nnirror

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1 .gitignore

```
dist/
dist-newstyle/
.ghc.environment*
cabal.project
*.log
*.net
*.png
*.ppm
*.mkv
*.mp4
*.prof
*.hp
score
-/
```

2 index.html

```
<!DOCTYPE html>
<html><head><title>nnirror :: mathr</title>
<meta name="description" content="A neural network looking at itself." />
<meta property="og:description" content="A neural network looking at itself." />
<style>
html { color: white; background-color: black; }
```

```
body { color: black; background-color: white; width: 512px; margin: auto; ↙
    ↳ padding-left: 10px; padding-right: 10px; }
h1, h2 { text-align: left; }
p { text-align: justify; }
img { vertical-align: middle; }
a { text-decoration: none; }
a img { border: 1px solid; }
</style></head><body>
<h1>nnirror</h1>
<p><a href="nnirror.png" title="nnirror"><img src="nnirror.jpg" alt="nnirror" ↙
    ↳ /></a><p>
A neural network looking at itself.
</p>
<h2>Process</h2>
<p>
There are two neural networks, Ego and Id.
Ego ideally outputs 1 when the input is its own weights, and 0 otherwise.
Id ideally outputs weights for the Ego net, that Ego scores highly.
These are continually trained against each other using a generative
adversarial network.
</p>
<h2>Output</h2>
<p><a href="nnirror.mp4" title="video">Video excerpt of training process (100MB)↙
    ↳ </a>.</p>
<p>
<a href="1" title="hi score table">Top ten highest scoring networks</a>
out of 1000 training sessions.
</p>
<h2>Source</h2>
<p>
<a href="https://code.mathr.co.uk/nnirror" title="nnirror">nnirror</a>
is implemented in Haskell using
<a href="https://hackage.haskell.org/package/grenade" title="grenade">grenade</a↙
    ↳ >.
</p>
<h2>Legal</h2>
<p>
Copyleft: This is a free work, you can copy, distribute, and
modify it under the terms of the
<a href="http://artlibre.org/licence/lal/en/" title="Free Art License">Free Art ↙
    ↳ License</a>.
</p>
<h2>Author</h2>
<p><a href=".." title="mathr.co.uk">Claude Heiland-Allen</a></p>
</body></html>
```

3 LICENSE.md

```
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```

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Attitude meetings which took place in Paris in 2000. For the first
time, these meetings brought together members of the Free Software
community, artists, and members of the art world. The goal was to adapt
the principles of Copyleft and free software to all sorts of creations.

------------------------------------------------------------------------

<http://www.artlibre.org>
```

```
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(without any changes).

Translation: Jonathan Clarke, Benjamin Jean, Griselda Jung, Fanny Mourguet,
Antoine Pitrou. Thanks to <http://framalang.org>
```

4 Makefile

```
nnirror-score: nnirror-score.c
	gcc -o nnirror-score nnirror-score.c -lm
```

5 nnirror.cabal

```
name:                nnirror
version:             0

license:             OtherLicense
license-file:        LICENSE.md
author:              Claude Heiland-Allen
maintainer:          claude@mathr.co.uk
copyright:           (c) 2018,2019 Claude Heiland-Allen

cabal-version:       >= 1.10
build-type:          Simple

category:            Art
synopsis:            self-reflective neural net
description:
  A neural network looking at itself.
  .
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homepage:            https://mathr.co.uk/nnirror

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

executable           nnirror
    main-is:         nnirror.hs
    default-language: Haskell2010
    other-extensions:
        BangPatterns
        DataKinds
        FlexibleContexts
        FlexibleInstances
        GADTs
        NoStarIsType
        PolyKinds
        ScopedTypeVariables
        TypeOperators
        UndecidableInstances
    build-depends:   base        == 4.12.*
```

```
                      , async        == 2.2.*
                      , cereal       == 0.5.*
                      , gl           == 0.8.*
                      , GLFW-b       == 3.2.*
                      , grenade      == 0.1.*
                      , hmatrix      == 0.19.*
                      , JuicyPixels  == 3.3.*
                      , MonadRandom  == 0.5.*
                      , singletons   == 2.5.*
                      , vector       == 0.12.*
    ghc-options: -rtsopts -threaded "-with-rtsopts=-N4 -A64M"
```

6 nnirror.gnuplot

```
u(x) = -log(1/x-1)
set autoscale
set xtics 1000
set ytics 2
set mxtics 10
set mytics 2
set grid xtics
set grid mxtics
set grid ytics
set grid mytics
unset key
set term pngcairo enhanced size 10080,7200 font "LMSans10,100" linewidth 3
set output "out.png"
set multiplot layout 4,1 title "becoming self-aware: training a neural network ↙
    ↳ to recognize itself"
set title "self-recognition"
set key bottom right maxrows 1 font ",75"
plot [0:9999][0:10] for [i=0:9] sprintf("%d.log", i) u 1:(u(column(2))) w l lc ↙
    ↳ rgbcolor hsv2rgb((i+1.5)/10,1,1) dt 1 t sprintf("%d", i)
set title "self-other demarcation"
set key bottom right maxrows 1 font ",75"
plot [0:9999][0:10] for [i=0:9] sprintf("%d.log", i) u 1:(-u(column(3))) w l lc ↙
    ↳ rgbcolor hsv2rgb((i+1.5)/10,1,1) dt 1 t sprintf("%d", i)
set title "pareidolia"
set key top right maxrows 1 font ",75"
plot [0:9999][-10:0] for [i=0:9] sprintf("%d.log", i) u 1:(u(column(4))) w l lc ↙
    ↳ rgbcolor hsv2rgb((i+1.5)/10,1,1) dt 1 t sprintf("%d", i)
set title "score"
set key bottom right maxrows 1 font ",75"
plot [0:9999][0:10] for [i=0:9] sprintf("%d.log", i) u 1:((2*u(column(2))-u(↙
    ↳ column(3))-u(column(4)))/4) w l lc rgbcolor hsv2rgb((i+1.5)/10,1,1) dt 1 t↙
    ↳  sprintf("%d", i)
unset multiplot
```

7 nnirror.hs

```
{-
  nnirror (c) 2018,2019 Claude Heiland-Allen
  A neural network looking at itself.

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```

