

bowntz

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2010–2019

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1 bowntz.cabal

```
name:                bowntz
version:             2
synopsis:             audio-visual pseudo-physical simulation of colliding ↯
    ↵ circles
homepage:            https://code.mathr.co.uk/bowntz
5  license:           GPL-3
license-file:        COPYING
author:              Claude Heiland-Allen
maintainer:          claude@mathr.co.uk
copyright:           2010,2013,2015,2016,2019 Claude Heiland-Allen
10 category:          Demo
build-type:          Simple
extra-source-files:  README
cabal-version:       >=1.10

15 executable bowntz
    main-is:          bowntz.hs
    build-depends:    base >=4.8 && <4.14
                        , containers >= 0.5 && <0.7
                        , GLUT >=2.7 && <2.8
20                      , hosc >=0.17 && <0.18
                        , hsc3 >=0.17 && <0.18
                        , random >=1.1 && <1.2
    default-language: Haskell2010

25 source-repository head
    type:             git
    location:          https://code.mathr.co.uk/bowntz.git

source-repository this
30  type:             git
    location:          https://code.mathr.co.uk/bowntz.git
    tag:              v2
```

2 bowntz.hs

```

{-
    Bowntz -- an audio-visual pseudo-physical simulation of colliding circles
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-}

20  import Graphics.UI.GLUT hiding (position)
    import Sound.OSC
    import Sound.SC3 hiding (decay, line, ID)
    import qualified Sound.SC3 as SC

25  import Control.Monad(forM_, when)
    import Data.IORef
    import System.Random

30  import qualified Data.Map as M
    import Data.Map(Map)
    import qualified Data.Set as S
    import Data.Set(Set)
    import Debug.Trace

35  type ID = Integer

    firstID :: ID
    firstID = 1000

40  type R = GLdouble

    data V = V { x :: R, y :: R }
        deriving (Eq, Ord, Read, Show)

45  infixl 8 'dot'
    infixl 7 '^*', '^*', '^/'
    infixl 6 '^+', '^-'

50  (^/) :: V -> R -> V
    u ^/ t = V (x u / t) (y u / t)

    (^*) :: V -> R -> V
    u ^* t = V (x u * t) (y u * t)

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(*^ ) :: R -> V -> V
s *^ v = V (s * x v) (s * y v)

(^+^ ) :: V -> V -> V
60 u ^+^ v = V (x u + x v) (y u + y v)

(^-^ ) :: V -> V -> V
u ^-^ v = V (x u - x v) (y u - y v)

65 dot :: V -> V -> R
dot u v = x u * x v + y u * y v

data Ball = Ball { mass :: R, radius :: R, position :: V, velocity :: V, ring :: R
    ↳ R }
    deriving (Eq, Ord, Read, Show)
70 data Collision = Collision { ctime :: R, ball1 :: ID, ball2 :: ID }
    deriving (Eq, Ord, Read, Show)

kineticEnergy :: Ball -> R
75 kineticEnergy b = 0.5 * mass b * velocity b `dot` velocity b

involves :: ID -> Collision -> Bool
involves i c = i == ball1 c || i == ball2 c

80 offset :: R -> Collision -> Collision
offset t c = c { ctime = ctime c + t }

