ZLayer

A RAY TRACING EXERCISE

Amsterdam Scala
28 Feb 2020

ZIO-101: PROGRAMS

- ZIO programs are values
- Concurrency based on fibers (green threads)

```
val prg: ZIO[Console with Random, Nothing, Long] = for {
  n <- random.nextLong                    // ZIO[Random, Nothing, Long]
  _ <- console.putStrLn(s"Extracted $n ") // ZIO[Console, Nothing, Unit]
} yield n

val allNrs: ZIO[Console with Random, Nothing, List[Long]] = ZIO.collectAll(List.fill(100)(prg))

val allNrsPar: ZIO[Console with Random, Nothing, List[Long]] = ZIO.collectAllPar(List.fill(100)(prg))

val allNrsParN: ZIO[Console with Random, Nothing, List[Long]] = ZIO.collectAllParN(10)(List.fill(100)(prg))
```

ZIO-101: R MEANS REQUIREMENT

```
val prg: ZIO[Console with Random, Nothing, Long] = ???

val autonomous: ZIO[Any, Nothing, Long] = ???

val getUserFromDb: ZIO[DBConnection, Nothing, User] = ???
```

ZIO-101: REQUIREMENTS ELIMINATION

```
val getUserFromDb: ZIO[DBConnection, Nothing, User] = ???

val provided: ZIO[Any, Nothing, User] =
  getUserFromDb.provide(DBConnection(...))

val user: User = Runtime.default.unsafeRun(provided)
```

ZIO-101: MODULES

Example: a module to collect metrics[1]

```
type Metrics = Has[Metrics.Service]
object Metrics {
  trait Service {
    def inc(label: String): IO[Nothing, Unit]
  }

  //accessor method
  def inc(label: String): ZIO[Metrics, Nothing, Unit] =
      ZIO.accessM(_.get.inc(label))
  }
}
```

[1] ZIO 1.0.0-RC17+443

ZIO-101: MODULES

Example: a module for logging

```
type Log = Has[Log.Service]
object Log {
  trait Service {
    def info(s: String): IO[Nothing, Unit]
    def error(s: String): IO[Nothing, Unit]
  }

  //accessor methods...
}
```

ZIO-101: MODULES

Write a program using existing modules

```
val prg: ZIO[Metrics with Log, Nothing, Unit] =
  for {
    _ <- Log.info("Hello")
    _ <- Metrics.inc("salutation")
    _ <- Log.info("Amsterdam")
    _ <- Metrics.inc("subject")
  } yield ()
```

ZIO-101: THE `Has` DATA TYPE

`Has[A]` is a dependency on a service of type `A`

```
val hasLog: Has[Log.Service]           // type Log     = Has[Log.Service]
val hasMetrics: Has[Metrics.Service] // type Metrics = Has[Metrics.Service]
val mix: Log with Metrics = hasLog ++ hasMetrics

//access each service
mix.get[Log.Service].info("Starting the application")
```

ZIO-101: THE `Has` DATA TYPE

```
val mix: Log with Metrics = hasLog ++ hasMetrics

mix.get[Log.Service].info("Starting the application")
```

- Is more powerful than trait mixins
- Is backed by a heterogeneus map `ServiceType -> Service`
- Can replace/update services

ZIO-101: `ZLayer`

```
ZLayer[-RIn, +E, +ROut <: Has[_]]
```

- A recipe to build an `ROut`
- Backed by `ZManaged`: safe acquire/release
- `type NoDeps[+E, +B <: Has[_]] = ZLayer[Any, E, B]`

ZIO-101: ZLayer

Construct from value

```
val layer: ZLayer.NoDeps[Nothing, UserRepo] =
  ZLayer.succeed(new UserRepo.Service)
```

ZIO-101: ZLayer

Construct from function

```
val layer: ZLayer[Connection, Nothing, UserRepo] =
  ZLayer.fromFunction { c: Connection =>
    new UserRepo.Service
  }
```

ZIO-101: ZLayer

Construct from effect

```
import java.sql.Connection

val e: ZIO[Connection, Error, UserRepo.Service]

val layer: ZLayer[Connection, Error, UserRepo] =
  ZLayer.fromEffect(e)
```

ZIO-101: ZLayer

Construct from resources

```
import java.sql.Connection

val connectionLayer: ZLayer.NoDeps[Nothing, Has[Connection]] =
  ZLayer.fromAcquireRelease(makeConnection) { c =>
     UIO(c.close())
  }
```

ZIO-101: ZLayer

Construct from other services

```
val usersLayer: ZLayer[UserRepo with UserValidation, Nothing, BusinessLogic] =

  ZLayer.fromServices[UserRepo.Service, UserValidation.Service] {
    (repoSvc, validSvc) =>
      new BusinessLogic.Service {
        // use repoSvc and validSvc
      }
    }
```

ZIO-101: ZLayer

Compose horizontally
(all inputs for all outputs)

```
val l1: ZLayer[Connection, Nothing, UserRepo]
val l2: ZLayer[Config, Nothing, AuthPolicy]

val hor: ZLayer[Connection with Config, Nothing, UserRepo with AuthPolicy] =
  l1 ++ l2
```

ZIO-101: ZLayer

Compose vertically
(output of first for input of second)

```
val l1: ZLayer[Config, Nothing, Connection]
val l2: ZLayer[Connection, Nothing, UserRepo]

val ver: ZLayer[Config, Nothing, UserRepo] =
  l1 >>> l2
```

ZIO-101: ZLayer

Create module instances

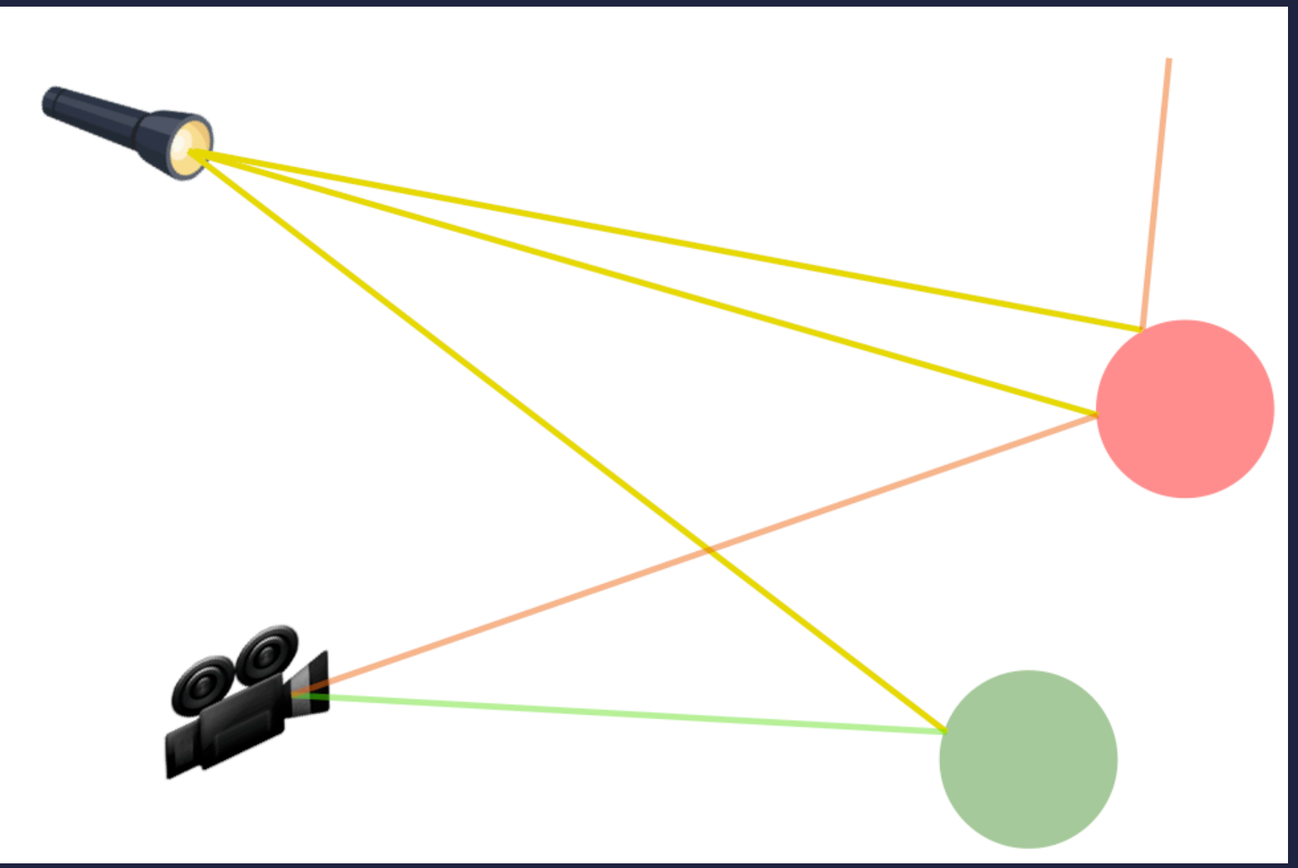
```scala
type UserRepo = Has[UserRepo.Service]

object UserRepo {
  trait Service {
    def getUser(userId: UserId): IO[DBError, Option[User]]
    def createUser(user: User): IO[DBError, Unit]
  }

  val inMemory: ZLayer.NoDeps[Nothing, UserRepo] = ZLayer.succeed(
    new Service {
      /* impl */
    }
  )

  val db: ZLayer[Connection, Nothing, UserRepo] = ZLayer.fromService { conn: Connection =>
    new Service {
      /* impl uses conn */
    }
  }
}
```

ZIO-101: ZLayer

Provide layers to programs

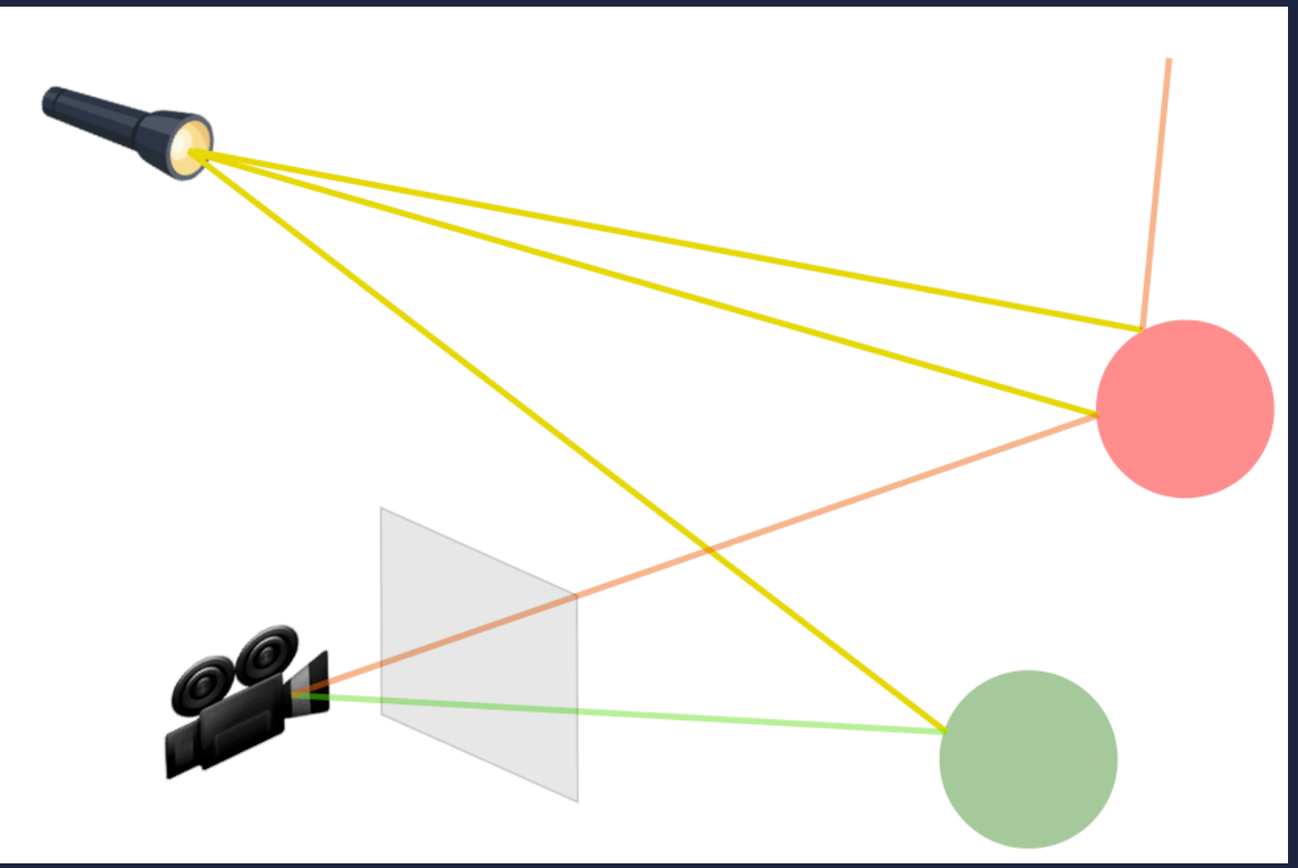
```
import zio.console.Console
val checkUser: ZIO[UserRepo with AuthPolicy with Console, Nothing, Boolean]

val liveLayer = UserRepo.inMemory ++ AuthPolicy.basicPolicy ++ Console.live

val full: ZIO[Any, Nothing, Boolean] = checkUser.provideLayer(
  liveLayer
)

val partial: ZIO[Console, Nothing, Boolean] = checkUser.provideSomeLayer(
  UserRepo.inMemory ++ AuthPolicy.basicPolicy
)

val updated: ZIO[Any, Nothing, Boolean] = checkUser.provideLayer(
  liveLayer ++ UserRepo.postgres
)
```

