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
```

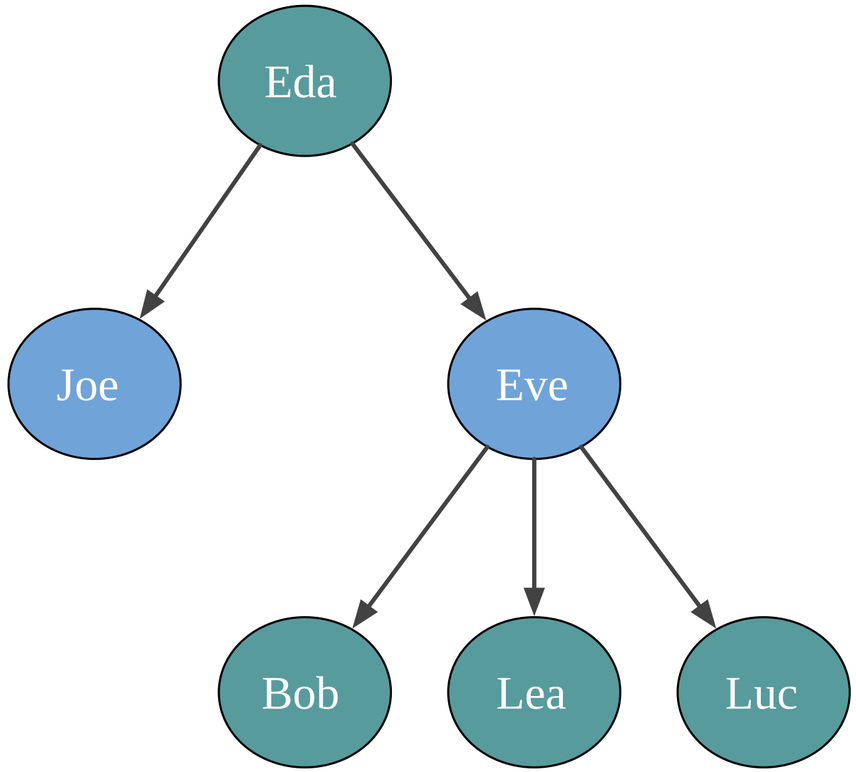
```
def printMany(n: Int, message: String): Unit = {
  var counter = n
  while (counter > 0) {
    counter -= 1
    println("FP is awesome")
  }
}

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"
  }
}
```

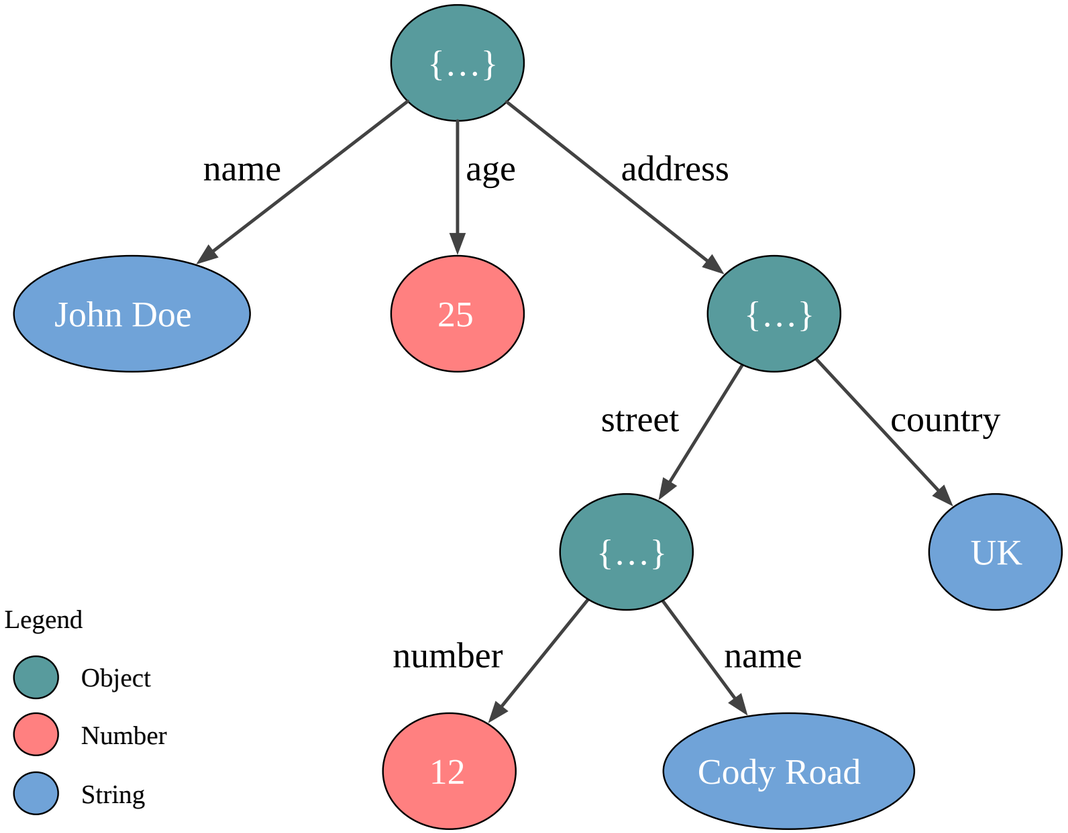
YAML

```
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)
  }
```

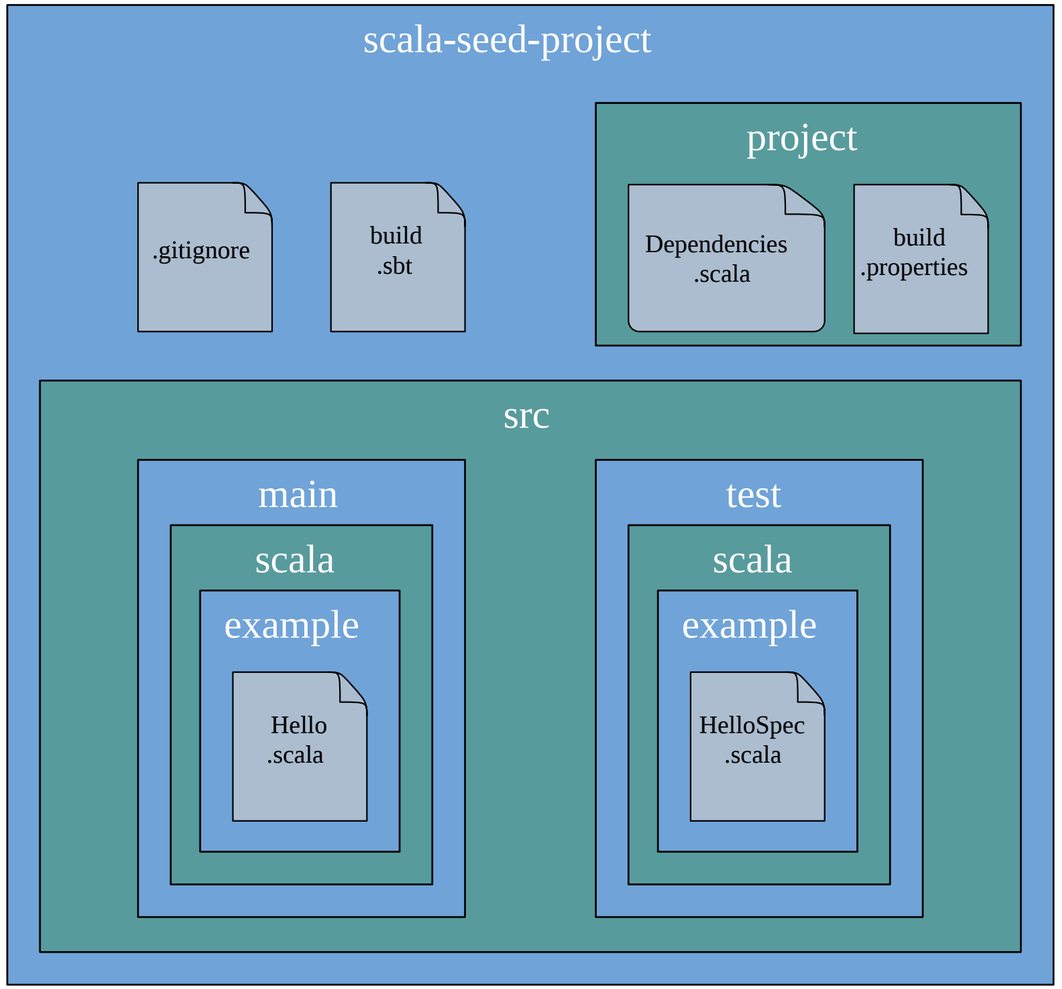
```
john
// john: Json = JsonObject(Map(
//   "name"    -> JsonString("John Doe"),
//   "age"     -> JsonNumber(25),
//   "email"   -> JsonString(" john@doe.com  "),
//   "address" -> JsonObject(Map(
//     "street-number" -> JsonNumber(12),
//     "post-code"     -> JsonString("E16 4SR  ")
// ))
```