collideOutside :: Ball -> Ball -> (Ball, Ball)
collideOutside b1 b2 = collideXside (radius b2 + radius b1) b1 b2
85 collideInside :: Ball -> Ball -> (Ball, Ball)
collideInside b1 b2 = collideXside (abs $ radius b2 - radius b1) b1 b2

collideXside :: R -> Ball -> Ball -> (Ball, Ball)
90 collideXside r b1 b2 = (b1 { velocity = v1, ring = ring b1 + abs e1 }, b2 {
    ↳ velocity = v2, ring = ring b2 + abs e2 })
    where n = (position b1 ^-^ position b2) ^/ r      -- normal vector
          t = V (-y n) (x n)                        -- tangent vector
          v1 = (e * velocity b1 `dot` t) *^ t ^+^ (mass b1 * velocity b1 `dot` n +
    ↳ mass b2 * velocity b2 `dot` n + e * mass b2 * (velocity b2 ^-^
    ↳ velocity b1) `dot` n) / (mass b1 + mass b2) *^ n
          v2 = (e * velocity b2 `dot` t) *^ t ^+^ (mass b2 * velocity b2 `dot` n +
    ↳ mass b1 * velocity b1 `dot` n + e * mass b1 * (velocity b1 ^-^
    ↳ velocity b2) `dot` n) / (mass b1 + mass b2) *^ n
95 e1 = 0.5 * mass b1 * v1 `dot` v1 - kineticEnergy b1
   e2 = 0.5 * mass b2 * v2 `dot` v2 - kineticEnergy b2
   e = elasticity

outside :: Ball -> Ball -> Bool
100 outside b1 b2 = v `dot` v > (radius b2 + radius b1) ^
    ↳ (2::Int)
    where v = position b2 ^-^ position b1

inside :: Ball -> Ball -> Bool
inside b1 b2 = radius b1 < radius b2 && v `dot` v < (radius b2 - radius b1) ^
    ↳ (2::Int)

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105     where v = position b2 ^-^ position b1

intersects :: Ball -> Ball -> Bool
intersects b1 b2 = not (b1 'outside' b2) && not (b1 'inside' b2) && not (b2 '↯
    ↳ inside' b1)

110 approaching :: Ball -> Ball -> Bool
approaching b1 b2 = (position b2 ^-^ position b1) 'dot' (velocity b1 ^-^ ↯
    ↳ velocity b2) > 0

data World = World { nextID :: ID, balls :: Map ID Ball, now :: R, collisions :: ↯
    ↳ Set Collision }
    deriving (Eq, Ord, Read, Show)

115 worldEnergy :: World -> R
worldEnergy w = sum . map kineticEnergy . M.elems $ balls w

initialWorld :: R -> World
120 initialWorld t = World { nextID = firstID, balls = M.empty, now = t, collisions ↯
    ↳ = S.empty }

insertBall :: Ball -> World -> IO World
insertBall b w = do
    let i = nextID w
125     createBall i b
    return $ insertBallAs i b w{ nextID = i + 1 }

insertBallAs :: ID -> Ball -> World -> World
insertBallAs i b w = w { balls = M.insert i b (balls w), collisions = S.union (↯
    ↳ collisions w) cs }
130     where cs = S.fromList . map (offset (now w)) . concatMap (collides (i, b)) . M↯
        ↳ . assocs $ balls w

collides :: (ID, Ball) -> (ID, Ball) -> [Collision]
collides (i, bi) (j, bj)
    | bi 'outside' bj = let
135         o | not (bi 'approaching' bj) = []
            | disc1 > 0 = [Collision t1 i j, Collision t2 i j]
            | disc1 == 0 = [Collision t1 i j]
            | otherwise = []
        in o
140     | bi 'inside' bj || bj 'inside' bi = let
        o | disc2 > 0 = [Collision t3 i j, Collision t4 i j]