RAY TRACING



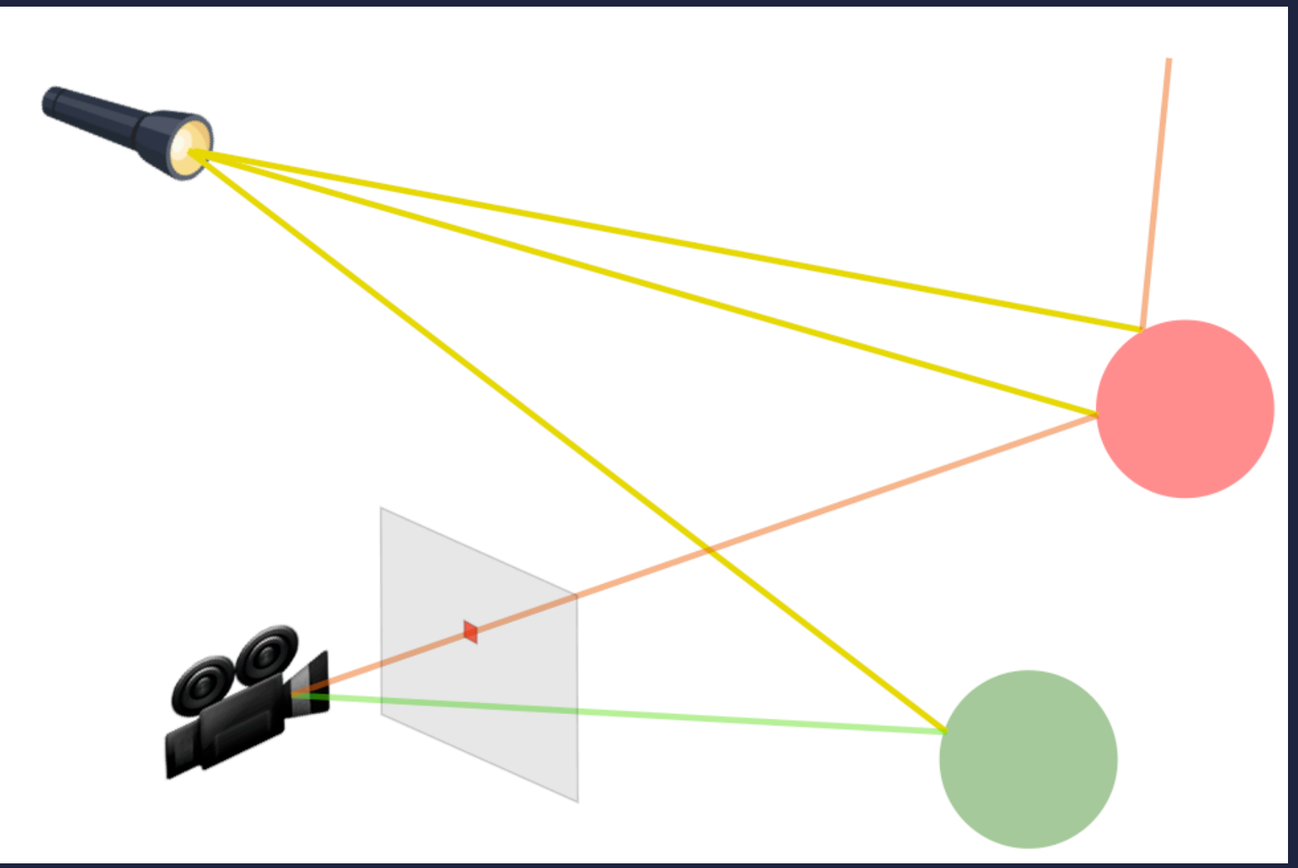
- World (spheres), light source, camera
- Incident rays
- Reflected rays

RAY TRACING



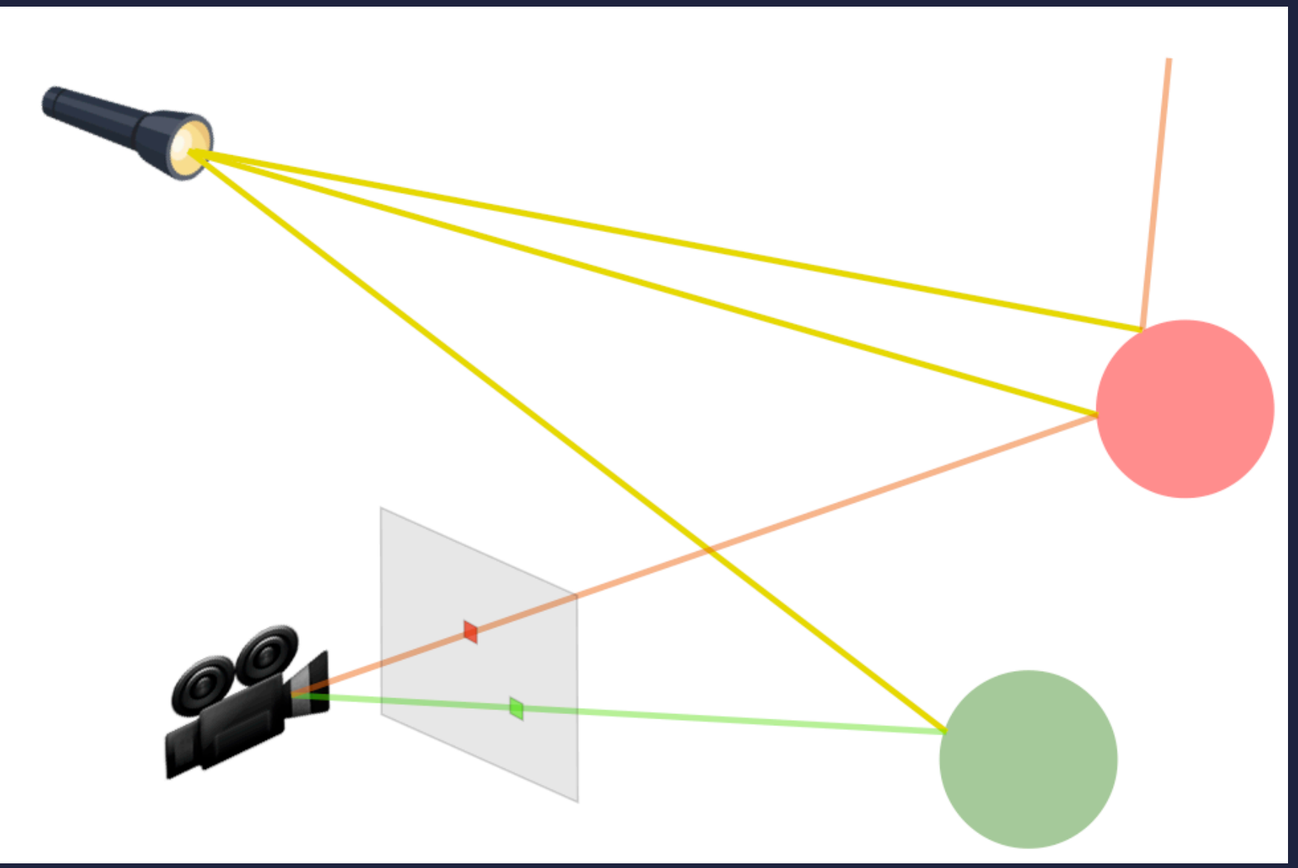
- World (spheres), light source, camera
- Incident rays
- Reflected rays
- Discarded rays
- Canvas

RAY TRACING



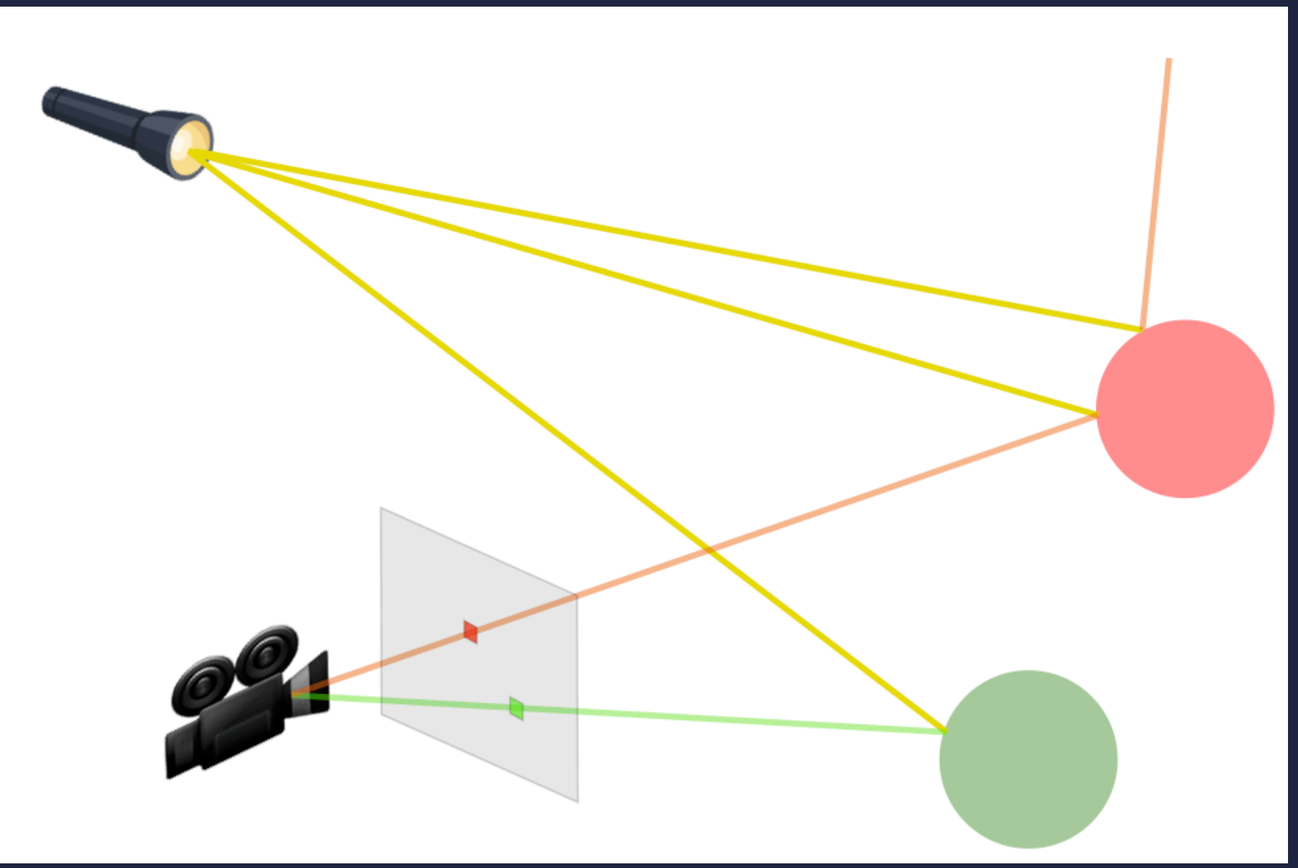
- World (spheres), light source, camera
- Incident rays
- Reflected rays
- Discarded rays
- Canvas
- Colored pixels

