The Eval Monad and Strategies

Stephen A. Edwards

Columbia University

Fall 2020
The Eval Monad: An Alternative to `seq` and `par`

When in doubt, create a Monad

```haskell
module Control.Parallel.Strategies where

data Eval a = ...

instance Monad Eval where ...

runEval :: Eval a -> a  -- Get the result

rpar :: a -> Eval a   -- Spark evaluation
rseq :: a -> Eval a   -- Wait for evaluation to WHNF
```
runEval $ do
  a <- rpar (f x)
  b <- rpar (f y)
  return (a, b)

Start parallel evaluation of f x and f y
Return immediately
runEval $ do
  a <- rpar (f x)
  b <- rseq (f y)
  return (a, b)

Start parallel evaluation of f x and f y
Wait for f y to finish, then return

*Do we really know f y is faster?*
runEval $ do
  a <- rpar (f x)
  b <- rseq (f y)
  rseq a
  return (a, b)

Equivalent and symmetrical:
runEval $ do
  a <- rpar (f x)
  b <- rpar (f y)
  rseq a
  rseq b
  return (a, b)

Start parallel evaluation of f x and f y
Wait for both to finish, then return
Marlow’s Sudoku Solver Example (single-threaded)

```haskell
import Sudoku ; import Control.Exception
import System.Environment ; import Data.Maybe

main :: IO ()
main = do [f] <- getArgs
            file <- readFile f
            let puzzles = lines file
                solutions = map solve puzzles
            print (length (filter isJust solutions))
```

$ wget https://github.com/simonmar/parconc-examples/archive/master.tar.gz
$ tar --strip-components=1 -zxf master.tar.gz \  
  parconc-examples-master/{Sudoku.hs,sudoku17.1000.txt}

$ stack ghc -- -O2 sudoku1.hs -rtsopts
$ ./sudoku1 sudoku17.1000.txt +RTS -s
import Sudoku
import Data.Maybe ; import System.Environment
import Control.Parallel.Strategies ; import Control.DeepSeq

main :: IO ()
main = do puzzles <- getArgs >>= \[f] -> lines <$> readFile f

    let (as,bs) = splitAt (length puzzles `div` 2) puzzles

    solutions = runEval $ do
        as' <- rpar (force (map solve as)) -- To normal
        bs' <- rpar (force (map solve bs)) -- form
        _ <- rseq as'
        _ <- rseq bs'
        return (as' ++ bs')

    print (length (filter isJust solutions))
The Problem with Static Partitioning

```
$ stack install parallel
$ stack ghc -- -O2 -Wall sudoku2.hs -threaded -rtsopts -eventlog
$ ./sudoku2 sudoku17.1000.txt +RTS -N2 -s -ls
$ threadscope sudoku2.eventlog
```

Speedup on two cores: $1.37/0.891 = 1.53 \times$
import Sudoku
import System.Environment ; import Data.Maybe
import Control.Parallel.Strategies hiding (parMap)

parMap :: (a -> b) -> [a] -> Eval [b]
parMap _ [] = return []
parMap f (a:as) = do b <- rpar (f a) -- Spark evaluation of f a
                       bs <- parMap f as -- Recurse
                       return (b:bs)

main :: IO ()
main = do puzzles <- getArgs >>= \[f] -> lines <$> readFile f
         let solutions = runEval (parMap solve puzzles)
         print (length (filter isJust solutions))
The Advantage of Dynamic Partitioning

$ \text{stack \hspace{1mm} ghc \hspace{1mm} --\hspace{1mm} -02\hspace{1mm} -Wall\hspace{1mm} sudoku3.hs\hspace{1mm} -threaded\hspace{1mm} -rtsopts\hspace{1mm} -eventlog}$

$ \text{./sudoku3\hspace{1mm} sudoku17.1000.txt\hspace{1mm} +RTS\hspace{1mm} -N2\hspace{1mm} -s\hspace{1mm} -ls}$