          | disc2 == 0 = [Collision t3 i j]
          | otherwise = []
        in o
145     | bi 'approaching' bj = let -- overlapped
        o | disc2 > 0 = [Collision t3 i j, Collision t4 i j]
          | disc2 == 0 = [Collision t3 i j]
          | otherwise = []
        in o
150     | otherwise = []
    where
        ri = radius bi
        rj = radius bj
        qi = position bi
155         qj = position bj

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vi = velocity bi
vj = velocity bj
a = vi `dot` vi + vj `dot` vj - 2 * vi `dot` vj
b = vi `dot` qj + qi `dot` vj - qi `dot` vi - qj `dot` vj
160 c = a
d1 = qi `dot` qi + qj `dot` qj - 2 * qi `dot` qj - (ri + rj)^(2::Int)
d2 = qi `dot` qi + qj `dot` qj - 2 * qi `dot` qj - (ri - rj)^(2::Int)
disc1 = (-2 * b)^(2::Int) - 4 * c * d1
t1 = 0.5 * (2 * b - sqrt disc1) / a
165 t2 = 0.5 * (2 * b + sqrt disc1) / a
disc2 = (-2 * b)^(2::Int) - 4 * c * d2
t3 = 0.5 * (2 * b - sqrt disc2) / a
t4 = 0.5 * (2 * b + sqrt disc2) / a

170 update :: R -> World -> IO World
update t w
  | t <= now w = return w
  | otherwise = update t ==<< update1 t w

175 update1 :: R -> World -> IO World
update1 t w
  | S.null future = return $ w { now = t, balls = newBalls t, collisions = S.↯
    ↪ empty }
  | t < ctime event = return $ w { now = t, balls = newBalls t, collisions = ↯
    ↪ future }
  | otherwise = do
180   triggerBall (ctime event) (ball1 event) (realToFrac $ ring b1 * mass b1)
   triggerBall (ctime event) (ball2 event) (realToFrac $ ring b2 * mass b2)
   return $ w { collisions = S.filter (\e -> ctime e /= ctime event) (↯
    ↪ collisions w) }
where
  w' = insertBallAs (ball1 event) b1 . insertBallAs (ball2 event) b2 $ w { now↯
    ↪ = ctime event, balls = M.delete (ball1 event) . M.delete (ball2 event)↯
    ↪ } $ newBallsE, collisions = S.filter (not . invalid event) future' }
185 (-past, future) = S.split (Collision (now w) (firstID -1) (firstID -1)) (↯
    ↪ collisions w)
(event, future') = S.deleteFindMin future
invalid c d = involves (ball1 c) d || involves (ball2 c) d
line dt b = b { position = position b ^+^ velocity b ^* dt, ring = ring b * ↯
    ↪ decay ** dt }
newBalls tt = M.map (line (tt - now w)) (balls w)
190 newBallsE = newBalls (ctime event)
(b1, b2)
  | (balls w M.! ball1 event) `outside` (balls w M.! ball2 event) = ↯
    ↪ collideOutside (newBallsE M.! ball1 event) (newBallsE M.! ball2 ↯
    ↪ event)
  | (balls w M.! ball1 event) `inside` (balls w M.! ball2 event) = ↯
    ↪ collideInside (newBallsE M.! ball1 event) (newBallsE M.! ball2 ↯
    ↪ event)
  | (balls w M.! ball2 event) `inside` (balls w M.! ball1 event) = ↯
    ↪ collideInside (newBallsE M.! ball2 event) (newBallsE M.! ball1 ↯
    ↪ event)
195 | otherwise = trace ("spurious collision event: " ++ show event) (↯
    ↪ newBallsE M.! ball1 event, newBallsE M.! ball2 event)

reshape :: IOREf World -> Size -> IO ()
reshape _worldRef vp@(Size w h) = do

