



RECURSIONS

Recursions

Recursive data structures

Recursive functions

Recursive functions

```
def printMany(n: Int, message: String): Unit =  
  if(n <= 0) () // do nothing  
  else {  
    println(message)  
    printMany(n - 1, message)  
  }
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

Recursive functions

```
def printMany(n: Int, message: String): Unit =  
  if(n <= 0) () // do nothing  
  else {  
    println(message)  
    printMany(n - 1, message)  
  }
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

```
def printMany(n: Int, message: String): Unit =  
{  
  var counter = n  
  while (counter > 0) {  
    counter -= 1  
    println("FP is awesome")  
  }  
}
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

Recursive functions

```
def printMany(n: Int, message: String): Unit =  
  if(n > 0) {  
    println(message)  
    printMany(n - 1, message)  
  }  
  else ()
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

```
def printMany(n: Int, message: String): Unit =  
{  
  var counter = n  
  while (counter > 0) {  
    counter -= 1  
    println("FP is awesome")  
  }  
}
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

Recursive functions

```
def printMany(n: Int, message: String): Unit =  
  (1 to n).foreach(_ => println(message))
```

```
printMany(3, "FP is awesome")  
// FP is awesome  
// FP is awesome  
// FP is awesome
```

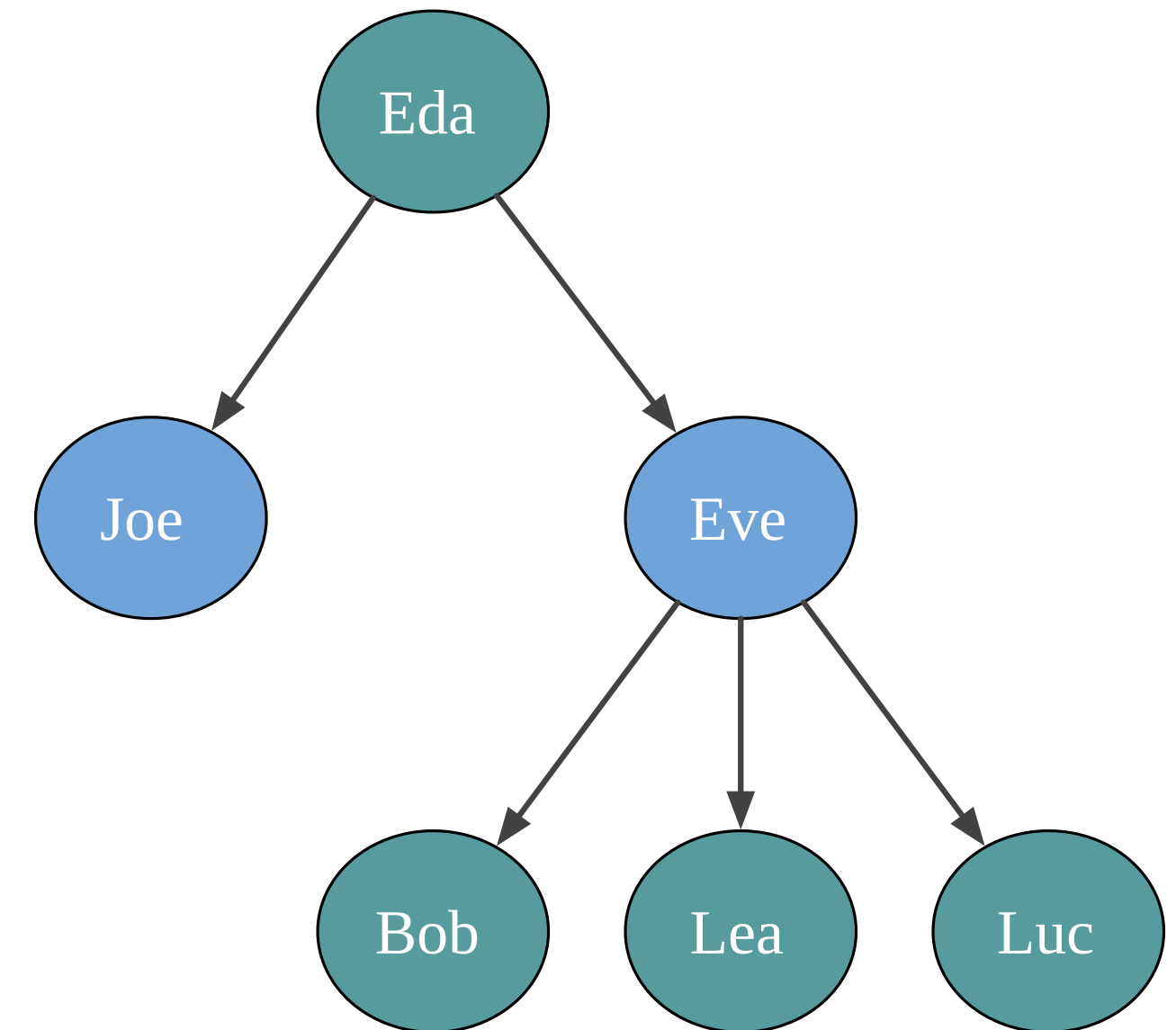
Recursive data structures

```
case class Person(name: String, children: List[Person])

val bob = Person("Bob", Nil)
val lea = Person("Lea", Nil)
val luc = Person("Luc", Nil)

val eve = Person("Eve", List(bob, lea, luc))
val joe = Person("Joe", Nil)

val eda = Person("Eda", List(joe, eve))
```



Recursive data structures

JSON

```
{
  "name": "John Doe",
  "age": 25,
  "address": {
    "street": {
      "number": 12,
      "name": "Cody road"
    },
    "country": "UK"
  }
}
```

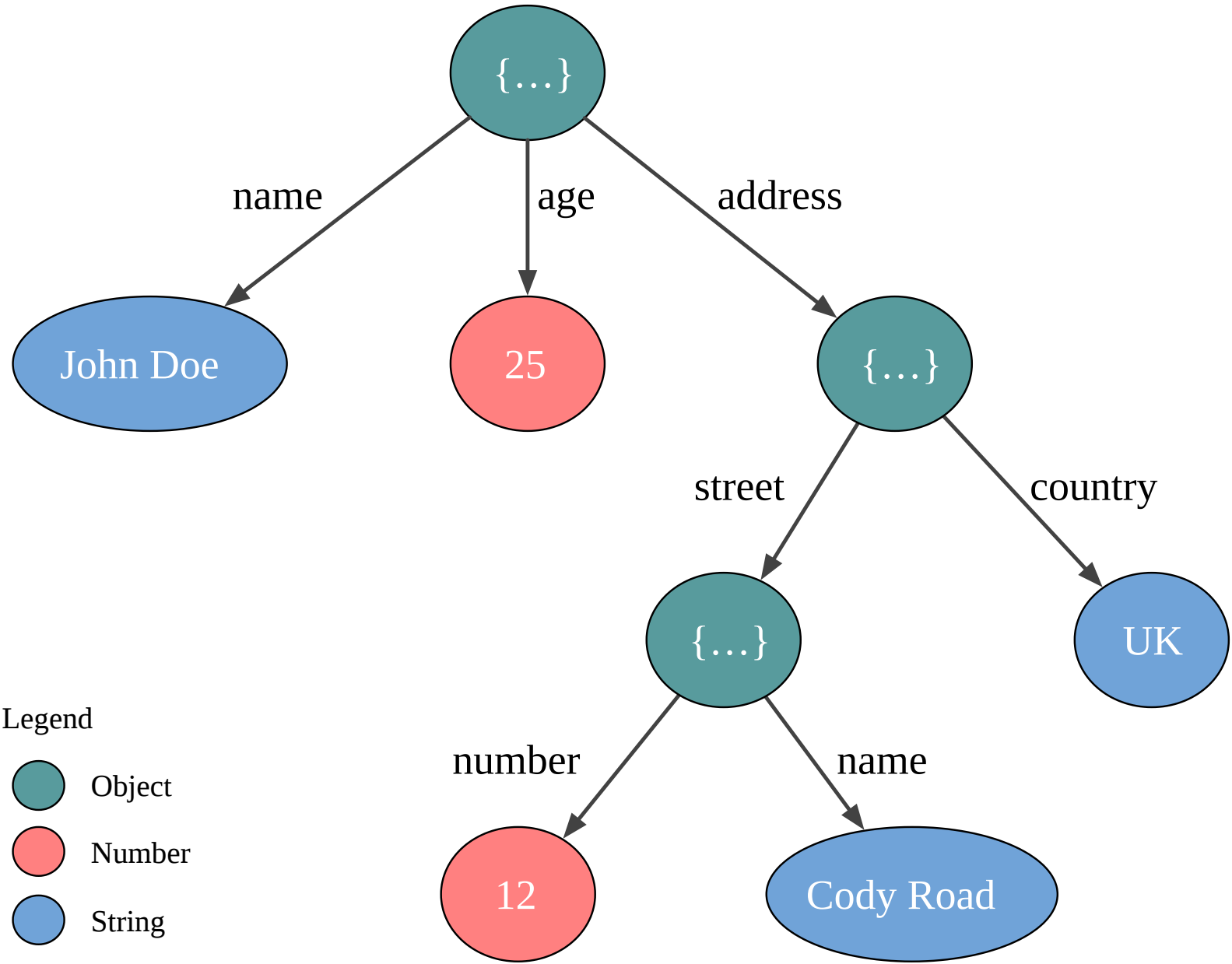
YAML

```
name: John Doe
age: 25
address:
  street: 12
    number: 12
    name: Cody road
  country: UK
```


Recursive data structures

JSON

```
{
  "name": "John Doe",
  "age": 25,
  "address": {
    "street": {
      "number": 12,
      "name": "Cody road"
    },
    "country": "UK"
  }
}
```



Is JSON a case class?

```
case class Json(  
  number: Double,  
  text   : String,  
  obj    : Map[String, Json],  
)
```

Is JSON a case class?

```
case class Json(  
  number: Option[Double],  
  text  : Option[String],  
  obj   : Option[Map[String, Json]],  
)  
  
val json = Json(  
  number = None,  
  text   = Some("John Doe"),  
  obj    = None  
)
```

Is JSON a case class?

