of the form
  %<type name>
  and match all instances of the <type name>
- All built-in types have associated type patterns such as %integer, %real, %string etc.
- User defined types are also supported,
  %<user defined type name>



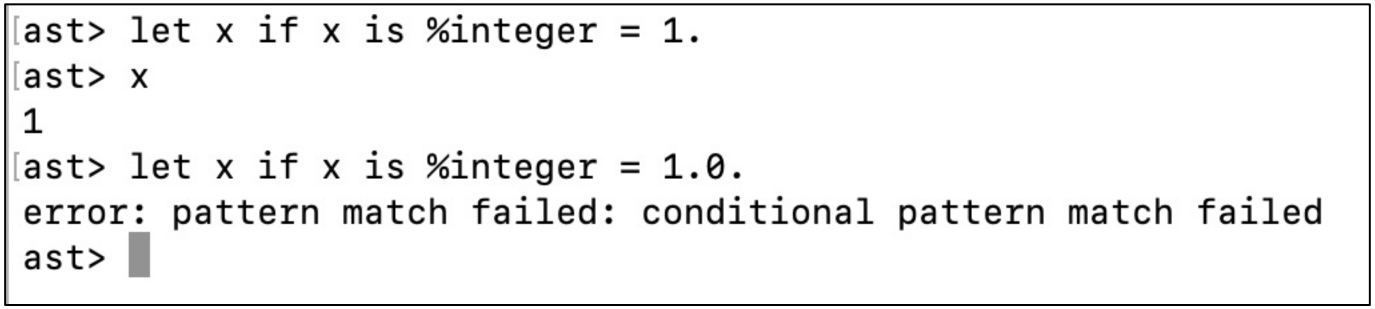
```
[ast> let %integer = 1.
[ast> let %integer = 1.0.
error: pattern match failed: expected type 'integer' got a term of type 'real'
ast> 
```



```
[ast> struct MyType with
error: expected 'EOF' found 'with'.
[ast> structure MyType with
[....    data a.
[....    data b.
[.... end
[ast> let %MyType = MyType(1,2).
[ast> let %MyType = 3.
error: pattern match failed: expected type 'MyType' got an object of type 'integer'
ast> 
```

Advanced Pattern Match Expressions

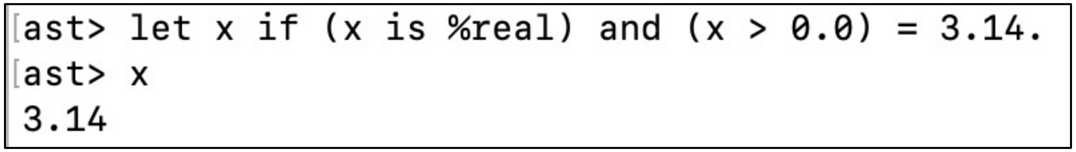
- We can combine conditional pattern matching with type patterns and the is predicate to express sophisticated patterns
- E.g., only assign a value to x if it is an integer value



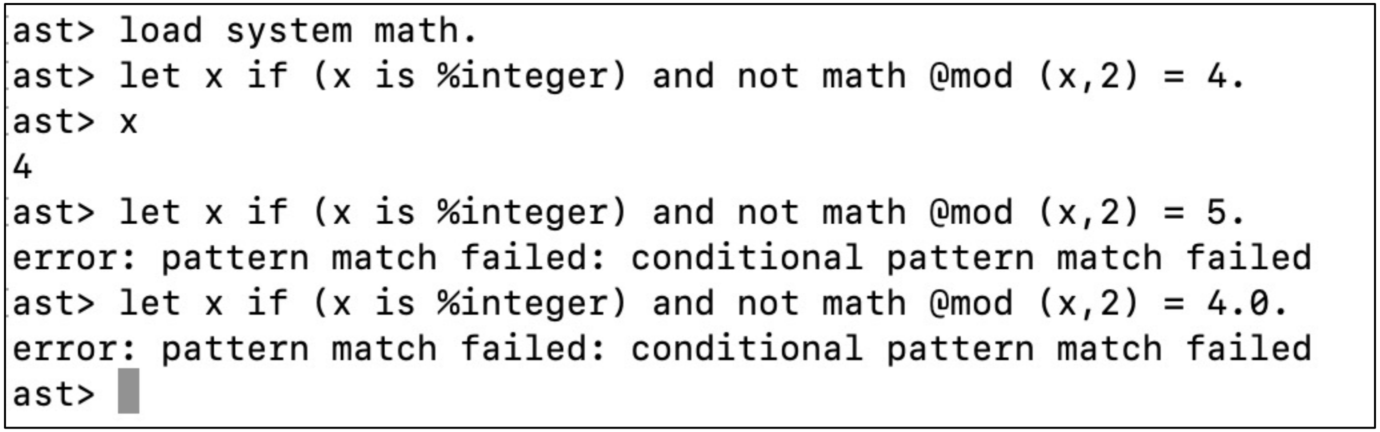
```
[ast> let x if x is %integer = 1.
[ast> x
 1
[ast> let x if x is %integer = 1.0.
 error: pattern match failed: conditional pattern match failed
 ast> 
```