```
-}

{-# LANGUAGE BangPatterns #-}
{-# LANGUAGE DataKinds #-}
{-# LANGUAGE FlexibleContexts #-}
{-# LANGUAGE FlexibleInstances #-}
{-# LANGUAGE GADTs #-}
{-# LANGUAGE NoStarIsType #-}
{-# LANGUAGE PolyKinds #-}
{-# LANGUAGE ScopedTypeVariables #-}
{-# LANGUAGE TypeOperators #-}
{-# LANGUAGE UndecidableInstances #-}

import Grenade
import Codec.Picture (readImage, DynamicImage(ImageRGBA8), Image(Image))
import Control.Concurrent.Async (async, wait)
import Control.Exception (catch, SomeException)
import Control.Monad (forM_, replicateM, unless, when)
import Control.Monad.Random (MonadRandom, randomRIO)
import Data.Either (lefts, rights)
import Data.IORef (newIORef, modifyIORef, readIORef)
import Data.List (sort, sortBy, transpose)
import Data.Ord (comparing)
import Data.Proxy (Proxy(Proxy))
import Data.Serialize (Serialize(..), runGet, runPut)
import Data.Singletons
import Data.Vector.Storable (Vector)
import qualified Data.Vector.Storable as V
import Data.Word (Word8)
import Foreign (allocaBytes, castPtr, nullPtr, peek, peekArray, plusPtr, sizeOf,↙
    ↳ with, withArray)
import Foreign.C.String (withCString)
import GHC.TypeLits
import Graphics.GL.Core33
import qualified Graphics.UI.GLFW as GLFW
import qualified Numeric.LinearAlgebra as LA
import Numeric.LinearAlgebra.Static as LAS hiding (C, (|||), (===), (<>))
import System.Environment (getArgs)
import System.Exit (exitFailure, exitSuccess)
import System.IO (hFlush, hPutBuf, hPutStr, hPutStrLn, stderr, stdout)

type C = 10
type F = 48

type Ego = Network
  '[ Pad 1 1 1 1, Convolution 3 C 3 3 1 1, Pooling 2 2 2 2, Logit
   , Pad 1 1 1 1, Convolution C C 3 3 1 1, Pooling 2 2 2 2, Logit
   , Pad 1 1 0 1, Convolution C C 3 3 1 1, Pooling 2 2 2 2, Logit
   , Pad 1 1 1 1, Convolution C C 3 3 1 1, Pooling 2 2 2 2, Logit
   , Reshape
   , FullyConnected (4 * 2 * C) F, Logit
   , FullyConnected F 1, Logit
   ]
  '[ 'D3 64 36 3
   , 'D3 66 38 3, 'D3 64 36 C, 'D3 32 18 C, 'D3 32 18 C
   , 'D3 34 20 C, 'D3 32 18 C, 'D3 16  9 C, 'D3 16  9 C
   , 'D3 18 10 C, 'D3 16  8 C, 'D3  8  4 C, 'D3  8  4 C
```

```
      , 'D3 10  6 C, 'D3  8  4 C, 'D3  4  2 C, 'D3  4  2 C
      , 'D1 (4 * 2 * C)
      , 'D1 F, 'D1 F
      , 'D1 1, 'D1 1
      ]

type Id = Network
   '[ FullyConnected F (4 * 2 * C), Logit
    , Reshape
    , Deconvolution C C 3 3 2 2, Logit
    , Pad 1 1 0 0
    , Convolution C C 3 3 1 1, Logit
    , Deconvolution C C 3 3 2 2, Logit
    , Pad 1 1 1 0
    , Convolution C C 3 3 1 1, Logit
    , Deconvolution C C 3 3 2 2, Logit
    , Pad 1 1 0 0
    , Convolution C C 3 3 1 1, Logit
    , Deconvolution C C 3 3 2 2, Logit
    , Pad 1 1 0 0
    , Convolution C 3 3 3 1 1, Logit
    ]
   '[ 'D1 F
    , 'D1 (4 * 2 * C), 'D1 (4 * 2 * C)
    , 'D3  4  2 C
    , 'D3  9  5 C, 'D3  9  5 C
    , 'D3 10  6 C
    , 'D3 8   4 C, 'D3  8  4 C
    , 'D3 17  9 C, 'D3 17  9 C
    , 'D3 18 11 C
    , 'D3 16  9 C, 'D3 16  9 C
    , 'D3 33 19 C, 'D3 33 19 C
    , 'D3 34 20 C
    , 'D3 32 18 C, 'D3 32 18 C
    , 'D3 65 37 C, 'D3 65 37 C
    , 'D3 66 38 C
    , 'D3 64 36 3, 'D3 64 36 3
    ]
-- deconvolution  outputRows ~ (inputRows - 1) * stride + kernelRows
-- convolution    outputRows ~ (inputRows - kernelRows) / stride + 1

reflE :: Ego -> S ('D3 64 36 3)
reflE = sigmoid . S3D . (\(Just j) -> j) . LAS.create . LA.reshape 36 . V.take ↙
    ↳ (64 * 36 * 3) . (<> V.replicate (64 * 36 * 3) 0) . reflect

reflI :: Id -> S ('D3 64 55 3)
reflI = sigmoid . S3D . (\(Just j) -> j) . LAS.create . LA.reshape 55 . V.take ↙
    ↳ (64 * 55 * 3) . (<> V.replicate (64 * 55 * 3) 0) . reflect

sigmoid x = 1 / (1 + exp (-x))
unsigmoid y = - log (1 / y - 1)

bashNaN x
  | isNaN x || isInfinite x = 0
  | otherwise = x

reiE :: S ('D3 64 36 3) -> Ego
```

```
reiE input@(S3D s) = case reify . map bashNaN . LA.toList . LA.flatten . extract
    ↳ . unsigmoid $ s of
  Just (ego, _) -> ego

reiI :: S ('D3 64 55 3) -> Id
reiI input@(S3D s) = case reify . map bashNaN . LA.toList . LA.flatten . extract
    ↳ . unsigmoid $ s of
  Just (id, _) -> id

gan :: (LearningParameters, LearningParameters) -> (Ego, Id) -> IO ((Ego, Id), [
    ↳ Double])
gan (learnE, learnI) (ego, id) = do
  noise <- randomOfShape
  poopE <- randomOfShape
  let up :: LearningParameters -> Gradients l -> Network l s -> Network l s
      up l grad net = applyUpdate l net grad

      upE = up learnE
      upI = up learnI

  a_realE <- async $ do
    let !realE             = reflE ego
    return realE
  a_fakeE <- async $ do
    let r@(!idT, !fakeE)   = {-# SCC "runNetwork/id" #-} (runNetwork id noise)
    return r
  realE <- wait a_realE
  (idT, fakeE) <- wait a_fakeE