```
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")
// ))
```

JsonExercises.scala

Recursive data structures

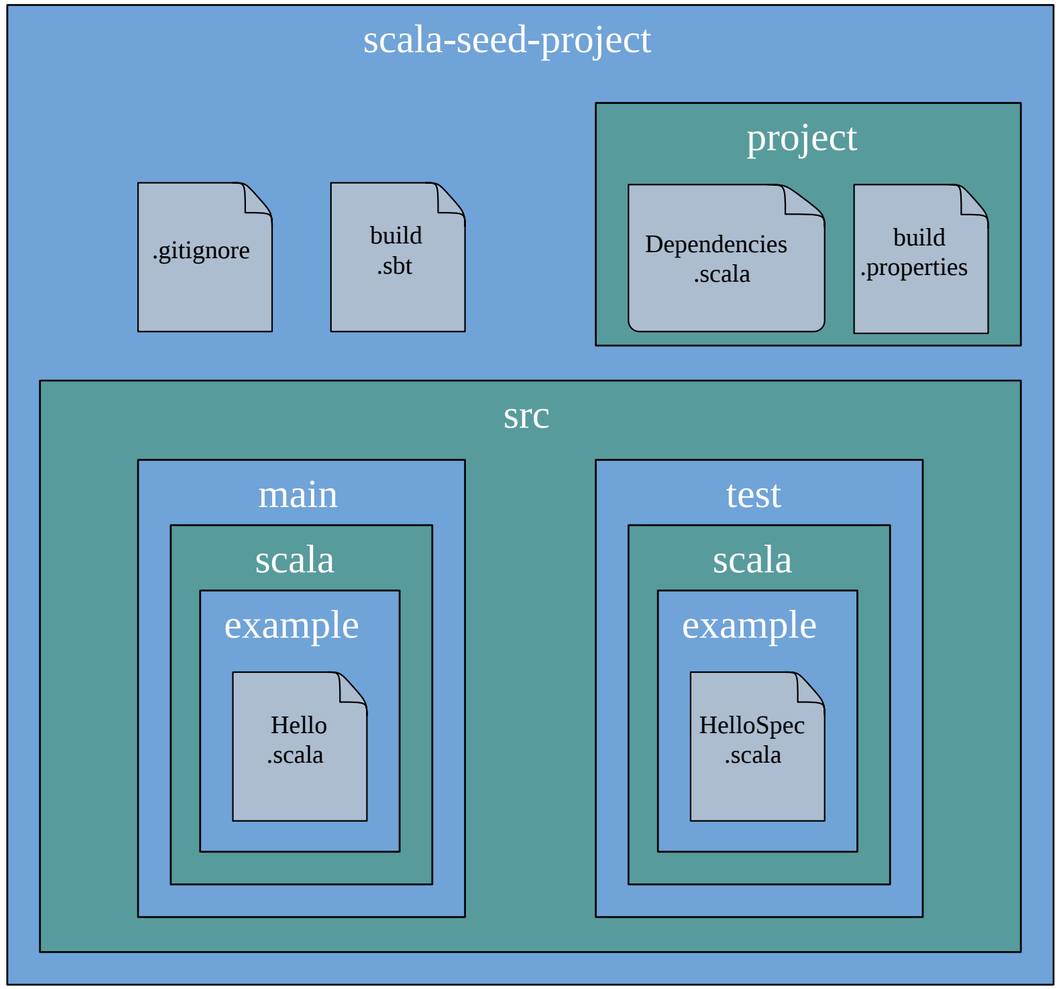
```
$ sbt new scala/scala-seed.g8
```



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

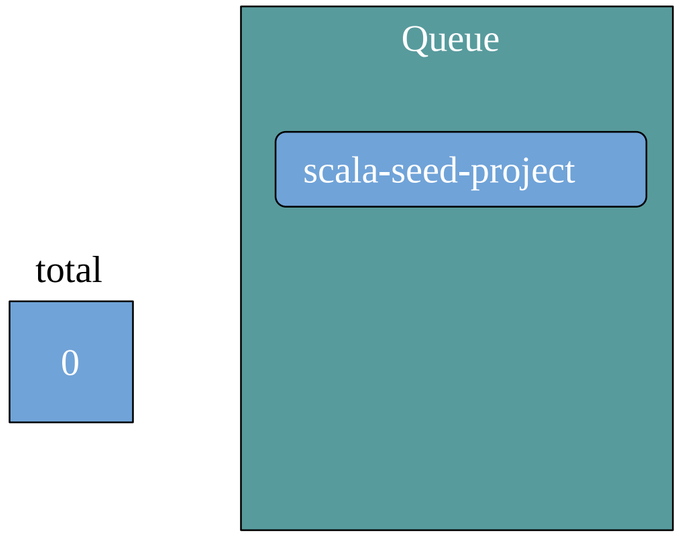
```
import java.io.File

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
}
```

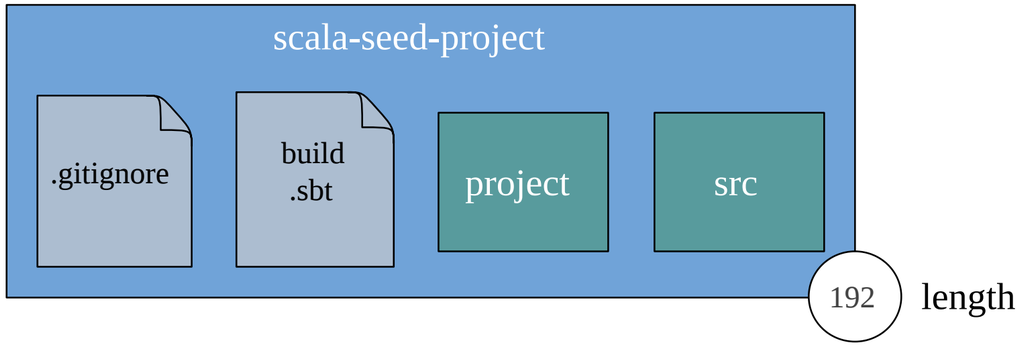
Imperative approach

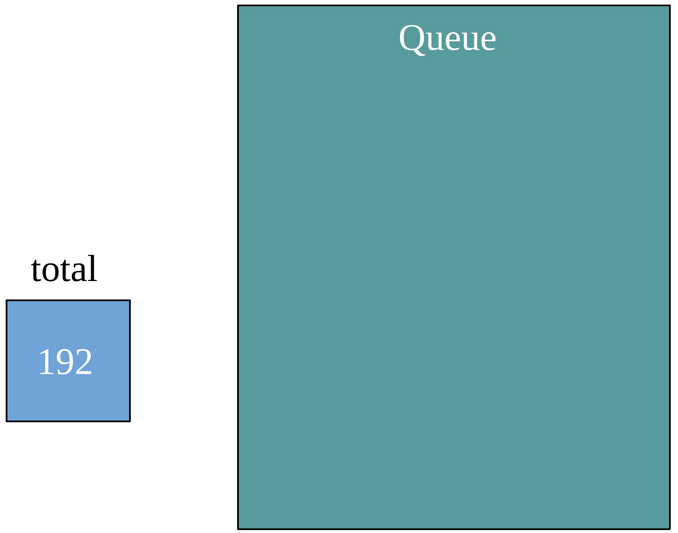
```
import java.io.File
import scala.collection.mutable