RAY TRACING



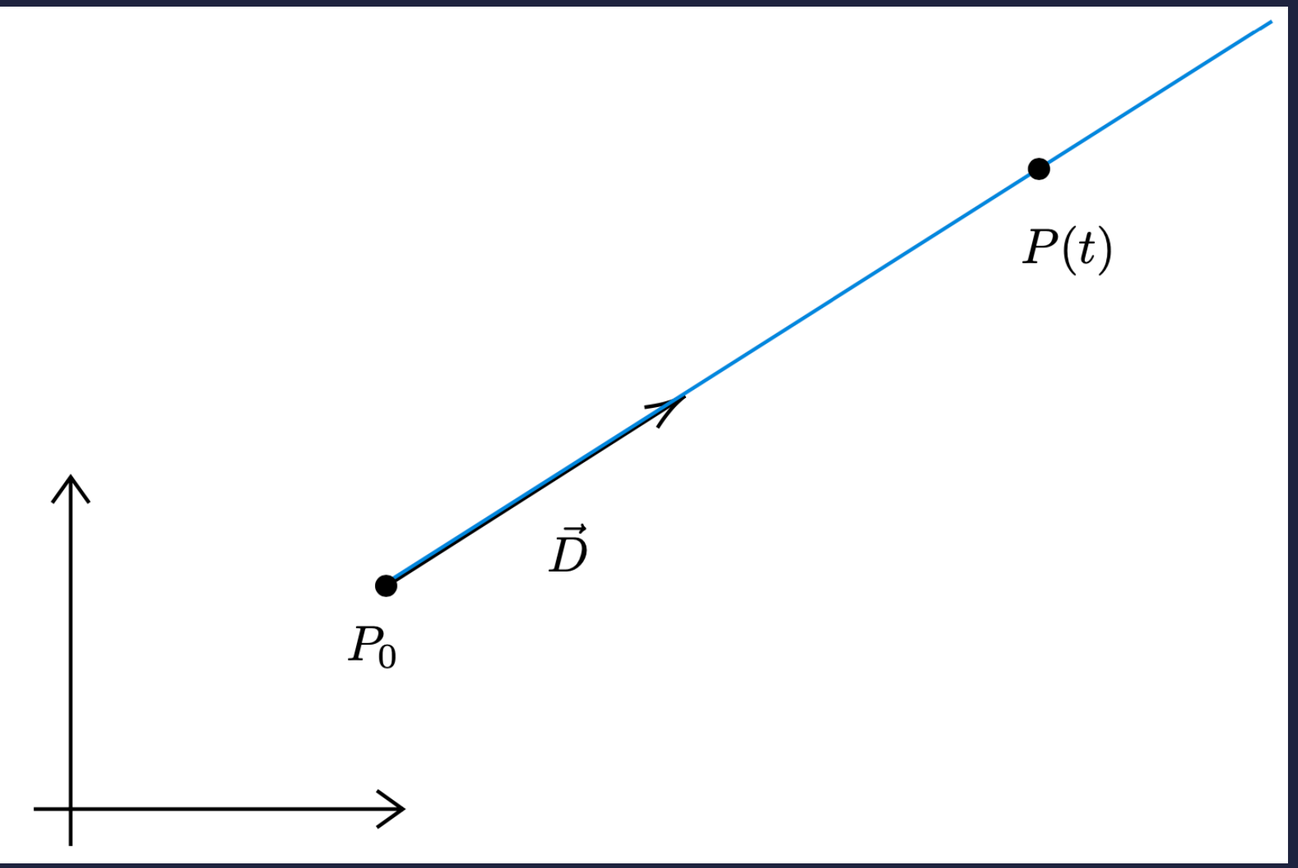
- World (spheres), light source, camera
- Incident rays
- Reflected rays
- Discarded rays
- Canvas
- Colored pixels

RAY TRACING



Options:

1. Compute all the rays (and discard most of them)
2. Compute only the rays outgoing from the camera through the canvas, and determine how they behave on the surfaces



RAY

$$P(t) = P_0 + t\vec{D}, t > 0$$

```
case class Ray(origin: Pt, direction: Vec) {
  def positionAt(t: Double): Pt =
    origin + (direction * t)
}
```

TRANSFORMATIONS MODULE

```
trait AT

type ATModule = Has[ATModule.Service]
object ATModule {
  /* Service */
  trait Service {
    def applyTf(tf: AT, vec: Vec): ZIO[ATError, Vec]
    def applyTf(tf: AT, pt: Pt): ZIO[ATError, Pt]
    def compose(first: AT, second: AT): ZIO[ATError, AT]
  }

  def applyTf(tf: AT, vec: Vec): ZIO[ATModule, ATError, Vec] =
    ZIO.accessM(_.aTModule.applyTf(tf, vec))
  def applyTf(tf: AT, pt: Pt): ZIO[ATModule, ATError, Pt] =
    ZIO.accessM(_.aTModule.applyTf(tf, pt))
  def compose(first: AT, second: AT): ZIO[ATModule, ATError, AT] =
    ZIO.accessM(_.aTModule.compose(first, second))
}
```

TRANSFORMATIONS MODULE

```
val rotatedPt =
  for {
    rotateX <- ATModule.rotateX(math.Pi / 2)
    _       <- Log.info("rotated of π/2")
    res     <- ATModule.applyTf(rotateX, Pt(1, 1, 1))
  } yield  res
```

TRANSFORMATIONS MODULE

```
val rotatedPt: ZIO[ATModule with Log, ATError, Pt] =
  for {
    rotateX <- ATModule.rotateX(math.Pi / 2)
    _       <- Log.info("rotated of π/2")
    res     <- ATModule.applyTf(rotateX, Pt(1, 1, 1))
  } yield  res
```

TRANSFORMATIONS MODULE - LIVE

```scala
val rotated: ZIO[ATModule, ATError, Vec] =
  for {
    rotateX <- ATModule.rotateX(math.Pi/2)
    res     <- ATModule.applyTf(rotateX, Pt(1, 1, 1))
  } yield res
```

- `Vec(x, y, z)` $\Rightarrow [x, y, z, 0]^T$
- `Pt(x, y, z)` $\Rightarrow [x, y, z, 1]^T$
-

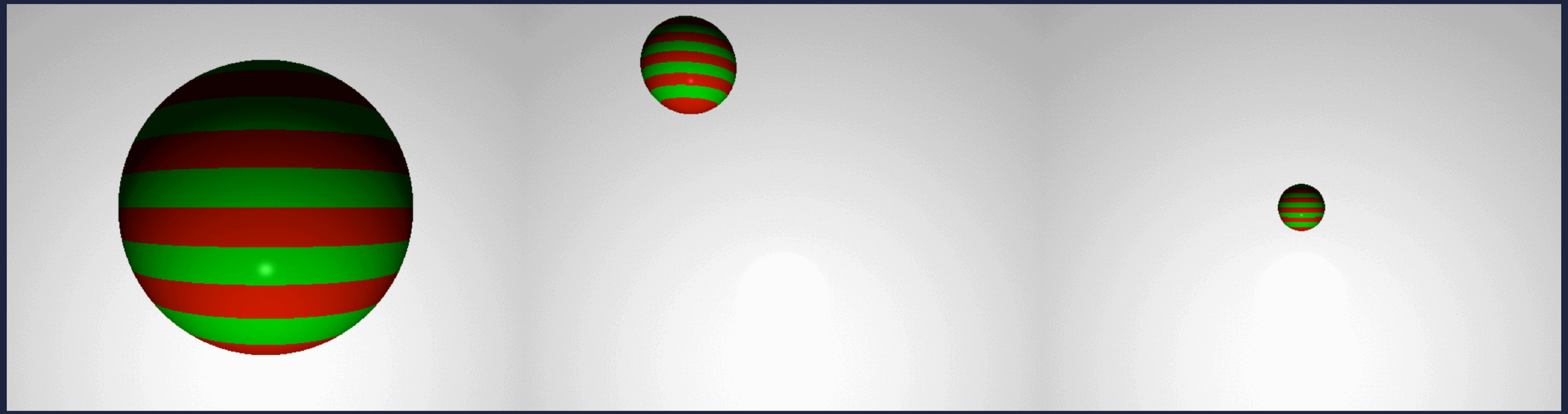
$$\texttt{rotated} = \begin{pmatrix} \cos \pi/2 & -\sin \pi/2 & 0 & 0 \\ \sin \pi/2 & \cos \pi/2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 0 \end{pmatrix}$$

TRANSFORMATIONS MODULE - LIVE

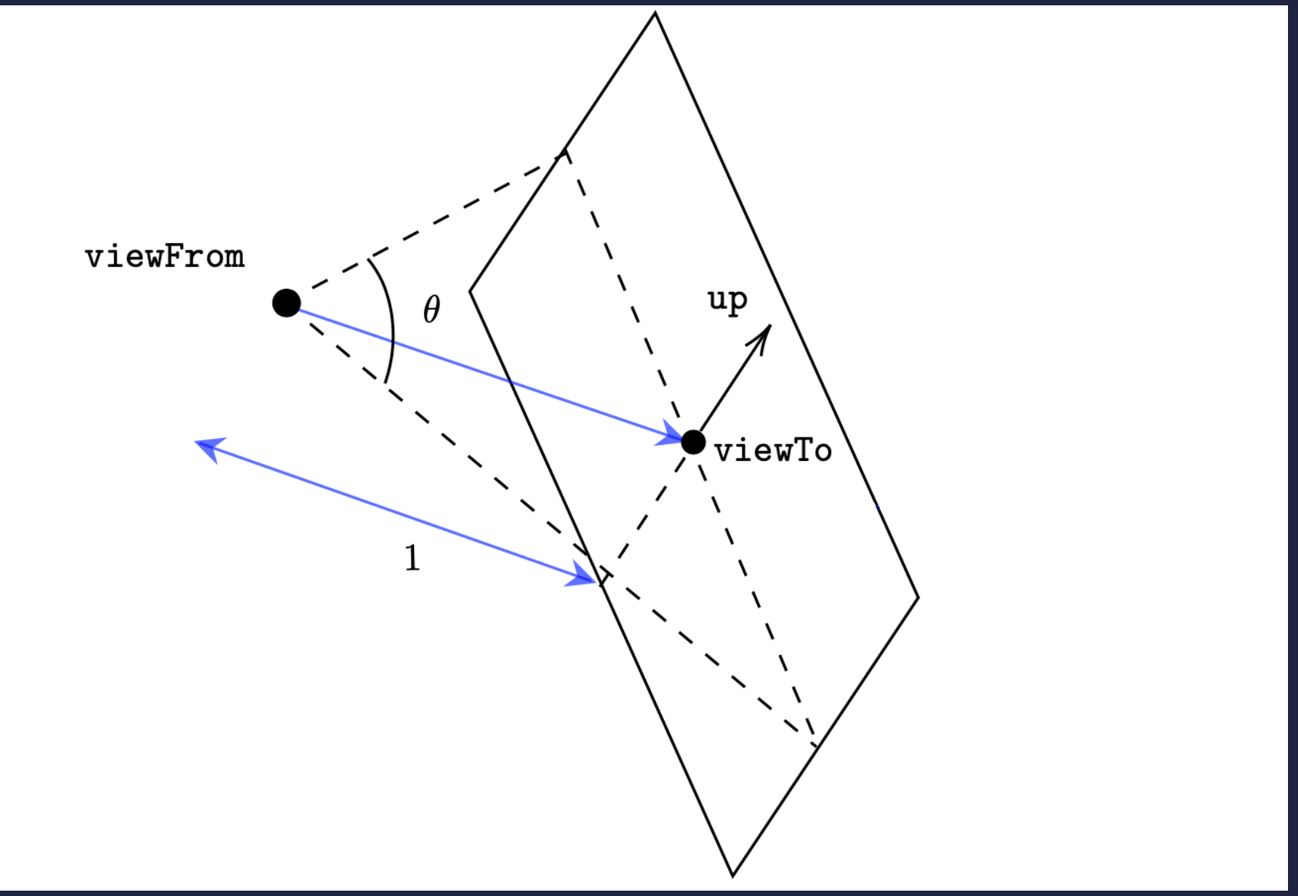
$$\texttt{rotated} = \begin{pmatrix} \cos \pi/2 & -\sin \pi/2 & 0 & 0 \\ \sin \pi/2 & \cos \pi/2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 0 \end{pmatrix}$$

```
val live: ZLayer[MatrixModule, Nothing, ATModule] =
  ZLayer.fromService { matrixSvc =>
    new Service {
      def applyTf(tf: AT, vec: Vec) =
        matrixSvc.mul(tf.direct, v)

      /* ...  */
    }
}
```

