Optimizing smallpt

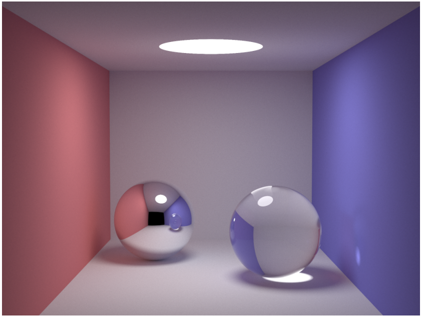
Davean Scies, Siddharth Bhat

Haskell Exchange

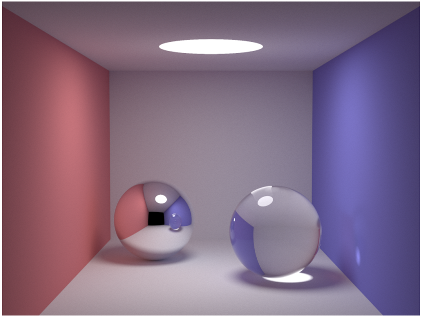
November 4th, 2020

What is smallpt anyway?

What is smallpt anyway?

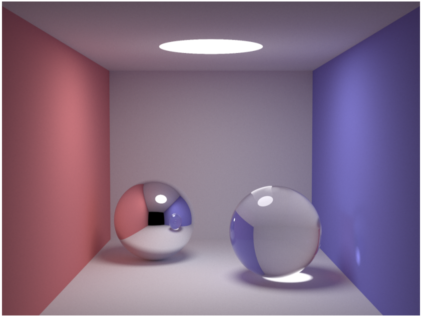


What is smallpt anyway?



- 100 LoC C demo of a raytracer

What is smallpt anyway?



- 100 LoC C demo of a raytracer
- Perfect for an optimization case study

What is smallpt anyway?

```
#include <math.h>
#include <stdlib.h>
#include <stdio.h>
struct Vec {
  double x, y, z; // position, also color (r,g,b)
  ... methods...
};
struct Ray { Vec o, d; Ray(Vec o_, Vec d_) : o(o_), d(d_) {} };
enum Refl_t { DIFF, SPEC, REFR };  // material types, used in radiance()
struct Sphere {
  double rad;    // radius
  Vec p, e, c;   // position, emission, color
  Refl_t refl;   // reflection type (DIFFuse, SPECular, REFRactive)
  ... methods ...
  double intersect(const Ray &r) const // returns distance, 0 if nohit
};
Sphere spheres[] = {//Scene: radius, position, emission, color, material
  Sphere(1e5, Vec( 1e5+1,40.8,81.6), Vec(),Vec(.75,.25,.25),DIFF),//Left
  ... initialization ...
};
inline bool intersect(const Ray &r, double &t, int &id)
```

What is smallpt anyway?

```
Vec radiance(const Ray &r, int depth, unsigned short *Xi){
  double t;                               // distance to intersection
  int id=0;                               // id of intersected object
  if (!intersect(r, t, id)) return Vec(); // if miss, return black
  const Sphere &obj = spheres[id];        // the hit object
  Vec x=r.o+r.d*t, n=(x-obj.p).norm(), nl=n.dot(r.d)<0?n:n*-1, f=obj.c;
  double p = f.x>f.y && f.x>f.z ? f.x : f.y>f.z ? f.y : f.z; // max refl
  if (++depth>5) if (erand48(Xi)<p) f=f*(1/p); else return obj.e; //R.R.
  if (obj.refl == DIFF){                  // Ideal DIFFUSE reflection
    double r1=2*M_PI*erand48(Xi), r2=erand48(Xi), r2s=sqrt(r2);
    Vec w=nl, u=((fabs(w.x)>.1?Vec(0,1):Vec(1))%w).norm(), v=w%u;
    Vec d = (u*cos(r1)*r2s + v*sin(r1)*r2s + w*sqrt(1-r2)).norm();
    return obj.e + f.mult(radiance(Ray(x,d),depth,Xi));
  } else if (obj.refl == SPEC)            // Ideal SPECULAR reflection
    return obj.e + f.mult(radiance(Ray(x,r.d-n*2*n.dot(r.d)),depth,Xi));
  Ray reflRay(x, r.d-n*2*n.dot(r.d));     // Ideal dielectric REFRACTION
  bool into = n.dot(nl)>0;                // Ray from outside going in?
  double nc=1, nt=1.5, nnt=into?nc/nt:nt/nc, ddn=r.d.dot(nl), cos2t;
  if ((cos2t=1-nnt*nnt*(1-ddn*ddn))<0)    // Total internal reflection
    return obj.e + f.mult(radiance(reflRay,depth,Xi));
  Vec tdir = (r.d*nnt - n*((into?1:-1)*(ddn*nnt+sqrt(cos2t)))).norm();
  double a=nt-nc, b=nt+nc, R0=a*a/(b*b), c = 1-(into?-ddn:tdir.dot(n));
  double Re=R0+(1-R0)*c*c*c*c*c,Tr=1-Re,P=.25+.5*Re,RP=Re/P,TP=Tr/(1-P);
  return obj.e + f.mult(depth>2 ? (erand48(Xi)<P ?   // Russian roulette
    radiance(reflRay,depth,Xi)*RP:radiance(Ray(x,tdir),depth,Xi)*TP) :
    radiance(reflRay,depth,Xi)*Re+radiance(Ray(x,tdir),depth,Xi)*Tr);
}
```