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
}
```



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
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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
}
```

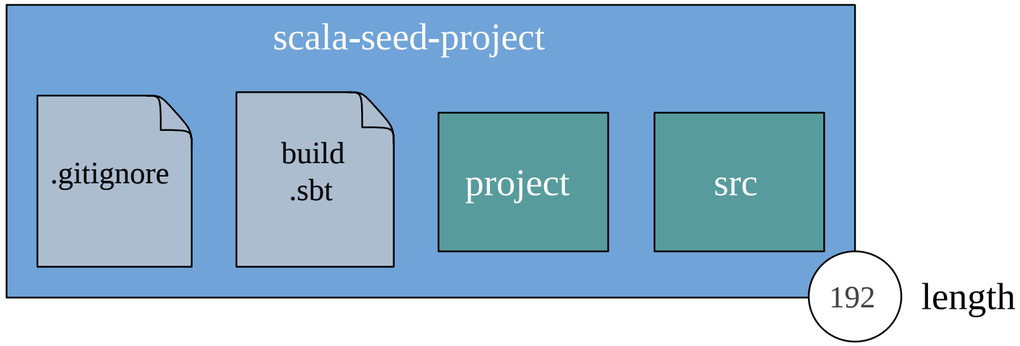

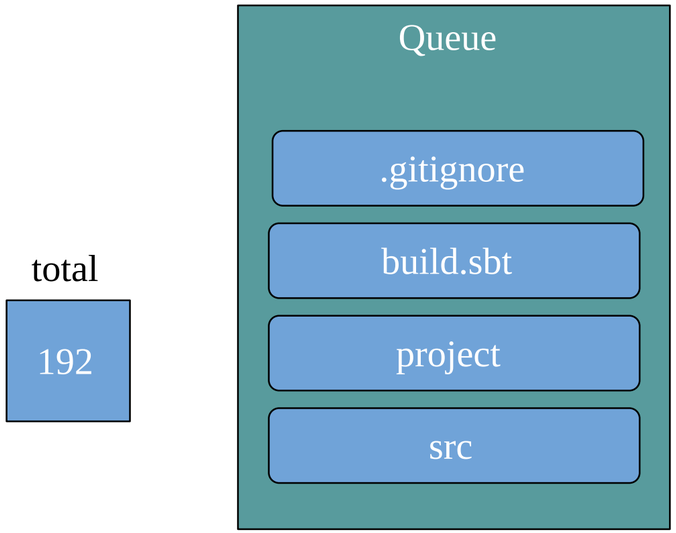

Imperative approach

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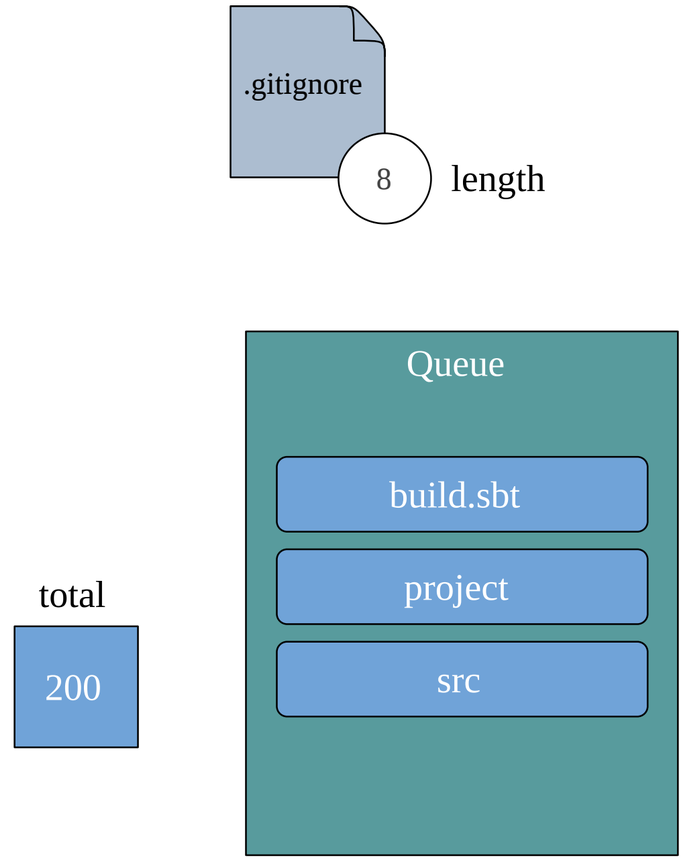
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

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

    total += file.length()

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

  total
}
```



Imperative approach

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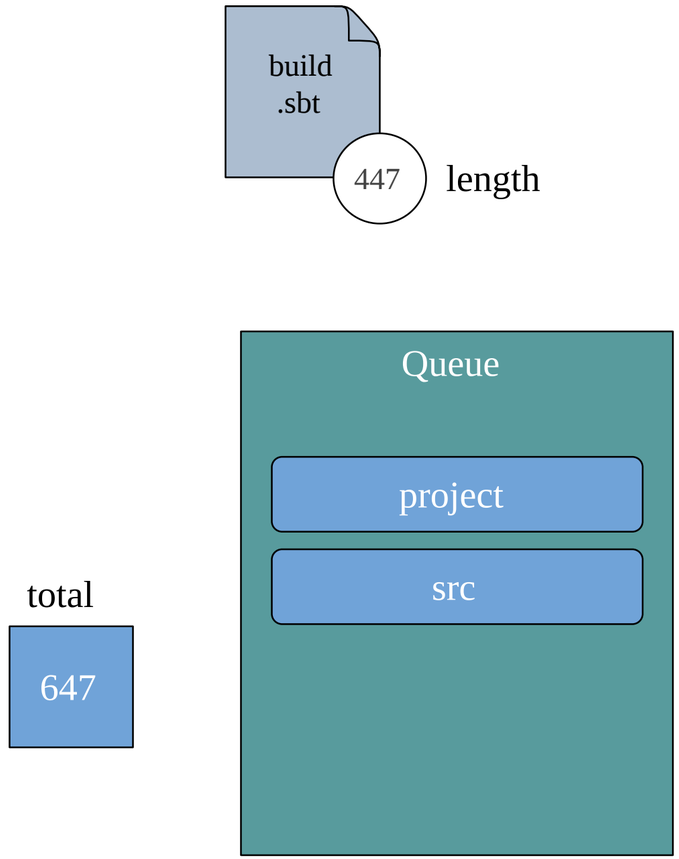
def diskUsage(input: File): Long = {
  var total = 0L
  val queue = mutable.Queue(input)

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

    total += file.length()

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

  total
}
```



Imperative approach

```
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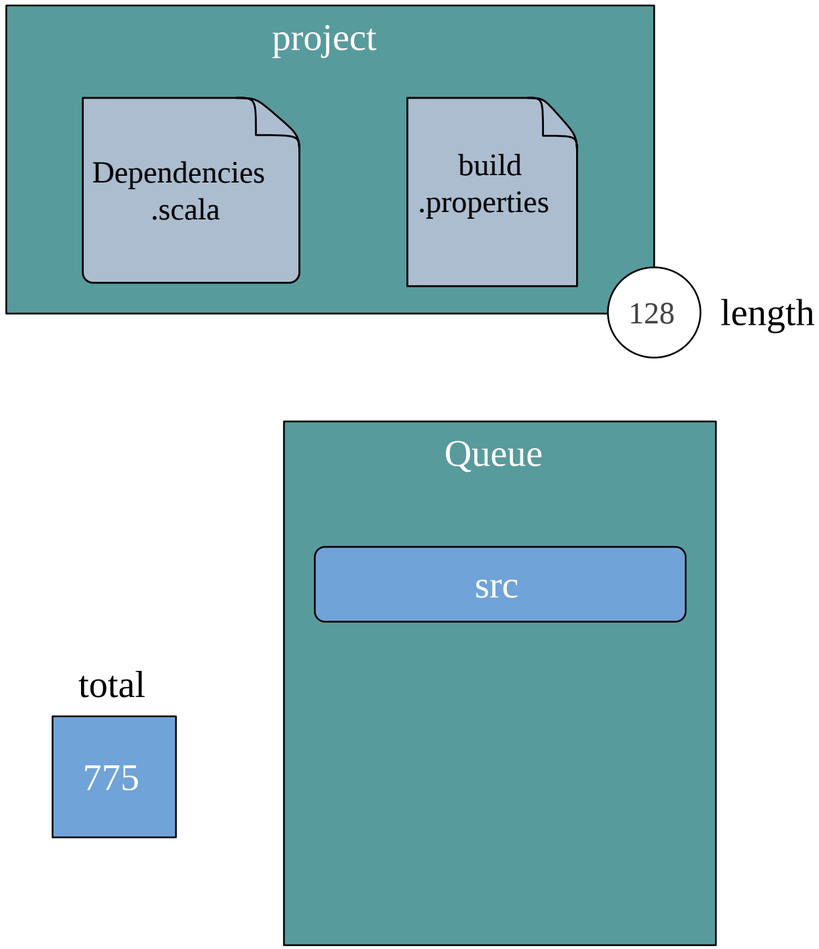
  var total = 0L
  val queue = mutable.Queue(input)

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

    total += file.length()

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

  total
}
```