      -- train Ego

  a_real <- async $ do
    let r@(!realTE, !realGE) = {-# SCC "runNetwork/ego/real"   #-} (runNetwork
        ↳ ego realE)
    return r
  a_fake <- async $ do
    let r@(!fakeTE, !fakeGE) = {-# SCC "runNetwork/ego/fake"   #-} (runNetwork
        ↳ ego fakeE)
    return r
  a_poop <- async $ do
    let r@(!poopTE, !poopGE) = {-# SCC "runNetwork/ego/poop"   #-} (runNetwork
        ↳ ego poopE)
    return r

  (realTE, realGE) <- wait a_real
  (fakeTE, fakeGE) <- wait a_fake
  (poopTE, poopGE) <- wait a_poop

  a_real'E <- async $ do
    let (!real'E, !_)      = {-# SCC "runGradient/ego/real1" #-} (runGradient
        ↳ ego realTE (realGE - 1))
    return real'E
  a_fake'E <- async $ do
    let (!fake'E, !_)      = {-# SCC "runGradient/ego/fake"  #-} (runGradient
        ↳ ego fakeTE  fakeGE)
    return fake'E
  a_poop'E <- async $ do
```

```
    let (!poop'E, !_)      = {-# SCC "runGradient/ego/poop"  #-} (runGradient ↙
        ↳ ego poopTE  poopGE)
    return poop'E

  a_realPE <- async $ do
    let (!_, !realPE)      = {-# SCC "runGradient/ego/real"  #-} (runGradient ↙
        ↳ ego realTE  realGE)
    return realPE
  a_fakePE <- async $ do
    let (!_, !fakePE)      = {-# SCC "runGradient/ego/fake1" #-} (runGradient ↙
        ↳ ego fakeTE (fakeGE - 1))
    return fakePE
  a_poopPE <- async $ do
    let (!_, !poopPE)      = {-# SCC "runGradient/ego/poop1" #-} (runGradient ↙
        ↳ ego poopTE (poopGE - 1))
    return poopPE

  a_real'I <- async $ do
    realPE <- wait a_realPE
    let (!real'I, !_)      = {-# SCC "runGradient/id/real" #-} (runGradient id  ↙
        ↳ idT     realPE)
    return real'I
  a_fake'I <- async $ do
    fakePE <- wait a_fakePE
    let (!fake'I, !_)      = {-# SCC "runGradient/id/fake" #-} (runGradient id  ↙
        ↳ idT     fakePE)
    return fake'I
  a_poop'I <- async $ do
    poopPE <- wait a_poopPE
    let (!poop'I, !_)      = {-# SCC "runGradient/id/poop" #-} (runGradient id  ↙
        ↳ idT     poopPE)
    return poop'I

  a_ego <- async $ do
    real'E <- wait a_real'E
    fake'E <- wait a_fake'E
    poop'E <- wait a_poop'E
    let !newEgo = {-# SCC "update/ego" #-} (upE poop'E . upE fake'E . upE real'E↙
        ↳ $ ego)
    return newEgo

  a_id <- async $ do
    real'I <- wait a_real'I
    fake'I <- wait a_fake'I
    poop'I <- wait a_poop'I
    let !newId  = {-# SCC "update/id"  #-} (upI poop'I . upI fake'I . upI real'I↙
        ↳ $ id)
    return newId

  newEgo <- wait a_ego
  newId <- wait a_id
  let !real = fromSingleton realGE
      !fake = fromSingleton fakeGE
      !poop = fromSingleton poopGE

  return ((newEgo, newId), [real, fake, poop, (2 * unsigmoid real - unsigmoid ↙
      ↳ fake - unsigmoid poop) / 4])
```

```
215
    pixel :: Double -> Word8
    pixel x = round $ 255 * clamp 0 1 x

    clamp :: Ord a => a -> a -> a -> a
220 clamp lo hi x = lo `max` x `min` hi

    {-
    image :: Int -> Int -> Int -> [Double] -> Image
    image h w c = take h . chunk w . chunk c . map pixel . (++ repeat 0)
225 -}
    chunk :: Int -> [a] -> [[a]]
    chunk _ [] = []
    chunk n xs = case splitAt n xs of (ys, zs) -> ys : chunk n zs
    {-
230 type Image = [[[Word8]]]

    (|||), (===) :: Image -> Image -> Image
    (|||) = zipWith (++)
    (===) = (++)
235
    hcat, vcat :: [Image] -> Image
    hcat = foldr (|||) (repeat [])
    vcat = foldr (===) []
    -}
240 toList :: S ('D3 w h c) -> [Double]
    toList (S3D f) = LA.toList . LA.flatten . extract $ f

    {-
    display :: FilePath -> Ego -> Ego -> Ego -> IO ()
245 display file oldEgo ego newEgo = do
      let newEgoW = reflE newEgo
          egoW    = reflE ego
          oldEgoW = reflE oldEgo
          b = (7200 - 6912) `div` 2
250       border = (replicate b 1 ++) . (++ replicate b 1)
          newDelta = 0.5 + 0.5 * signum (egoW - oldEgoW)
          oldDelta = 0.5 + 0.5 * signum (newEgoW - egoW)
          diff = 1 - abs (newDelta - oldDelta)
          row = B.pack . map pixel . border . toList $ diff
255   B.appendFile file row
    -}

    recognition :: Ego -> S ('D3 64 36 3) -> Double
    recognition ego = fromSingleton . snd . runNetwork ego
260
    fromSingleton :: S ('D1 1) -> Double
    fromSingleton (S1D s) = case LA.toList (extract s) of [t] -> t

    {-
265 load :: Serialize a => FilePath -> IO a
    load file = either fail return . runGet get =<< B.readFile file

    save :: Serialize a => FilePath -> a -> IO ()
    save file = B.writeFile file . runPut . put
270 -}
```

```
orElse :: IO a -> IO a -> IO a
orElse a e = a `catch` \(_::SomeException) -> e

randomEgoId :: IO (Ego, Id)
randomEgoId = do
  ego <- randomNetwork
  id <- randomNetwork
  return (ego, id)

randomLearning :: IO LearningParameters
randomLearning =
  LearningParameters <$> randomRIO (0.25, 0.75) <*> randomRIO (0.25, 0.75) <*> ↙
      ↳ fmap (10**) (randomRIO (-16, 0))