LAYER 1: TRANSFORMATIONS



CAMERA




```
object Camera {
  def make(
    viewFrom: Pt,
    viewTo: Pt,
    upDirection: Vec,
    visualAngleRad: Double,
    hRes: Int,
    vRes: Int):
    ZIO[ATModule, AlgebraicError, Camera] =
    worldTransformation(viewFrom, viewTo, upDirection).map {
      worldTf => Camera(hRes, vRes, visualAngleRad, worlfTf)
    }
```

WORLD

- `Sphere.canonical` $\{(x, y, z) : x^2 + y^2 + z^2 = 1\}$
- `Plane.canonical` $\{(x, y, z) : y = 0\}$

```
sealed trait Shape {
  def transformation: AT
  def material: Material
}

case class Sphere(transformation: AT, material: Material) extends Shape
case class Plane(transformation: AT, material: Material) extends Shape
```

WORLD

MAKE A WORLD

```
object Sphere {
  def make(center: Pt, radius: Double, mat: Material): ZIO[ATModule, ATError, Sphere] = for {
    scale     <- ATModule.scale(radius, radius, radius)
    translate <- ATModule.translate(center.x, center.y, center.z)
    composed  <- ATModule.compose(scale, translate)
  } yield Sphere(composed, mat)
}

object Plane {
  def make(...): ZIO[ATModule, ATError, Plane] = ???
}

case class World(pointLight: PointLight, objects: List[Shape])
```

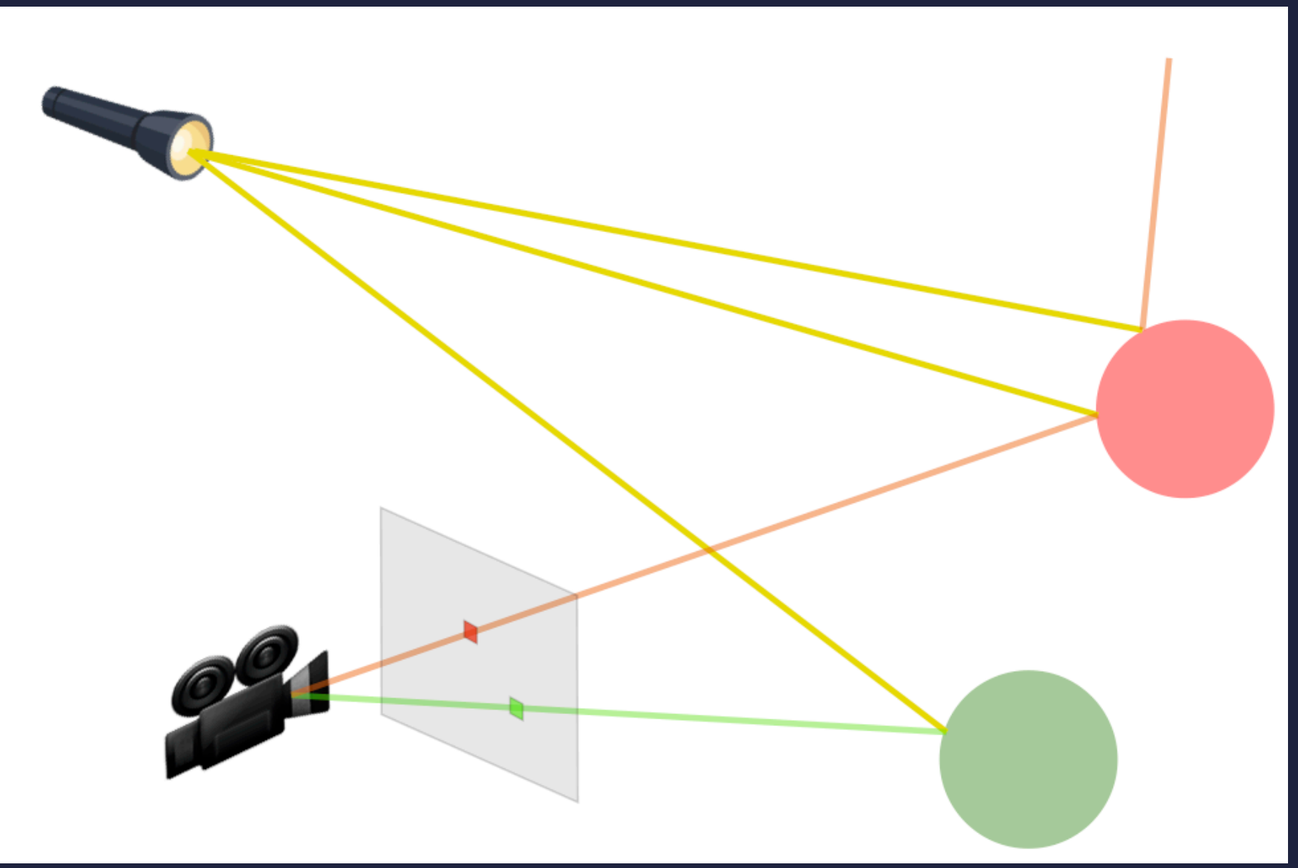
- Everything requires `ATModule`

WORLD RENDERING - TOP DOWN

RASTERING - GENERATE A STREAM OF COLORED PIXELS

```
type RasteringModule = Has[Service]
object RasteringModule {
  trait Service {
    def raster(world: World, camera: Camera):
      Stream[RayTracerError, ColoredPixel]
  }
}
```

WORLD RENDERING - TOP DOWN



RASTERING - *Live*

- Camera module - Ray per pixel

```
type CameraModule = Has[Service]
object CameraModule {
  trait Service {
    def rayForPixel(
      camera: Camera, px: Int, py: Int
    ): UIO[Ray]
  }
}
```

- World module - Color per ray

```
type WorldModule = Has[Service]
object WorldModule {
  trait Service {
    def colorForRay(
      world: World, ray: Ray
    ): IO[RayTracerError, Color]
  }
}
```

WORLD RENDERING - TOP DOWN

RASTERING *Live* - MODULE DEPENDENCY

```
val chunkRasteringModule: ZLayer[CameraModule with WorldModule, Nothing, RasteringModule] =
  ZLayer.fromServices[cameraModule.Service, worldModule.Service, rasteringModule.Service] {
    (cameraSvc, worldSvc) =>
      new Service {
        override def raster(world: World, camera: Camera):
          Stream[Any, RayTracerError, ColoredPixel] = {
          val pixels: Stream[Nothing, (Int, Int)] = ???
          pixels.mapM{
            case (px, py) =>
              for {
                ray   <- cameraModule.rayForPixel(camera, px, py)
                color <- worldModule.colorForRay(world, ray)
              } yield data.ColoredPixel(Pixel(px, py), color)
          }
      }
    }
  }
```

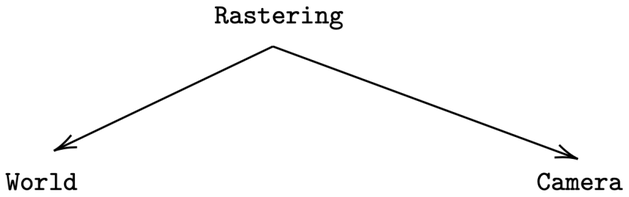
LAYERS

TAKEAWAY

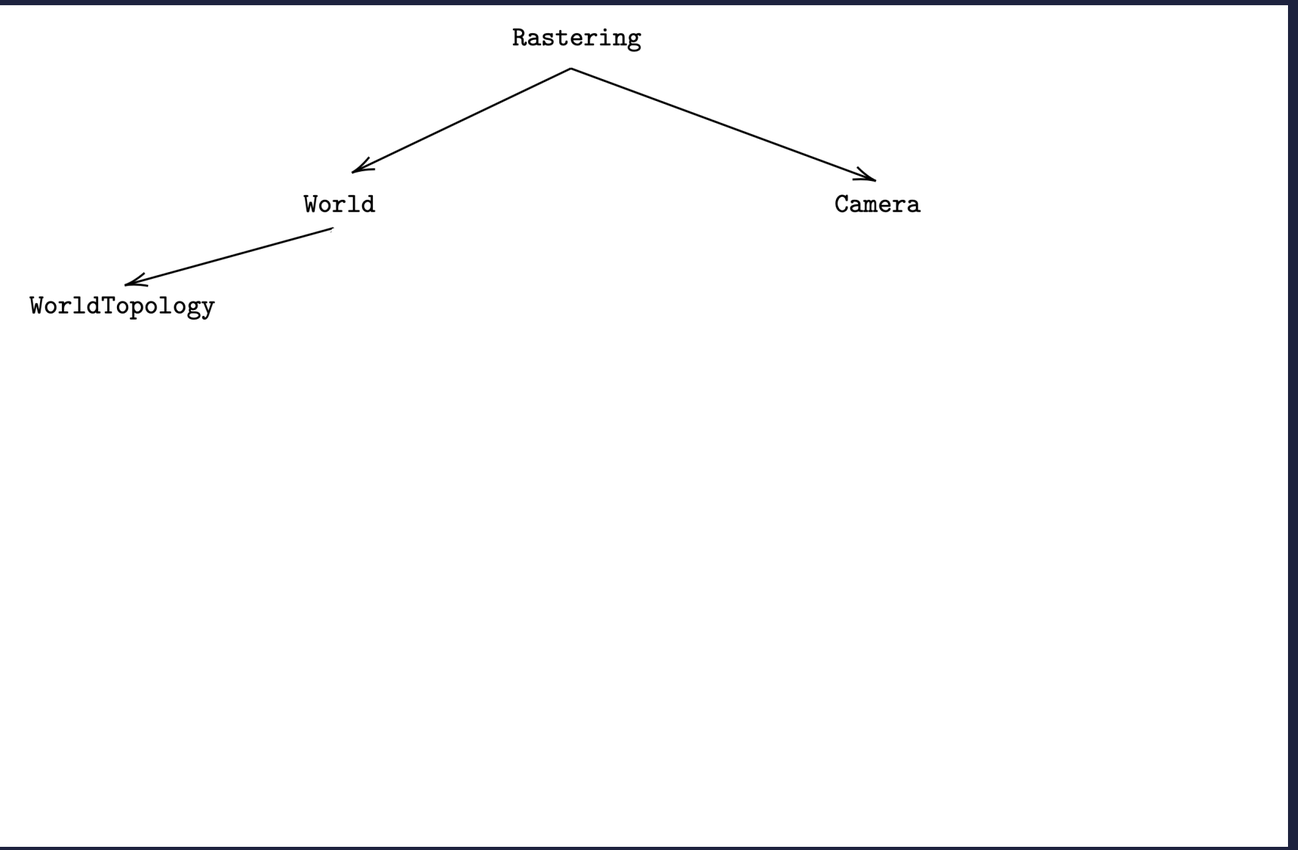
IMPLEMENT AND TEST EVERY LAYER ONLY IN TERMS OF THE IMMEDIATELY UNDERLYING LAYER