```

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let s = 1.75
200   (x0,x1,y0,y1) = if w > h then let v = s * fromIntegral h / fromIntegral w ↵
        ↵ in (-s,s,-v,v)
                                else let v = s * fromIntegral w / fromIntegral h ↵
        ↵ in (-v,v,-s,s)

viewport $= (Position 0 0, vp)
matrixMode $= Projection
loadIdentity
205 ortho x0 x1 y0 y1 (-1) 1
matrixMode $= Modelview 0
loadIdentity
postRedisplay Nothing

210 display :: IORef World -> IO ()
display worldRef = do
  w <- readIORef worldRef
  clear [ColorBuffer]
  lineWidth $= 1
215 renderPrimitive Lines $ do
  mapM drawBall $ M.elems (balls w)
  swapBuffers

drawBall :: Ball -> IO ()
220 drawBall b = do
  let n = 144 :: R
      r = radius b
      p = position b
      d = mass b / radius b ^ (2::Int)
225   a = (((d - minDensity) / (maxDensity - minDensity)) 'min' 1) * (pi / 2)
      mk = 1 + 5 * ring b * cos (16 * 2 * pi * k / n) / radius b
  color $ if d > maxDensity then Color3 0 0 1 else Color3 (sin a 'max' 0) (cos a ↵
        ↵ 'max' 0) 0
  forM_ [1 .. n] (\i -> do
    vertex $ Vertex2 (r * m (i - 1) * cos (2 * pi * (i - 1) / n) + x p) (r * m ( ↵
        ↵ i - 1) * sin (2 * pi * (i - 1) / n) + y p)
230    vertex $ Vertex2 (r * m i * cos (2 * pi * i / n) + x p) (r * m ↵
        ↵ i * sin (2 * pi * i / n) + y p))

physics :: Timeout -> IORef World -> IO ()
physics dt worldRef = do
  reallyNow <- time
235 w <- readIORef worldRef
  writeIORef worldRef ==<< update (realToFrac reallyNow + fromIntegral dt / 1000) ↵
        ↵ w
  addTimerCallback dt $ physics dt worldRef
  postRedisplay Nothing

240 spawn :: Timeout -> IORef World -> IO ()
spawn dt worldRef = do
  w <- readIORef worldRef
  let e = worldEnergy w
  when (e < realToFrac spawnThreshold) $ do
245   d <- realToFrac 'fmap' randomRIO (realToFrac minDensity, realToFrac ↵
        ↵ maxDensity :: Double)
      r <- realToFrac 'fmap' randomRIO (realToFrac minSize, realToFrac maxSize :: ↵
        ↵ Double)
      pr <- realToFrac 'fmap' randomRIO (0.0, 1.0 :: Double)

```

```

    pa <- realToFrac 'fmap' randomRIO (-pi, pi)      :: Double)
    va <- realToFrac 'fmap' randomRIO (-pi, pi)      :: Double)
250   let m = d * r ^ (2::Int)
        px = pr * cos pa
        py = pr * sin pa
        vr = sqrt $ 2 * spawnEnergy / m
        vx = vr * cos va
255   vy = vr * sin va
        b = Ball { mass = m, radius = r, position = V px py, velocity = V vx vy, ↵
                ↵ ring = 0 }
        when (not (any (intersects b) (M.elems (balls w)))) $ do
            w' <- insertBall b w
            writeIORef worldRef w'
260   addTimerCallback dt $ spawn dt worldRef
        postRedisplay Nothing

main :: IO ()
main = do
265   (_, _args) <- getArgsAndInitialize
        initialWindowSize $= Size 788 576
        initialDisplayMode $= [RGBAMode, DoubleBuffered]
        _ <- createWindow "bowntz"
        withSC3 (sendMessage (g_new [(1, AddToTail, 0)])) -- new group 1 under root 0 ↵
                ↵ group
270   _ <- withSC3 ballSynth
        t0 <- time
        w <- insertBall (Ball{ mass = 1e6, radius = 1, position = V 0 0, velocity = V ↵
                ↵ 0 0, ring = 0 }) $ initialWorld (realToFrac t0)
        worldRef <- newIORef w
        displayCallback $= display worldRef
275   reshapeCallback $= Just (reshape worldRef)
        let mspf = floor (1000 / 60 :: Double)
        addTimerCallback mspf $ physics mspf worldRef
        addTimerCallback 125 $ spawn 125 worldRef
        mainLoop
280   createBall :: ID -> Ball -> IO ()
        createBall i b = withSC3 (sendMessage (s_new "Ball" (fromIntegral i) AddToTail 1 ↵
                ↵ [("freq", realToFrac $ 50 / radius b)]))

        triggerBall :: R -> ID -> Double -> IO ()
285   triggerBall t i v = withSC3 (sendBundle (bundle (realToFrac (t + latency)) [ ↵
                ↵ n_set1 (fromIntegral i) "t_amp" v]))