--random :: IO (Ego, Id, LearningParameters, LearningParameters)
random = do
  (ego, id) <- randomEgoId
  learnE <- randomLearning
  learnI <- randomLearning
  return (ego, id, reflE ego, reflI id, learnE, learnI)

image :: S ('D3 w h 3) -> Vector Word8
image (S3D i) = normalize . LA.flatten . extract $ i

image' :: S ('D3 w h 3) -> Vector Word8
image' (S3D i) = V.map (pixel . (+ 0.5) . (/ 12) . unsigmoid) . LA.flatten . ↙
    ↳ extract $ i

normalize xs =
  let n = V.length xs
      mi = V.minimum xs
      ma = V.maximum xs
      f x = pixel $ (x - mi) / (ma - mi)
  in  V.map f xs

main :: IO ()
main = do
      let width, height :: Num a => a
          width  = 1920
          height = 1080
      args <- getArgs
      let record = "record" `elem` args
      GLFW.setErrorCallback (Just $ \err msg -> hPutStrLn stderr msg >> ↙
          ↳ exitFailure)
      True <- GLFW.init
      GLFW.windowHint $ GLFW.WindowHint'Resizable False
      GLFW.windowHint $ GLFW.WindowHint'ContextVersionMajor 3
      GLFW.windowHint $ GLFW.WindowHint'ContextVersionMinor 3
      GLFW.windowHint $ GLFW.WindowHint'OpenGLProfile GLFW.OpenGLProfile'Core
      GLFW.windowHint $ GLFW.WindowHint'OpenGLForwardCompat True
      Just window <- GLFW.createWindow width height "nnirror" Nothing Nothing
      GLFW.makeContextCurrent $ Just window
      --GLFW.swapInterval 2
      glViewport 0 0 width height
      glPixelStorei GL_PACK_ALIGNMENT 1
      glPixelStorei GL_UNPACK_ALIGNMENT 1
```

```
        tex <- withArray [0,0,0,0,0,0,0] $ \ptr -> glGenTextures 7 ptr >> ↙
            ↳ peekArray 7 ptr
        glActiveTexture GL_TEXTURE0
        glBindTexture GL_TEXTURE_2D (tex !! 0)
        glTexImage2D GL_TEXTURE_2D 0 GL_RGB 36 64 0 GL_RGB GL_UNSIGNED_BYTE ↙
            ↳ nullPtr
330     glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
        glActiveTexture GL_TEXTURE1
335     glBindTexture GL_TEXTURE_2D (tex !! 1)
        glTexImage2D GL_TEXTURE_2D 0 GL_RGB 55 64 0 GL_RGB GL_UNSIGNED_BYTE ↙
            ↳ nullPtr
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
340     glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
        glActiveTexture GL_TEXTURE2
        glBindTexture GL_TEXTURE_2D (tex !! 2)
        glTexImage2D GL_TEXTURE_2D 0 GL_RGB 36 64 0 GL_RGB GL_UNSIGNED_BYTE ↙
            ↳ nullPtr
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_NEAREST
345     glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
        glActiveTexture GL_TEXTURE3
        glBindTexture GL_TEXTURE_2D (tex !! 3)
350     glTexImage2D GL_TEXTURE_2D 0 GL_RGB 55 64 0 GL_RGB GL_UNSIGNED_BYTE ↙
            ↳ nullPtr
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
355     glActiveTexture GL_TEXTURE4
        glBindTexture GL_TEXTURE_2D (tex !! 4)
        glTexImage2D GL_TEXTURE_2D 0 GL_RGB 143 1 0 GL_RGB GL_UNSIGNED_BYTE ↙
            ↳ nullPtr
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_NEAREST
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_NEAREST
360     glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
        glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
        glActiveTexture GL_TEXTURE5
        glBindTexture GL_TEXTURE_2D (tex !! 5)
        e <- readImage "training.png"
365     case e of
          Right (ImageRGBA8 (Image w h dat)) -> V.unsafeWith dat $ \ptr -> do
            glTexImage2D GL_TEXTURE_2D 0 GL_RGBA (fromIntegral w) (fromIntegral h)↙
                ↳  0 GL_RGBA GL_UNSIGNED_BYTE (castPtr ptr)
            glGenerateMipmap GL_TEXTURE_2D
            glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER ↙
                ↳ GL_LINEAR_MIPMAP_LINEAR
370         glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_LINEAR
            glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
            glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE
        glActiveTexture GL_TEXTURE6
        glBindTexture GL_TEXTURE_2D (tex !! 6)
```

```
375       e <- readImage "scoreboard.png"
          case e of
            Right (ImageRGBA8 (Image w h dat)) -> V.unsafeWith dat $ \ptr -> do
              glTexImage2D GL_TEXTURE_2D 0 GL_RGBA (fromIntegral w) (fromIntegral h) 0 GL_RGBA GL_UNSIGNED_BYTE (castPtr ptr)
              glGenerateMipmap GL_TEXTURE_2D
380           glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MIN_FILTER GL_LINEAR_MIPMAP_LINEAR
              glTexParameteri GL_TEXTURE_2D GL_TEXTURE_MAG_FILTER GL_LINEAR
              glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_S GL_CLAMP_TO_EDGE
              glTexParameteri GL_TEXTURE_2D GL_TEXTURE_WRAP_T GL_CLAMP_TO_EDGE