$ \text{threadscope\hspace{1mm} sudoku3.eventlog}$

Speedup on two cores: $1.37/0.751 = 1.82 \times$ versus $1.53 \times$ with static partitioning
Validity of the single processor approach to achieving large scale computing capabilities

by DR. GENE M. AMDAHL
International Business Machines Corporation
Sunnyvale, California

AFIPS Joint Computer Conference, 1967

\[ S = \frac{1}{(1 - P) + P/N} \]

**Validity of the single processor approach to achieving large scale computing capabilities**

*P* is the parallel fraction of the task

*N* is the degree of parallelism

*S* is the speedup

\[ \lim_{N \to \infty} S \text{ is the depressing part:} \]

If \( P = 0.5 \), \( S \to 2 \) as \( N \to \infty \)

If \( P = 0.95 \), \( S \to 20 \) as \( N \to \infty \)
DeepSeq and Normal Form

Weak Head Normal Form = Top is data constructor or lambda, not application

Normal Form = Data constructors or lambdas all the way down

In Control.Deepseq,

class NFData a where
    rnf :: a -> ()          -- ”Reduce to Normal Form”
    rnf a = a `seq` ()     -- Default, e.g., for numbers

deepseq :: NFData a => a -> b -> b
    deepseq a b = rnf a `seq` b -- Evaluate a to NF; return b

force :: NFData a => a -> a
    force a = a `deepseq` a    -- Evaluate a to NF; return it

($!!) :: NFData a => (a -> b) -> a -> b
    f $!! x = x `deepseq` f x    -- evaluate x then f x
Normal Form vs. Weak Head Normal Form

Prelude> import Control.DeepSeq
Prelude Control.DeepSeq> let x = [1..10] :: [Int]
Prelude Control.DeepSeq> :sprint x
x = _
Prelude Control.DeepSeq> :sprint x
x = _
Prelude Control.DeepSeq> x `seq` ()
()
Prelude Control.DeepSeq> :sprint x
x = 1 : _
Prelude Control.DeepSeq> (last $ take 3 x) `seq` ()
()
Prelude Control.DeepSeq> :sprint x
x = 1 : 2 : 3 : _
Prelude Control.DeepSeq> x `deepseq` ()
()
Prelude Control.DeepSeq> :sprint x
x = [1,2,3,4,5,6,7,8,9,10]
Roll-your-own NFData

```haskell
import Control.DeepSeq

data Tree a = Empty | Branch (Tree a) a (Tree a)

instance NFData a => NFData (Tree a) where
    rnf Empty = ()
    rnf (Branch l a r) = rnf l `seq` rnf a `seq` rnf r

*Main> let singleton x = Branch Empty x Empty
*Main> let x = Branch (singleton 'a') 'b' (singleton 'c')
*Main> :sprint x
x = Branch _ 'b' _
*Main> x `seq` ()
()
*Main> :sprint x
x = Branch _ 'b' _
*Main> rnf x
()
*Main> :sprint x
x = Branch (Branch Empty 'a' Empty) 'b' (Branch Empty 'c' Empty)
```
Evaluation Strategies

“Strategies are a means for modularizing parallel code by separating the algorithm from the parallelism. Sometimes they require you to rewrite your algorithm, but once you do so, you will be able to parallelize it in different ways just by substituting a new Strategy.” —Simon Marlow

