Clarke-Wright vehicle routing algorithm Implementation Report

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1 Introduction

Realistic Real time physics simulation is highly sought after in interactive applications, especially games. Achieving high-accuracy while maintaining performance in often resource restricted environments(I.E a games console) requires the highest level of optimisations and often results in a trade-off with simulation speed against Accuracy. This project attempts to record and analyse the performance of various optimisations on a simulated scene. This will be taken further by applying the project to various different processing architectures. The scene that will be simulated is a large set of Bouncy balls, travelling down a hill. [Clarke and Wright 1964] [Lysgaard 1997]

Physics Engines Large and complex video games tend to use 3rd party physics solutions, this vastly cuts down on the project development man-hours, and the maintenance thereafter. Third party physics solutions have the benefit of being battle tested out in the wild beforehand, so internal reliability is usually a given. A further benefit is that being developed solely for the purpose of being a "a good physics engine" by people who are usually experts in the field, large optimisations are already implemented. The problems arise in the implementation, the coupling of a physics engine and the existing codebase. While they are usually well coded, they are not tailor made to each game.

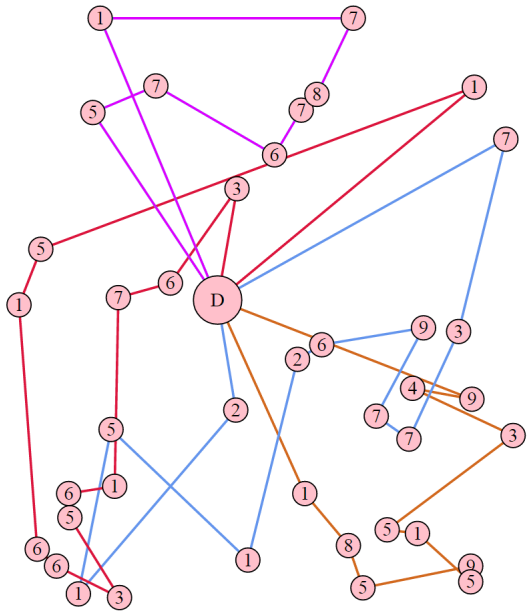

Figure 1: ***Bullet Physics PS3 Pipeline*** *- Requires Intermediate Data Swapping Between PPU and SPU*

2 Method

Optimising for Physics Engines Trying to regain performance from an external physics engine can be a hard task, diving into the source code requires expert knowledge of the inner-workings of the whole system. A common path is to shape the design of the game code to conform better to the demands of the physics engine and hope that the internal optimisations will be sufficient. Often enough, they are not.

3 Results

Optimising for Physics Engines Trying to regain performance from an external physics engine can be a hard task, diving into the source code requires expert knowledge of the inner-workings of the whole system. A common path is to shape the design of the game code to conform better to the demands of the physics engine and hope that the internal optimisations will be sufficient. Often enough, they are not.

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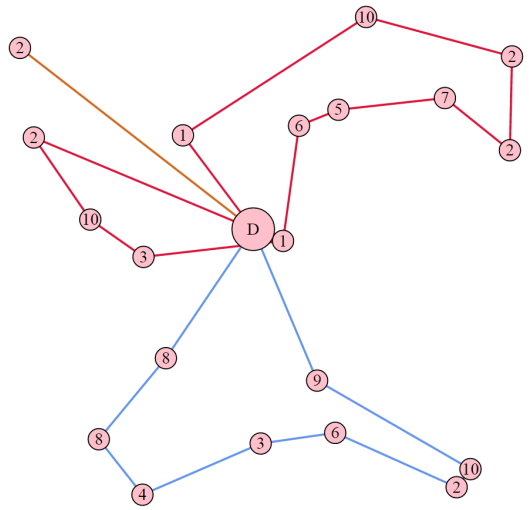

Figure 2: ***Bullet Physics PS3 Pipeline*** *- Requires Intermediate Data Swapping Between PPU and SPU*

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4 Conclusions

Optimising for Physics Engines Trying to regain performance from an external physics engine can be a hard task, diving into the source code requires expert knowledge of the inner-workings of the whole system. A common path is to shape the design of the game code to conform better to the demands of the physics engine and hope that the internal optimisations will be sufficient. Often enough, they are not.

5 Appendix

References

CLARKE, G., AND WRIGHT, J. 1964. Scheduling of vehicles from a central depot to a number of delivery points. *Operations Research 12*, 4, 568–581.