385       frag <- glCreateShader GL_FRAGMENT_SHADER
          withCString (unlines
            [ "#version 330 core"
            , "uniform sampler2D dego, did, ego, id, score, mask;"
            , "uniform ivec2 size;"
390         , "layout(location = 0) out vec4 cout;"
            , "void main() {"
            , "  vec4 m = texture(mask, vec2(0.0, 1.0) + vec2(1.0, -1.0) * gl_FragCoord.xy / vec2(size));"
            , "  vec4 c = vec4(vec3(0.0), 1.0);" -- texture(score, vec2(1.0, 0.5)).yxzw;"
            , "  vec2 t = gl_FragCoord.xy * vec2(254.0, 143.0) / vec2(size);"
395         , "  if (5.0 <= t.x && t.x < 5.0 + 36.0 && 5.0 <= t.y && t.y < 5.0 + 64.0) { c = texture(dego, (t - vec2(5.0, 5.0)) / vec2(36.0, 64.0)); }"
            , "  if (5.0 + 36.0 + 5.0 <= t.x && t.x < 5.0 + 36.0 + 5.0 + 55.0 && 5.0 <= t.y && t.y < 5.0 + 64.0) { c = texture(did, (t - vec2(5.0 + 36.0 + 5.0, 5.0)) / vec2(55.0, 64.0)); }"
            , "  if (5.0 <= t.x && t.x < 5.0 + 36.0 && 5.0 + 64.0 + 5.0 <= t.y && t.y < 5.0 + 64.0 + 5.0 + 64.0) { c = texture(ego, (t - vec2(5.0, 5.0 + 64.0 + 5.0)) / vec2(36.0, 64.0)); }"
            , "  if (5.0 + 36.0 + 5.0 <= t.x && t.x < 5.0 + 36.0 + 5.0 + 55.0 && 5.0 + 64.0 + 5.0 <= t.y && t.y < 5.0 + 64.0 + 5.0 + 64.0) { c = texture(id, (t - vec2(5.0 + 36.0 + 5.0, 5.0 + 64.0 + 5.0)) / vec2(55.0, 64.0)); }"
            , "  if (5.0 + 36.0 + 5.0 + 55.0 + 5.0 <= t.x && t.x < 5.0 + 36.0 + 5.0 + 55.0 + 5.0 + 143.0 && 5.0 <= t.y && t.y < 5.0 + 41.0 ) { c = vec4(vec3((t.y - 5.0) / 41.0 < texture(score, vec2((t.x - (5.0 + 36.0 + 5.0 + 55.0 + 5.0))/143.0, 0.5))[2] ? 0.75 : 0.25), 1.0); }"
400         , "  if (5.0 + 36.0 + 5.0 + 55.0 + 5.0 <= t.x && t.x < 5.0 + 36.0 + 5.0 + 55.0 + 5.0 + 143.0 && 5.0 + 41.0 + 5.0 <= t.y && t.y < 5.0 + 41.0 + 5.0 + 41.0) { c = vec4(vec3((t.y - (5.0 + 41.0 + 5.0)) / 41.0 < texture(score, vec2((t.x - (5.0 + 36.0 + 5.0 + 55.0 + 5.0))/143.0, 0.5))[1] ? 0.75 : 0.25), 1.0); }"
            , "  if (5.0 + 36.0 + 5.0 + 55.0 + 5.0 <= t.x && t.x < 5.0 + 36.0 + 5.0 + 55.0 + 5.0 + 143.0 && 5.0 + 41.0 + 5.0 + 41.0 + 5.0 <= t.y && t.y < 5.0 + 41.0 + 5.0 + 41.0 + 5.0 + 41.0) { c = vec4(vec3((t.y - (5.0 + 41.0 + 5.0 + 41.0 + 5.0)) / 41.0 < texture(score, vec2((t.x - (5.0 + 36.0 + 5.0 + 55.0 + 5.0))/143.0, 0.5))[0] ? 0.75 : 0.25), 1.0); }"
            , "  cout = mix(c, m, m.a);\n"
            , "}"
            ]) $ \s -> with s $ \string -> glShaderSource frag 1 string nullPtr
405       glCompileShader frag
          vert <- glCreateShader GL_VERTEX_SHADER
```

```
        withCString (unlines
          [ "#version 330 core"
          , "void main() {"
410       , "  if (gl_VertexID == 0) gl_Position = vec4(-1.0, -1.0, 0.0, 1.0);"
          , "  if (gl_VertexID == 1) gl_Position = vec4(-1.0,  1.0, 0.0, 1.0);"
          , "  if (gl_VertexID == 2) gl_Position = vec4( 1.0, -1.0, 0.0, 1.0);"
          , "  if (gl_VertexID == 3) gl_Position = vec4( 1.0,  1.0, 0.0, 1.0);"
          , "}"
415       ]) $ \s -> with s $ \string -> glShaderSource vert 1 string nullPtr
        glCompileShader vert
        prog <- glCreateProgram
        glAttachShader prog vert
        glAttachShader prog frag
420     glLinkProgram prog
        glUseProgram prog
        flip glUniform1i 0 =<< (withCString "dego" $ glGetUniformLocation prog)
        flip glUniform1i 1 =<< (withCString "did"  $ glGetUniformLocation prog)
        flip glUniform1i 2 =<< (withCString "ego"  $ glGetUniformLocation prog)
425     flip glUniform1i 3 =<< (withCString "id"   $ glGetUniformLocation prog)
        flip glUniform1i 4 =<< (withCString "score"$ glGetUniformLocation prog)
        flip glUniform1i 5 =<< (withCString "mask" $ glGetUniformLocation prog)
        (\l -> glUniform2i l width height) =<< (withCString "size" $ ↙
            ↳ glGetUniformLocation prog)
        vao <- with 0 $ \p -> glGenVertexArrays 1 p >> peek p
430     glBindVertexArray vao

        frag <- glCreateShader GL_FRAGMENT_SHADER
        withCString (unlines
          [ "#version 330 core"
435       , "in float hue;"
          , "layout(location = 0) out vec4 cout;"
          , "// http://lolengine.net/blog/2013/07/27/rgb-to-hsv-in-glsl"
          , "vec3 hsv2rgb(vec3 c)"
          , "{"
440       , "    vec4 K = vec4(1.0, 2.0 / 3.0, 1.0 / 3.0, 3.0);"
          , "    vec3 p = abs(fract(c.xxx + K.xyz) * 6.0 - K.www);"
          , "    return c.z * mix(K.xxx, clamp(p - K.xxx, 0.0, 1.0), c.y);"
          , "}"
          , "void main() {"
445       , "  cout = vec4(1.0);//vec4(hsv2rgb(vec3(hue, 1.0, 1.0)), 1.0);\n"
          , "}"
          ]) $ \s -> with s $ \string -> glShaderSource frag 1 string nullPtr
        glCompileShader frag
        vert <- glCreateShader GL_VERTEX_SHADER
450     withCString (unlines
          [ "#version 330 core"
          , "layout(location = 0) in vec4 v;"
          , "out float hue;"
          , "void main() {"
455       , "  hue = -log(v.z) / (20.0 * log(10.0));"
          , "  int n = int(round(abs(v.w))) - 1;"
          , "  float s = float((n % 30) / 5 * 5);"
          , "  float t = float(n / 30);"
          , "  vec2 p;"
460       , "  p.x = float(n % 5);"
          , "  p.y = float(gl_VertexID % 2);"
          , "  if ((gl_VertexID % 2) == 1 && (n % 5) == 4) { p.x = 3.0 - p.x; }"
```