Imperative approach

```
import java.io.File
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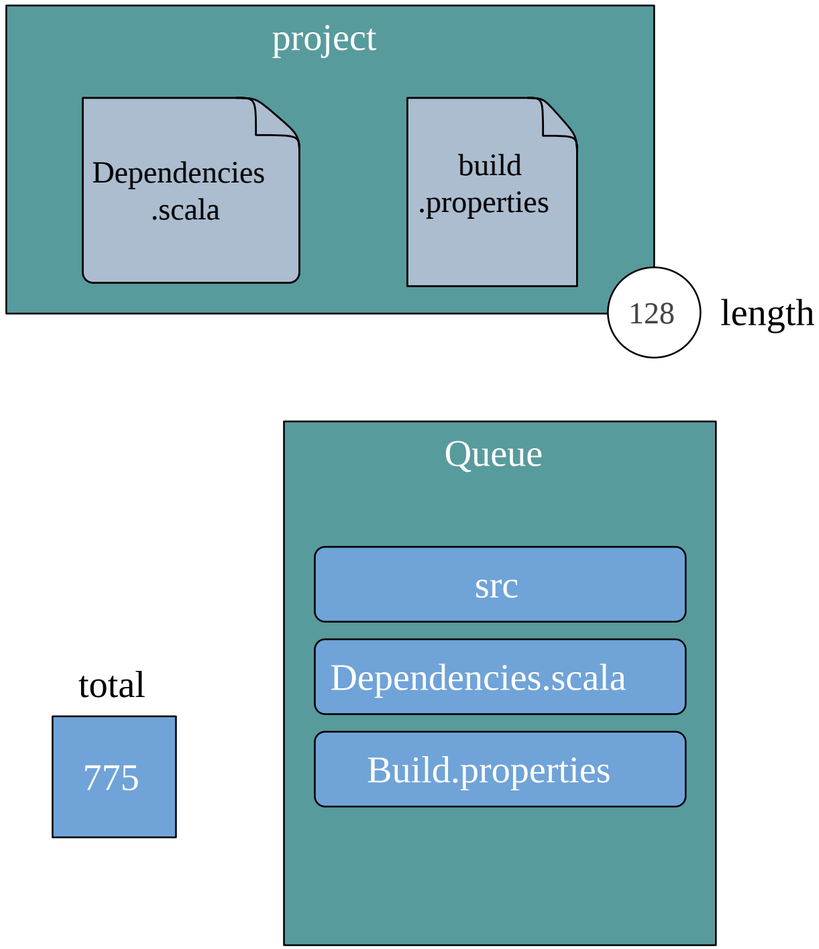
  var total = 0L
  val queue = mutable.Queue(input)

  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
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  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

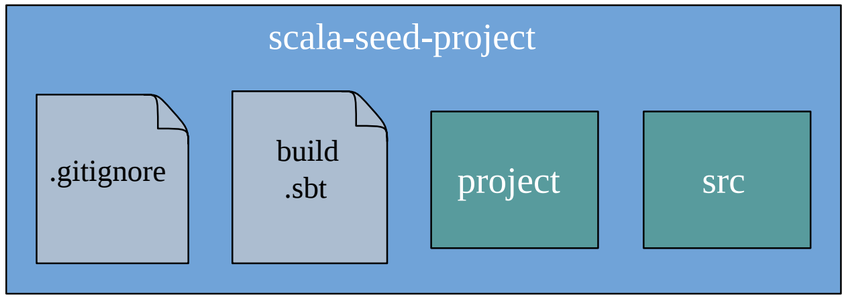
    file.length() + childrenDiskUsage
  } else
    file.length()
```

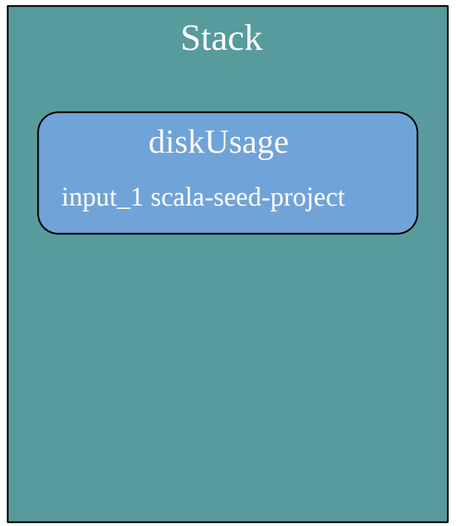
File system: disk usage

```
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) {
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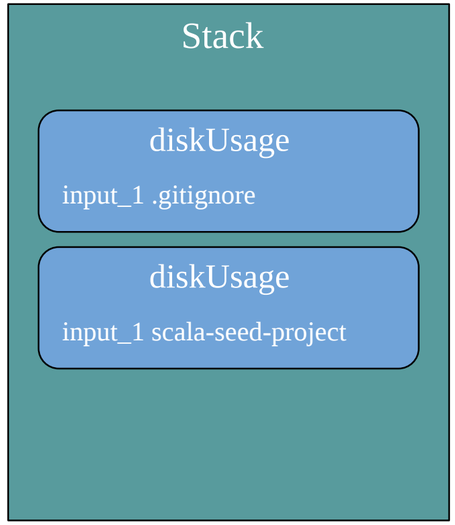
      .sum            // Long

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



File system: disk usage

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  if(file.isDirectory) {
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      .map(diskUsage) // Array[Long]
      .sum            // Long

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

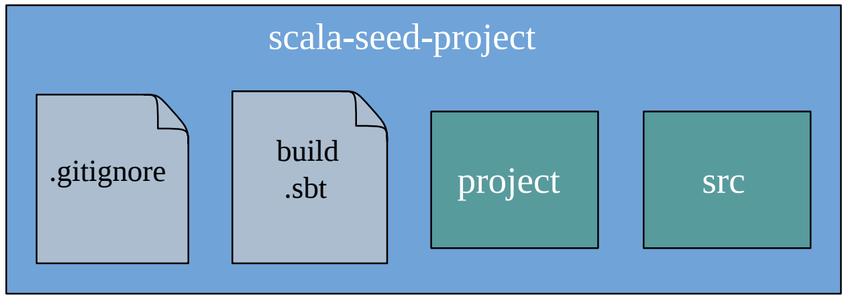

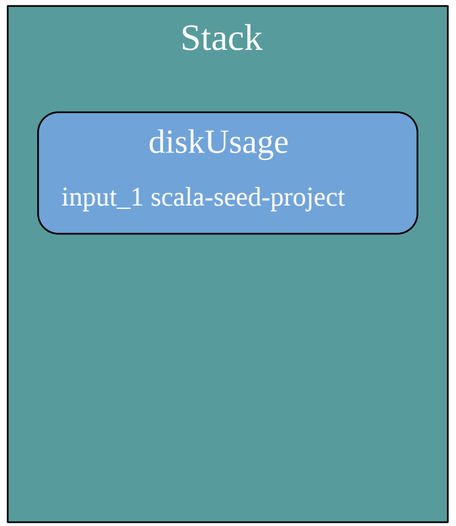

File system: disk usage