LYSGAARD, J. 1997. Clarke and wright's savings algorithm http://pure.au.dk/portal-asb-student/files/36025757/bilag_e_savingsnote.pdf. *Department of Management Science and Logistics, The Aarhus School of Business*.

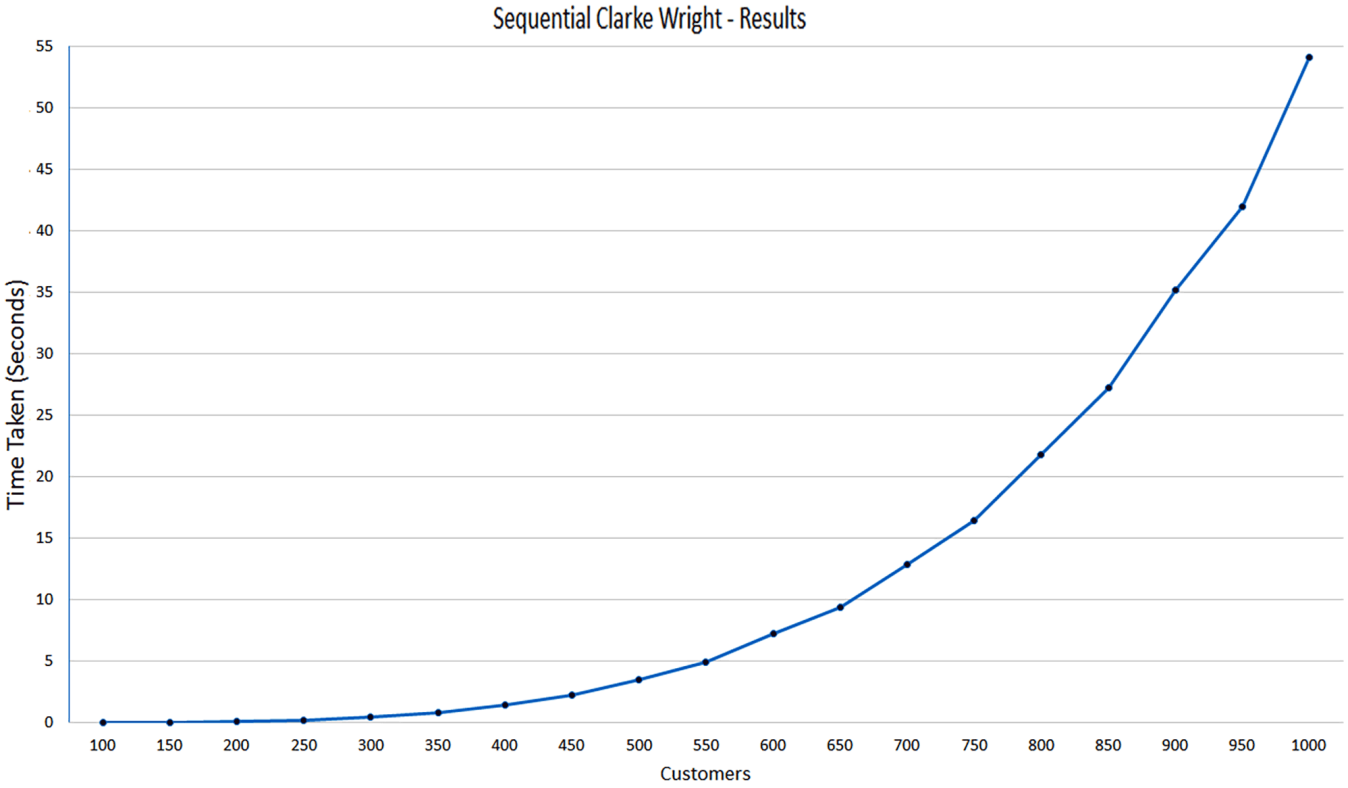

Figure 3: ***Sequential Clark Wright implementation results*** *- Requires Intermediate Data Swapping Between PPU and SPU*