1. Build a lazy data structure representing the computation
2. Apply a Strategy that traverses the computation applying $rpar$ and $rseq$


```
type Strategy = a \rightarrow Eval\ a
```
An Example: A Parallel Strategy for Pairs

\[
\begin{align*}
\text{rpar} &: \quad \text{Strategy}\ a & \quad \text{-- Spark evaluation} \\
\text{runEval} &: \quad \text{Eval}\ a \rightarrow a & \quad \text{-- Evaluate; return value} \\
\text{parPair} &: \quad \text{Strategy}\ (a,b) & \quad \text{-- Simple parallel strategy for pairs} \\
\text{parPair}\ (a,b) &= \text{do} \\
& \quad a' \leftarrow \text{rpar}\ a & \quad \text{-- Spark parallel evaluation of} \\
& \quad b' \leftarrow \text{rpar}\ b & \quad \text{-- } a \text{ and } b \text{ to WHNF} \\
& \quad \text{return}\ (a',b')
\end{align*}
\]

\[\text{runEval}\ (\text{parPair}\ (\text{fib}\ 35,\ \text{fib}\ 36))\]

More elegantly,

\[
\begin{align*}
\text{using} &: \quad a \rightarrow \text{Strategy}\ a \rightarrow a & \quad \text{-- In Control.Parallel.Strategies} \\
\text{x \text{\`using\` s = runEval\ (s x)} & \quad \text{-- Apply s, return x} \\
\text{(fib}\ 35,\ \text{fib}\ 36) \text{\`using\` parPair}
\end{align*}
\]
Basic Strategies

In Control.Parallel.Strategies:

\[ r_0 \quad :: \quad \text{Strategy} \ a \]
\[ r_0 \ x \quad = \quad \text{return} \ x \quad \quad \quad \text{-- Do not evaluate} \ x \]

\[ rSeq \quad :: \quad \text{Strategy} \ a \quad \text{-- Evaluate to WHNF; wait for completion} \]

\[ rDeepSeq \quad :: \quad \text{NFData} \ a \Rightarrow \text{Strategy} \ a \quad \text{-- Fully evaluate then proceed} \]
\[ rDeepSeq \ x = rSeq \ (rnf \ x) \gg \text{return} \ x \]

\[ rPar \quad :: \quad \text{Strategy} \ a \quad \text{-- Spark evaluation (in parallel) to WHNF} \]

\[ rParWith \quad :: \quad \text{Strategy} \ a \Rightarrow \text{Strategy} \ a \]
\[ rParWith \ s \ x \quad \quad \quad \text{-- Spark evaluation of} \ x \ 'using' \ s \]
Building Strategies from Strategies

A skeleton for expressing strategies for evaluating tuples:

```haskell
-- In Control.Parallel.Strategies,

evalTuple2 :: Strategy a -> Strategy b -> Strategy (a, b)
evalTuple2 sa sb (a, b) = do a' <- sa a
                                b' <- sb b
                                return (a', b')

parPair :: Strategy (a, b)
parPair = evalTuple2 rpar rpar -- Spark elements’ evaluation to WHNF
```

What if we wanted to fully evaluate the two elements in parallel?

```haskell
parPair :: Strategy a -> Strategy b -> Strategy (a, b)
parPair sa sb = evalTuple2 (rparWith sa) (rparWith sb)
```

```haskell
parPair rdeepseq rdeepseq (fib 25, fib 26)
```
parPair rdeepseq rdeepseq (a, b)

“Spark two parallel threads that fully evaluate a and b to normal form”

A cartoon of how this works:

\[
\text{parPair } rdeepseq \ rdeepseq \ (a, b) = \text{evalTuple2 (rparWith rdeepseq) (rparWith rdeepseq) (a, b)} \\
= \text{do } a' \leftarrow (\text{rparWith rdeepseq}) a \\
\quad b' \leftarrow (\text{rparWith rdeepseq}) b \\
\quad \text{return } (a', b') \\
= \text{do } a' \leftarrow \text{rpar (a `using` \( x \rightarrow \text{rseq (rnf x)} \gg \text{return x})} \\
\quad b' \leftarrow \text{rpar (b `using` \( x \rightarrow \text{rseq (rnf x)} \gg \text{return x})} \\
\quad \text{return } (a', b')
\]
Evaluating a List in Parallel