Establishing baselines

```
main :: IO ()
main = smallptM 200 200 256

smallptM :: Int -> Int -> Int -> IO ()
smallptM !w !h !nsamps = do
  -- ... processing
  withFile "image.ppm" WriteMode $ \hdl -> do
        hPrintf hdl "P3\n%d %d\n%d\n" w h (255::Int)
        flip mapM_ [0..w*h-1] $ \i -> do
          Vec r g b <- VM.unsafeRead c i
          hPrintf hdl "%d %d %d " (toInt r) (toInt g) (toInt b)
```

- Sha256 hash of the output image (deterministic)

Haskell: the first stab

How do we communicate the code? x(

```
radiance :: Ray -> CInt -> Ptr CUShort -> IO Vec
radiance ray@(Ray o d) depth xi =
 case intersects ray of
  (Nothing,_) -> return zerov
  (Just (D# t),Sphere r p e c refl) -> do
    let x = addv o (mulvs d t)
        n = norm $ x `subv` p
        nl = if isTrue# ((dot n d) <## 0.0##) then n else mulvs n (-1.0##)
        pr = maxv c
        depth' = depth + 1
        continue f = case refl of
          DIFF -> do
            (CDouble (D# r)) <- erand48 xi
            let r1 = (2.0## *## 3.141592653589793238##) *##  r
            (CDouble (D# r2)) <- erand48 xi
            let r2s = sqrtDouble# r2
                w@(Vec wx _ _) = nl
                u = norm (cross (if isTrue# (fabsDouble# wx >## 0.1##) then (Vec 0.0## 1.0## 0.0##) else (Vec 1.0## 0.0## 0.0#
                v = w `cross` u
                d' = norm $ (u`mulvs`(cosDouble# r1*##r2s)) `addv` (v`mulvs`(sinDouble# r1*##r2s)) `addv` (w`mulvs`sqrtDouble#
            rad <- radiance (Ray x d') depth' xi
            return $ e `addv` (f `mulv` rad)

          SPEC -> do
            let d' = d `subv` (n `mulvs` (2.0## *## (n`dot`d)))
            rad <- radiance (Ray x d') depth' xi
            return $ e `addv` (f `mulv` rad)

          REFR -> do
            let reflRay = Ray x (d `subv` (n `mulvs` (2.0## *## n`dot`d))) -- Ideal dielectric REFRACTION
                into = n`dot`nl >## 0.0##                  -- Ray from outside going in?
                nc = 1.0##
                nt = 1.5##
                nnt = if isTrue# into then nc/##nt else nt/##nc
```

Optimisation 1: manual unrolling + unboxing

Optimisation 2: Optimizing Ray

Optimisation 3: Newtyping `Refl`

Optimisation 4: Unbox tuple of intersects

Optimisation 3: Only expose `main`

Optimisation 3: Strictify intersect

Optimisation ...: Enable LLVM

```
diff --git a/smallpt-hs.cabal b/smallpt-hs.cabal
index 83ec118..64d2788 100644
--- a/smallpt-hs.cabal
+++ b/smallpt-hs.cabal
@@ -26,4 +26,5 @@ executable smallpt-hs
                        vector

   -- no -Wall as type signature are purposely missing
+  ghc-options:         -O2 -rtsopts -fllvm
-  ghc-options:         -O2
```

Perf delta here

Takeaways

Takeaways

- Haskell can be fast

Takeaways

- Haskell can be fast
- ... with a lot of work!

Takeaways

- Haskell can be fast
- ... with a lot of work!
- Accumulate optimizations to accrue performance wins.

Takeaways

- Haskell can be fast
- ... with a lot of work!
- Accumulate optimizations to accrue performance wins.
- Raw Google Sheet of our transformations
- `github.com/bollu/smallpt-opt`