```
case class Json(  
  number: Option[Double],  
  text   : Option[String],  
  obj    : Option[Map[String, Json]],  
)  
  
val json1 = Json(  
  Some(25),  
  Some("John Doe"),  
  None  
)  
  
val json2 = Json(None, None, None)
```

JSON is a recursive enumeration

```
enum Json {  
  
  // Leaves  
  case JsonNumber(number: Double)  
  case JsonString(text : String)  
  
  // Branch  
  case JsonObject(obj: Map[String, Json])  
  
}
```

JSON is a recursive enumeration

```
enum Json {  
  
  // Leaves  
  case JsonNumber(number: Double)  
  case JsonString(text : String)  
  
  // Branch  
  case JsonObject(obj: Map[String, Json])  
  
}  
  
val json: Json = Json.JsonNumber(25)  
  
import Json._  
  
val number: Json = JsonNumber(25)  
val text  : Json = JsonString("John Doe")  
val obj   : Json = JsonObject(Map())
```

JSON is a recursive enumeration

In Scala 3

```
enum Json {  
  
  // Leaves  
  case JsonNumber(number: Double)  
  case JsonString(text : String)  
  
  // Branch  
  case JsonObject(obj: Map[String, Json])  
  
}
```

In Scala 2

```
sealed trait Json  
  
// Leaves  
case class JsonNumber(number: Double) extends Json  
case class JsonString(text : String) extends Json  
  
// Branch  
case class JsonObject(obj: Map[String, Json])  
  extends Json
```

JSON is a recursive enumeration

```
sealed trait Json
```

```
// Leaves
```

```
case class JsonNumber(number: Double) extends Json
```

```
case class JsonString(text : String) extends Json
```

```
// Branch
```

```
case class JsonObject(obj: Map[String, Json])  
  extends Json
```

```
val number = JsonNumber(12)
```

```
// number: JsonNumber = JsonNumber(12.0)
```

```
val json: Json = JsonNumber(12)
```

```
// json: Json = JsonNumber(12.0)
```


Working with recursive enumerations

```
val john: Json = JsonObject(Map(  
  "name"      -> JsonString("John Doe"),  
  "age"       -> JsonNumber(25),  
  "email"     -> JsonString(" john@doe.com  "),  
  "address"   -> JsonObject(Map(  
    "street-number" -> JsonNumber(12),  
    "post-code"     -> JsonString("E16 4SR  ")  
  ))  
))
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  ???
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case JsonNumber(num)   => ???  
    case JsonString(text)  => ???  
    case JsonObject(obj)   => ???  
  }
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case JsonNumber(num) => ???  
    case JsonObject(obj) => ???  
  }  
// warning: match may not be exhaustive.  
// It would fail on the following input: JsonString(_)  
//   json match {  
//     ^^^^
```

Transform this warning into an error

```
scalacOptions += "-Wconf:cat=other-match-analysis:error"
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case JsonNumber(num) => JsonNumber(num) // do nothing  
    case JsonString(text) => ???  
    case JsonObject(obj)  => ???  
  }
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case _: JsonNumber    => json  
    case JsonString(text) => ???  
    case JsonObject(obj)  => ???  
  }
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case _: JsonNumber    => json  
    case JsonString(text) => JsonString(text.trim)  
    case JsonObject(obj)  => ???  
  }
```

Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case _: JsonNumber    => json  
    case JsonString(text) => JsonString(text.trim)  
    case JsonObject(obj)  =>  
      val newObj = obj.map {  
        case (key, value) => (key, trimAll(value))  
      }  
      JsonObject(newObj)  
  }
```


Working with recursive enumerations

```
def trimAll(json: Json): Json =  
  json match {  
    case _: JsonNumber    => json  
    case JsonString(text) => JsonString(text.trim)  
    case JsonObject(obj)  =>  
      val newObj = obj.map {  
        case (key, value) => (key, trimAll(value))  
      }  
      JsonObject(newObj)  
  }
```

```
john  
// john: Json = JsonObject(Map(  
//   "name"      -> JsonString("John Doe"),  
//   "age"       -> JsonNumber(25),  
//   "email"     -> JsonString(" john@doe.com  "),  
//   "address"  -> JsonObject(Map(  
//     "street-number" -> JsonNumber(12),  
//     "post-code"    -> JsonString("E16 4SR  ")  
//   ))
```

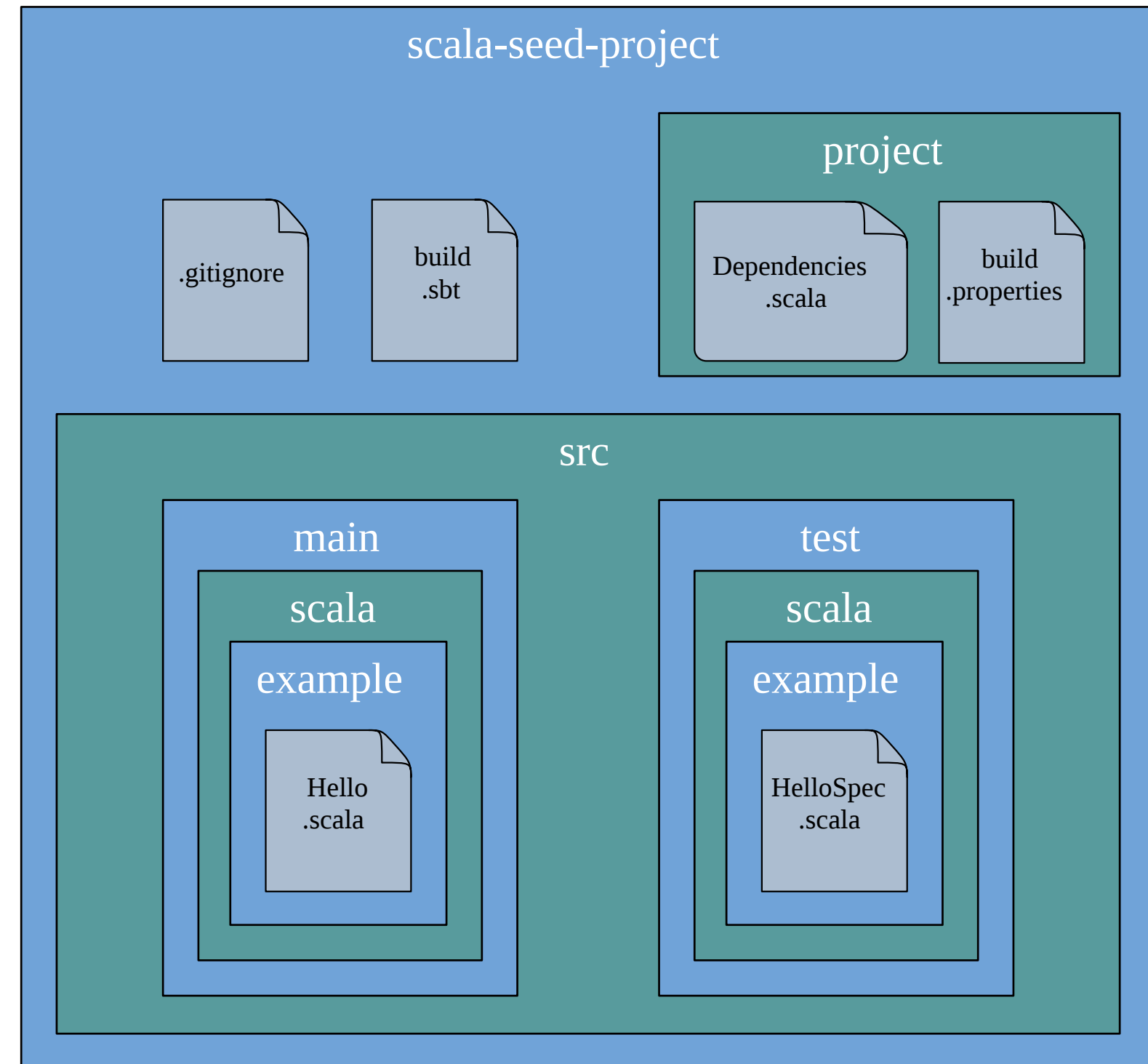
```
trimAll(john)  
// res: Json = JsonObject(Map(  
//   "name"      -> JsonString("John Doe"),  
//   "age"       -> JsonNumber(25),  
//   "email"     -> JsonString("john@doe.com"),  
//   "address"  -> JsonObject(Map(  
//     "street-number" -> JsonNumber(12),  
//     "post-code"    -> JsonString("E16 4SR")  
//   ))
```

The background of the slide features a complex, abstract network of light blue lines and dots. The dots, representing nodes, vary in size and are interconnected by thin lines, creating a web-like structure that spans the entire frame. The overall aesthetic is clean and modern, with a light blue color palette.

JsonExercises.scala

Recursive data structures

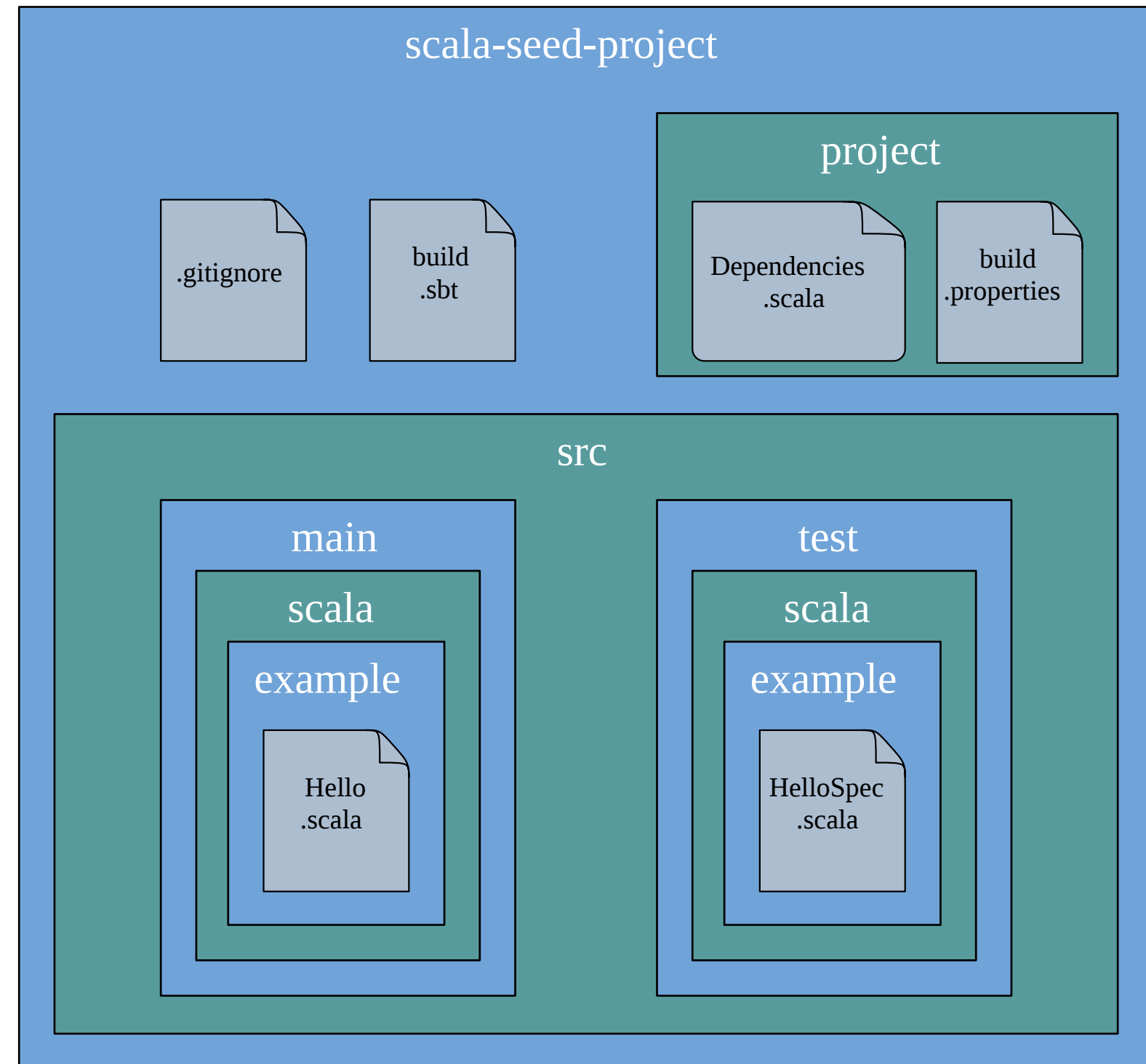
```
$ sbt new scala/scala-seed.g8
```



File system: disk usage

```
$ sbt new scala/scala-seed.g8
```

```
$ cd scala-seed-project
$ du -b .
249  ./project
344  ./src/test/scala/example
440  ./src/test/scala
536  ./src/test
234  ./src/main/scala/example
330  ./src/main/scala
426  ./src/main
1090 ./src
1986 .
```