        ballSynth :: Connection UDP Packet
        ballSynth = do let f = control IR "freq" 0
                        a = tr_control "t_amp" 0
290   d = out 0 (fSinOsc AR (mce [f, f]) 0 * (SC.decay a 0.7))
                        sendMessage (d_recv (synthdef "Ball" d))
                        waitAddress "/done"

        minSize, maxSize, minDensity, maxDensity, spawnThreshold, spawnEnergy, decay, ↵
                ↵ elasticity, latency :: R
295   minSize = 0.02
        maxSize = 0.8
        minDensity = 40
        maxDensity = 60

```

```
spawnThreshold = 0.1
300 spawnEnergy = spawnThreshold / 8
    decay = 0.0001
    elasticity = 0.99
    latency = 1 / 30
```

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4 .gitignore

```
*~
*.o
*.hi
bowntz
5 .cabal-sandbox
  cabal.sandbox.config
  dist
```

5 README

Bowntz -- an audio-visual pseudo-physical simulation of colliding circles
 Copyright (C) 2010,2013,2015,2016 Claude-Heiland-Allen <claude@mathr.co.uk>

5 Build

```
-----

$ cabal sandbox init
$ cabal install
```

Usage

```
15 $ scsynth -u 57110 &
   -- wait for scsynth to start, connect its JACK ports --
$ ./bowntz
```

Bowntz requires a "clean" SC3 server to be running on its usual port.
 Bowntz leaves this SC3 server in an "unclean" state when it exits.

This situation is far from ideal, but it's the current state of the code.

25 Notes

The world is a collection of N circles which each move at a constant speed in a straight line (in the absence of collisions). Given two such circles it is possible to calculate the precise time of their next collision. For N circles, $O(N^2)$ such "next" collisions may occur.

Pick the soonest next collision between circles A and B. This collision will change the velocities of A and B, but no other circle. Update the collection of collisions, by removing all the other "next" collisions involving either A or B, and computing the new collisions of A and B with all the other circles ($O(N)$ collisions). For maintaining a consistent time-base for all circles in the world, it makes sense to advance in a straight line each circle to its position at the time of the collision.

Given a world at time T , to find the world at time $T+dT$ simply step through the future collisions one by one until the soonest collision is after $T+dT$, at which point one can just advance the circles in straight lines to $T+dT$.

[illegible]

Care needs to be taken in case of numerical imprecision: one can get an infinite number of collisions without time increasing.

To do

General code clean-up and documentation.

Optimizations based on collision possibility tree, example:

60	A	7 possible	
		$A \sim B$	
	+---B	$A \sim E$	5 impossible
	+---C	$B \sim C$	$A \sim C$
65	+---D	$B \sim D$	$A \sim D$
		$C \sim D$	$C \sim F$
	+---E	$B \sim E$	$D \sim F$
	+---F	$E \sim F$	$A \sim F$

```

70      data Node = Node ID [Node]
           possibles n@(Node _ ns) = possible n `map` ns ++ liftM2 possible ns

```

Infinite zoom into circles within circles within circles within circles?
When (if ever) would it be safe to prune "outside"?

Some kind of loop where circles contain themselves (I did try this in another unreleased version but it resulted in hyperexponential kinetic energy increase, which naturally caused problems).

80 Non-flat space.

Angular momentum affecting collisions.

Remove all sources of non-determinism to enable two-pass rendering:

85	1	pass	to	record	audio	from	SC3	in	realtime
	2	pass	to	record	video	from	OpenGL	in	non-realtime

Or just record ball positions in the first pass for later drawing (because callback races and/or timing instability might affect the reproducibility unless very precise care is taken at all stages..)

90 Interactivity.

More impressive audio-visuals.

Won't

100 Anything other than circles (ok, maybe infinite lines would be ok, but asymmetry with angular momentum would quickly make collision detection get horribly complicated).

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105 -----

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6 Setup.hs

```
import Distribution.Simple
main = defaultMain
```