PFP Final Project Report
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Project Description

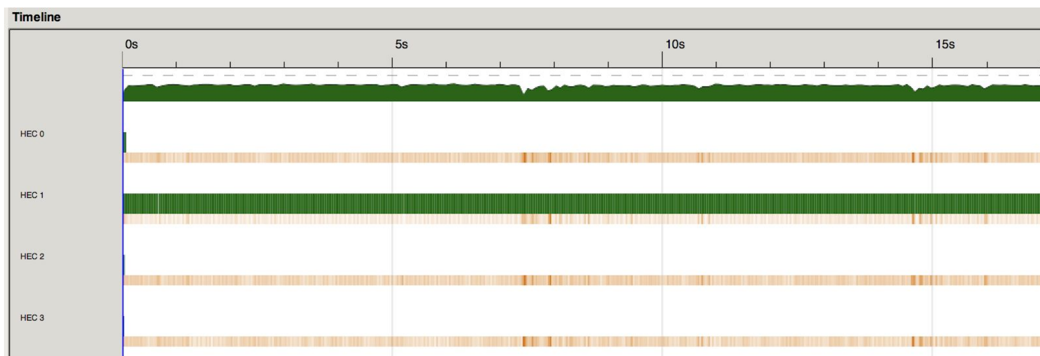
- What we implemented and how
  - All-pairs shortest distance problem
    - Find the shortest distance between all possible pairs of nodes in a graph using Dijkstra's algorithm for shortest path
  - Parallelization component: calculate distance between pairs in the graph in parallel rather than sequentially to reduce runtime
- The executable takes in an integer **n**, randomly generates a graph with **n** nodes, then outputs a calculation of all-pairs for the graph

Performance Figures:

Single-Threaded

```
$ time ./final 200 +RTS -N1 -ls

real  0m17.106s
user  0m24.718s
sys   0m2.136s
```



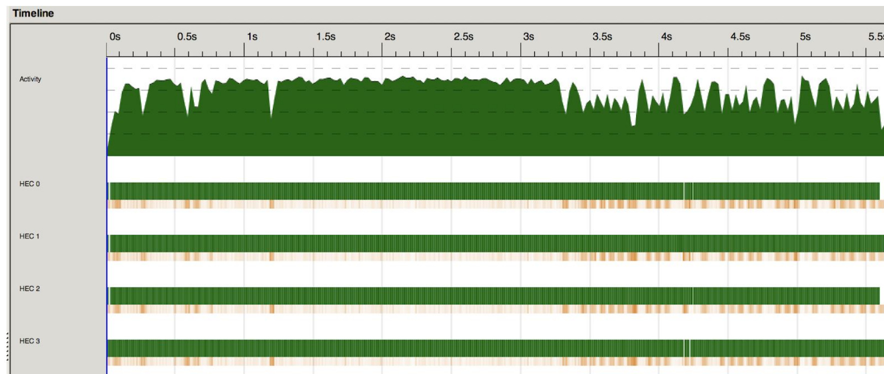
Parallelized w/ Four Cores

```
$ time ./final 200 +RTS -N4 -ls

real  0m5.705s
user  0m20.116s
```

```
sys   0m0.466s

Speedup = user/real = 20.116/5.705 = 3.53
```