Imperative approach

```
import java.io.File

def diskUsage(file: File): Long =
  ???
```

Imperative approach

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory)
    ???
  else // normal file
    file.length()
```

Imperative approach

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    var total = 0L

    for (child <- file.listFiles())
      total += child.length()

    total
  } else
    file.length()
```

Imperative approach

```
import java.io.File

def diskUsage(file: File): Long = {
  var total = file.length()

  if(file.isDirectory) {
    for (child <- file.listFiles())
      total += child.length()
  }

  total
}
```


Imperative approach

```
import java.io.File
import scala.collection.mutable

def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```

Imperative approach

```
import java.io.File
import scala.collection.mutable

def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

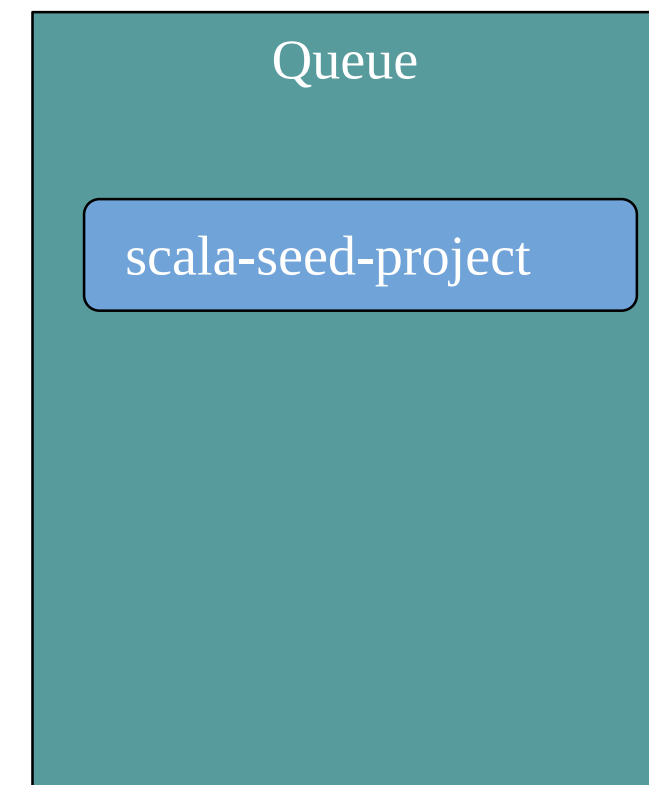
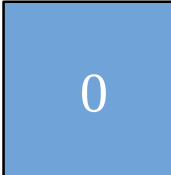
  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```

total



Imperative approach

```
import java.io.File
import scala.collection.mutable

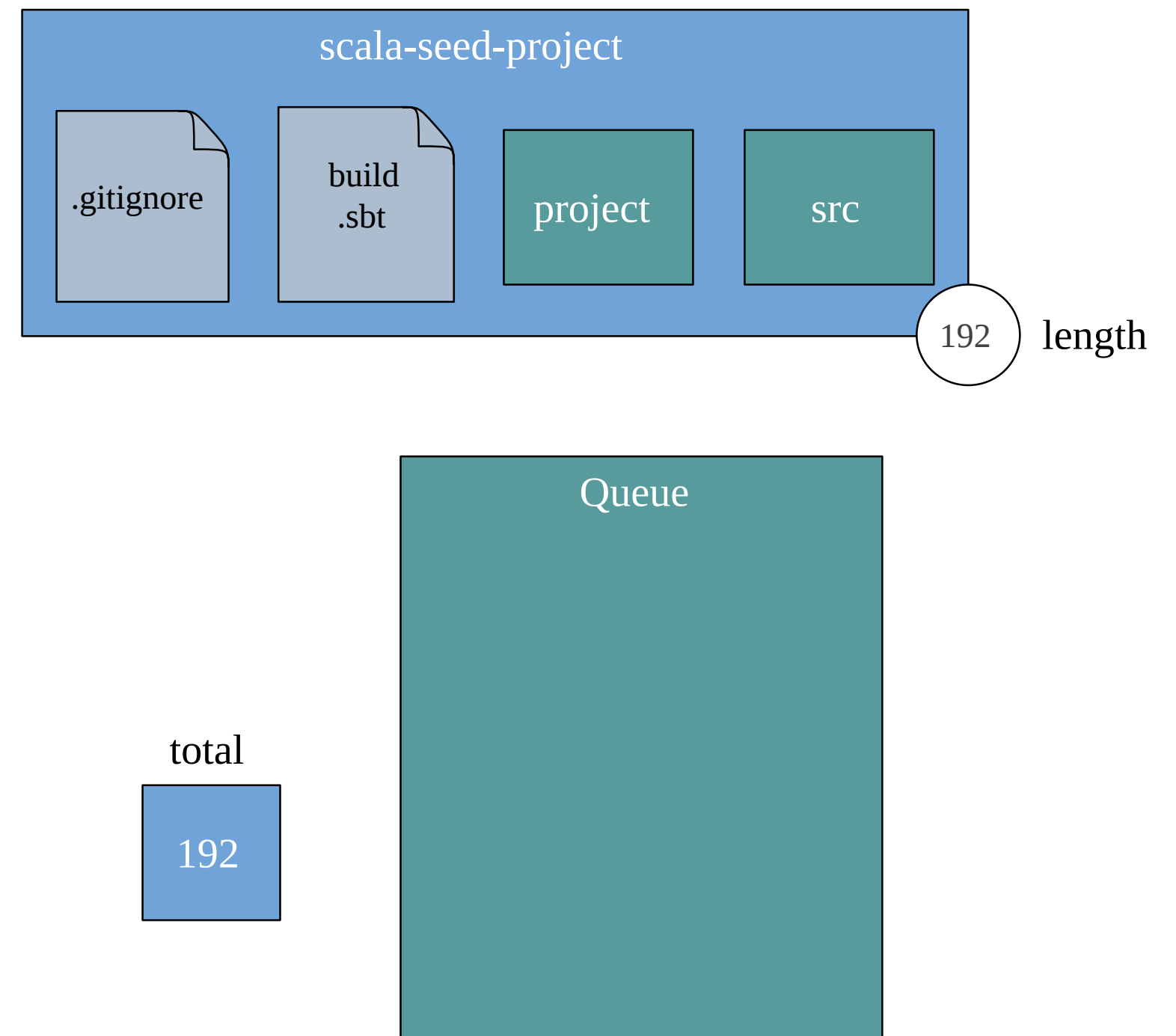
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



Imperative approach

```
import java.io.File
import scala.collection.mutable

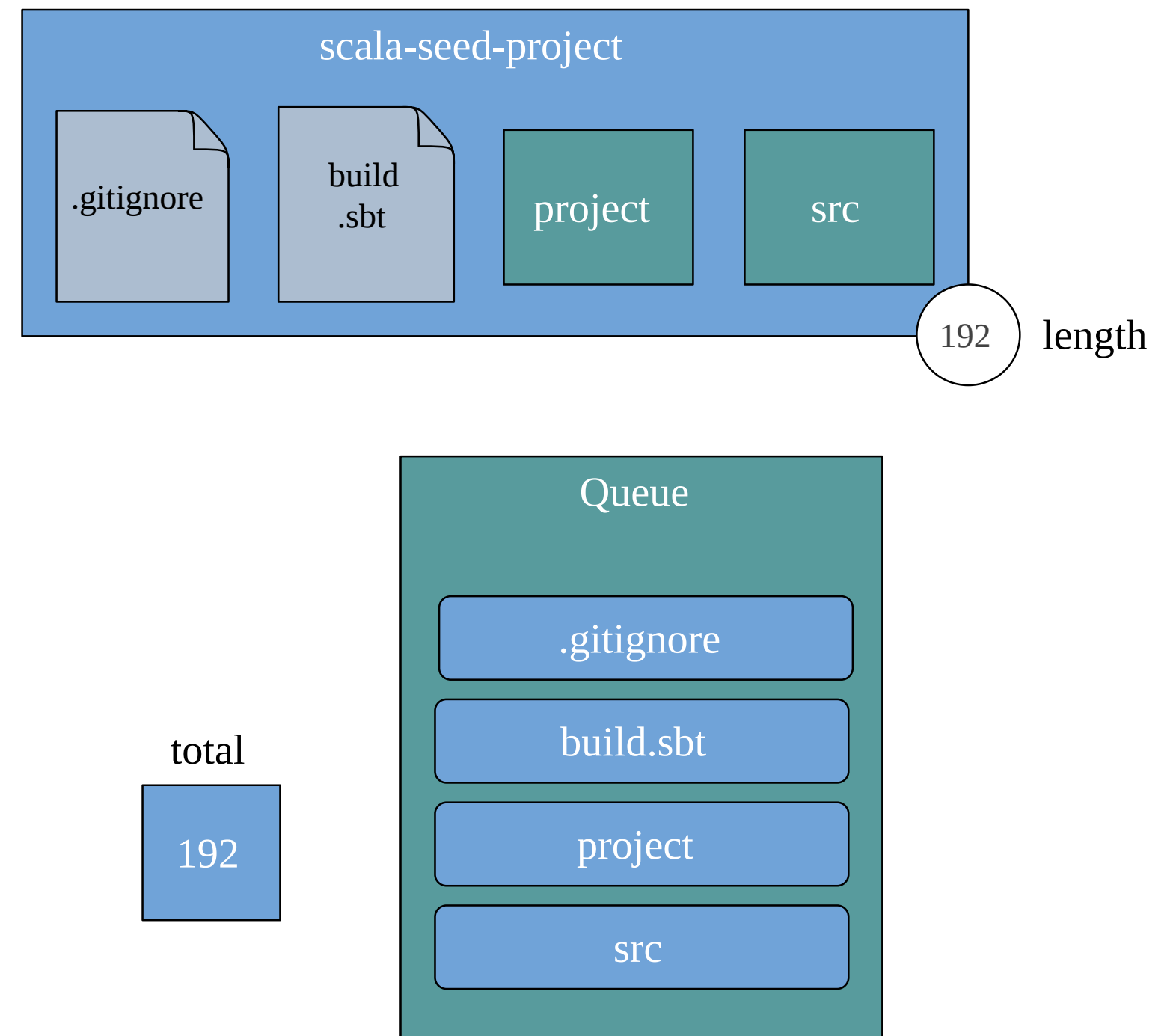
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



