Generating a Fast GPU Median Filter with Haskell

Michal Dobrogost

June 5th, 2014

Overview

- Entire approach is based on a paper by Perrot[1].
- Thank you Point Grey Research
- Overview
  - GPU Programming
  - Median Filter
  - Naive Selection
  - Forgetful Selection
  - DSL Extensions

GPU Programming

3 Slide Crash Course

- 1000's of concurrant threads
- Memory latency hiding
- Careful
  - Multiple threads share an instruction pointer (SIMT)
  - Memory hierarchy but no cache
  - *Static* arrays may be far away
- C like languages: CUDA, OpenCL

GPU Programming

Single Instruction Multiple Thread (SIMT)

```
int sumOfProducts(int k, int* data, int size) {
    if (k == 0) { return 0; }

    int accum = 0;
    for (int i = 0; i < size; i++) {
        accum = accum + k * data[i];
    }
    return accum;
}
```

GPU Programming

Static Array vs Registers

```c
void clean(int* data) {
    int cache[3];
    for (int i = 0; i < 3; i++) {
        cache[i] = data[i];
    }
    // Access cache many times
}

void fast(int* data) {
    int c0, c1, c2;
    c0 = data[0];
    c1 = data[1];
    c2 = data[2];
    // Access c0,c1,c2 many times
}
```

Median Filter

A Road Median

[1] http://en.wikipedia.org/wiki/File:N11_dual-carriageway_median_barrier.jpg

Median Filter

Corrupted Image

Median Filter

Salt and Pepper Noise

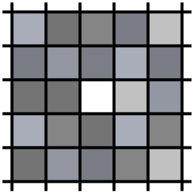
Median Filter

Restored Image

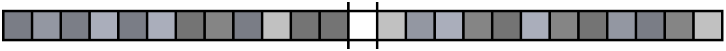
Median Filter

How it works

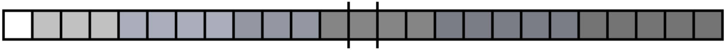
- For each pixel take a 5x5 window



- Linearize pixel intensities into a single collection

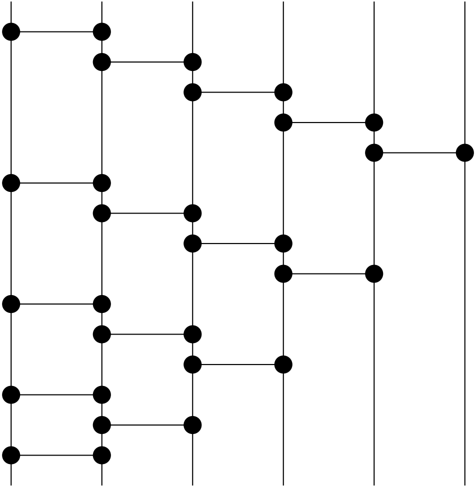


- Find the median value



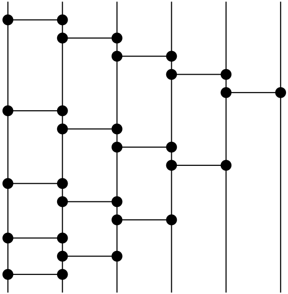
Naive Selection

Sorting Networks



Naive Selection

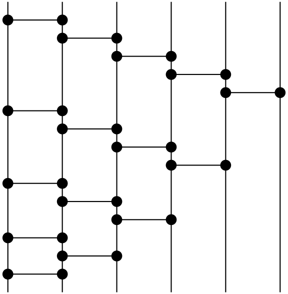
Domain Specific Language



```
[(0,1),(1,2),(2,3),(3,4),(4,5),
 (0,1),(1,2),(2,3),(3,4),
 (0,1),(1,2),(2,3),
 (0,1),(1,2),
 (0,1)]
```