IT'S MODULES
ALL THE WAY DOWN
imgflip.com

LIVE CameraModule




```scala
object CameraModule {
  val live: ZLayer[ATModule, Nothing, CameraModule] =
    ZLayer.fromService { atSvc =>
      /* ... */
    }
}
```



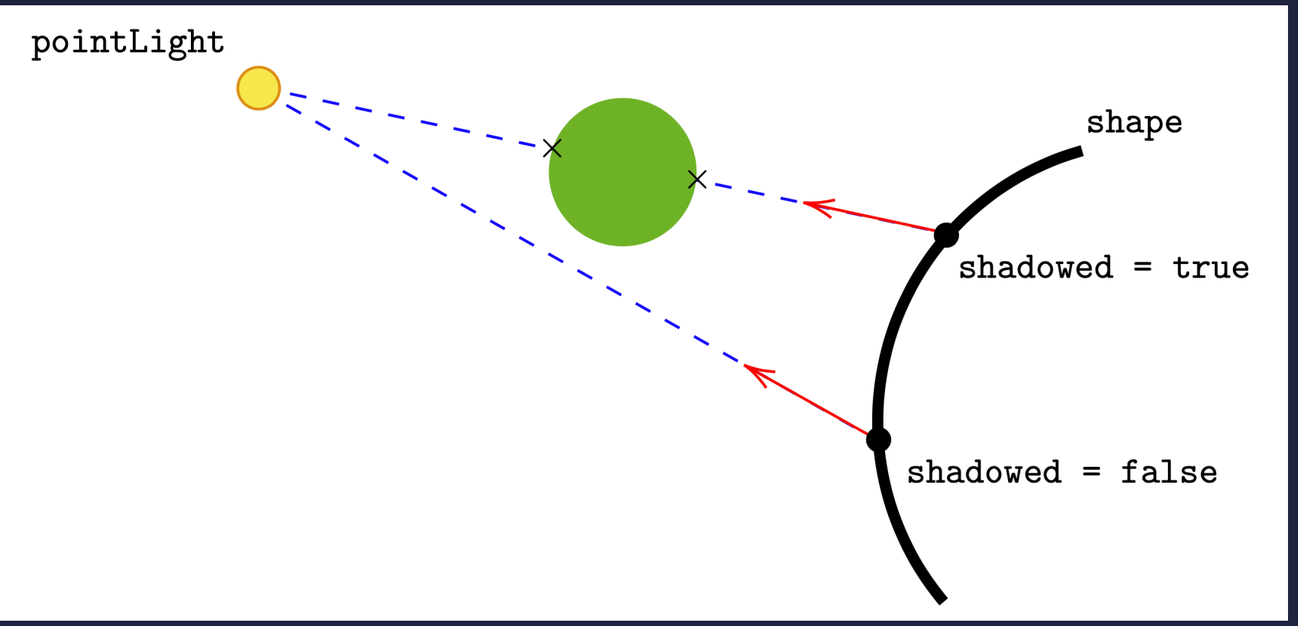
LIVE WorldModule

WorldTopologyModule

```
object WorldTopologyModule {
  trait Service {
    def intersections(world: World, ray: Ray):
      UIO[List[Intersection]]

    def isShadowed(world: World, pt: Pt):
      UIO[Boolean]
  }
}
```

LIVE WorldModule



WorldTopologyModule

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object WorldTopologyModule {
  trait Service {
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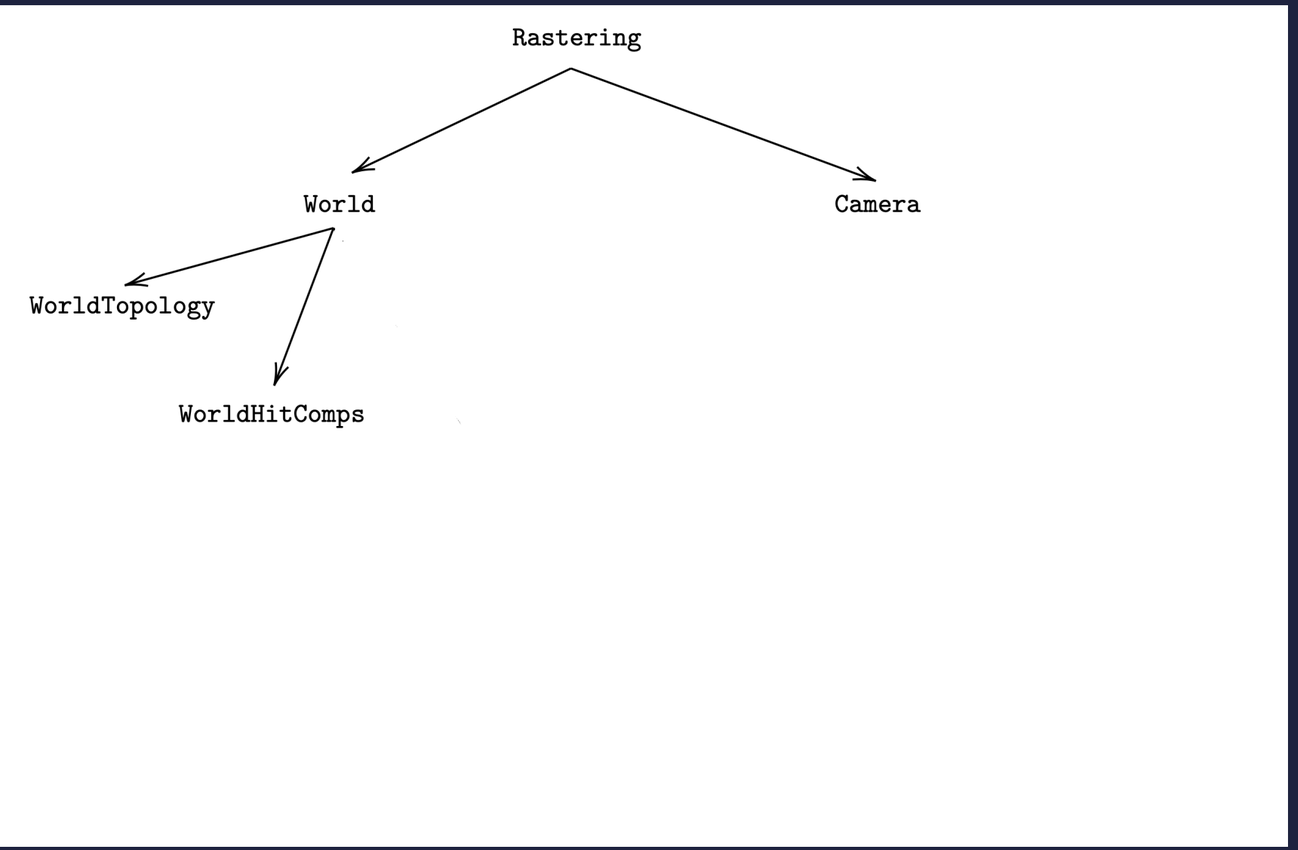
      UIO[List[Intersection]]

    def isShadowed(world: World, pt: Pt):
      UIO[Boolean]
  }
}
```

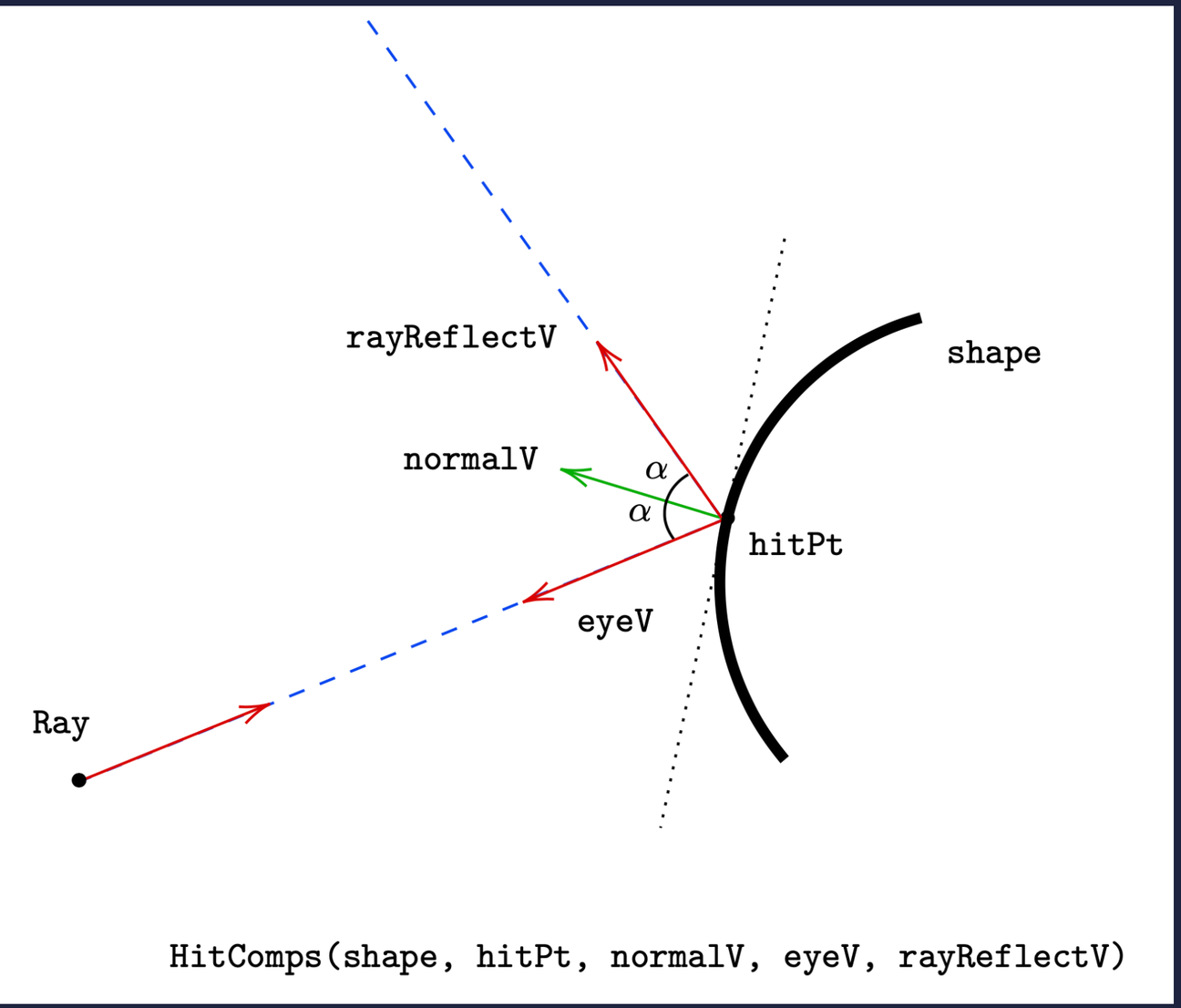


LIVE WorldModule

WorldHitCompsModule