Imperative approach

```
import java.io.File
import scala.collection.mutable

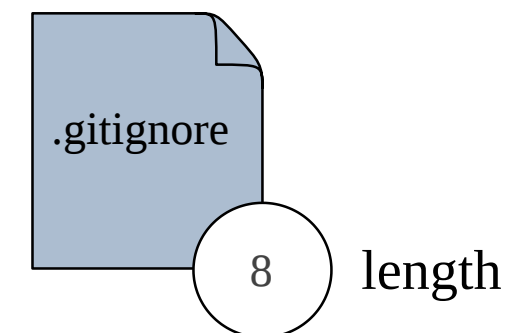
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

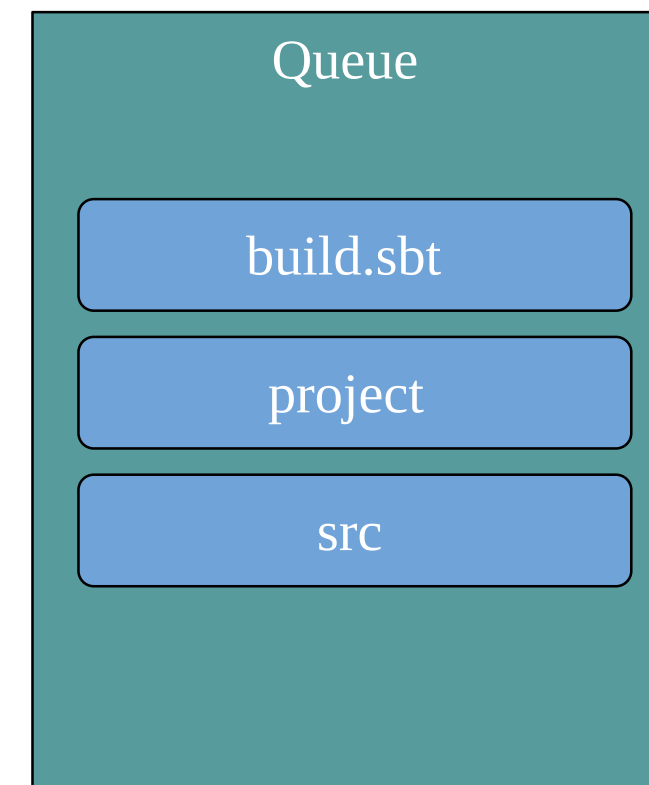
    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



total
200



Imperative approach

```
import java.io.File
import scala.collection.mutable

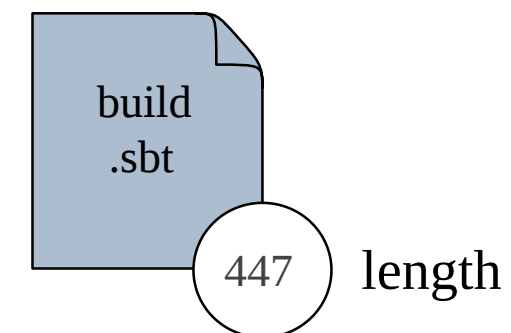
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

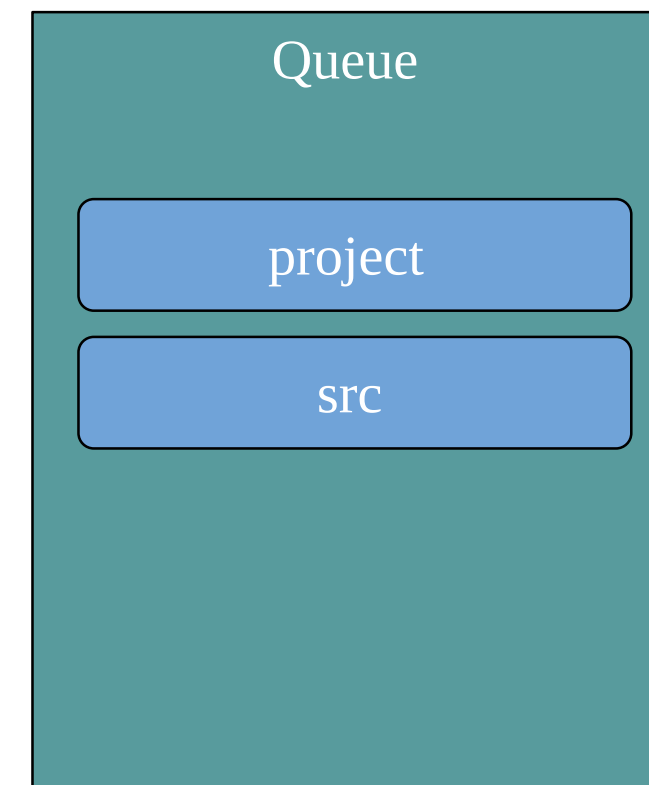
    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



total

647



Imperative approach

```
import java.io.File
import scala.collection.mutable

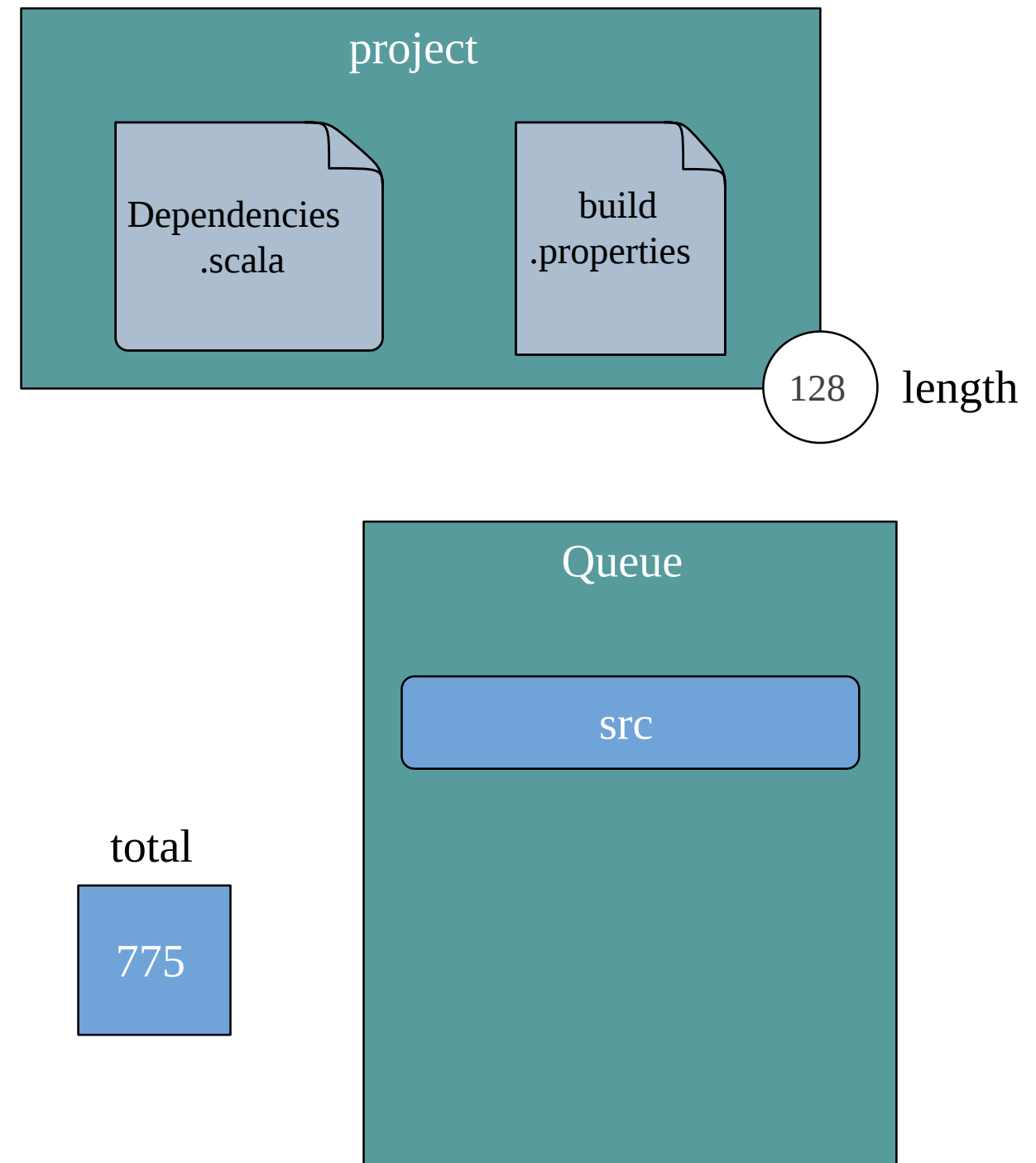
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



Imperative approach

```
import java.io.File
import scala.collection.mutable

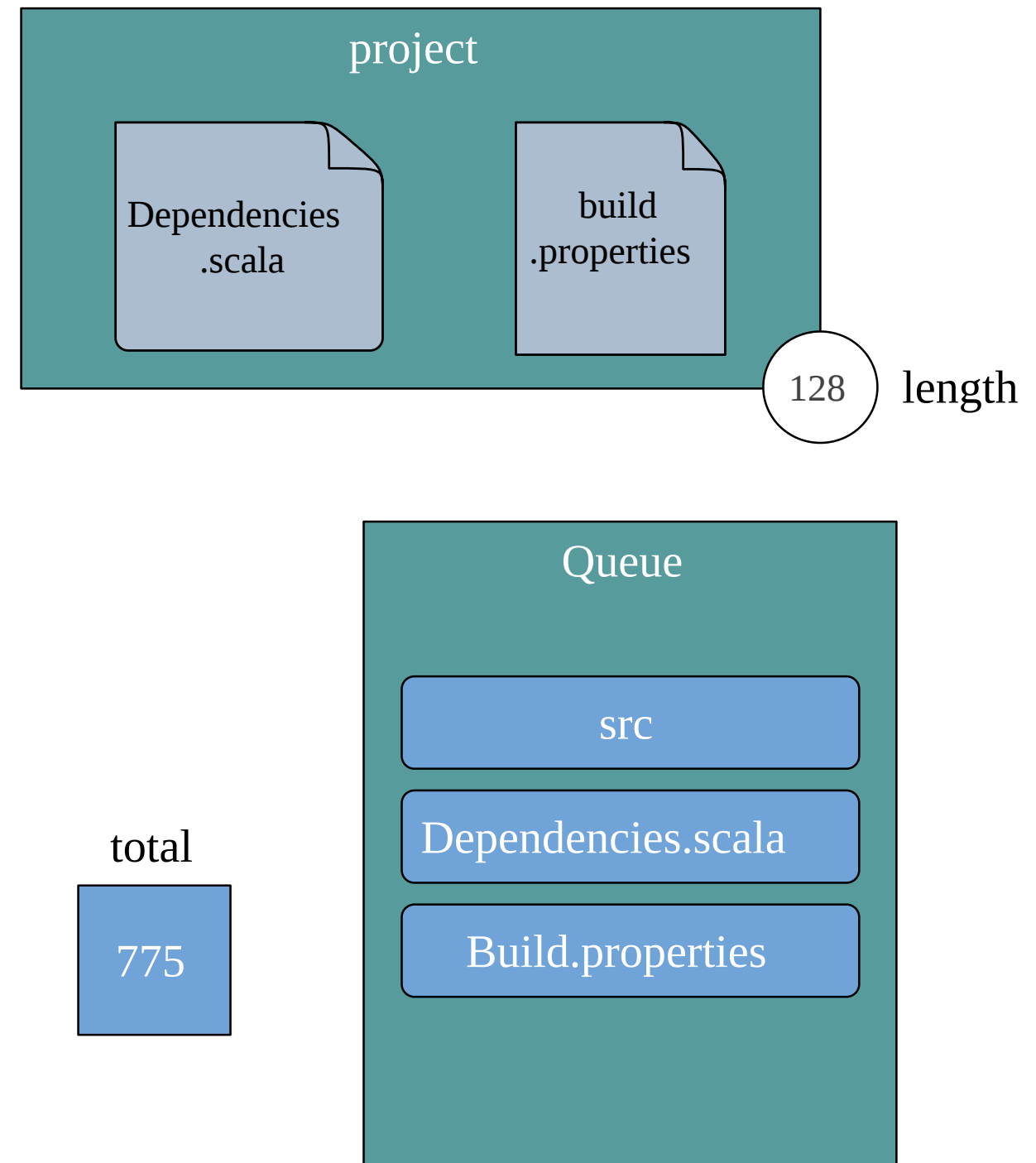
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```