```
    , "  if (v.w < 0.0) { p.y = 1.0 - p.y; }"
    , "  gl_Position = vec4(  (1.0 + p.x + 0.25 * (v.x - 0.5) + s + 0.5) / 32.0 * (v.w > 0.0 ? -1.0 : 1.0) + (v.w > 0.0 ? 1.0 : -1.0)"
    , "                     , ((p.y + 0.25 * (v.y - 0.5) + t / 0.5) / 32.0 - 0.5) * (16.0/9.0), 0.0, 1.0);"
    , "}"
    ]) $ \s -> with s $ \string -> glShaderSource vert 1 string nullPtr
  glCompileShader vert
  prog2 <- glCreateProgram
  glAttachShader prog2 vert
  glAttachShader prog2 frag
  glLinkProgram prog2
  glUseProgram prog2
  vbo <- with 0 $ \p -> glGenBuffers 1 p >> peek p
  glBindBuffer GL_ARRAY_BUFFER vbo
  glBufferData GL_ARRAY_BUFFER (fromIntegral $ 1000 * 2 * 4 * sizeOf (0 :: Float)) nullPtr GL_STREAM_DRAW
  vao2 <- with 0 $ \p -> glGenVertexArrays 1 p >> peek p
  glBindVertexArray vao2
  glVertexAttribPointer 0 4 GL_FLOAT GL_FALSE 0 nullPtr
  glEnableVertexAttribArray 0

  frag <- glCreateShader GL_FRAGMENT_SHADER
  withCString (unlines
    [ "#version 330 core"
    , "uniform sampler2D mask;"
    , "uniform ivec2 size;"
    , "layout(location = 0) out vec4 cout;"
    , "void main() {"
    , "  cout = texture(mask, vec2(0.0, 1.0) + vec2(1.0, -1.0) * gl_FragCoord.xy / vec2(size));"
    , "}"
    ]) $ \s -> with s $ \string -> glShaderSource frag 1 string nullPtr
  glCompileShader frag
  vert <- glCreateShader GL_VERTEX_SHADER
  withCString (unlines
    [ "#version 330 core"
    , "void main() {"
    , "  if (gl_VertexID == 0) gl_Position = vec4(-1.0, -1.0, 0.0, 1.0);"
    , "  if (gl_VertexID == 1) gl_Position = vec4(-1.0,  1.0, 0.0, 1.0);"
    , "  if (gl_VertexID == 2) gl_Position = vec4( 1.0, -1.0, 0.0, 1.0);"
    , "  if (gl_VertexID == 3) gl_Position = vec4( 1.0,  1.0, 0.0, 1.0);"
    , "}"
    ]) $ \s -> with s $ \string -> glShaderSource vert 1 string nullPtr
  glCompileShader vert
  prog3 <- glCreateProgram
  glAttachShader prog3 vert
  glAttachShader prog3 frag
  glLinkProgram prog3
  glUseProgram prog3
  flip glUniform1i 6 =<< (withCString "mask" $ glGetUniformLocation prog3)
  (\l -> glUniform2i l width height) =<< (withCString "size" $ glGetUniformLocation prog3)

  framesR <- newIORef 0
  let showScoreboard 0 _ = return ()
      showScoreboard n count = do
```

```
515             when record $ capturePPM width height
                modifyIORef framesR (+1)
                frames <- readIORef framesR
                when (record && frames == 9000) exitSuccess
               GLFW.swapBuffers window
520             glClearColor 0 0 0 1
                glClear (GL_COLOR_BUFFER_BIT + GL_DEPTH_BUFFER_BIT)
                glUseProgram prog2
                glBindVertexArray vao2
                glDrawArrays GL_LINES 0 (count * 2)
525             glUseProgram prog3
                glBindVertexArray vao
                glEnable GL_BLEND
                glBlendFunc GL_SRC_ALPHA GL_ONE_MINUS_SRC_ALPHA
                glDrawArrays GL_TRIANGLE_STRIP 0 4
530             glDisable GL_BLEND
               GLFW.pollEvents
                stop <- GLFW.windowShouldClose window
                e <- glGetError
                when (e /= 0) $ hPutStrLn stderr $ "ERROR   " ++ show e
535             unless stop $ showScoreboard (n - 1) count

            uploadScoreboard scoreboard = do
              withArray (concat
                [ map realToFrac [ x0, y0, z0, w, x1, y1, z1, w ]
540             | ((LearningParameters x0 y0 z0, LearningParameters x1 y1 z1), w)
                  <- (lefts  scoreboard `zip` [-1,-2..]) ++
                     (rights scoreboard `zip` [1..])
                ] :: [Float]) $
                glBufferSubData GL_ARRAY_BUFFER 0 (fromIntegral $ fromIntegral (↙
                    ↳ length scoreboard) * 2 * 4 * sizeOf (0 :: Float)) . castPtr
545
            loop n m history scoreboard lastTime = do
              s@(ego, id, e0, i0, learnE, learnI) <- case m of
                Nothing -> random
                Just s -> pure s
550             a <- async $ do gan (learnE, learnI) (ego, id)
                when record $ capturePPM width height
                modifyIORef framesR (+1)
                frames <- readIORef framesR
                when (record && frames == 9000) exitSuccess
555             GLFW.swapBuffers window
                ((newEgo, newId), scores@(real:fake:poop:total:_)) <- wait a
                let s' = (newEgo, newId, e1, i1, learnE, learnI)
                    history' = drop 3 history ++ [ real, fake, poop ]
                    px :: S ('D3 143 1 3)
560                 px = S3D . LAS.fromList $ history'
                    !e1 = reflE newEgo
                    !i1 = reflI newId
                    !de = e1 - e0
                    !di = i1 - i0
565             glActiveTexture GL_TEXTURE0
                V.unsafeWith (image  de) $ glTexSubImage2D GL_TEXTURE_2D 0 0 0 36 64↙
                    ↳ GL_RGB GL_UNSIGNED_BYTE . castPtr
                glActiveTexture GL_TEXTURE1
                V.unsafeWith (image  di) $ glTexSubImage2D GL_TEXTURE_2D 0 0 0 55 64↙
                    ↳ GL_RGB GL_UNSIGNED_BYTE . castPtr
```