```
case class HitComps(
  shape: Shape, hitPt: Pt, normalV: Vec, eyeV: Vec,
  rayReflectV: Vec, n1: Double = 1, n2: Double = 1
)

object WorldHitCompsModule {
  trait Service {
    def hitComps(
      ray: Ray, hit: Intersection,
      intersections: List[Intersection]
    ): IO[GenericError, HitComps]
  }
}
```



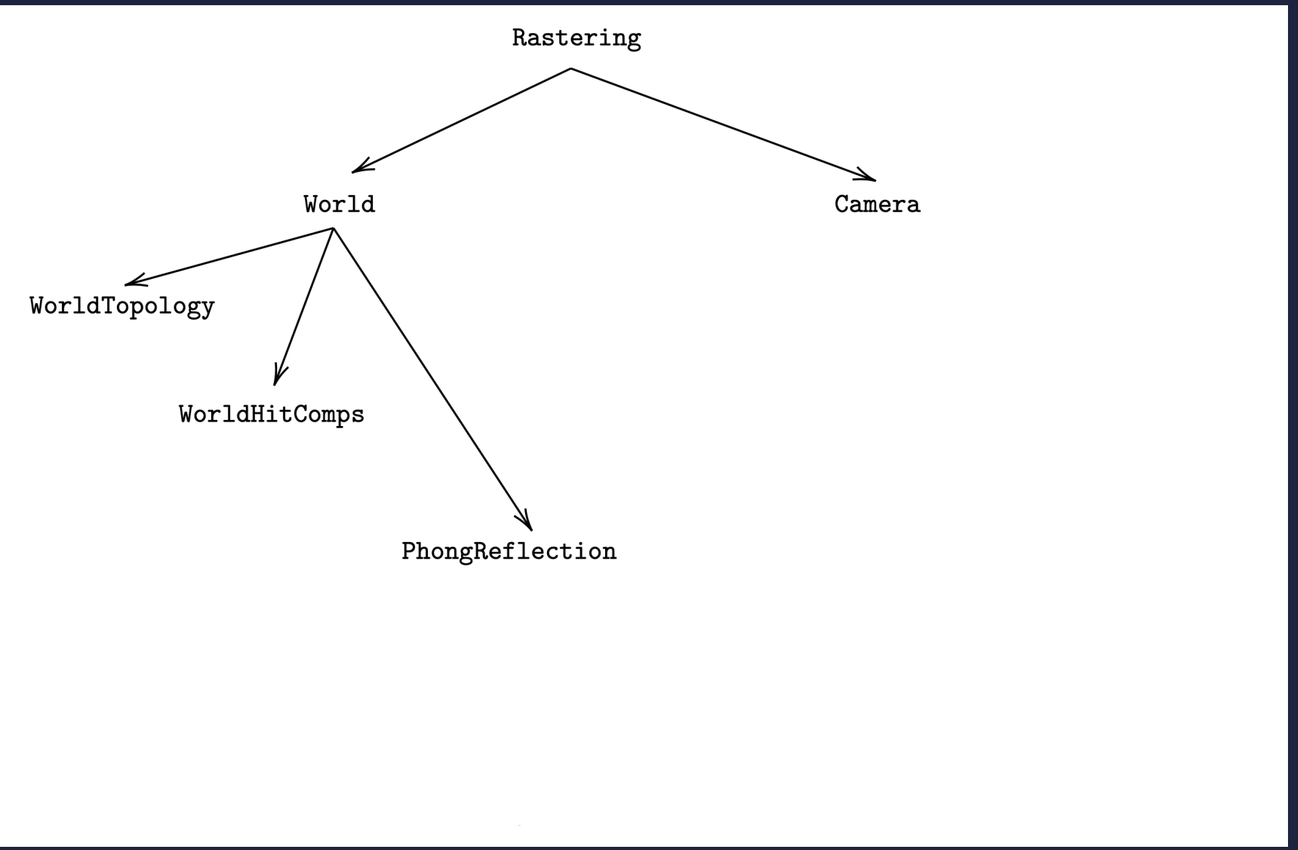
HitComps(shape, hitPt, normalV, eyeV, rayReflectV)

LIVE WorldModule

WorldHitCompsModule

```
case class HitComps(
  shape: Shape, hitPt: Pt, normalV: Vec, eyeV: Vec,
  rayReflectV: Vec, n1: Double = 1, n2: Double = 1
)

object WorldHitCompsModule {
  trait Service {
    def hitComps(
      ray: Ray, hit: Intersection,
      intersections: List[Intersection]
    ): IO[GenericError, HitComps]
  }
}
```

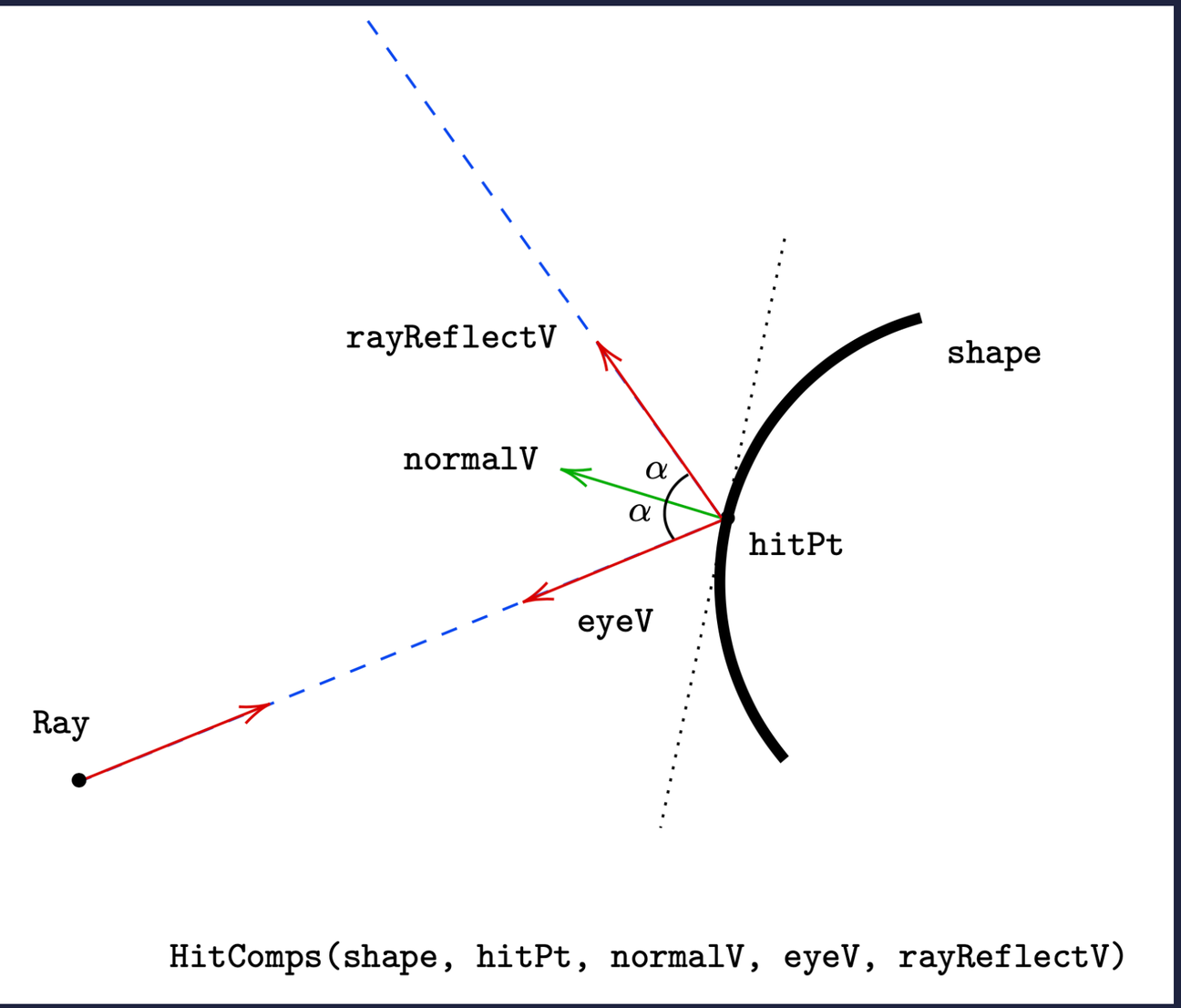


LIVE WorldModule

PhongReflectionModule

```
case class PhongComponents(
  ambient: Color, diffuse: Color, reflective: Color
) {
  def toColor: Color = ambient + diffuse + reflective
}

object PhongReflectionModule {
  trait Service {
    def lighting(
      pointLight: PointLight, hitComps: HitComps,
      inShadow: Boolean
    ): UIO[PhongComponents]
  }
}
```



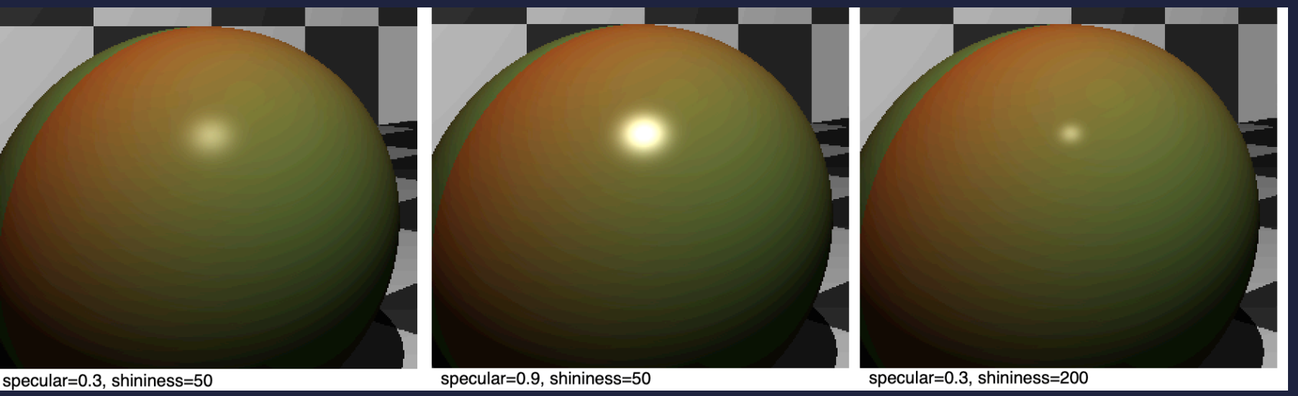
LIVE WorldModule

PhongReflectionModule

```
case class PhongComponents(
  ambient: Color, diffuse: Color, reflective: Color
) {
  def toColor: Color = ambient + diffuse + reflective
}