Recursive approach

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory)
    ???
  else
    ???
```

Recursive approach

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage: Long = ???

    file.length() + childrenDiskUsage
  } else
    file.length()
```

Recursive approach

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles      // Array[File]
      .map(diskUsage) // Array[Long]
      .sum           // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

Imperative

```
import java.io.File
import scala.collection.mutable

def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```

Recursive

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles
      .map(diskUsage)
      .sum

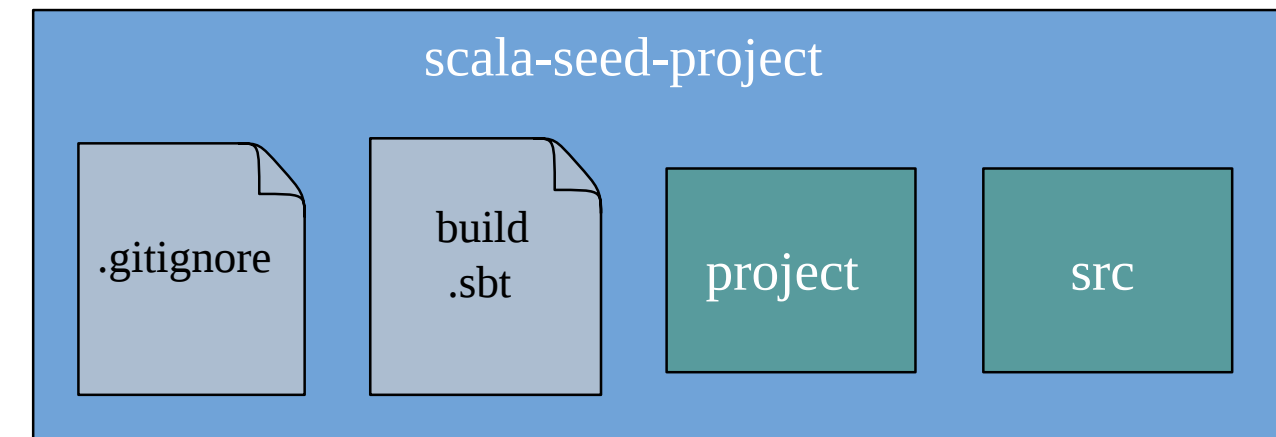
    file.length() + childrenDiskUsage
  } else
    file.length()
```

File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                 // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

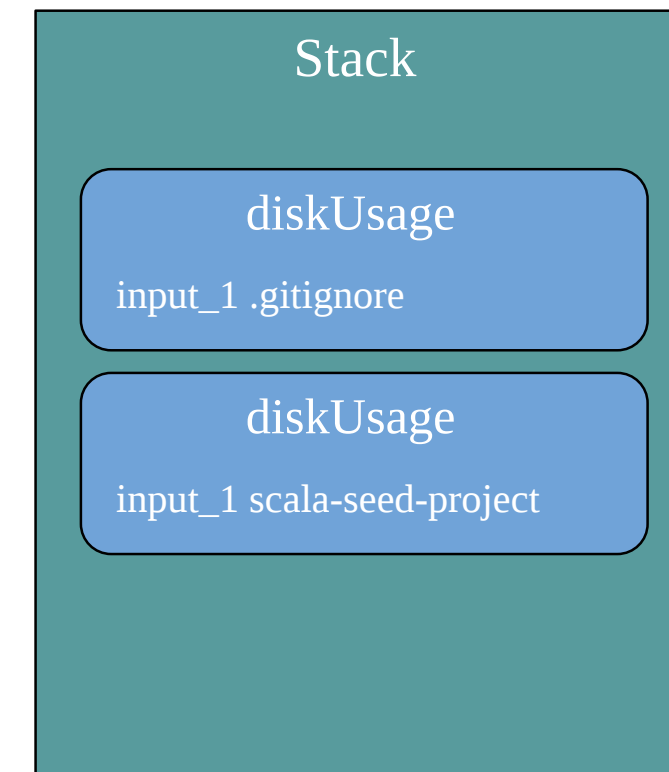


File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

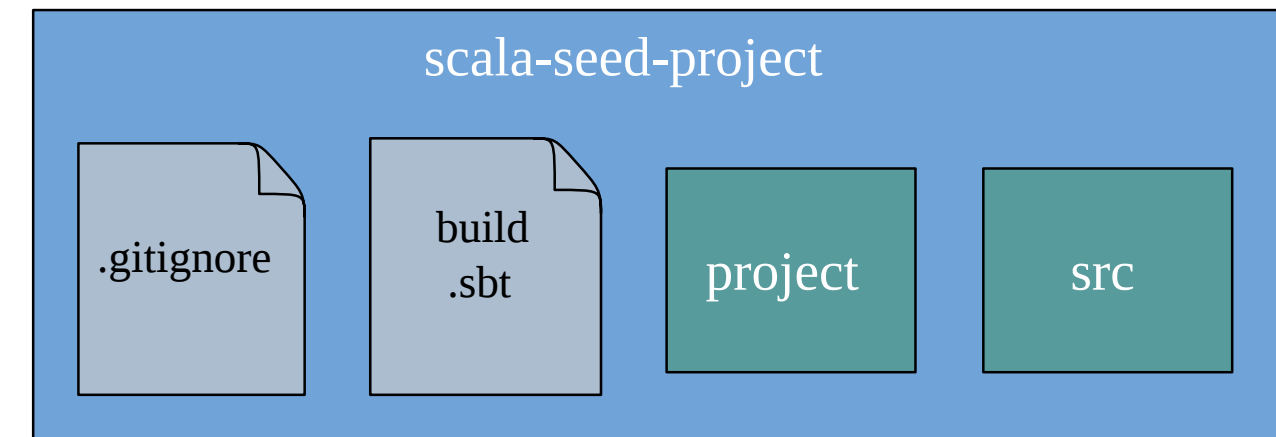


File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles          // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

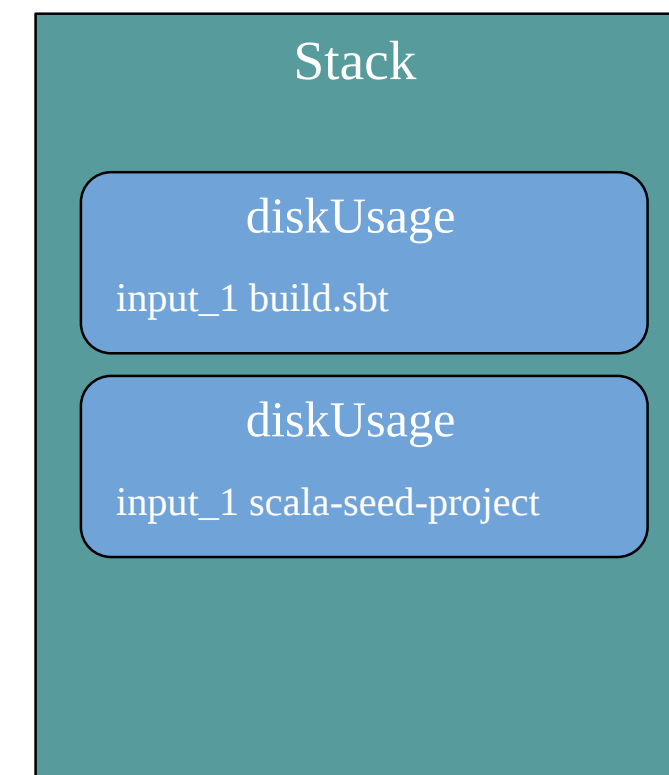
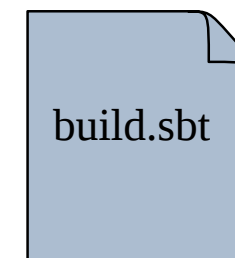


File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

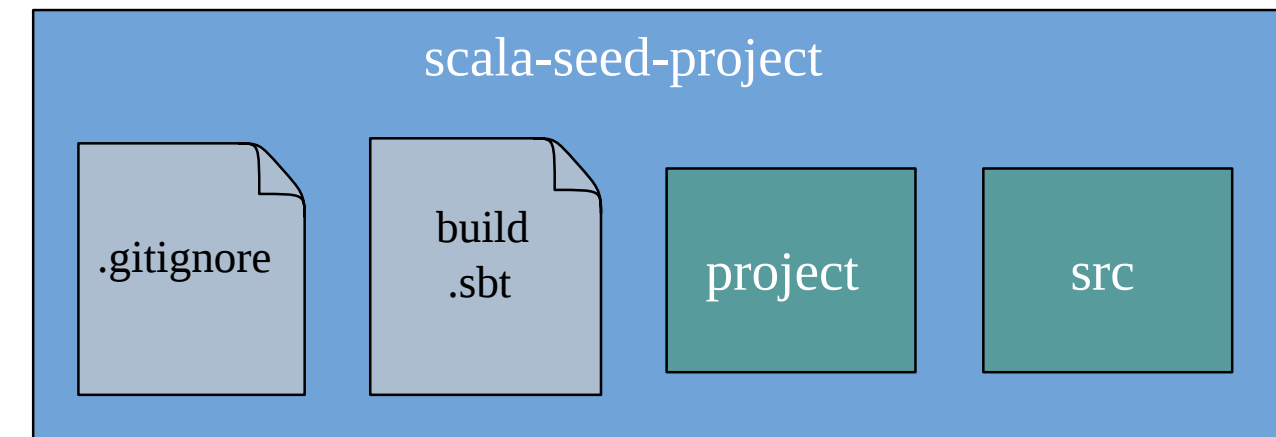


File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                 // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

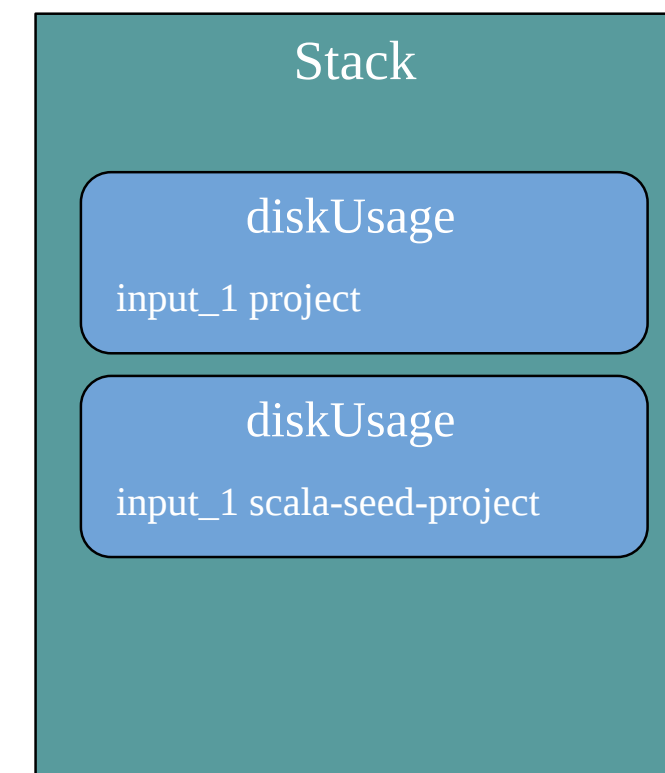
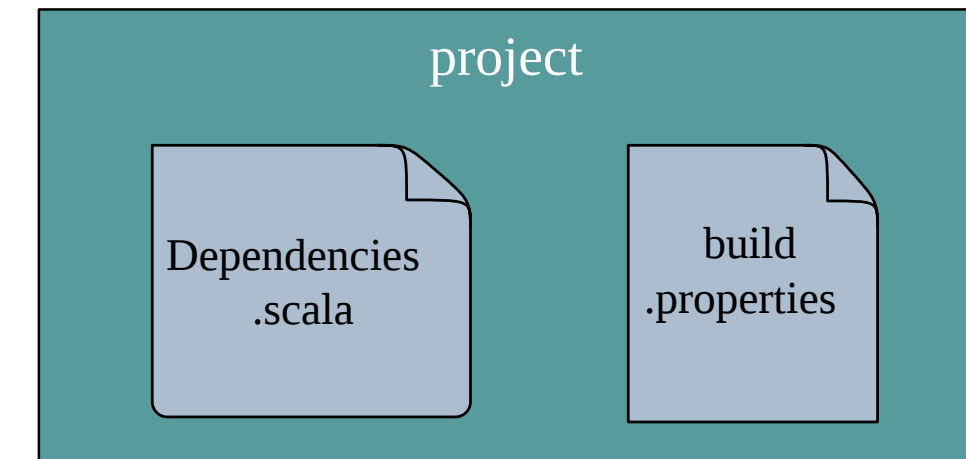