In Control.Parallel.Strategies,

\[
\text{evalList :: } \text{Strategy } a \rightarrow \text{Strategy } [a] \quad -- \text{Apply a strategy}
\]
\[
\text{evalList } _\varepsilon [\ ] = \text{return } [\ ] \quad -- \text{to each list element}
\]
\[
\text{evalList } s \ (x:xs) = \begin{do}
  x' \leftarrow s \ x
  \quad xs' \leftarrow \text{evalList } s \ xs
  \quad \text{return } (x':xs')
\end{do}
\]

\[
\text{parList :: } \text{Strategy } a \rightarrow \text{Strategy } [a] \quad -- \text{Evaluate each list element}
\]
\[
\text{parList } s = \text{evalList } (\text{rparWith } s) \quad -- \text{in parallel with strategy}
\]

Combining these to evaluate all list elements to WHNF in parallel:

\[
\text{parMap :: } (a \rightarrow b) \rightarrow [a] \rightarrow [b]
\]
\[
\text{parMap } f \ xs = \text{map } f \ xs \ \text{`using` parList } \text{rseq}
\]
import Sudoku(solve)
import System.Environment(getArgs)
import Data.Maybe(isJust)
import Control.Parallel.Strategies(using, parList, rseq)

main :: IO ()
main = do [fname] <- getArgs
        puzzles <- lines <$> readFile fname

        let solutions = map solve puzzles `using` parList rseq

        print $ length $ filter isJust solutions

Note that rseq only evaluates to WHNF, but that suffices for Sudoku
About the same performance as the “parMap” version presented earlier
Example: The K-Means Problem

Lloyd’s (approximation) algorithm

Give a number of clusters $k$,

1. Guess a center for each cluster
2. Group points by closest centerpoint
3. Calculate the centroid (average) of each group
4. Repeat steps 3–4 until satisfied
Example: The K-Means Problem

```
$ wget https://github.com/simonmar/parconc-examples/archive/master.tar.gz
$ tar --strip-components=1 -zxf master.tar.gz \
    parconc-examples-master/kmeans
```

2D points (to simplify visualization) and clusters, in KMeansCore.hs,

```hs
data Point = Point !Double !Double  -- ! disables laziness

zeroPoint :: Point
zeroPoint = Point 0 0

sqDistance :: Point -> Point -> Double  -- Distance squared for speed
sqDistance (Point x1 y1) (Point x2 y2) = ((x1-x2)^2) + ((y1-y2)^2)
```

```hs
data Cluster = Cluster { clId :: Int  -- number of this cluster
                          , clCent :: Point  -- centroid of this cluster
                          }
```
Example: The K-Means Problem

For computing the centroids (average of all points in a cluster), in kmeans.hs,

data PointSum = PointSum !Int !Double !Double

addToPointSum :: PointSum -> Point -> PointSum
addToPointSum (PointSum count xs ys) (Point x y)
    = PointSum (count+1) (xs + x) (ys + y)

pointSumToCluster :: Int -> PointSum -> Cluster
pointSumToCluster i (PointSum count xs ys) = Cluster {
    clId   = i
    , clCent = Point (xs / fromIntegral count)
    (ys / fromIntegral count)
1. Accumulate Points in PointSums for Nearest Centroid

```haskell
assign :: Int -> [Cluster] -> [Point] -> Vector PointSum
assign nclusters clusters points = Vector.create $ do
  vec <- MVector.replicate nclusters (PointSum 0 0 0)

  let addpoint p = do
      let c = nearest p ; cid = clId c
      ps <- MVector.read vec cid
      MVector.write vec cid $! addToPointSum ps p
  mapM_ addpoint points
  return vec

where
  nearest p = fst $ minimumBy (compare `on` snd)
    [ (c, sqDistance (clCent c) p) | c <- clusters ]
```