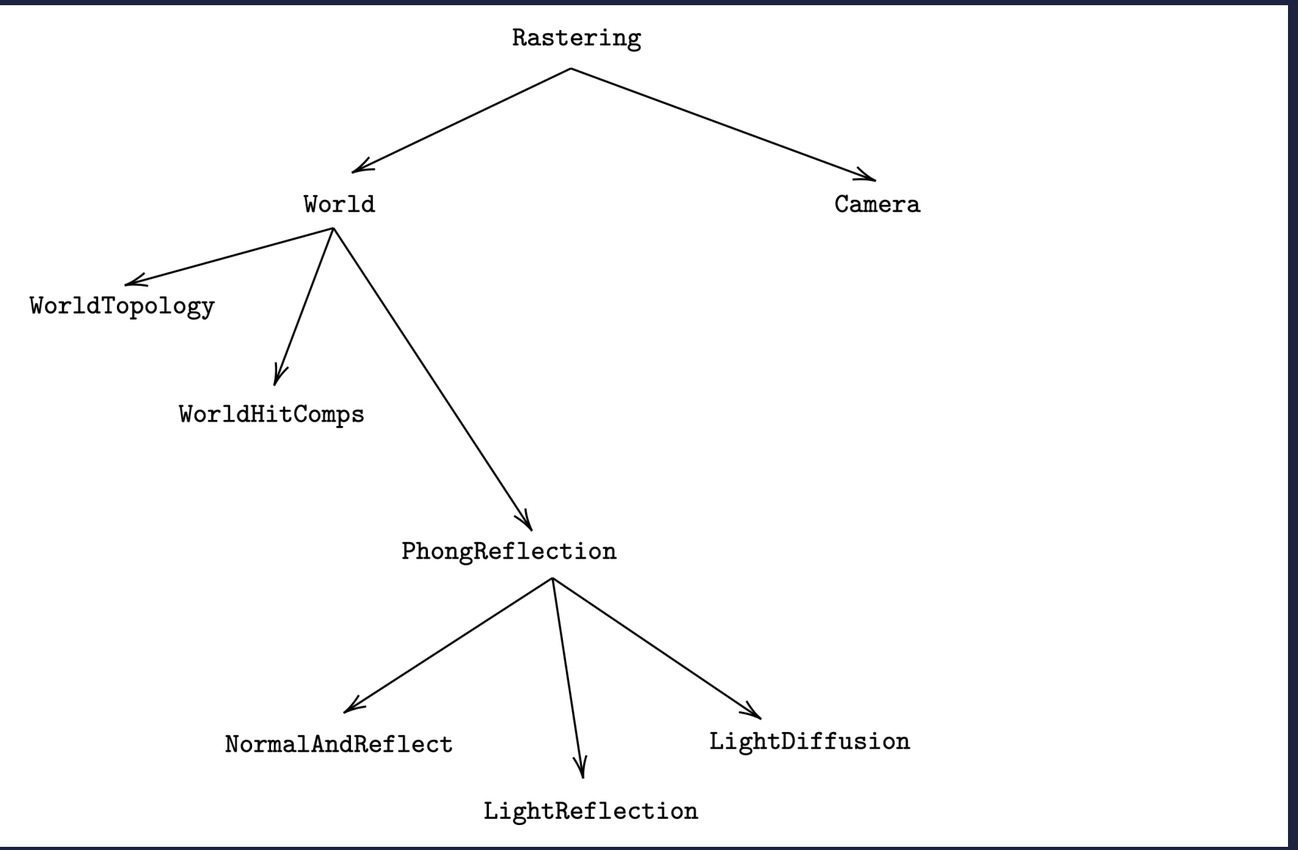
object PhongReflectionModule {
  trait Service {
    def lighting(
      pointLight: PointLight, hitComps: HitComps,
      inShadow: Boolean
    ): UIO[PhongComponents]
  }
}
```

REFLECT THE LIGTHT SOURCE



Describe material properties

```
case class Material(
  color: Color, // the basic color
  ambient: Double,  // ∈ [0, 1]
  diffuse: Double,  // ∈ [0, 1]
  specular: Double, // ∈ [0, 1]
  shininess: Double, // ∈ [10, 200]
)
```



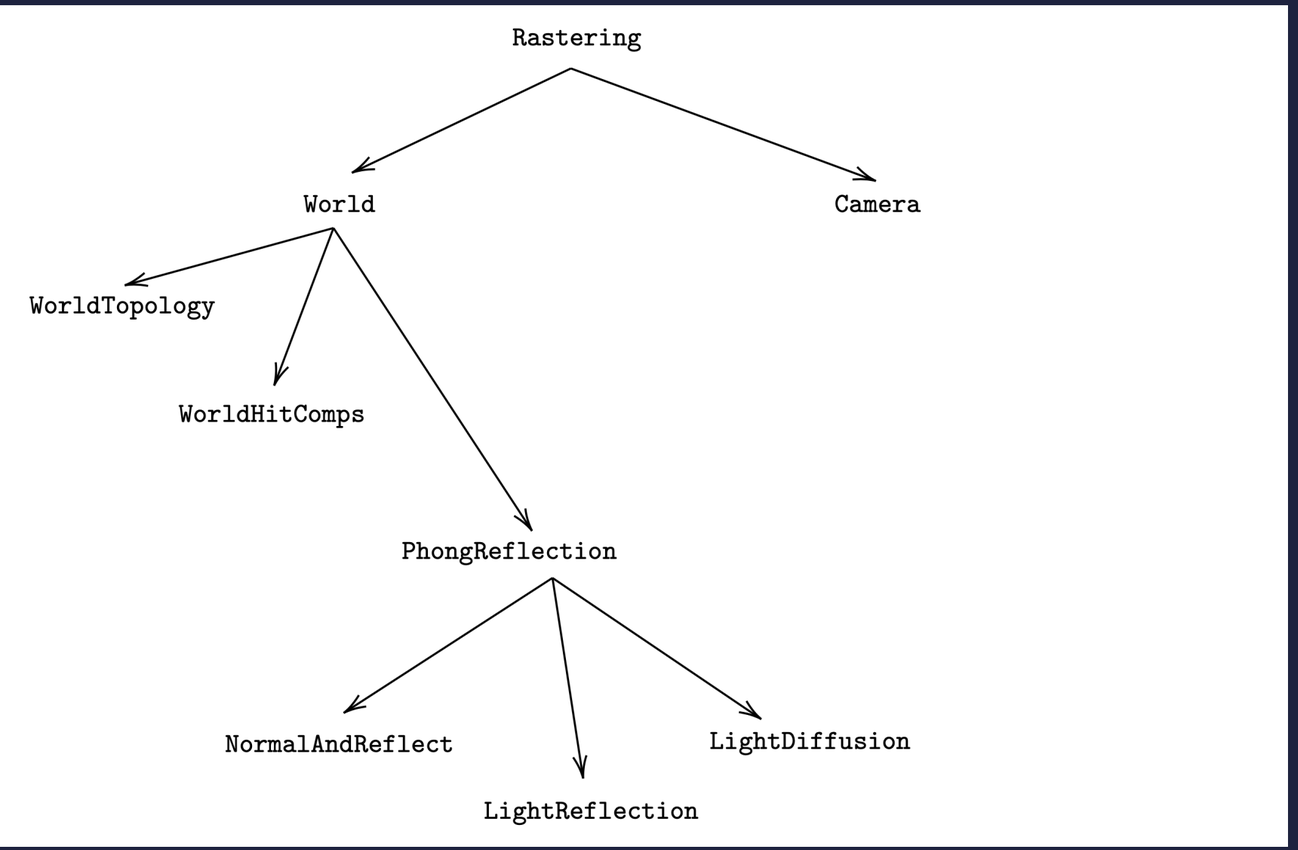
LIVE PhongReflectionModule

WITH LightDiffusion AND LightReflection

```
object PhongReflectionModule {
  trait Service { }

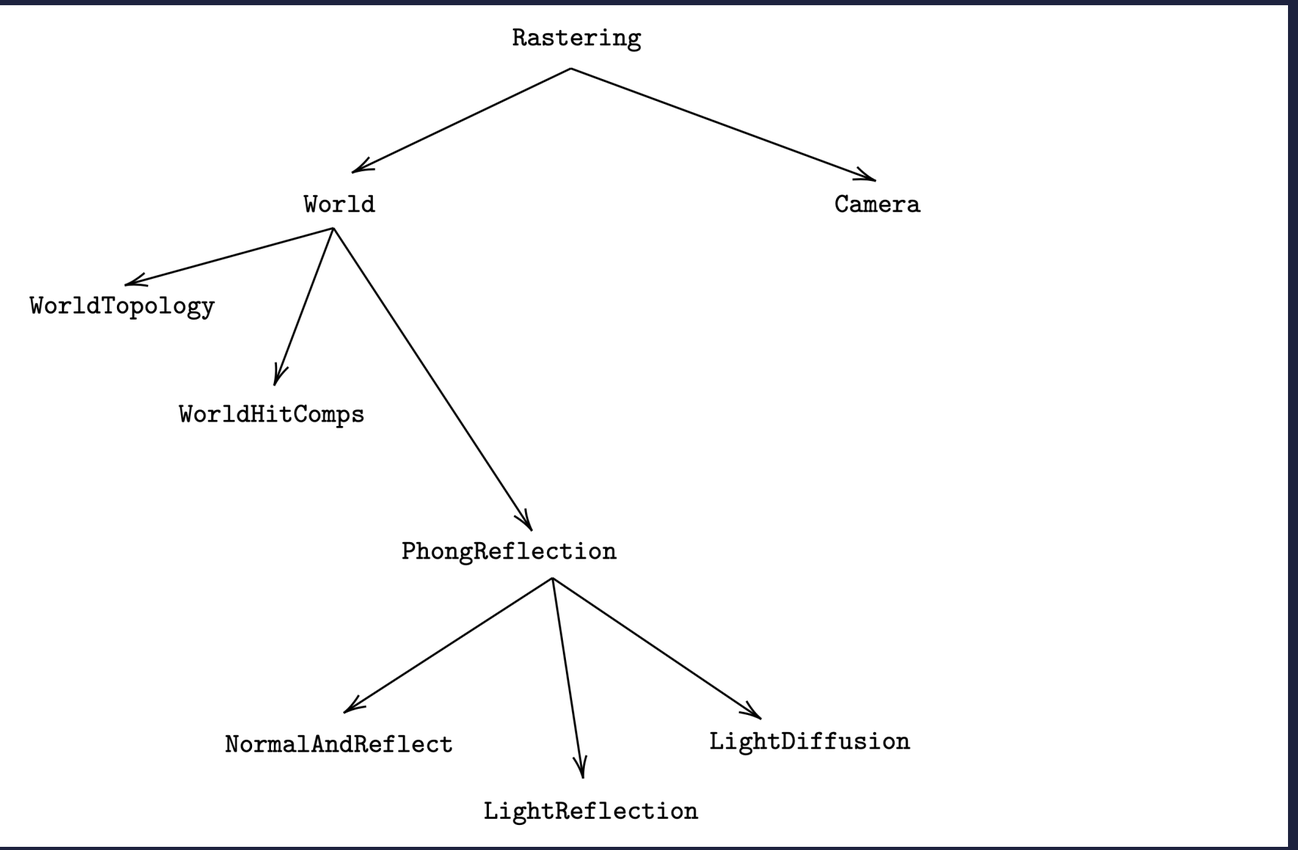
  val live: ZLayer[ATModule
    with LightDiffusionModule
    with LightReflectionModule,
    Nothing,
    PhongReflectionModule]
}
```

DRAWING PROGRAM

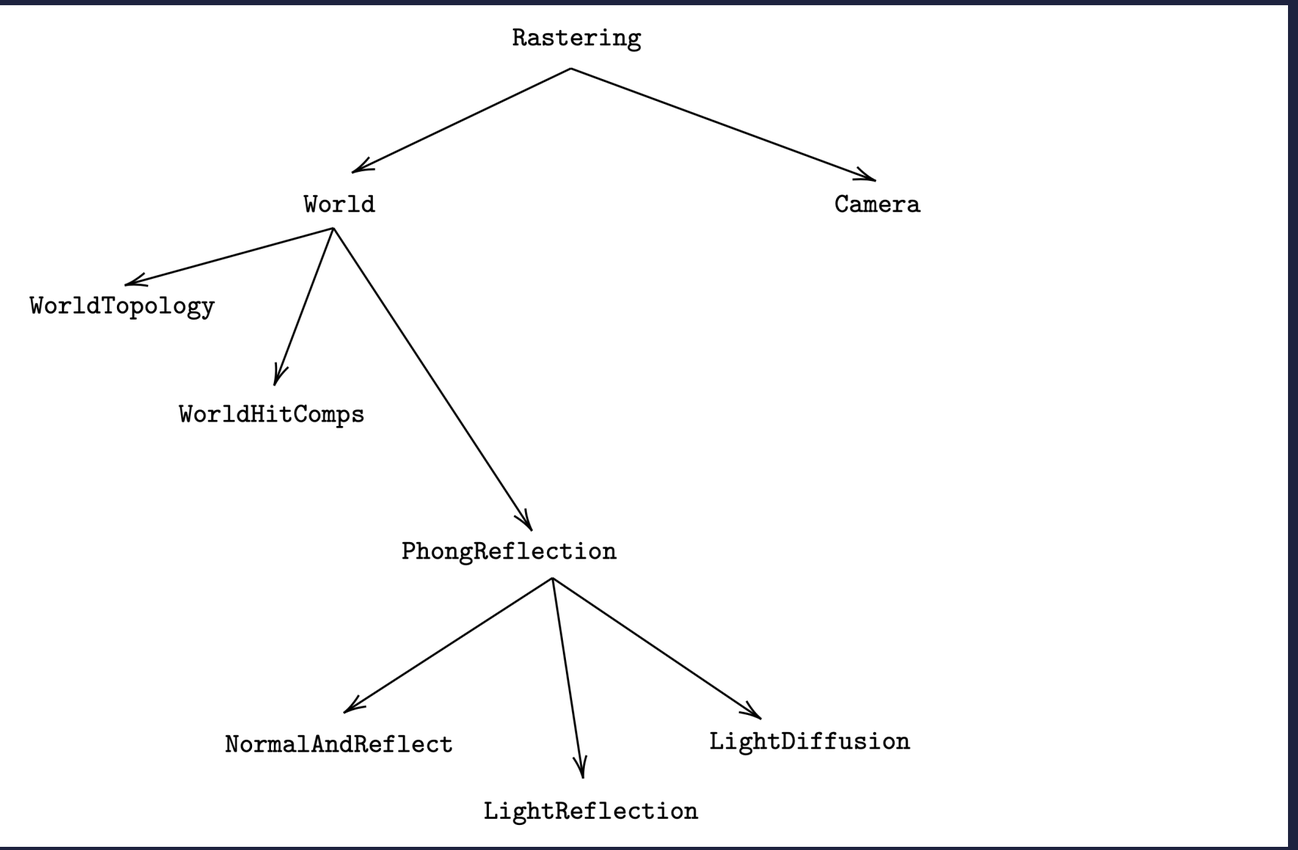