```
import java.io.File

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

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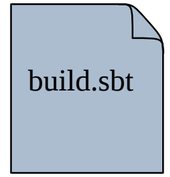
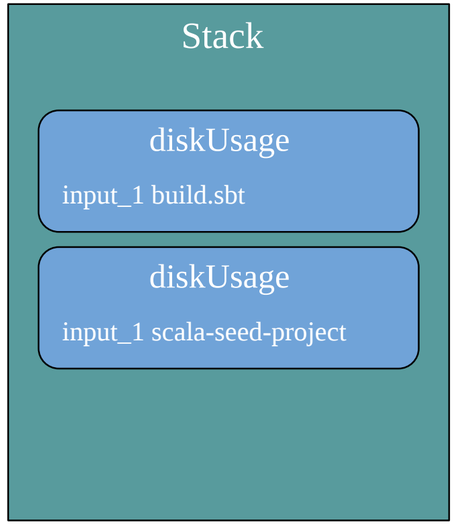
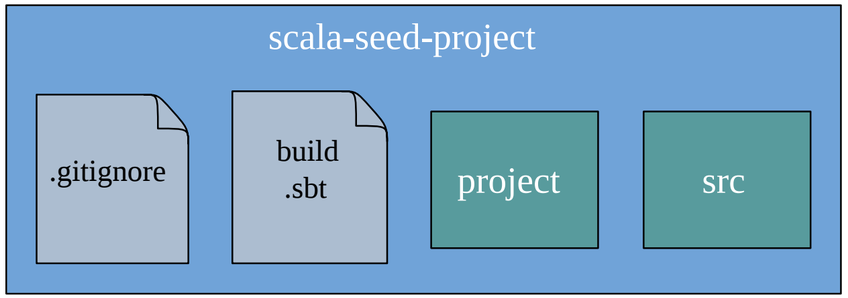
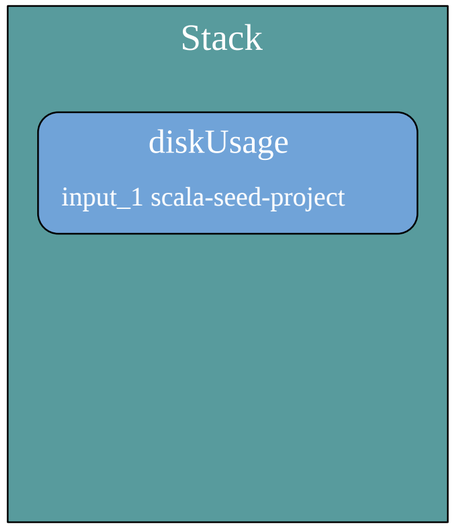





File system: disk usage

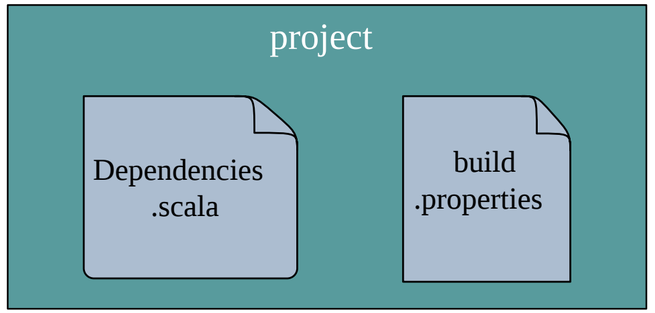
```
import java.io.File

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()
```

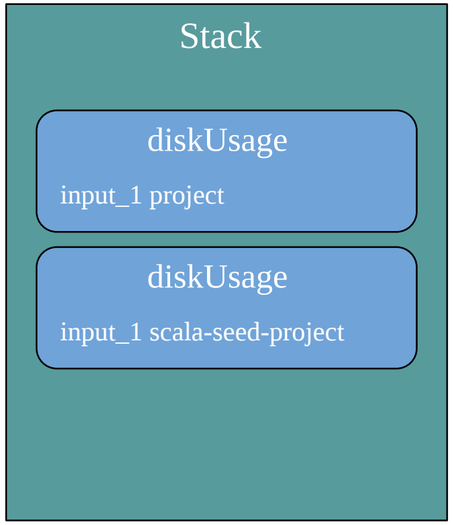




File system: disk usage

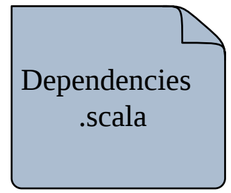
```
import java.io.File

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()
```