Vectors are Haskell’s fixed-length, random-access arrays that are “mutable” in the right monad. See Data.Vector and Data.Vector.Mutable
makeNewClusters :: Vector PointSum -> [Cluster]
makeNewClusters vec =
  [ pointSumToCluster i ps
   | (i,ps@(PointSum count _ _)) <- zip [0..] (Vector.toList vec)
     , count > 0
  ]

One step of the algorithm: group by nearest centroid; calculate new centroids

step :: Int -> [Cluster] -> [Point] -> [Cluster]
step nclusters clusters points
  = makeNewClusters (assign nclusters clusters points)
The Sequential Loop: step until converged or give up

kmeans_seq :: Int -> [Point] -> [Cluster] -> IO [Cluster]
kmeans_seq nclusters points clusters =
  let loop :: Int -> [Cluster] -> IO [Cluster]
      loop n clusters | n > tooMany = do
        putStrLn "giving up."
        return clusters
  loop n clusters = do
    printf "iteration %d\n" n
    putStrLn (unlines (map show clusters))
    let clusters' = step nclusters clusters points
    if clusters' == clusters
      then return clusters
      else loop (n+1) clusters'
  in loop 0 clusters

tooMany = 80
Generating a Data Set

$ cabal install normaldistribution
$ ghc -O2 GenSamples.hs
$ ./GenSamples 5 50000 100000 1010
$ ls -l points.bin
-rw-rw-r-- 1 sedwards sedwards 16M Nov 23 14:58 points.bin
$ gnuplot -e 'set terminal png;set nokey;plot "points"' > points.png
Compiling and Running K-Means

```
$ stack install monad-par
$ cd kmeans
$ stack ghc -- -O2 -threaded -rtsopts -eventlog kmeans.hs
```

Run it in sequential mode:

```
$ ./kmeans seq
...
iteration 20
Cluster {clId = 0, clCent = Point -5.84359465 -5.46502314}
Cluster {clId = 1, clCent = Point 8.316354592 -8.33043084}
Cluster {clId = 2, clCent = Point -9.06455081 7.561852464}
Cluster {clId = 3, clCent = Point 9.243597731 6.138576051}
Cluster {clId = 4, clCent = Point -3.62170911 -1.82458124}
Total time: 0.73
```
Parallelizing K-Means

Computing nearest center for each point is the main operation to parallelize. This is a fold with an associative accumulation function `addToPointSum`.

Too many points and not enough work per point for per-point parallelism; overhead would dominate. Better to split work into coarser chunks.

```haskell
split :: Int -> [a] -> [[a]]  -- Divide into numChunks chunks
split numChunks xs = chunk (length xs `quot` numChunks) xs

chunk :: Int -> [a] -> [[a]]  -- Split into n-point chunks
chunk _ [] = []
chunk n xs = let (as,bs) = splitAt n xs in as : chunk n bs

addPointSums :: PointSum -> PointSum -> PointSum  -- Accumulate PointSums
addPointSums (PointSum c1 x1 y1) (PointSum c2 x2 y2)
  = PointSum (c1+c2) (x1+x2) (y1+y2)

combine :: Vector PointSum -> Vector PointSum -> Vector PointSum  -- Accumulate vectors
combine = Vector.zipWith addPointSums
```
Code for a Parallel step

Analyze the chunks in parallel; merge; and make new clusters:

\[
\text{parSteps\_strat} :: \text{Int} \rightarrow \text{[Cluster]} \rightarrow \text{[[Point]]} \rightarrow \text{[Cluster]}
\]

\[
\text{parSteps\_strat} n\text{clusters} \text{ clusters} \text{ pointss} = \text{makeNewClusters} \$
\]

\[
\text{foldr1} \ \text{combine} \$ \quad -- \text{Merge the results from each chunk}
\]

\[
\text{(map} \ (\text{assign} \ n\text{clusters} \ \text{clusters}) \ \text{pointss} \ -- \text{Analyze chunks}
\]