```
def draw(sceneBundle: SceneBundle):
  ZIO[CanvasSerializer
    with RasteringModule
    with ATModule,
    Nothing,
    Array[Byte]]
```

WITH HTTP4S



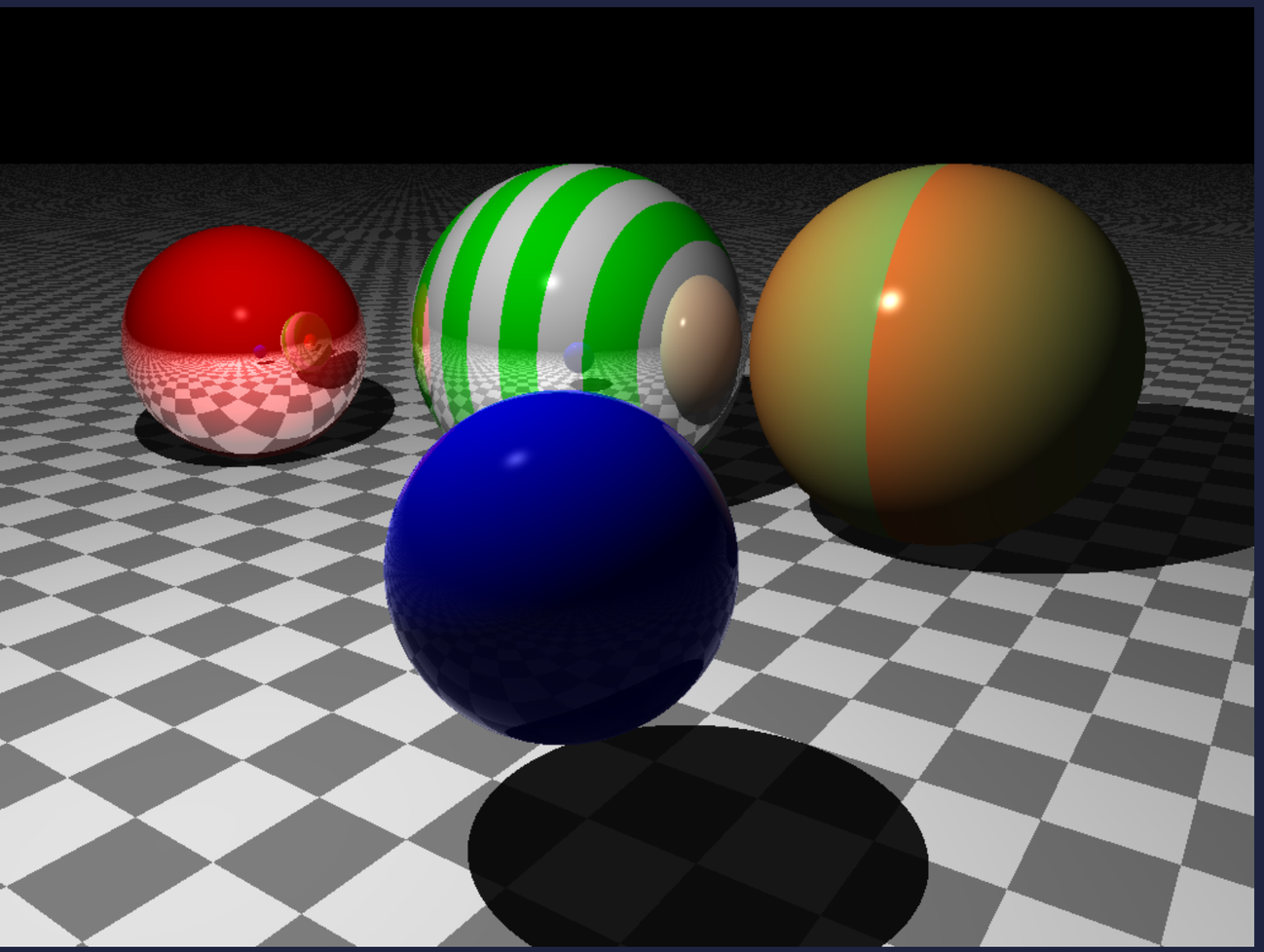

```scala
class DrawRoutes[R <: CanvasSerializer with RasteringModule with ATModule] {
  type F[A] = RIO[R, A]
  private val http4sDsl = new Http4sDsl[F] {}
  import http4sDsl._

  val httpRoutes: HttpRoutes[F] = HttpRoutes.of[F] {
    case req @ POST -> Root / "draw" =>
      req.decode[Scene] { scene =>
        (for {
          bundle    <- Http2World.httpScene2World(scene)
          bytes     <- draw(bundle)
        } yield bytes).foldM {
          e => InternalServerError(s"something went wrong"),
          Ok(bytes, "image/png")
        }
      }
  }
}
```



AND IN MAIN

Provide the layers

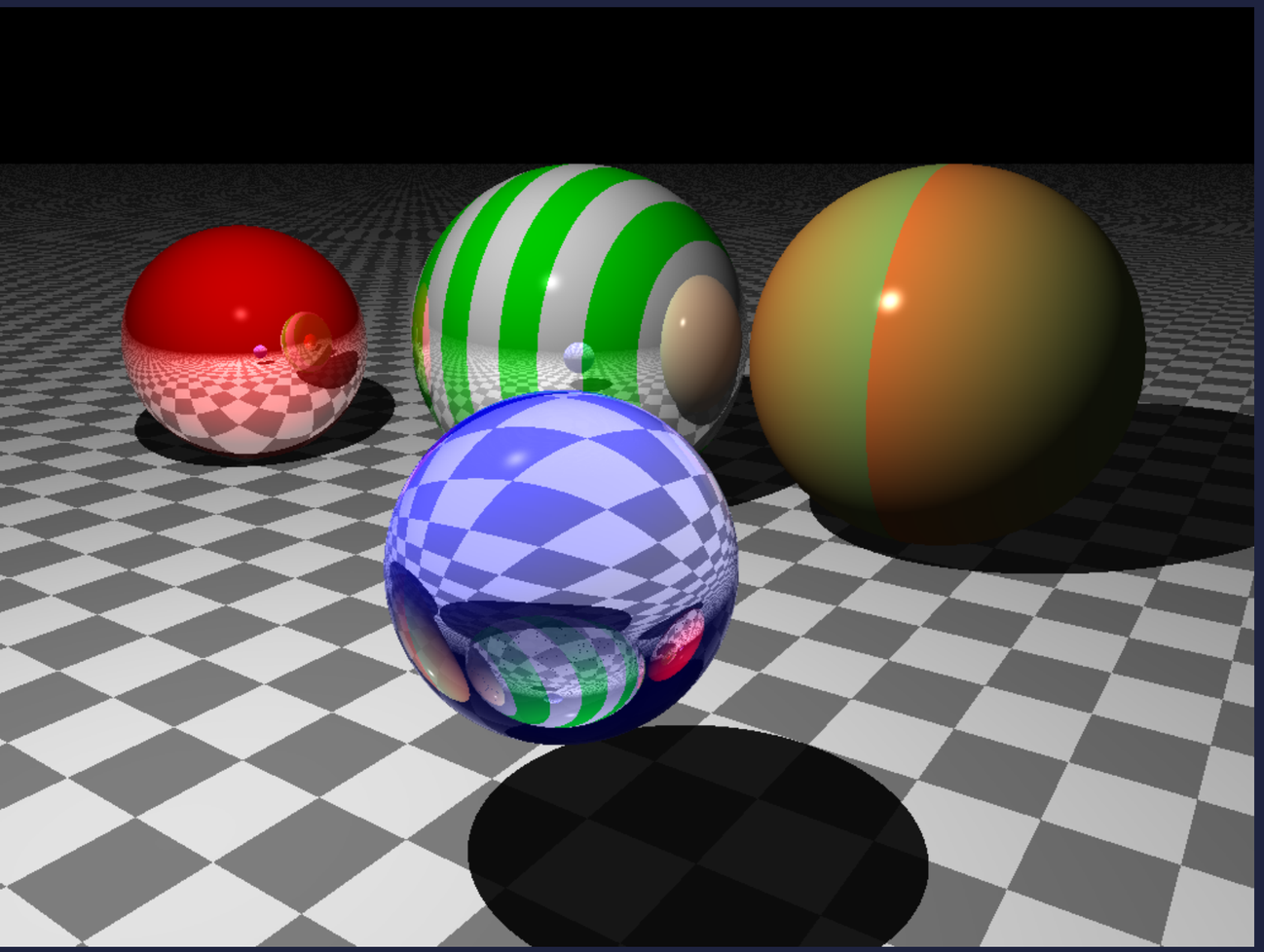
```
val world: ZLayer[ATModule, Nothing, WorldModule] =
  (topologyM ++ hitCompsM ++ phongM) >>> worldModule.live

val rastering: ZLayer[ATModule, Nothing, RasteringModule] =
  (world ++ cameraModule.live) >>> rasteringModule.chunkRasteringModule

val full: ZLayer.NoDeps[Nothing, Rastering] = (layers.atM >>> rastering)

object Main extends zio.App {

  override def run(args: List[String]): ZIO[ZEnv, Nothing, Int] =
    httpProgram.provideLayer(full)
}
```



Swapping modules

- Red: reflective = 0.9
- Green/white: reflective = 0.6
- Blue: reflective = 0.9, transparency: 1

```
val world: ZLayer[ATModule, Nothing, WorldModule] =
  (topologyM ++ hitCompsM ++ phongM) >>> worldModule.opaque
```



Swapping modules

- Red: reflective = 0.9
- Green/white: reflective = 0.6
- Blue: reflective = 0.9, transparency: 1

```
val world: ZLayer[ATModule, Nothing, WorldModule] =
  (topologyM ++ hitCompsM ++ phongM) >>> worldModule.live
```

CONCLUSION - *ZLayer*

- Dependency graph in the code 💪
- Type safety, no magic 🙌
- Compiler helps to satisfy requirements 🤗
- Try it out, and join ZIO Discord channel 😊

Thank you!

 @pierangelocecc

 https://github.com/pierangeloc/ray-tracer-zio