File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                 // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

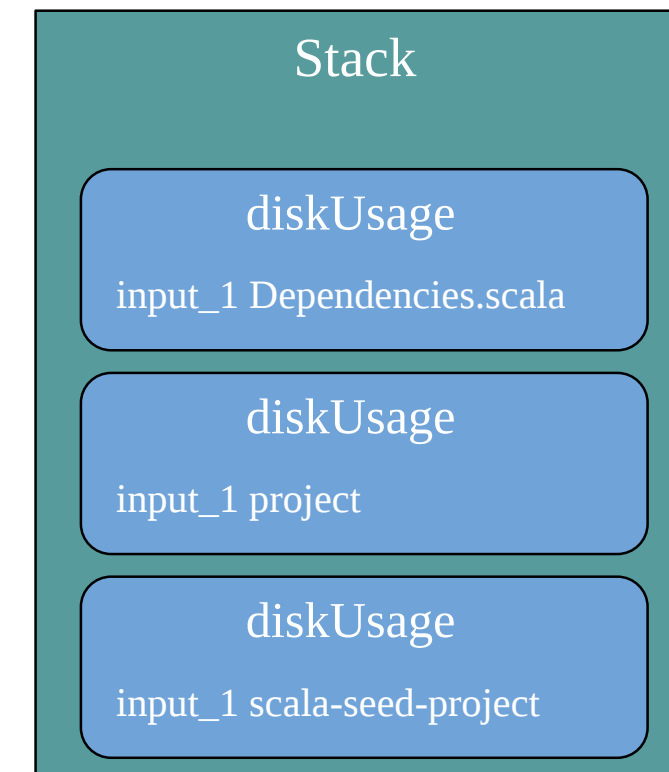
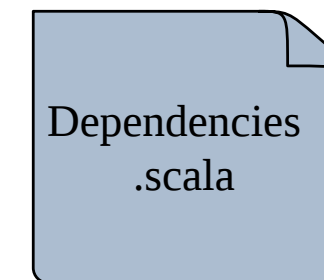


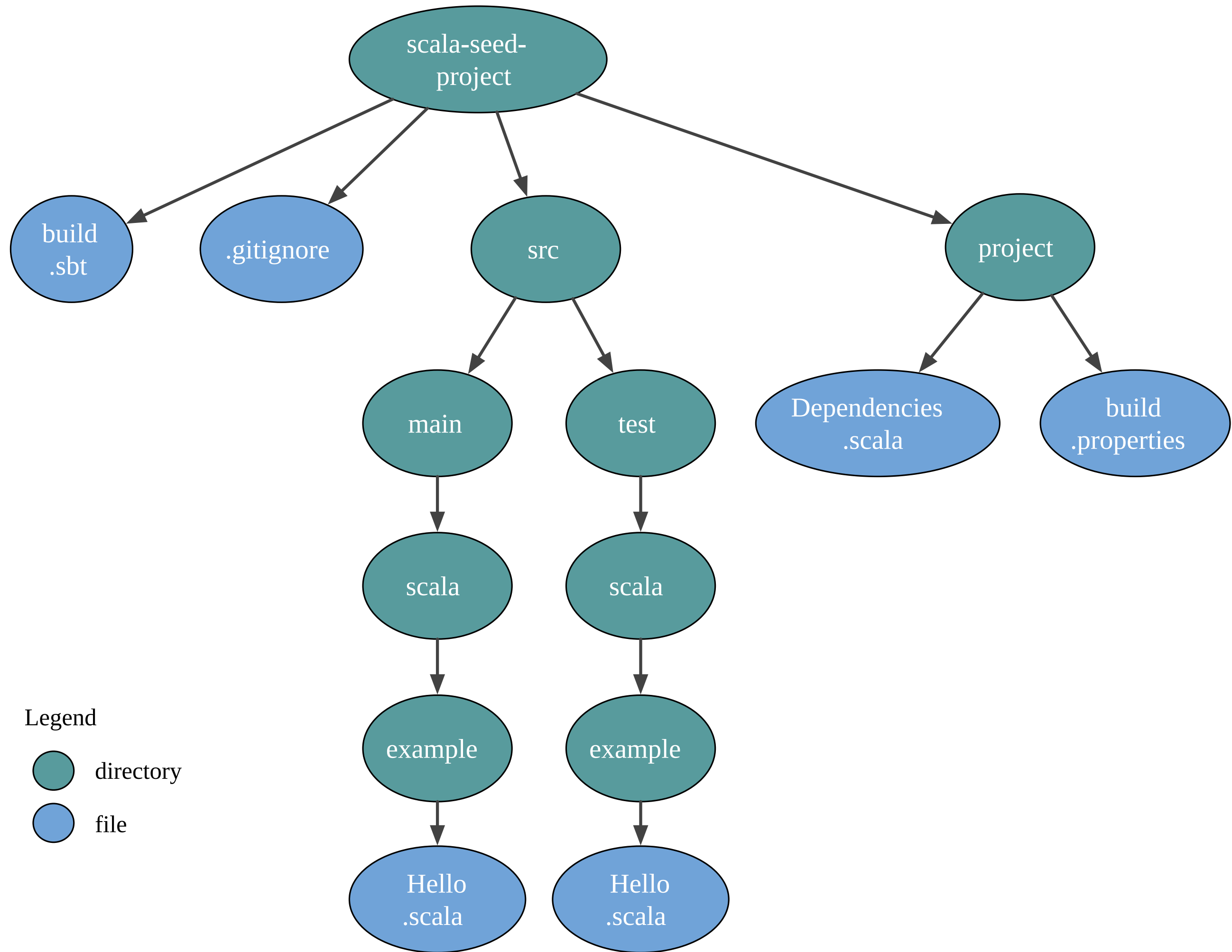
File system: disk usage

```
import java.io.File

def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles          // Array[File]
      .map(diskUsage)     // Array[Long]
      .sum                // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

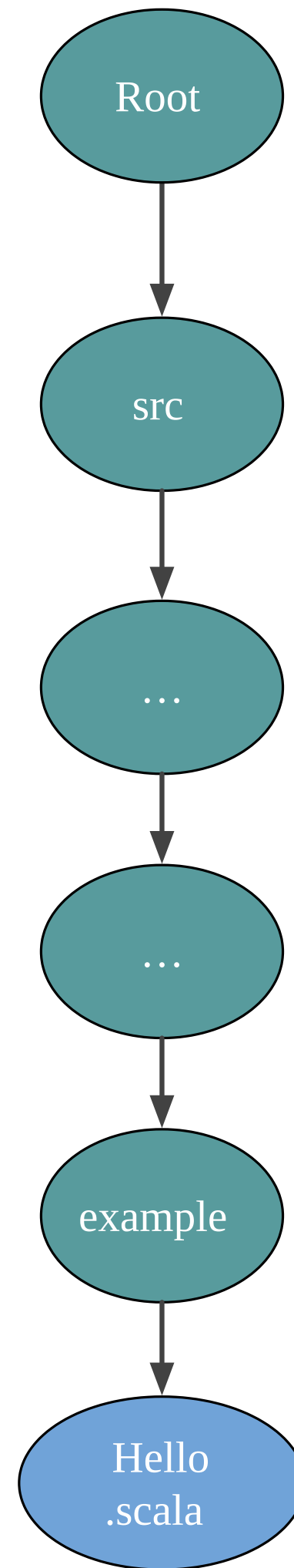




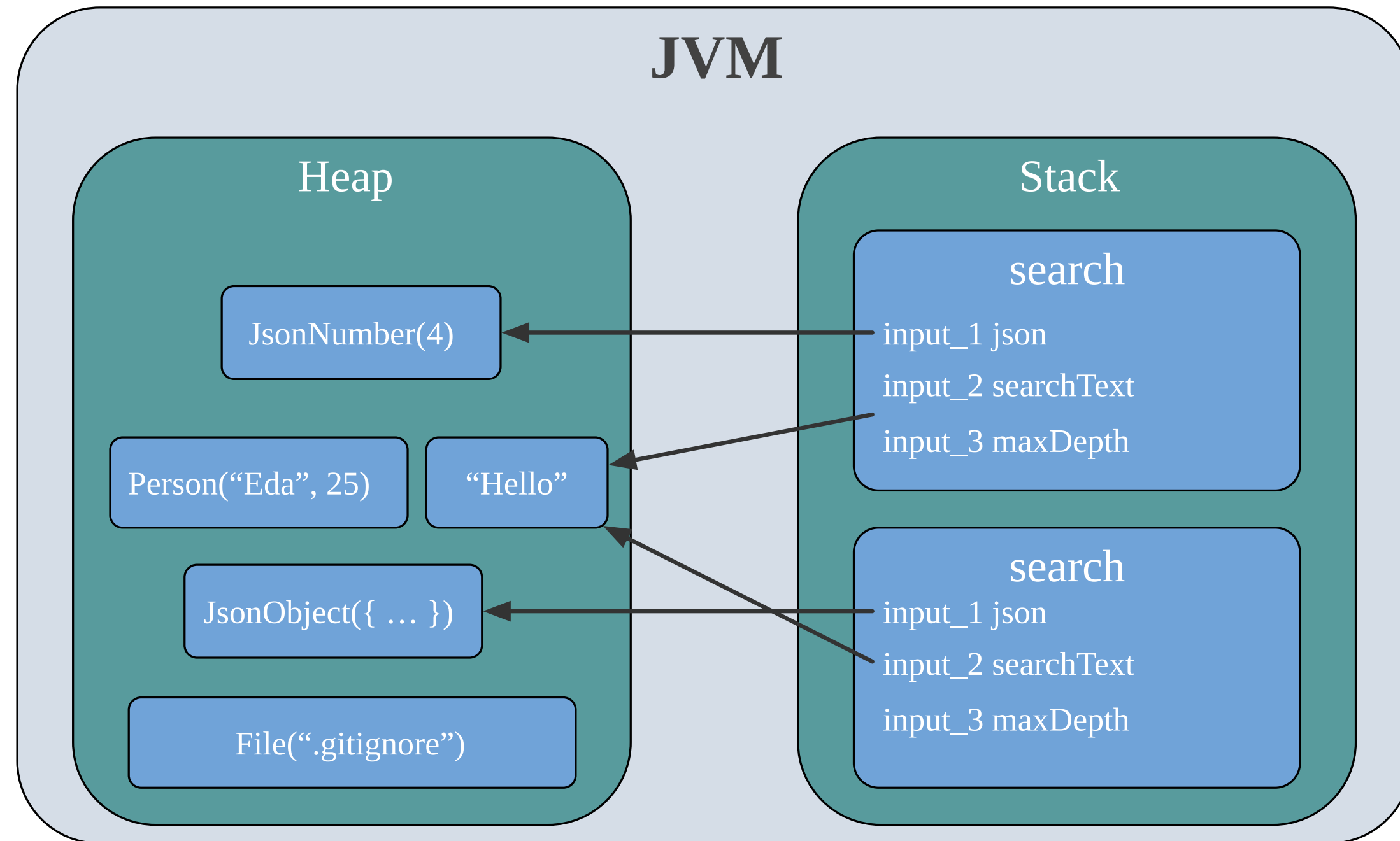
Legend

● directory

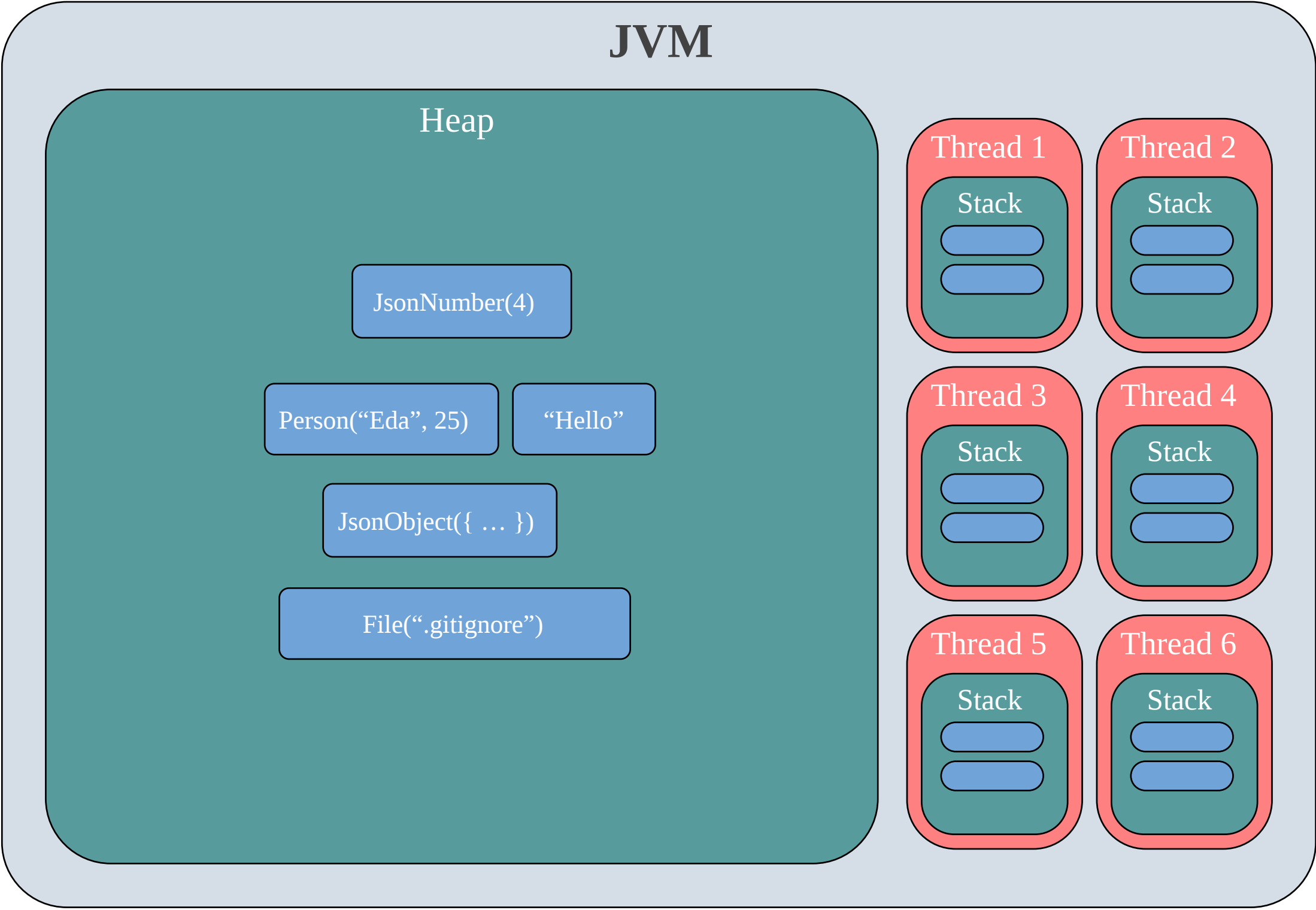
● file



JVM memory model



JVM memory model



Explicit data structure