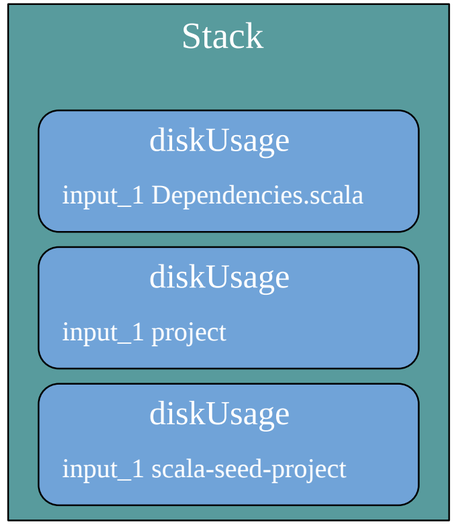


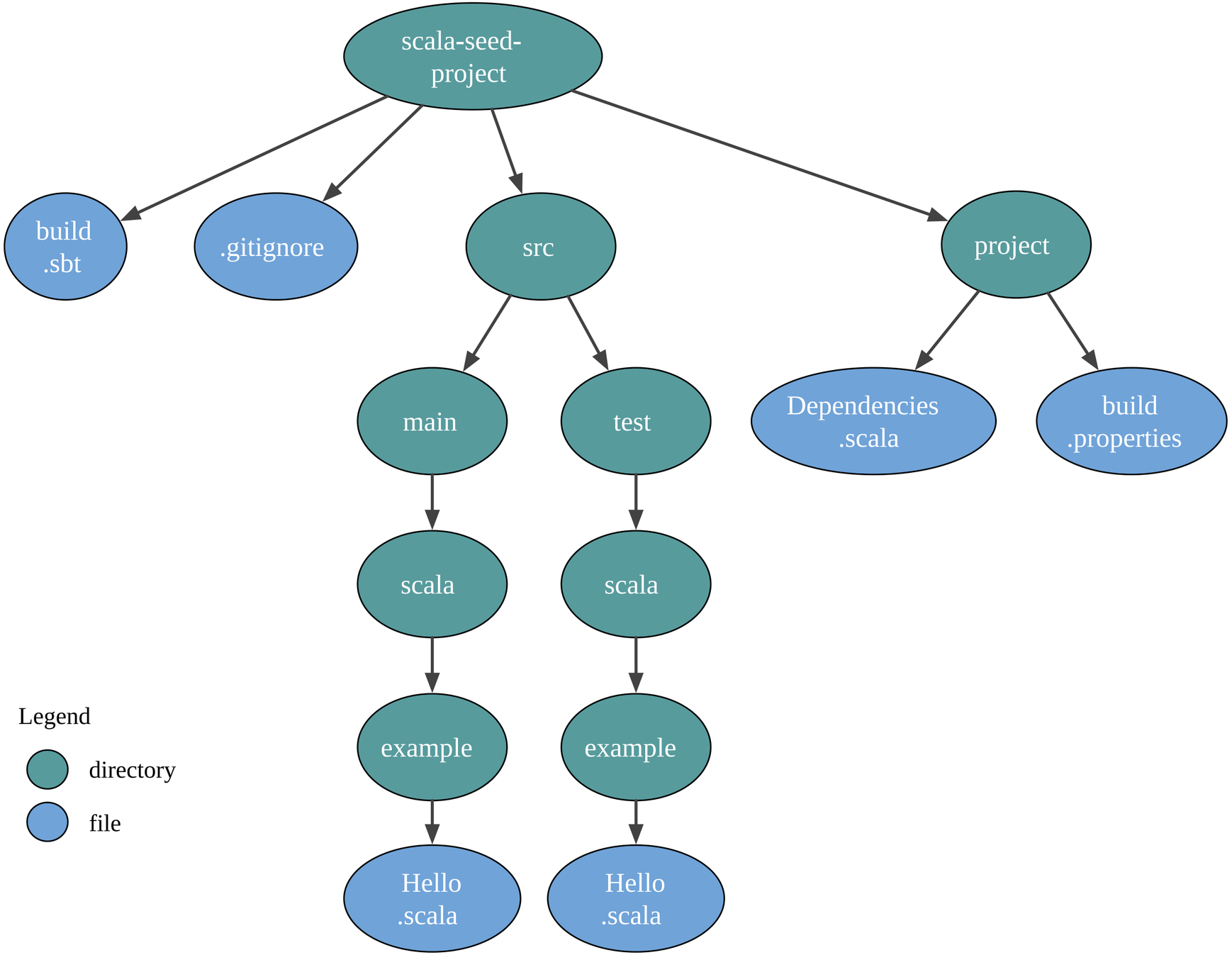


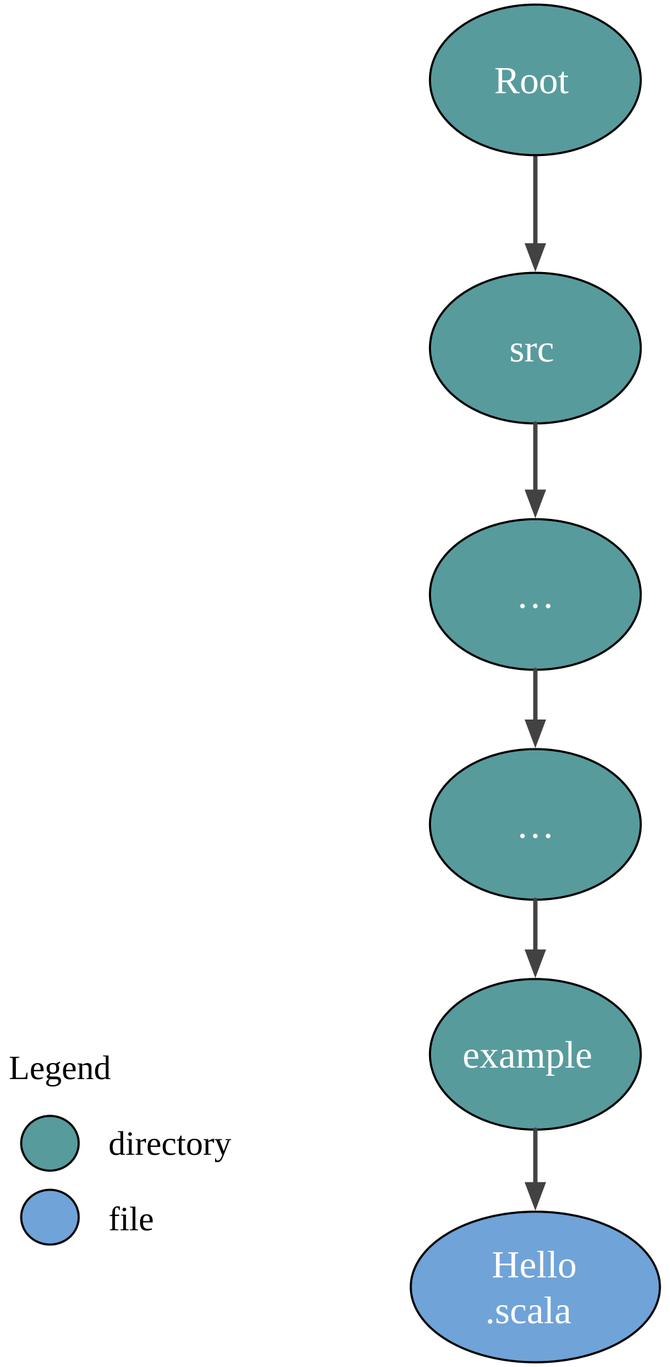
File system: disk usage

```
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()
```