Full Code Listing

```
import            Data.Graph
import            Data.IntMap.Lazy
import            Data.Set
import            System.Random                  ( randomRIO
                                                 , getStdRandom
                                                 , randomR
                                                 )
import            Control.Monad                  ( replicateM )
import            Data.List                      ( nub )
import            Control.Parallel.Strategies    ( parMap
                                                 , rdeepseq
                                                 )
import            System.Environment             ( getArgs
                                                 , getProgName
                                                 )
import            System.Exit                    ( die )

{-
 MUST INSTALL PACKAGES:
 -- $ cabal install --lib random
    $ stack install parallel

 References:

https://www.schoolofhaskell.com/school/starting-with-haskell/librarie
s-and-frameworks/randoms
```

```
https://stackoverflow.com/questions/30740366/list-with-random-numbers
-in-haskell
 http://zvon.org/other/haskell/Outputrandom/randomR_f.html

https://stackoverflow.com/questions/45194657/how-do-i-run-through-a-l
ist-with-an-io-operation

https://www.schoolofhaskell.com/school/starting-with-haskell/librarie
s-and-frameworks/randoms

-}

main :: IO ()
main = do
  args <- getArgs
  case args of
    [strNum] -> do
      let numNodes = read strNum :: Int
      (g, intMapArr) <- allPairsParallel numNodes
      putStrLn "Graph:"
      print g
      putStrLn "IntMap:"
      mapM_ print intMapArr
    _ -> do
      pn <- getProgName
      die $ "Usage: " ++ pn ++ " <number of nodes in random graph>"

generateTestGraph :: Graph
generateTestGraph = buildG (0, 6) [(0, 1), (2, 3), (5, 1), (6, 1),
(5, 4), (1, 3), (4, 5), (3, 6)]

generateTestGraphTwo :: Graph
generateTestGraphTwo = buildG (0, 9) [(0, 2), (1, 0), (1, 3), (2, 0),
(3, 8), (3, 9), (4, 3), (4, 8), (5, 6), (6, 3), (6, 4), (7, 1), (7,
2), (7, 5), (8, 3), (9, 1)]

allPairsParallel :: Int -> IO (Graph, [IntMap Double])
allPairsParallel numNodes = do
  g <- randGraph numNodes
  let distanceMaps = computeDistancesParallel [0 .. numNodes] g
  return (g, distanceMaps)
```

```
computeDistancesParallel :: [Int] -> Graph -> [IntMap Double]
computeDistancesParallel [] _ = []
computeDistancesParallel l  g = parMap rdeepseq (dijkstra g) l

allPairs :: Int -> IO (Graph, [IntMap Double])
allPairs numNodes = do
  g <- randGraph numNodes
  let distanceMaps = computeDistances [0 .. numNodes] g
  return (g, distanceMaps)

computeDistances :: [Int] -> Graph -> [IntMap Double]
computeDistances []       _ = []
computeDistances (n : ns) g = dijkstra g n : computeDistances ns g

randDijkstra :: Int -> Int -> IO (Graph, IntMap Double)
randDijkstra numNodes startNode = do
  g <- randGraph numNodes
  let distanceMap = dijkstra g startNode
  return (g, distanceMap)

randGraph :: Int -> IO Graph
randGraph n = do
  edgs <- allEdges n
  return $ buildG (0, n) edgs

allEdges :: Int -> IO [Edge]
allEdges n = do
  listOfEdges <- sequence $ zipWith randEdges [0 .. n] (replicate (n
+ 1) n)
  let allEdgeList = concat listOfEdges
  return allEdgeList

randEdges :: Int -> Int -> IO [Edge]
randEdges currNode numNodes = do
  randInts <- randIntList numNodes
  return [ (currNode, m) | m <- randInts, currNode /= m ]

randIntList :: Int -> IO [Int]
randIntList n = do
  deps <- numDependencies n
  ints <- replicateM deps $ randomRIO (0, n)
  return $ nub ints
```

```
numDependencies :: Int -> IO Int
numDependencies n = do
  r <- getStdRandom (randomR (1, n))
  return r

dijkstra :: Graph -> Int -> IntMap Double
dijkstra g start = dijkstraHelper g distanceMap visitedSet
 where
  distanceMap = initializeIntMap start (vertices g)
  visitedSet  = initializeSet

dijkstraHelper :: Graph -> IntMap Double -> Set Int -> IntMap Double
dijkstraHelper g distances visitedSet = case smallestDistanceNode of
  Nothing -> distances
  Just _  -> dijkstraHelper
    g
    updatedDistanceMap
    (addToSet visitedSet unwrappedSmallestDistanceNode)
 where
  smallestDistanceNode =
    getSmallestDistanceNode (vertices g) visitedSet distances
  Just unwrappedSmallestDistanceNode =
    getSmallestDistanceNode (vertices g) visitedSet distances
  updatedDistanceMap = updateDistanceMap
    unwrappedSmallestDistanceNode
    (getAdjacentVertices g unwrappedSmallestDistanceNode)
    distances

getSmallestDistanceNode :: [Int] -> Set Int -> IntMap Double -> Maybe
Int
getSmallestDistanceNode q visited distances = case validNodes of
  [] -> Nothing
  _  -> Just
    $ Prelude.foldl (\x y -> getCloserNode x y distances) firstElem
validNodes
 where
  validNodes = Prelude.filter (\x -> Data.Set.notMember x visited) q
  firstElem  = head validNodes

getCloserNode :: Int -> Int -> IntMap Double -> Int
getCloserNode a b m = case (compare l r) of
  LT -> a
  EQ -> a
```

```
  GT -> b
 where
  Just l = Data.IntMap.Lazy.lookup a m
  Just r = Data.IntMap.Lazy.lookup b m

getAdjacentVertices :: Graph -> Int -> [Int]
getAdjacentVertices g v = convertEdgeToOutNodes $ getEdgesOutOf g v

getEdgesOutOf :: Graph -> Int -> [Edge]
getEdgesOutOf g i = Prelude.filter (\(s, _) -> s == i) $ edges g

convertEdgeToOutNodes :: [Edge] -> [Int]
convertEdgeToOutNodes []            = []
convertEdgeToOutNodes ((_, o) : xs) = o : convertEdgeToOutNodes xs

initializeIntMap :: Int -> [Int] -> IntMap Double
initializeIntMap s l = adjust
  f
  s
  (Data.IntMap.Lazy.fromList [ (x, 1 / 0) | x <- l ])
  where f _ = 0

initializeSet :: Set Int
initializeSet = Data.Set.fromList []

addToSet :: Set Int -> Int -> Set Int
addToSet s i = Data.Set.insert i s

updateDistanceMap :: Int -> [Int] -> IntMap Double -> IntMap Double
updateDistanceMap _       []       m = m
updateDistanceMap closest (a : as) m = updateDistanceMap closest
                                                         as

updatedDistanceMap
 where
  Just closestDistance = Data.IntMap.Lazy.lookup closest m
  updatedDistanceMap   = updateDistanceNode closestDistance a m

updateDistanceNode :: Double -> Int -> IntMap Double -> IntMap Double
updateDistanceNode closestDistance adj m =
  case (compare (closestDistance + 1) adjDistance) of
    LT -> updatedMap
    EQ -> updatedMap
```

```
    GT -> m
  where
   Just adjDistance = Data.IntMap.Lazy.lookup adj m
   f _ = closestDistance + 1.0
   updatedMap = adjust f adj m
```