```
import java.io.File
import scala.collection.mutable

def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```

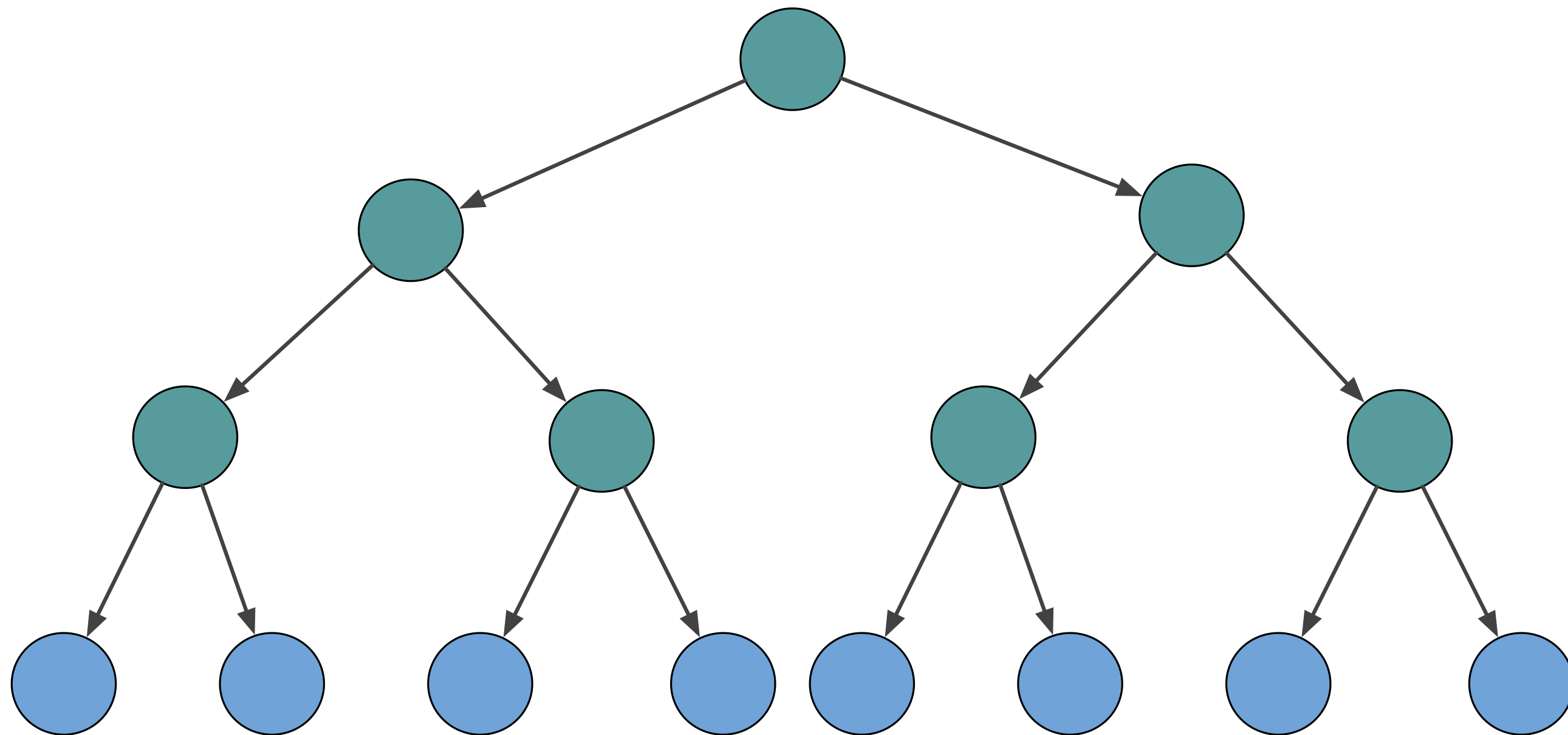
Implicit data structure

```
import java.io.File

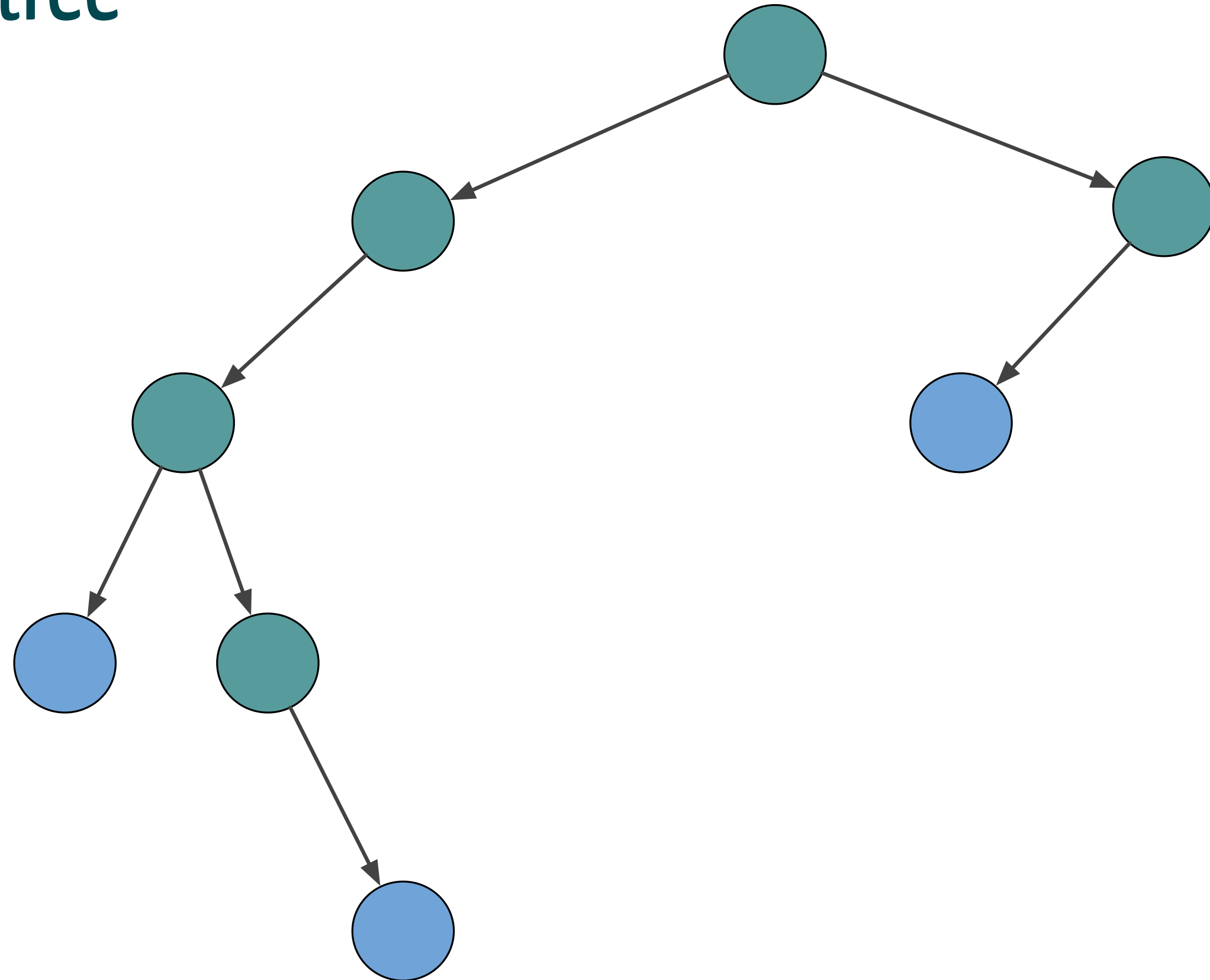
def diskUsage(file: File): Long =
  if(file.isDirectory) {
    val childrenDiskUsage = file
      .listFiles           // Array[File]
      .map(diskUsage)      // Array[Long]
      .sum                 // Long

    file.length() + childrenDiskUsage
  } else
    file.length()
```