Advanced Pattern Match Expressions

- Here are some additional examples,



```
ast> let x if (x is %real) and (x > 0.0) = 3.14.
ast> x
3.14
```

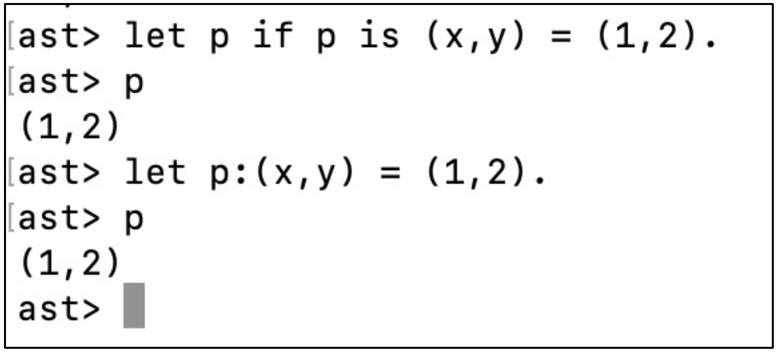


```
ast> load system math.
ast> let x if (x is %integer) and not math @mod (x,2) = 4.
ast> x
4
ast> let x if (x is %integer) and not math @mod (x,2) = 5.
error: pattern match failed: conditional pattern match failed
ast> let x if (x is %integer) and not math @mod (x,2) = 4.0.
error: pattern match failed: conditional pattern match failed
ast>
```

Note: ‘mod’ is the modulus function

Named Patterns

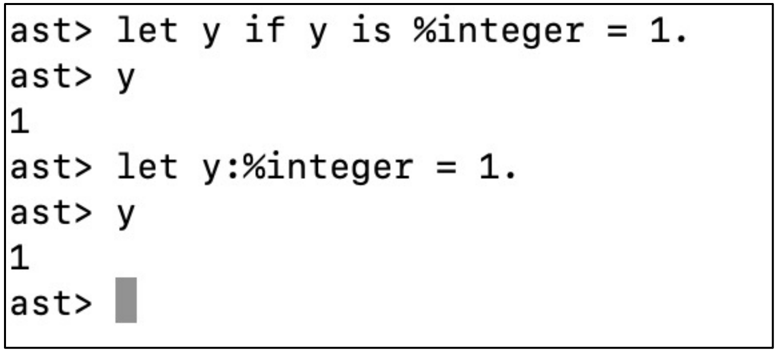
- The simple conditional pattern
  x if x is <pattern>
  appears a lot in Asteroid programs
- Named patterns of the form
  x:<pattern>
  represent a shorthand for the simple conditional pattern above
- E.g.



```
[ast> let p if p is (x,y) = (1,2).
[ast> p
(1,2)
[ast> let p:(x,y) = (1,2).
[ast> p
(1,2)
ast>
```