```
                glActiveTexture GL_TEXTURE2
570             V.unsafeWith (image  e1) $ glTexSubImage2D GL_TEXTURE_2D 0 0 0 36 64↙
                    ↳ GL_RGB GL_UNSIGNED_BYTE . castPtr
                glActiveTexture GL_TEXTURE3
                V.unsafeWith (image  i1) $ glTexSubImage2D GL_TEXTURE_2D 0 0 0 55 64↙
                    ↳ GL_RGB GL_UNSIGNED_BYTE . castPtr
                glActiveTexture GL_TEXTURE4
                V.unsafeWith (image' px) $ glTexSubImage2D GL_TEXTURE_2D 0 0 0 143 1↙
                    ↳ GL_RGB GL_UNSIGNED_BYTE . castPtr
575             glClearColor 0 0 0 1
                glClear (GL_COLOR_BUFFER_BIT + GL_DEPTH_BUFFER_BIT)
                glUseProgram prog
                glBindVertexArray vao
                glDrawArrays GL_TRIANGLE_STRIP 0 4
580             GLFW.pollEvents
                stop <- GLFW.windowShouldClose window
                e <- glGetError
                when (e /= 0) $ hPutStrLn stderr $ "ERROR   " ++ show e
                unless stop $ case () of
585               _ | total > 4.5 -> do
                        Just now <- GLFW.getTime
                        hPutStrLn stderr $ "SUCCESS " ++ show n
                        hPutStrLn stderr $ "FPS " ++ show (fromIntegral n / (now - ↙
                            ↳ lastTime))
                        hFlush stderr
590                     let scoreboard' = take 1024 $ Right (learnE, learnI) : ↙
                            ↳ scoreboard
                        uploadScoreboard scoreboard'
                        showScoreboard (15 * 5) (fromIntegral $ length scoreboard')
                        Just now <- GLFW.getTime
                        loop 0 Nothing (replicate (143 * 3) 0) scoreboard' now
595                   | n >= 999 -> do
                        Just now <- GLFW.getTime
                        hPutStrLn stderr $ "FAILURE " ++ show total
                        hPutStrLn stderr $ "FPS " ++ show (fromIntegral n / (now - ↙
                            ↳ lastTime))
                        hFlush stderr
600                     let scoreboard' = take 1024 $ Left (learnE, learnI) : ↙
                            ↳ scoreboard
                        uploadScoreboard scoreboard'
                        showScoreboard (15 * 5) (fromIntegral $ length scoreboard')
                        Just now <- GLFW.getTime
                        loop 0 Nothing (replicate (143 * 3) 0) scoreboard' now
605                   | otherwise -> do
                        loop (n + 1) (Just s') history' scoreboard lastTime
          glClearColor 0 0 0 1
          glClear (GL_COLOR_BUFFER_BIT + GL_DEPTH_BUFFER_BIT)
          Just now <- GLFW.getTime
610       loop 0 Nothing (replicate (143 * 3) 0) [] now

showN :: Show a => Char -> Int -> a -> String
showN c n = reverse . take n . (++ repeat c) . reverse . show

615 capturePPM :: Int -> Int -> IO ()
capturePPM vw vh = do
  let p6 = "P6\n" ++ show vw ++ " " ++ show vh ++ "\n255\n"
  allocaBytes (vw*vh*3) $ \ptr -> do
```

```
    glReadPixels 0 0 (fromIntegral vw) (fromIntegral vh) GL_RGB GL_UNSIGNED_BYTE↙
      ↳ (castPtr ptr)
    hPutStr stdout p6
    forM_ [0..vh-1] $ \y -> hPutBuf stdout (ptr `plusPtr` ((vh-1-y)*vw*3)) (vw↙
      ↳ *3)
    hFlush stdout

class Concrete a where
  reflect :: a -> Vector Double
  reify   :: [Double] -> Maybe (a, [Double])

instance Concrete (Pad a b c d) where
  reflect _ = V.empty
  reify xs = Just (Pad, xs)

instance Concrete (Crop a b c d) where
  reflect _ = V.empty
  reify xs = Just (Crop, xs)

instance Concrete (Pooling a b c d) where
  reflect _ = V.empty
  reify xs = Just (Pooling, xs)

instance Concrete Reshape where
  reflect _ = V.empty
  reify xs = Just (Reshape, xs)

instance Concrete Relu where
  reflect _ = V.empty
  reify xs = Just (Relu, xs)

instance Concrete Logit where
  reflect _ = V.empty
  reify xs = Just (Logit, xs)

instance ( KnownNat i
         , KnownNat o
         , KnownNat kx
         , KnownNat ky
         , KnownNat sx
         , KnownNat sy
         , KnownNat (kx * ky * i)
         ) => Concrete (Convolution i o kx ky sx sy) where
  reflect (Convolution ws _) = LA.flatten . extract $ ws
  reify xs = case splitAt n xs of
    (me, rest)
      | length me == n -> do
          ws <- create . LA.reshape o . LA.fromList $ me
          pure (Convolution ws (konst 0), rest)
    _ -> Nothing
    where
      n  = i * o * kx * ky
      i  = fromIntegral $ natVal (Proxy :: Proxy i)
      o  = fromIntegral $ natVal (Proxy :: Proxy o)
      kx = fromIntegral $ natVal (Proxy :: Proxy kx)
      ky = fromIntegral $ natVal (Proxy :: Proxy ky)
```

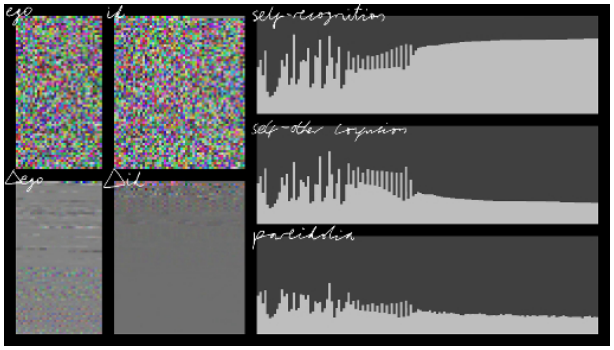
```
instance ( KnownNat i
         , KnownNat o
         , KnownNat kx
         , KnownNat ky
         , KnownNat sx
         , KnownNat sy
         , KnownNat (kx * ky * o)
         ) => Concrete (Deconvolution i o kx ky sx sy) where
  reflect (Deconvolution ws _) = LA.flatten . extract $ ws
  reify xs = case splitAt n xs of
    (me, rest)
      | length me == n -> do
          ws <- create . LA.reshape i . LA.fromList $ me
          pure (Deconvolution ws (konst 0), rest)
    _ -> Nothing
    where
      n  = i * o * kx * ky
      i  = fromIntegral $ natVal (Proxy :: Proxy i)
      o  = fromIntegral $ natVal (Proxy :: Proxy o)
      kx = fromIntegral $ natVal (Proxy :: Proxy kx)
      ky = fromIntegral $ natVal (Proxy :: Proxy ky)