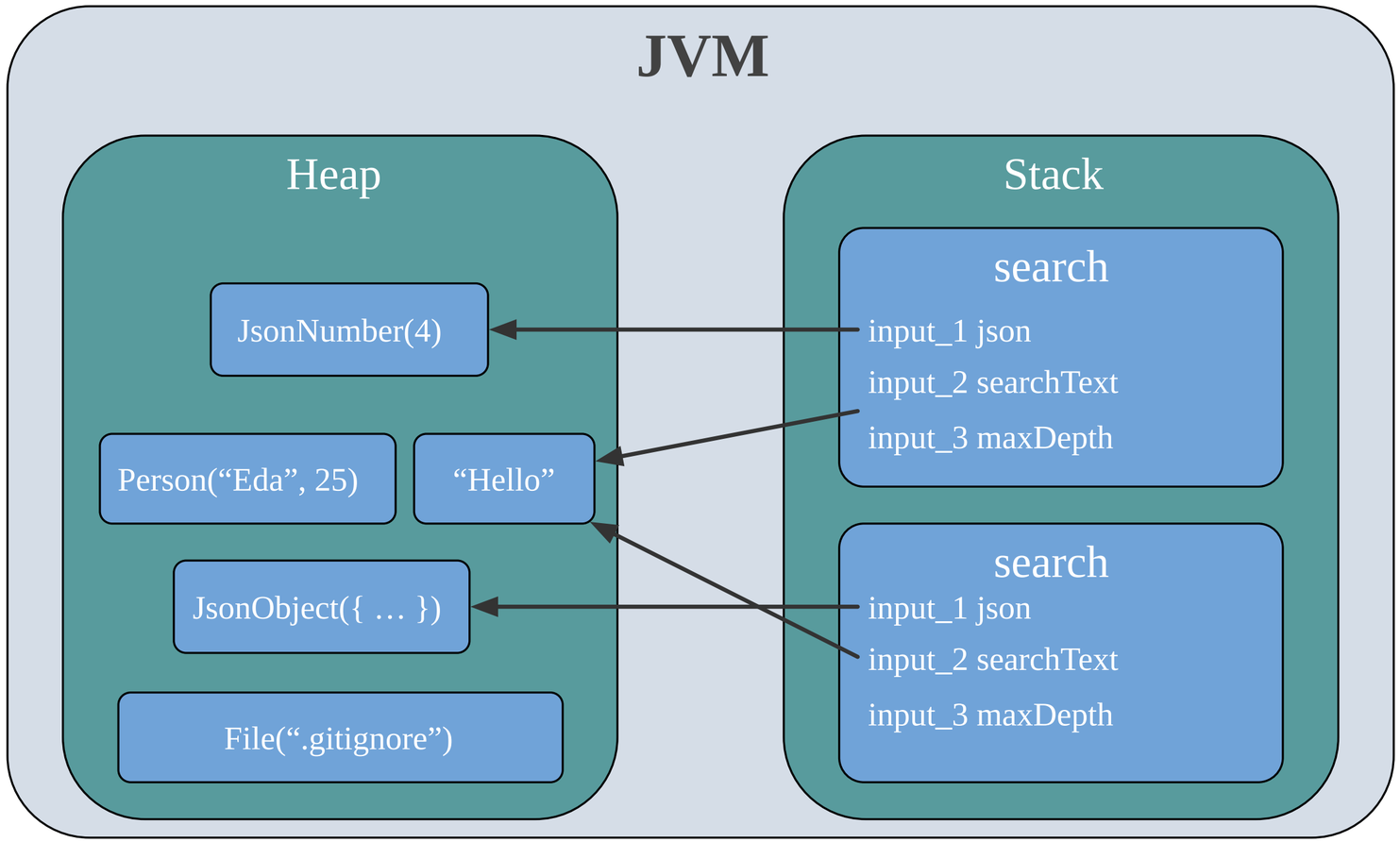




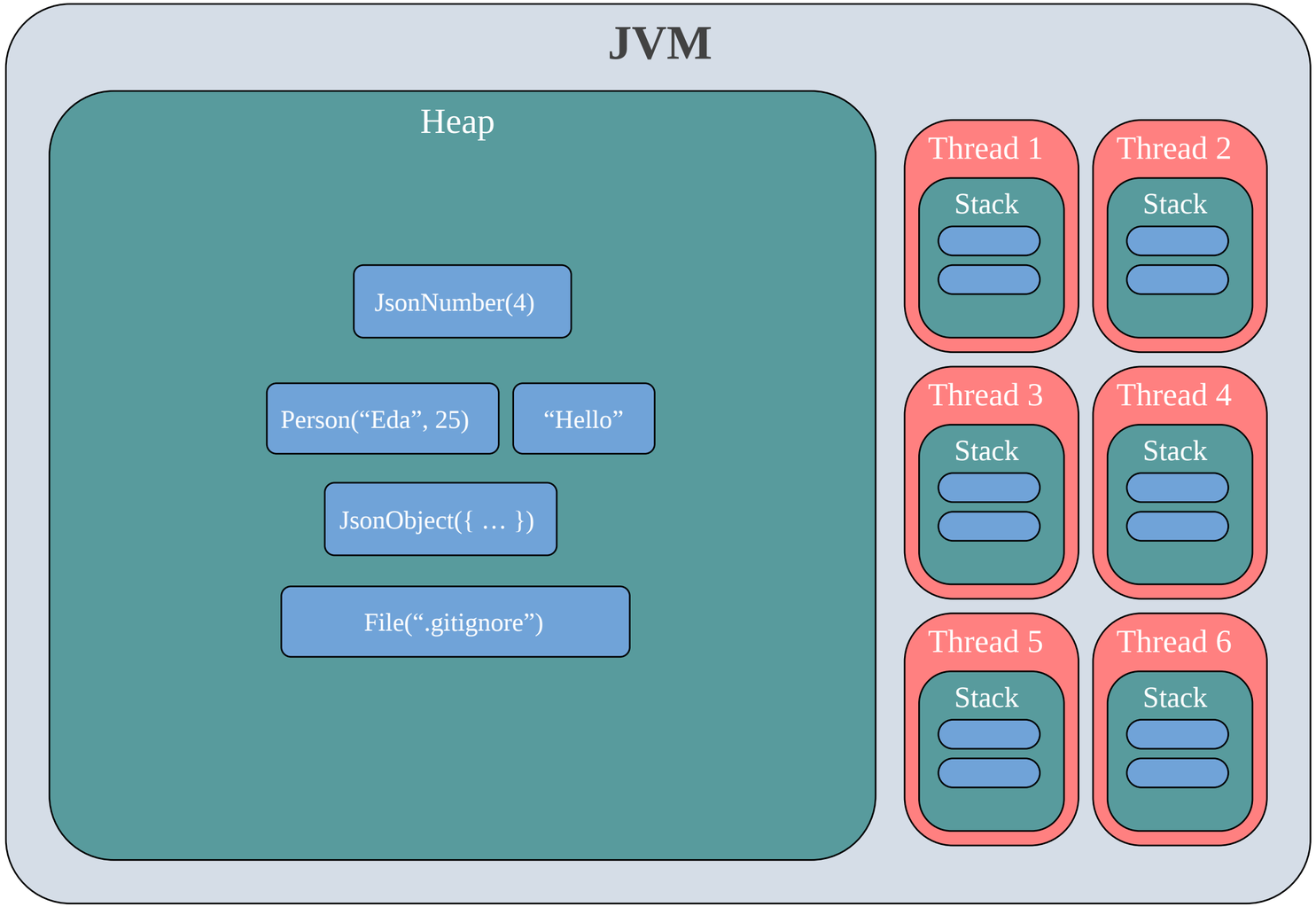

scala-seed-
project
build
.sbt
.gitignore
src
project
main
test
Dependencies
.scala
build
.properties
scala
scala
example
example
Hello
.scala
Hello
.scala
Legend
directory
file


Root
src
…
…
example
Hello
.scala
Legend
directory
file

JVM memory model



JVM memory model



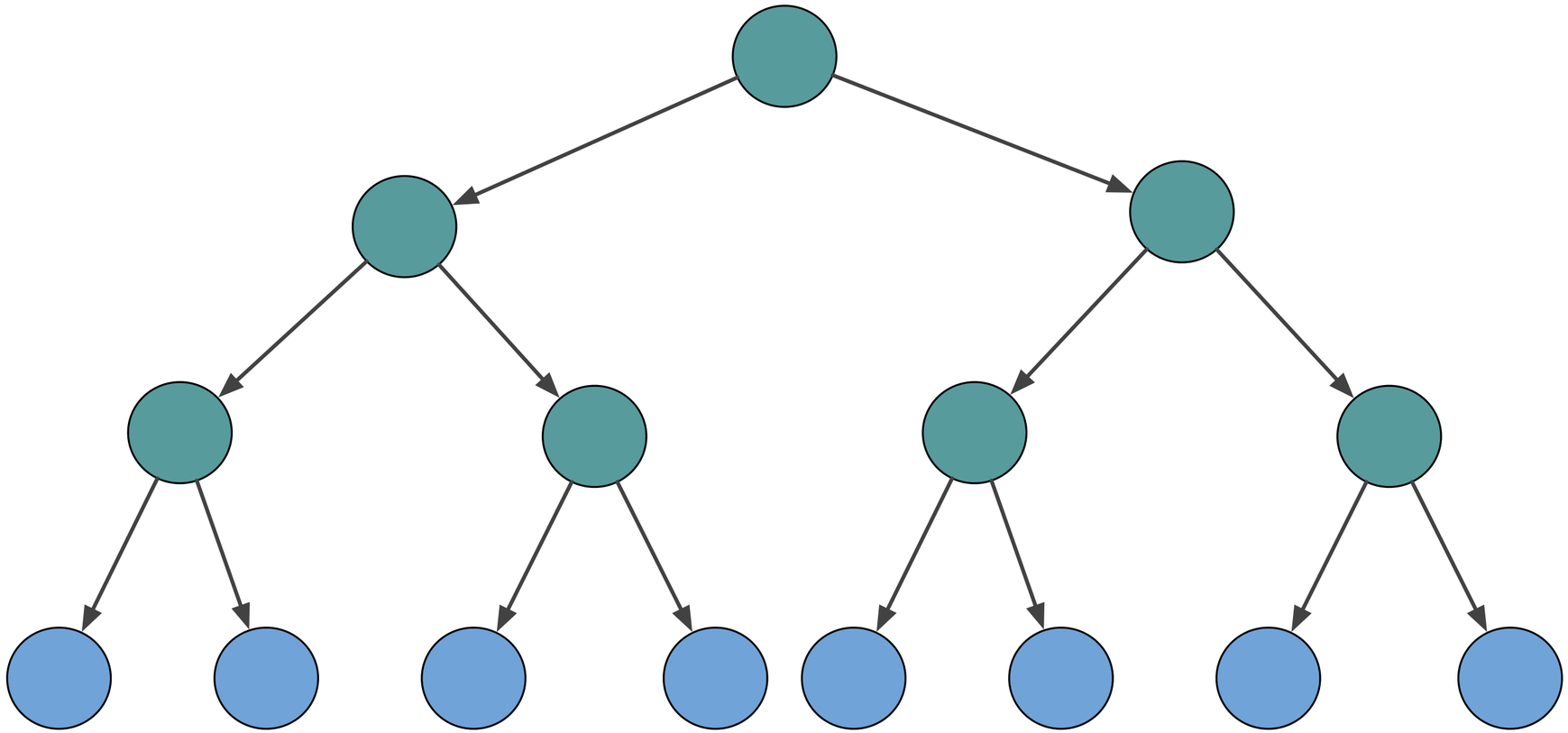
Explicit data structure

```
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
}
```