6 Code

6.1 ClarkeWright.java

```
import java.util.ArrayList;
import java.util.Collections;
import java.util.HashSet;
import java.util.List;

class Route implements Comparable<Route>
{
   private int _capacity;
   private int _weight;
   private double _cost;
   private double _savings;
   public ArrayList<Customer> customers;

   private void calculateSavings(){
      double originalCost = 0;
      double newCost = 0;
      double tempcost =0;
      Customer prev = null;

      //Foreach customer in the route:
      for(Customer c:customers){
         // Distance from Depot
         tempcost = Math.sqrt((c.x*c.x)+(c.y*c.y));
         originalCost += (2.0*tempcost);

         if(prev != null){
            // Distance from previous customer to this customer
            double x = (prev.x - c.x);
            double y = (prev.y - c.y);
            newCost += Math.sqrt((x*x)+(y*y));
         }else{
            //If this is the first customer in the route, no change
            newCost += tempcost;
         }
         prev = c;
      }
      newCost += tempcost;
      _cost = newCost;
      _savings = originalCost - newCost;
   }

   public Route(int capacity){
      _capacity = capacity;
      customers = new ArrayList<Customer>();
      _weight =0;
      _cost= 0;
      _savings =0;
   }

   public void addCustomer(Customer c, boolean order){
      //Add customer to the start or end of the route?
      if(order){
         customers.add(0,c);
      }else{
         customers.add(c);
      }

      if(c.c > _capacity){
         System.out.println("Customer order too large");
      }

      _weight += c.c;

      if(_weight > _capacity){
         System.out.println("Route Overloaded");
      }

      calculateSavings();
   }

   public double getSavings(){
      return _savings;
   }
   public double getCost(){
      return _cost;
   }
   public int getWeight(){
      return _weight;
   }
   public int compareTo(Route r) {
      return Double.compare(r.getSavings(), this._savings);
   }

}

//
//##Sequential solver##
//

public class ClarkeWright
{
   public static int truckCapacity = 0;

   public static ArrayList<List<Customer>> solve(ArrayList<Customer> customers){
      ArrayList<List<Customer>> solution = new ArrayList<List<Customer>>();
      HashSet<Customer> abandoned = new HashSet<Customer>();

      //calculate the savings of all the pairs
      ArrayList<Route> pairs = new ArrayList<Route>();

      for(int i=0; i<customers.size(); i++){
         for(int j=i+1; j<customers.size(); j++){
            Route r = new Route(truckCapacity);
            r.addCustomer(customers.get(i),false);
            r.addCustomer(customers.get(j),false);
            pairs.add(r);
         }
      }
      //order pairs by savings
      Collections.sort(pairs);

      HashSet<Route> routes = new HashSet<Route>();
      routes.add(pairs.get(0));
      pairs.remove(0);

      //start combining pairs into routes
      for(Route ro :routes)
      {
         Customer cr1 = ro.customers.get(0);
         Customer cr2 = ro.customers.get(ro.customers.size()-1);

         for(int i=0; i<pairs.size(); i++){
            Route r = pairs.get(i);
            Customer c1 = r.customers.get(0);
            Customer c2 = r.customers.get(r.customers.size()-1);

            //do they have any common nodes?
            if(c1 == cr1 || c1 == cr2){
               //could we combine these based on weight?
               if(c2.c + ro.getWeight() <= truckCapacity){
                  //Does the route already contain BOTH these nodes?
                  if(!ro.customers.contains(c2)){
                     //no, but is it in another route already?
                     boolean istaken = false;
                     for(Route rr :routes)
                     {
                        if(rr.customers.contains(c2)){
                           istaken = true;
                           break;
                        }
                     }
                     if(!istaken){
                        //No other route have this, add to route
                        if(c1 == cr1){
                           ro.addCustomer(c2, true);
                        }else{
                           ro.addCustomer(c2, false);
                        }
                     }
                  }
```

```
                abandoned.remove(c2);
                pairs.remove(r);
                i--;
                continue;
            }
        }
        if (c2 == cr1 || c2 ==cr2){
            //could we combine these based on weight?
            if(c1.c + ro.getWeight() <= truckCapacity){
                //Does the route already contain BOTH these nodes?
                if(!ro.customers.contains(c1)){
                    //no, but is it in another route already?
                    boolean istaken = false;
                    for(Route rr :routes)
                    {
                        if(rr.customers.contains(c1)){
                            istaken = true;
                            break;
                        }
                    }
                    if(!istaken){
                        if(c2 == cr1){
                            ro.addCustomer(c1, true);
                        }else{
                            ro.addCustomer(c1, false);
                        }
                    }
                }
                abandoned.remove(c1);
                pairs.remove(r);
                i--;
                continue;
            }
        }

        //If we reach here, the pair hasn't been added to any routes
        boolean a = false;
        boolean b = false;
        for(Route rr :routes)
        {
            for(Customer cc:r.customers){
                if(rr.customers.contains(c1)){
                    a = true;
                }
                if(rr.customers.contains(c2)){
                    b = true;
                }
            }
        }
        if(!(a||b)){
            //no routes have any of these customers, make new route
            abandoned.remove(c1);
            abandoned.remove(c2);
            routes.add(r);
        }else{
            //Some routes have some of these customers already
            if(!a){
                abandoned.add(c1);
            }
            if(!b){
                abandoned.add(c2);
            }
        }
        pairs.remove(r);
        i--;

    }

}

//Edge case: A single Customer can be left out of all routes due to capacity constraints
outerloop:for(Customer C:abandoned){
    //we could tack this onto the end of a route if it would fit
    for(Route r:routes){
        if(r.getWeight() + C.c < truckCapacity)
        {
            //would this be more efficient than sending a new truck?
            Customer cc = r.customers.get(r.customers.size()-1);
            {
                double X = C.x - cc.x;
                double Y = C.y - cc.y;