instance (KnownNat i, KnownNat o) => Concrete (FullyConnected i o) where
  reflect (FullyConnected (FullyConnected' bs ws) _) = extract bs <> (LA.flatten↙
      ↪ . extract) ws
  reify xs = case splitAt o xs of
    (me, ys)
      | length me == o -> do
          bs <- create . LA.fromList $ me
          case splitAt (i * o) ys of
            (me, rest)
              | length me == i * o -> do
                  ws <- create . LA.reshape i . LA.fromList $ me
                  pure (FullyConnected (FullyConnected' bs ws) (FullyConnected' ↙
                      ↪ (konst 0) (konst 0)), rest)
            _ -> Nothing
    _ -> Nothing
    where
      i = fromIntegral $ natVal (Proxy :: Proxy i)
      o = fromIntegral $ natVal (Proxy :: Proxy o)

instance SingI i => Concrete (Network '[] '[i]) where
  reflect NNil = V.empty
  reify xs = Just (NNil, xs)

instance (SingI i, SingI o, Layer x i o, Concrete x, Concrete (Network xs (o ': ↙
    ↪ rs))) => Concrete (Network (x ': xs) (i ': o ': rs)) where
  reflect (x :~> r) = reflect x <> reflect r
  reify xs = do
    (x, ys) <- reify xs
    (r, zs) <- reify ys
    pure (x :~> r, zs)
```

8 nnirror.jpg

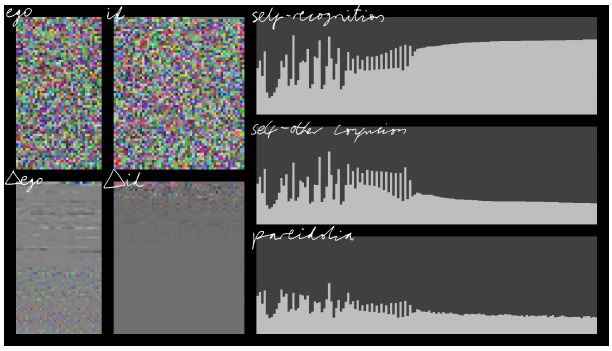


9 nnirror-plot.sh

```
#!/bin/bash
o=$1
mkdir -p "nnirror/${o}"
for i in 0 1 2 3 4 5 6 7 8 9
do
  shift
  j=$1
  rm "${i}.log"
  pushd "${j}"
  nnirror nets to images
  popd
  ln -s "${j}/nnirror.log" "${i}.log"
  convert "${j}.png" -rotate 270 -geometry 700x500 -quality 100 "nnirror/${o}/${i}-learn.jpg" &
  convert "${j}.png" -rotate 270                                 "nnirror/${o}/${i}-learn.png" &
  pnmenlarge 108 < "${j}/ego.ppm" | pnmpad -white -left 144 -right 144 -top 144 -bottom 144 > "${j}/ego_large.ppm"
  pnmenlarge 108 < "${j}/id.ppm"  | pnmpad -white -left 144 -right 144 -top 144 -bottom 144 > "${j}/id_large.ppm"
  convert "${j}/ego_large.ppm" -geometry 700x500 -quality 100 "nnirror/${o}/${i}-ego.jpg" &
  convert "${j}/ego_large.ppm"                                 "nnirror/${o}/${i}-ego.png" &
  convert "${j}/id_large.ppm"  -geometry 700x500 -quality 100 "nnirror/${o}/${i}-id.jpg" &
  convert "${j}/id_large.ppm"                                  "nnirror/${o}/${i}-id.png" &
  wait
  rm "${j}/ego_large.ppm" "${j}/id_large.ppm"
done
gnuplot < ../nnirror.gnuplot
convert "out.png" -geometry 700x500 -quality 100 "nnirror/${o}/metrics.jpg"
mv out.png "nnirror/${o}/metrics.png"
cat <<EOF > "nnirror/${o}/index.html"
<!DOCTYPE html>
<html><head><title>#${o} :: nnirror :: mathr</title><style>
body { width: 1500px; margin: auto; }
h1, h2, p { text-align: center; }
```

```
img { vertical-align: middle; }
a { text-decoration: none; }
a img { border: 1px solid; }
</style></head><body>
<h1>nnirror #${o}</h1>
<h2>metrics</h2><p><a href="metrics.png" title="metrics"><img src="metrics.jpg" alt="metrics" /></a></p>
EOF
for i in 0 1 2 3 4 5 6 7 8 9
do
  echo "<h2>${i}</h2><p><a href=\"${i}-learn.png\" title=\"${i} learn\"><img src=\"${i}-learn.jpg\" alt=\"${i} learn\" /></a> <a href=\"${i}-ego.png\" title=\"${i} ego\"><img src=\"${i}-ego.jpg\" alt=\"${i} ego\" /></a> <a href=\"${i}-id.png\" title=\"${i} id\"><img src=\"${i}-id.jpg\" alt=\"${i} id\" /></a></p>"
done >> "nnirror/${o}/index.html"
cat <<EOF >> "nnirror/${o}/index.html"
<hr />
<p><a href=".." title="nnirror">nnirror</a></p>
</body></html>
EOF
```

10 nnirror.png



11 nnirror-score.c

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>

double u(double x)
{
  return -log(1 / x - 1);
}

int main(int argc, char **argv)
{
  if (argc != 4) return 1;
  double a = atof(argv[1]);
  double b = atof(argv[2]);
  double c = atof(argv[3]);
  double s = (2 * u(a) - u(b) - u(c)) / 4;
  printf("%f\n", s);
```

```
  return 0;
}
```

12 nnirror.sh

```
#!/bin/bash
nnirror1() {
  mkdir $1
  cd $1
  nnirror $1
  pnmtopng -compression 9 < nnirror.ppm > ../$1.png
  rm nnirror.ppm
  cd ..
}
export -f nnirror1
mkdir output &&
cd output &&
seq -w 0 999 |
parallel nnirror1 &&
for o in ???
do
  tail -n 1 $o/nnirror.log |
  ( read it a b c ; echo "$(../nnirror-score $a $b $c)" "$o" )
done |
sort -g -r |
cut -d\  -f 2 |
xargs -n 10 echo |
cat -n |
xargs -n 11 ../nnirror-plot.sh
cd nnirror
ls -1 |
sort -g |
while read n
do
  mv n $((n - 1))
done
rename s/^/0/ ?
cd ..
cd ..
```

13 scoreboard.png

14 Setup.hs

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

15 training.png