\[
\text{`using` parList rseq) -- in parallel}
\]
The Parallel Loop: Divide into chunks; apply parSteps_strat

kmeans_strat :: Int -> Int -> [Point] -> [Cluster] -> IO [Cluster]
kmeans_strat numChunks nclusters points clusters =
  let chunks = split numChunks points
             -- One big change

loop :: Int -> [Cluster] -> IO [Cluster]
loop n clusters | n > tooMany = do
  printf "giving up."
  return clusters
loop n clusters = do
  printf "iteration %d\n" n
  putStrLn (unlines (map show clusters))
  let clusters' = parSteps_strat nclusters clusters chunks
  if clusters' == clusters
     then return clusters
     else loop (n+1) clusters'
in loop 0 clusters
Performance of `kmeans_strat` on 1–8 Cores

```
./kmeans_strat 64 +RTS -N1
./kmeans_strat 64 +RTS -N8
```

<table>
<thead>
<tr>
<th>Cores</th>
<th>Time (s)</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.77</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.40</td>
<td>1.91</td>
</tr>
<tr>
<td>3</td>
<td>0.29</td>
<td>2.70</td>
</tr>
<tr>
<td>4</td>
<td>0.22</td>
<td>3.45</td>
</tr>
<tr>
<td>5</td>
<td>0.23</td>
<td>3.28</td>
</tr>
<tr>
<td>6</td>
<td>0.22</td>
<td>3.45</td>
</tr>
<tr>
<td>7</td>
<td>0.22</td>
<td>3.47</td>
</tr>
<tr>
<td>8</td>
<td>0.25</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Using “Total time” reported by the program; ignores reading point data
Lots of sequential file processing start: not being counted against speedup
Off to a difficult start; iterations are periodic hiccups; big garbage collect
Program suddenly turns completely sequential; darn Amdahl.
Marlow found printing was a major culprit, but removing it didn’t matter on
Iteration: sudden spark creation activity in single HEC pool, then slow conversion. Main thread migrated after 8 iterations. (Under the “Traces” tab)
The Effects of Granularity (N=8)

Time (ms) ← unbalanced

overhead dominates →

Chunks
parList/evalList creates a new list, which seems wasteful

\[
\text{parList} :: \text{Strategy} \ a \\
\quad \rightarrow \ \text{Strategy} \ [a] \\
\text{parList} \ s = \\
\quad \text{evalList} (\text{rparWith} \ s)
\]

\[
\text{evalList} :: \text{Strategy} \ a \\
\quad \rightarrow \ \text{Strategy} \ [a] \\
\text{evalList} \ [] = \text{return} [] \\
\text{evalList} \ s \ (x:xs) = \\
\quad \text{do} \ x' <- s \ x \\
\quad \quad xs' <- \text{evalList} \ s \ xs \\
\quad \text{return} (x':xs') \quad \rightarrow \text{Cons}
\]

Consider this walk-the-list alternative that “touches” elements with \textit{rparWith}

\[
\text{parList} :: \text{Strategy} \ a \\
\quad \rightarrow \ \text{Strategy} \ [a] \\
\text{parList} \ \text{strat} \ xs = \text{do} \ \text{go} \ \text{xs} \\
\quad \text{return} \ \text{xs}
\]

\[
\text{where} \\
\quad \text{go} \ [] = \text{return} () \\
\quad \text{go} \ (x:xs) = \text{do} \ \text{rparWith} \ \text{strat} \ x \\
\quad \quad \text{go} \ \text{xs}
\]

Doesn’t work: each spark created by \textit{rparWith} is garbage-collected because it is never used. \textbf{Critical that the result of \textit{rpar/rparWith} be returned.}
Heap Layout of Working parList: New List Inhibits Spark GC