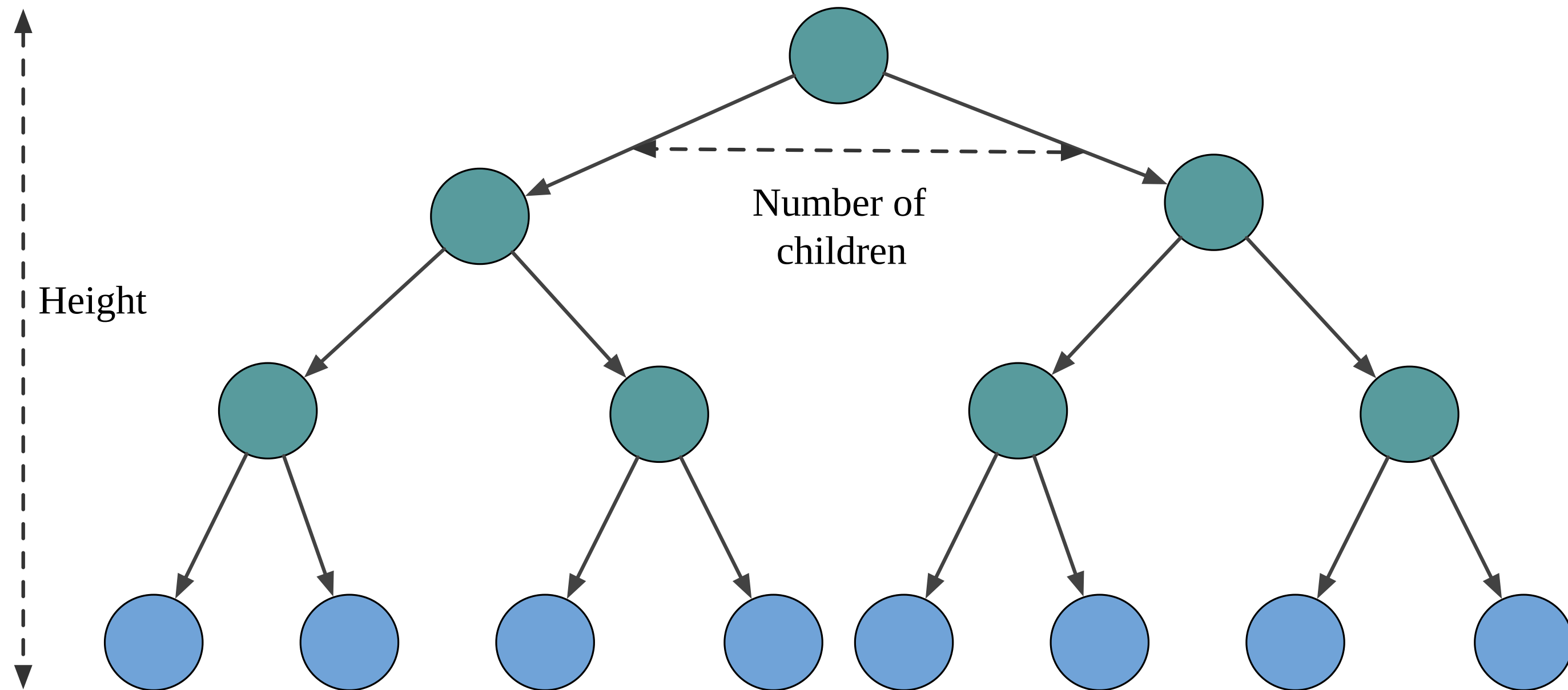

How many elements?



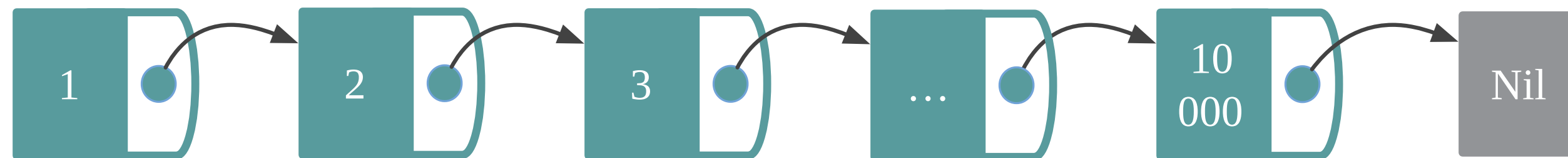
Unbalanced tree



How many elements?



List



Recursive sum

```
def sum(numbers: List[Int]): Int =  
  ???
```

Recursive sum

```
def sum(numbers: List[Int]): Int =  
  numbers match {  
    case Nil          => ???  
    case head :: tail => ???  
  }
```

```
enum List[+A] {  
  case Nil  
  case ::(head: A, tail: List[A])  
}
```

Recursive sum

```
def sum(numbers: List[Int]): Int =  
  numbers match {  
    case Nil => ???  
    case head :: tail => ???  
  }
```

```
def sum(numbers: List[Int]): Int =  
  numbers match {  
    case Nil => ???  
    case ::(head, tail) => ???  
  }
```

```
enum List[+A] {  
  case Nil  
  case ::(head: A, tail: List[A])  
}
```

Recursive sum

```
def sum(numbers: List[Int]): Int =  
  numbers match {  
    case Nil => 0  
    case head :: tail => sum(tail) + head  
  }
```


Recursive sum

```
def sum(numbers: List[Int]): Int =  
  numbers match {  
    case Nil => 0  
    case head :: tail => sum(tail) + head  
  }
```

```
sum(List(1,2,3,4,5))  
// res47: Int = 15
```

```
val largeList = List.range(1, 10000)  
// largeList: List[Int] = List(1,2,3,4,...,10000)  
  
sum(largeList)  
// java.lang.StackOverflowError
```

Recursive contains

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
contains(List(1,2,3,4), 3)  
// res49: Boolean = true
```

```
contains(List(1,2,3,4), 5)  
// res50: Boolean = false
```

Recursive contains

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
contains(List(1,2,3,4), 3)  
// res52: Boolean = true
```

```
contains(List(1,2,3,4), 5)  
// res53: Boolean = false
```

Recursive contains

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
val largeList = List.range(1, 10000)  
// largeList: List[Int] = List(1,2,3,4,...,10000)  
  
contains(largeList, 5)  
// res: Boolean = true
```

Recursive contains

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
val largeList = List.range(1, 10000)  
// largeList: List[Int] = List(1,2,3,4,...,10000)  
  
contains(largeList, 5)  
// res: Boolean = true  
  
contains(largeList, -1)  
// res: Boolean = false
```

Recursive functions

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
def sum(list: List[Int]): Int =  
  list match {  
    case Nil => 0  
    case head :: tail =>  
      sum(tail) + head  
  }
```

Recursive functions

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
def sum(list: List[Int]): Int =  
  list match {  
    case Nil => 0  
    case head :: tail =>  
      head + sum(tail)  
  }
```

Recursive functions

```
def contains(list: List[Int], number: Int): Boolean =  
  list match {  
    case Nil => false  
    case head :: tail =>  
      if (head == number)  
        true  
      else  
        contains(tail, number)  
  }
```

```
def sum(list: List[Int]): Int =  
  list match {  
    case Nil => 0  
    case head :: tail =>  
      val rest = sum(tail)  
      head + rest  
  }
```


Tail recursion

```
import scala.annotation.tailrec

@tailrec
def contains(list: List[Int], number: Int): Boolean
=
  list match {
    case Nil => false
    case head :: tail =>
      if (head == number)
        true
      else
        contains(tail, number)
  }
```

```
import scala.annotation.tailrec

@tailrec
def sum(list: List[Int]): Int =
  list match {
    case Nil => 0
    case head :: tail =>
      sum(tail) + head
  }

// [error] could not optimize @tailrec
// annotated method sum:
// it contains a recursive call not in
// tail position
```

Tail recursive sum

```
import scala.annotation.tailrec

@tailrec
def sum(numbers: List[Int], state: Int): Int =
  numbers match {
    case Nil          => state
    case head :: tail => sum(tail, state + head)
  }
```

```
sum(List(1,2,3,4,5), 0)
// res: Int = 15

sum(List.range(1, 10000), 0)
// res: Int = 49995000
```

Tailrec vs imperative

```
import scala.annotation.tailrec

@tailrec
def sum(numbers: List[Int], state: Int): Int =
  numbers match {
    case Nil          => state
    case head :: tail => sum(tail, state + head)
  }
```

```
def sum(numbers: List[Int]): Int = {
  var state = 0

  for (number <- numbers)
    state += number

  state
}
```

Tailrec vs imperative

```
import scala.annotation.tailrec

@tailrec
def sum(numbers: List[Int], state: Int): Int =
  numbers match {
    case Nil          => state
    case head :: tail => sum(tail, state + head)
  }

def sum(numbers: List[Int]): Int =
  sum(numbers, state = 0)
```

```
def sum(numbers: List[Int]): Int = {
  var state = 0

  for (number <- numbers)
    state += number

  state
}
```

Hide tailrec implementation

Private method

```
@tailrec
private def sum(numbers: List[Int], state: Int): Int =
  numbers match {
    case Nil => state
    case head :: tail => sum(tail, state + head)
  }

def sum(numbers: List[Int]): Int =
  sum(numbers, state = 0)
```

Nested method

```
def sum(numbers: List[Int]): Int = {
  @tailrec
  def go(numbers: List[Int], state: Int): Int =
    numbers match {
      case Nil => state
      case head :: tail => sum(tail, state + head)
    }

  go(numbers, state = 0)
}
```



StackSafeRecursiveExercises.scala

Summary

- Recursive functions are convenient to traverse recursive data structures
- Stack-safety concerns
- Solutions:
 - limit the depth
 - tailrec annotation

Tail recursive sum

```
def sum(numbers: List[Int]): Int = {  
  @tailrec  
  def go(numbers: List[Int], state: Int): Int =  
    numbers match {  
      case Nil => state  
      case head :: tail => sum(tail, state + head)  
    }  
  go(numbers, state = 0)  
}
```


Imperative diskUsage

```
import java.io.File
import scala.collection.mutable

def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

  while (queue.nonEmpty) {
    val file = queue.dequeue()

    total += file.length()

    if(file.isDirectory)
      queue.addAll(file.listFiles())
  }

  total
}
```