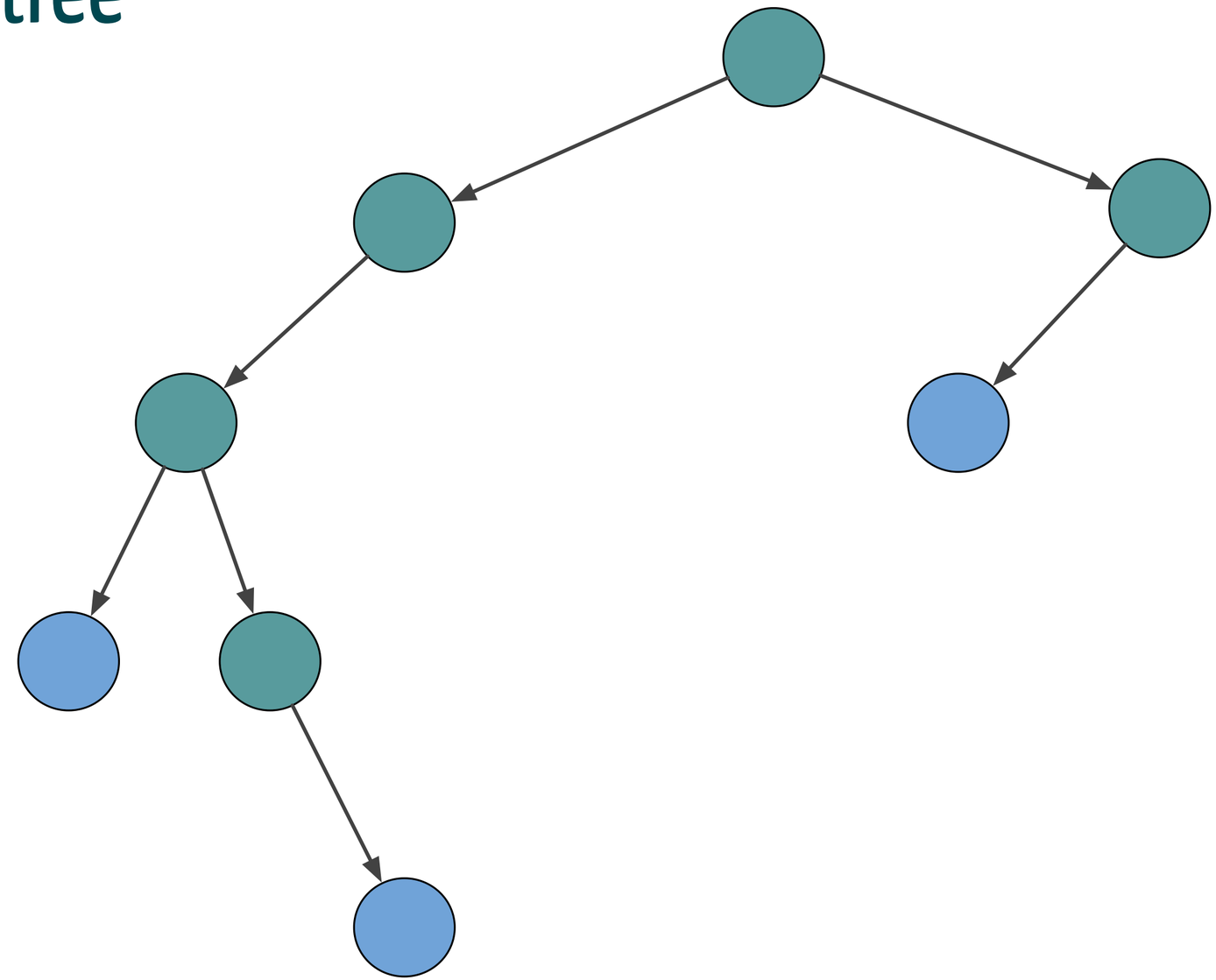
Implicit data structure

```
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()
```

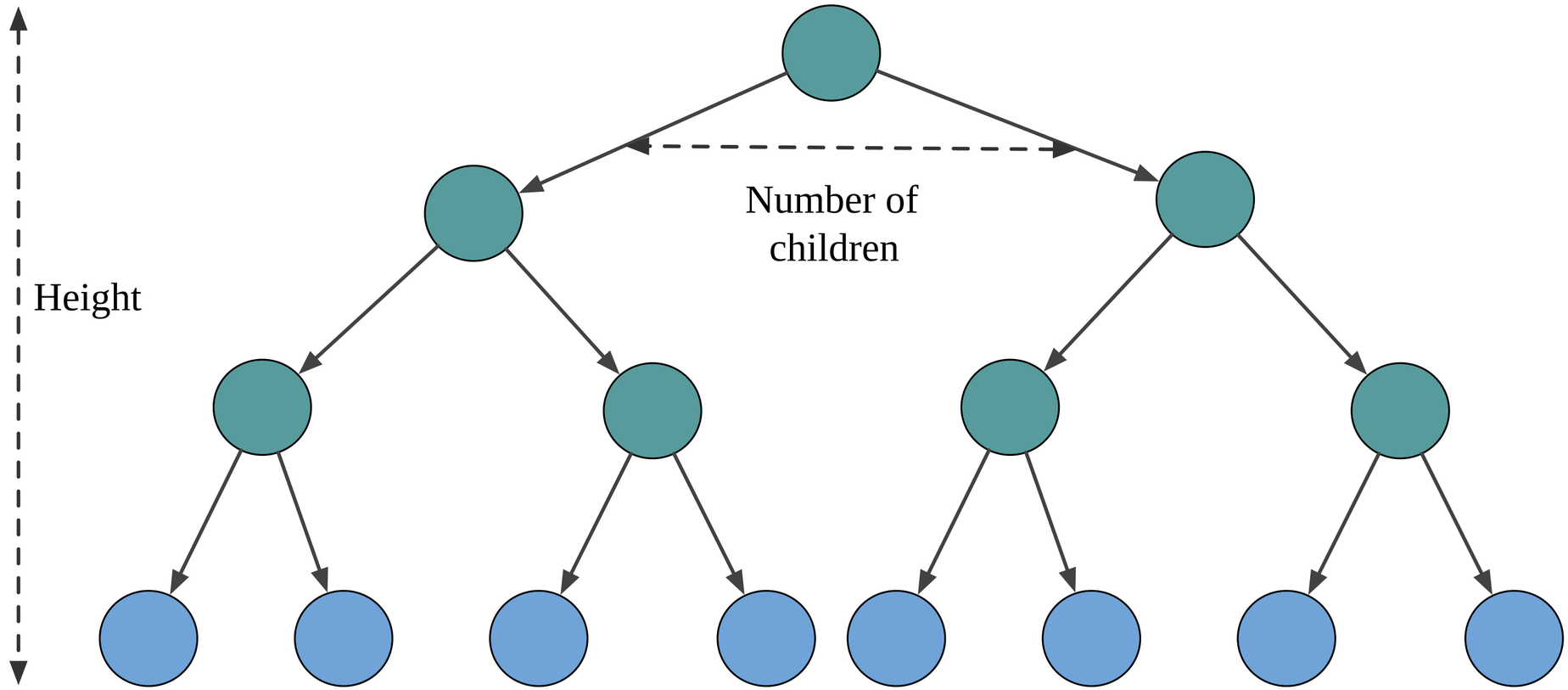
How many elements?



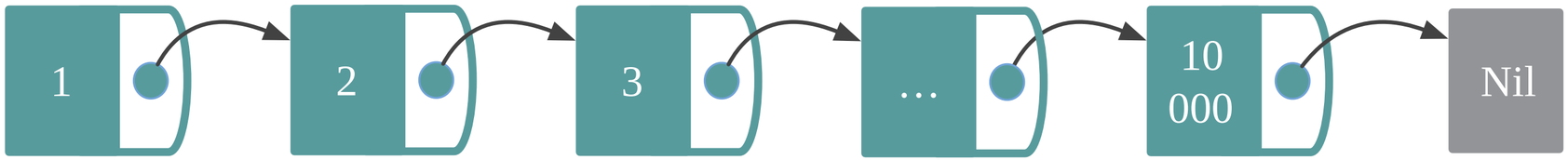
Unbalanced tree



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

```scala
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)
  }
```

```scala
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

```scala
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)
  }
```

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

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

Tailrec vs imperative

```scala
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)
  }
```

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

  for (number <- numbers)
    state += number

  state
}
```

Tailrec vs imperative

```scala
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)
```

```scala
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
}
```