Original list

List elements

Sparks: apply the strategy to evaluate list elements

→ New list provides second pointer to each spark

New list

Array of pointers to sparks

Marlow, fig. 3-8
Parallelizing Lazy Streams: RSA Encoder/Decoder from Marlow

```
$ stack ghc -- -O2 -Wall -rtsopts rsa
$ ./rsa encrypt /usr/share/dict/words > /dev/null +RTS -s
  5,089,757,232 bytes allocated in the heap
  3,043,360 bytes copied during GC
  107,888 bytes maximum residency (3 sample(s))
  27,968 bytes maximum slop
  0 MB total memory in use

Total time 5.740s ( 5.767s elapsed)

$ ls -sh /usr/share/dict/american-english
  920K /usr/share/dict/american-english
```

Dictionary file is about 1 MB, but runtime only uses 107,888 bytes maximum because of Data.ByteString.Lazy.Char8
Parallelizing RSA

Sequential implementation:

\[
\text{encrypt :: Integer -> Integer -> ByteString -> ByteString}
\]

\[
\text{encrypt n e = B.unlines} \\
\quad \text{. map (B.pack . show . power e n . code)} \\
\quad \text{. chunk (size n)}
\]

First try (rsa1.hs): use \textit{parList rdeepseq}

\[
\text{encrypt n e = B.unlines} \\
\quad \text{. withStrategy (parList rdeepseq)} \\
\quad \text{. map (B.pack . show . power e n . code)} \\
\quad \text{. chunk (size n)}
\]

\textit{withStrategy s e = e `using` s}
Speedup using *parList rdeepseq*

```
$ stack ghc -- -O2 -Wall -threaded -rtsopts rsa1
$ ./rsa1 encrypt /usr/share/dict/words > /dev/null +RTS -N8 -s

5,319,033,432 bytes allocated in the heap
18,619,728 bytes copied during GC
3,029,464 bytes maximum residency (10 sample(s))
570,920 bytes maximum slop
2 MB total memory in use

SPARKS: 9988
(8254 converted, 1734 overflowed, 0 dud, 0 GC'd, 0 fizzled)

Total time 14.403s ( 2.991s elapsed)
```

Speedup of 1.92 over sequential (rsa.hs) (4.8× itself)

Maximum memory use now 3 MB (cf. 107 KB): *parList traverses the whole list*. 
Control.Parallel.Strategies.parBuffer: Regulate number of outstanding sparks

`parBuffer 100` creates 100 outstanding sparks; sparks more once consumed

```haskell
parBuffer :: Int -> Strategy a -> Strategy [a]
```

```haskell
encrypt n e = B.unlines -- rsa2.hs
  . withStrategy (parBuffer 100 rdeepseq) -- 100 max
  . map (B.pack . show . power e n . code)
  . chunk (size n)
```

```
$ ./rsa2 encrypt /usr/share/dict/words > /dev/null +RTS -N8 -s
  506,640 bytes maximum residency (18 sample(s))
  SPARKS: 9988
    (9987 converted, 0 overflowed, 0 dud, 0 GC'd, 1 fizzled)
  Total time 12.160s ( 1.641s elapsed)
```

Down to 500 KB residency, 3.5× over sequential, excellent 7.4× self-speedup
Spark Creation and Pool with parBuffer

HEC5 got the spark creation process
Spark pool remains around 100
Hiccups primarily garbage collection
No creation or pools on other HECs
Gray on graph denotes variance
About 11% overhead
<table>
<thead>
<tr>
<th>Technique</th>
<th>Memory (K)</th>
<th>Sparks</th>
<th>Time (s)</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Converted</td>
<td>Overflowed</td>
<td>Dud</td>
</tr>
<tr>
<td>Sequential</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>parList</td>
<td>2958</td>
<td>8254</td>
<td>1734</td>
<td>0</td>
</tr>
<tr>
<td>parBuffer</td>
<td>495</td>
<td>9987</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Both generate the same number of sparks

*parList* forces the entire file to be loaded (memory consumption) and generates all the sparks at the beginning (spark pool overflow).