                if(Math.sqrt((X*X)+(Y*Y)) < Math.sqrt((C.x*C.x)+(C.y*C.y))){
                    r.addCustomer(C, false);
                    break outerloop;
                }
            }
            cc  = r.customers.get(0);
            {
                double X = C.x - cc.x;
                double Y = C.y - cc.y;
                if(Math.sqrt((X*X)+(Y*Y)) < Math.sqrt((C.x*C.x)+(C.y*C.y))){
                    r.addCustomer(C, true);
                    break outerloop;
                }
            }
        }
    }

    //Send a new truck, just for this Customer
    ArrayList<Customer> l = new ArrayList<Customer>();
    l.add(C);
    solution.add(l);
}

//output
for(Route r:routes){
    ArrayList<Customer> l = new ArrayList<Customer>();
    l.addAll(r.customers);
    solution.add(l);
}
return solution;
}

//
//##Parallel solver##
//

public static ArrayList<List<Customer>> solveP(ArrayList<Customer> customers){
    ArrayList<List<Customer>> solution = new ArrayList<List<Customer>>();
    HashSet<Customer> abandoned = new HashSet<Customer>();

    //calculate the savings of all the pairs
    ArrayList<Route> pairs = new ArrayList<Route>();

    for(int i=0; i<customers.size(); i++){
        for(int j=i+1; j<customers.size(); j++){
            Route r = new Route(truckCapacity);
            r.addCustomer(customers.get(i),false);
            r.addCustomer(customers.get(j),false);
            pairs.add(r);
        }
    }
    //order pairs by savings
    Collections.sort(pairs);

    HashSet<Route> routes = new HashSet<Route>();
    routes.add(pairs.get(0));
    pairs.remove(0);

    //start combining pairs into routes
    outerloop: for(int j=0; j<pairs.size(); j++){
        Route r = pairs.get(j);
        Customer c1 = r.customers.get(0);
        Customer c2 = r.customers.get(r.customers.size()-1);

        for(Route ro :routes)
        {
            Customer cr1 = ro.customers.get(0);
            Customer cr2 = ro.customers.get(ro.customers.size()-1);

            //do they have any common nodes?
            if(c1 == cr1 || c1 == cr2){
```

```
303             //could we combine these based on weight?
304             if(c2.c + ro.getWeight() <= truckCapacity){
305                //Does the route already contain BOTH these nodes?
306                if(!ro.customers.contains(c2)){
307                   //no, but is it in another route already?
308                   boolean istaken = false;
309                   for(Route rr :routes)
310                   {
311                      if(rr.customers.contains(c2)){
312                         istaken = true;
313                         break;
314                      }
315                   }
316                   if(!istaken){
317                      //No other route have this, add to route.
318                      if(c1 == cr1){
319                         ro.addCustomer(c2, true);
320                      }else{
321                         ro.addCustomer(c2, false);
322                      }
323                   }
324                }
325                abandoned.remove(c2);
326                pairs.remove(r);
327                j--;
328                continue outerloop;
329             }
330          }
331          if (c2 == cr1 || c2 ==cr2){
332             //could we combine these based on weight?
333             if(c1.c + ro.getWeight() <= truckCapacity){
334                //Does the route already contain BOTH these nodes?
335                if(!ro.customers.contains(c1)){
336                   //no, but is it in another route already?
337                   boolean istaken = false;
338                   for(Route rr :routes)
339                   {
340                      if(rr.customers.contains(c1)){
341                         istaken = true;
342                         break;
343                      }
344                   }
345                   if(!istaken){
346                      if(c2 == cr1){
347                         ro.addCustomer(c1, true);
348                      }else{
349                         ro.addCustomer(c1, false);
350                      }
351                   }
352                }
353                abandoned.remove(c1);
354                pairs.remove(r);
355                j--;
356                continue outerloop;
357             }
358          }
359       }
360
361       //If we reach here, the pair hasn't been added to any routes
362       boolean a = false;
363       boolean b = false;
364       for(Route ro :routes)
365       {
366          for(Customer cc:r.customers){
367             if(ro.customers.contains(c1)){
368                a = true;
369             }
370             if(ro.customers.contains(c2)){
371                b = true;
372             }
373          }
374       }
375       if(!(a||b)){
376          //no routes have any of these customers, make new route
377          abandoned.remove(c1);
378          abandoned.remove(c2);
379          routes.add(r);
380       }else{
381          //Some routes have some of these customers already
382             if(!a){
383                abandoned.add(c1);
384             }
385             if(!b){
386                abandoned.add(c2);
387             }
388          }
389          pairs.remove(r);
390          j--;
391
392       }
393
394       //Edge case: A single Customer can be left out of all routes due to capacity constraints
395       outerloop:for(Customer C:abandoned){
396          //we could tack this onto the end of a route if it would fit
397          for(Route r:routes){
398             if(r.getWeight() + C.c < truckCapacity)
399             {
400                //would this be more efficient than sending a new truck?
401                Customer cc = r.customers.get(r.customers.size()-1);
402                {
403                   double X = C.x - cc.x;
404                   double Y = C.y - cc.y;
405                   if(Math.sqrt((X*X)+(Y*Y)) < Math.sqrt((C.x*C.x)+(C.y*C.y))){
406                      r.addCustomer(C, false);
407                      break outerloop;
408                   }
409                }
410                cc  = r.customers.get(0);
411                {
412                   double X = C.x - cc.x;
413                   double Y = C.y - cc.y;
414                   if(Math.sqrt((X*X)+(Y*Y)) < Math.sqrt((C.x*C.x)+(C.y*C.y))){
415                      r.addCustomer(C, true);
416                      break outerloop;
417                   }
418                }
419             }
420          }
421
422          //Send a new truck, just for this Customer
423          ArrayList<Customer> l = new ArrayList<Customer>();
424          l.add(C);
425          solution.add(l);
426       }
427
428       //output
429       for(Route r:routes){
430          ArrayList<Customer> l = new ArrayList<Customer>();
431          l.addAll(r.customers);
432          solution.add(l);
433       }
434       return solution;
435    }
436 }
```