Naive Selection

Leverage Parent Language



```haskell
link :: [Int] -> [(Int, Int)]
link xs = zip xs $ tail xs

bubble :: Int -> [(Int,Int)]
bubble n = concatMap iter [n-1,n-2..1]
    where iter k = link [0..k]
```

Naive Selection

C "compiler"

```haskell
swap :: String -> String -> String
swap x y = "T tmp(" ++ x ++ "); " ++
           x ++ " = " ++ y ++ "; " ++
           y ++ " = tmp;"

printC :: [(Int,Int)] -> String
printC []           = ""
printC ((x,y):xs) = res ++ printC xs
    where x' = "x" ++ show x
          y' = "x" ++ show y
          res = "if (" ++ x' ++ " > " ++ y' ++ ") { " ++
                    swap x' y' ++
                " }\\n"
```

Naive Selection

Generated C Code

```
if (x0 > x1) { T tmp(x0); x0 = x1; x1 = tmp; }
if (x1 > x2) { T tmp(x1); x1 = x2; x2 = tmp; }
if (x2 > x3) { T tmp(x2); x2 = x3; x3 = tmp; }
if (x3 > x4) { T tmp(x3); x3 = x4; x4 = tmp; }
if (x4 > x5) { T tmp(x4); x4 = x5; x5 = tmp; }
if (x0 > x1) { T tmp(x0); x0 = x1; x1 = tmp; }
if (x1 > x2) { T tmp(x1); x1 = x2; x2 = tmp; }
if (x2 > x3) { T tmp(x2); x2 = x3; x3 = tmp; }
if (x3 > x4) { T tmp(x3); x3 = x4; x4 = tmp; }
if (x0 > x1) { T tmp(x0); x0 = x1; x1 = tmp; }
if (x1 > x2) { T tmp(x1); x1 = x2; x2 = tmp; }
if (x2 > x3) { T tmp(x2); x2 = x3; x3 = tmp; }
if (x0 > x1) { T tmp(x0); x0 = x1; x1 = tmp; }
if (x1 > x2) { T tmp(x1); x1 = x2; x2 = tmp; }
if (x0 > x1) { T tmp(x0); x0 = x1; x1 = tmp; }
```

Naive Selection

LaTeX "compiler"

```haskell
printTex :: [(Int,Int)] -> String
printTex comps =
    "\\documentclass[tikz]{standalone}\n" ++
    "\\usepackage{tikz}\n" ++
    "\\begin{document}\n" ++
    "\\begin{tikzpicture}\n" ++
    verticalWires ++ connections ++
    "\\end{tikzpicture}\n" ++
    "\\end{document}\n"
    where
        verticalWires = ...
        connections = ...
```

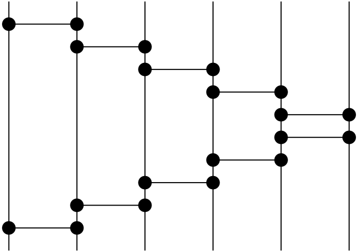
Forgetful Selection

Trace on a 3x3 Window

```
          starting point is 5 = ceil(9/2)
                           /
Data: 0   1   2   3   4   5   6   7   8
      |   |   |   |   |   |   |   |   |
     min  x   x   x   x  max  |   |   |
          |   |   |   |       |   |   |
          |   |   |   |   /---/   |   |
         min  x   x   x  max      |   |
              |   |   |           |   |
              |   |   |   /-------/   |
             min  x   x  max          |
                  |   |               |
                  |   |   /-----------/
                 min  x  max
                       \
                      median
```

Forgetful Selection

Row Step — Basic

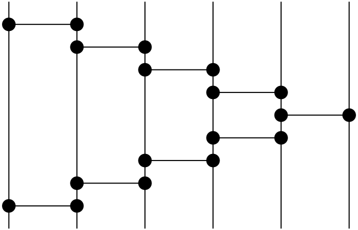


```haskell
step :: [Int] -> [(Int,Int)]
step ixs = (\x -> x ++ reverse x) $ link ixs

-- step [0..5]
```