Named Patterns

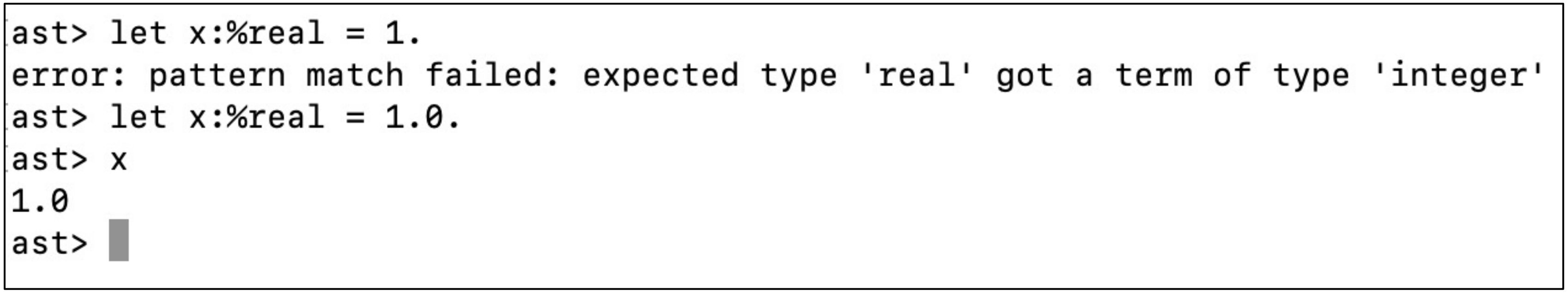
- This shorthand notation is especially useful when combined with type patterns,



```
ast> let y if y is %integer = 1.
ast> y
1
ast> let y:%integer = 1.
ast> y
1
ast> 
```

Named Patterns

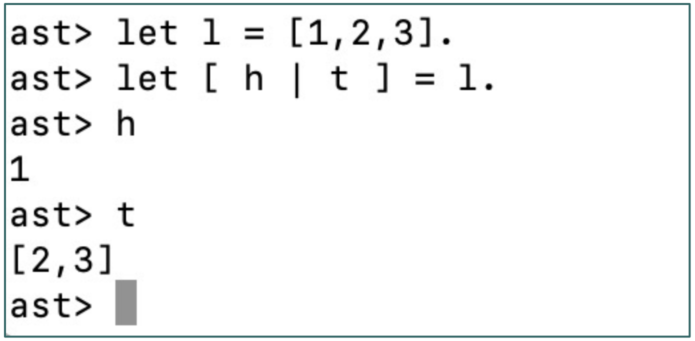
- Beware: even though named patterns with type patterns look like a declarations they are not!
- They are pattern match statements; consequently, implicit type conversions we are used to from other programming languages do not work!



```
ast> let x:%real = 1.
error: pattern match failed: expected type 'real' got a term of type 'integer'
ast> let x:%real = 1.0.
ast> x
1.0
ast>
```

Head-Tail Pattern

- The head-tail pattern
  [<head var> | <tail var>]
  is a useful pattern that allows us to destructure a list into into its first element and the rest of the list; the list with its first element removed.
- As we will see later, this pattern will prove extremely useful when dealing with recursion or iteration over lists.



```
ast> let l = [1,2,3].
ast> let [ h | t ] = l.
ast> h
1
ast> t
[2,3]
ast>
```

Pattern Matching with Regular Expressions

- Regular expressions are patterns that can be applied to strings
- e.g., the regex
  “a(b)*”
  matches any string that starts with an a followed by zero or more b’s.
- In Asteroid regular expressions are considered patterns and therefore we can write expressions like
  “abbbb” is “a(b)*”
- Asteroid’s regex syntax follows Python’s regex syntax
  - https://docs.python.org/3/library/re.html

Pattern Matching with Regular Expressions

- Regular expressions is a formal language that defines lexical patterns of character strings
- As shown before, the regular expression

  “a(b)*”

  describes a pattern that matches any string that starts with an ‘a’ character followed by zero or more ‘b’ characters.
- Possible matches are

  “a”, “ab”, “abb”, “abbb”, etc

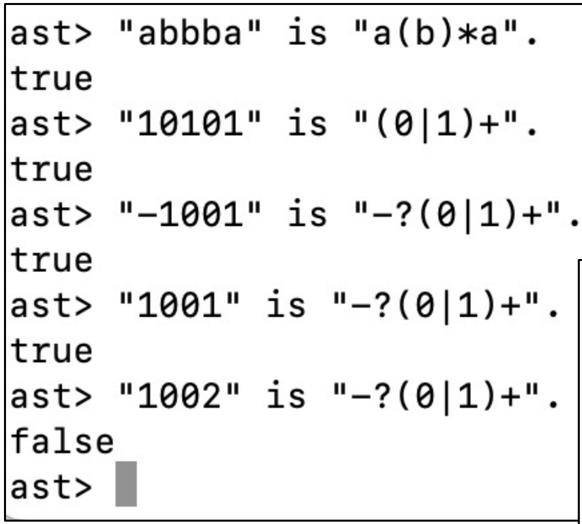
Pattern Matching with Regular Expressions