6.2 VRSolution.java

Lines 20 to 28

```
1
2    //Students should implement another solution
3    public void clarkeWrightSolution(boolean b){
4       ClarkeWright cw = new ClarkeWright();
5       cw.truckCapacity = prob.depot.c;
6       if(b){
7          this.soln = cw.solveP(prob.customers);
8       }else{
```

6.3 Experiment.java

```
import java.util.*;
public class Experiment {

    public static void main(String[] args)throws Exception{
        String outdir = "output/";
        String problemdir = "tests/";
        String [] probs = {
                "rand00010",
                "rand00020",
                "rand00030",
                "rand00040",
                "rand00050",
                "rand00060",
                "rand00070",
                "rand00080",
                "rand00090",
                "rand00100",
                "rand00150",
                "rand00200",
                "rand00250",
                "rand00300",
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                "rand00750",
                "rand00800",
                "rand00850",
                "rand00900",
                "rand00950",
                "rand01000",
                "fail00002",
                "fail00004"
                };
        for (String f:probs){
            ArrayList<Long> timing = new ArrayList<Long>();
            VRProblem vrp = new VRProblem(problemdir+f+"prob.csv"↩
        );
            VRSolution vrs = new VRSolution(vrp);
            System.out.printf("%s, %d\n",f,vrp.size());
            for(int i=0;i<50;i++){
                long start = System.nanoTime();
                vrs.clarkeWrightSolution(false);
                long delta = System.nanoTime()-start;
                timing.add(delta);
                System.out.print(delta+", ");
            }
            System.out.print("\n\n");
            //vrs.writeOut(outdir+f+"CWsn.csv");
        }

    }
}
```