Forgetful Selection

Row Step — No Duplicates



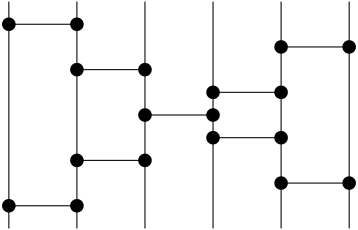
```haskell
-- group :: Eq a => [a] -> [[a]]

noDup :: Eq a => [a] -> [a]
noDup xs = map head $ group xs

step :: [Int] -> [(Int,Int)]
step ixs = noDup $ (\x -> x ++ reverse x) $ link ixs
```

Forgetful Selection

Row Step — Minimize Dependancies

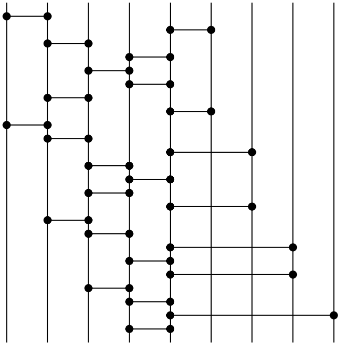


```
interleave :: [a] -> [a] -> [a]
interleave []     ys = ys
interleave (x:xs) ys = x : interleave' xs ys
    where interleave' xs []     = xs
          interleave' xs (y:ys) = y : interleave xs ys

step :: [Int] -> [(Int,Int)]
step ixs = noDup $ (\x -> interleave x $ reverse x) $ link ixs
```

Forgetful Selection

Full Algorithm

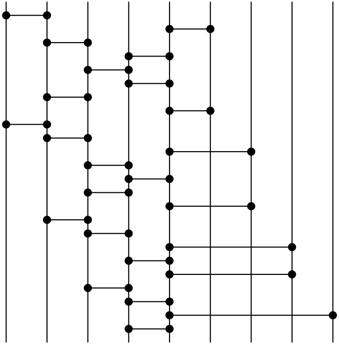


```
forgetful :: Int -> [(Int,Int)]
forgetful n = concatMap step rows
    where (row0, rest) = splitAt ((n+1) `div` 2) [0..n-1]
          rows = zipWith (\r x -> r ++ [x]) (tails row0) rest
```

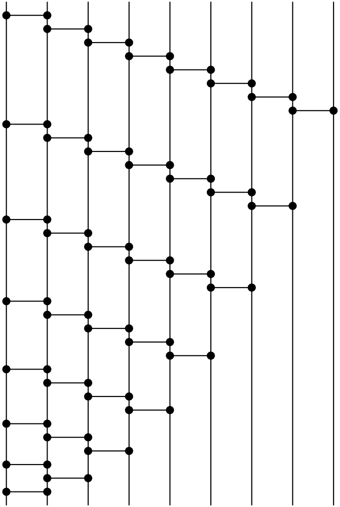
Forgetful Selection

Comparison on a 3x3 Window

Forgetful Select (24)



Bubble Sort (36)



DSL Extensions

Late Loads

```haskell
data DSL = Comp Int Int | Load Int Int

mkComp :: (Int,Int) -> DSL
mkComp (x,y) = Comp x y

genLoads :: (Int,Int) -> Int -> [DSL] -> [DSL]
genLoads (winX,winY) stride instrs = ...

printC :: [DSL] -> String
```

Conclusion

- Haskell can be extremely effective for throw away scripting
- Suitable datatypes go a long way
- Leverage Haskell to boost your DSL
- Original implementation
  - $\sim$ 4 hours
  - 28 lines
  - *forgetful* was a monster
- Presentation code
  - Time hard to judge – shared with presentation
  - 22 lines
  - *link* is the key ingredient

References

Gilles Perrot, Stphane Domas, Raphal Couturier *Fine-tuned High-speed Implementation of a GPU-based Median Filter*. Journal of Signal Processing Systems, 2013-07-05.

THANK YOU