- Any single, printable character is a RE, e.g., “A” or “1”
- The concatenation “<RE1><RE2>” is also an RE, e.g. “ab”
- The “<RE>*” operator means match the RE zero or more times, e.g. “a*” and “(ab)*”
- The “<RE>+” operator means match the RE one or more times, e.g. “a+” and “(ab)+”
- The “<RE>?” operator means match the RE if it exists, e.g. “a(b)?c”
- The “<RE1>|<RE2>” operator means match either RE1 or RE2.
- The ”.” operator matches any character

“a+” = “a(a)*”

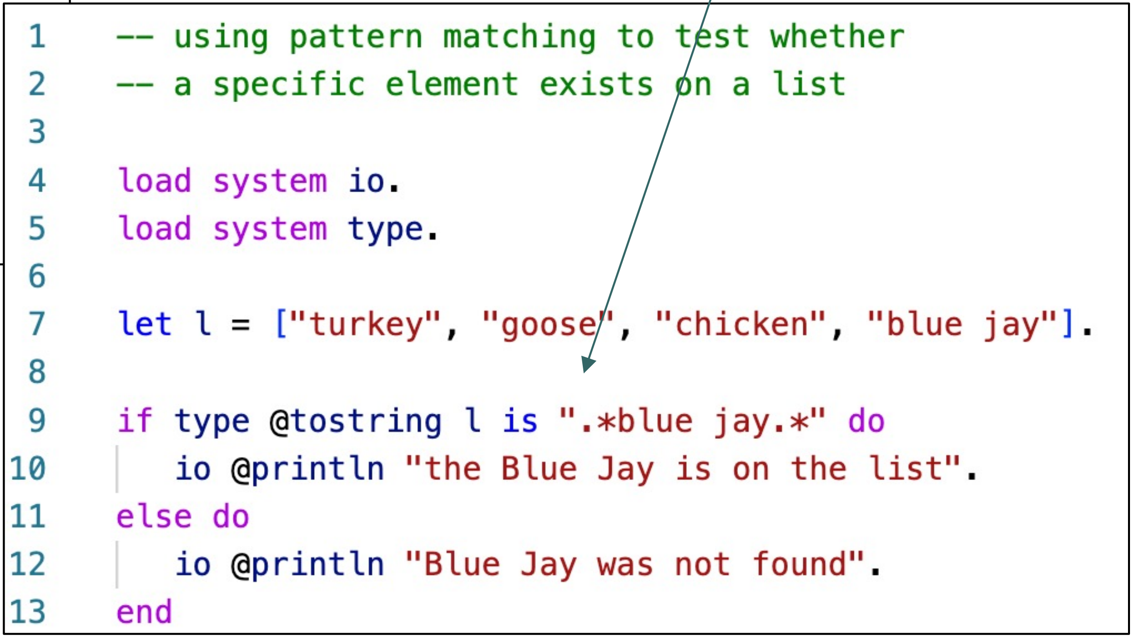
Note: REs are a very rich language, see more at https://docs.python.org/3/library/re.html

Pattern Matching with Regular Expressions



```
ast> "abbba" is "a(b)*a".
true
ast> "10101" is "(0|1)+".
true
ast> "-1001" is "-?(0|1)+".
true
ast> "1001" is "-?(0|1)+".
true
ast> "1002" is "-?(0|1)+".
false
ast> 
```

Pattern matching with regex



```
-- using pattern matching to test whether
-- a specific element exists on a list

load system io.
load system type.

let l = ["turkey", "goose", "chicken", "blue jay"].

if type @tostring l is ".*blue jay.*" do
   io @println "the Blue Jay is on the list".
else do
   io @println "Blue Jay was not found".
end
```

ln004/list1.ast

Reading

- The Let Statement
  - asteroid-lang.readthedocs.io/en/latest/User%20Guide.html#the-let-statement