Modelos y Optimización I

Trabajo práctico: Problema Combinatorio

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Contents

TRABAJO PRÁCTICO

Problema Combinatorio

IngFraTech está evaluando ahora la ubicación de los datacenters necesarios para proveer los nuevos servicios.

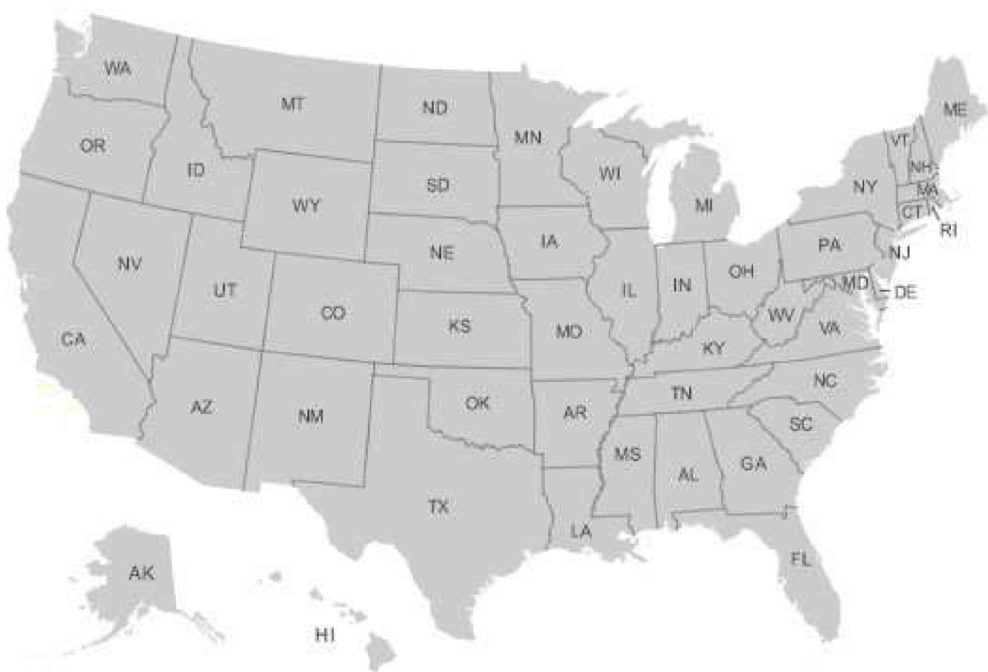
Dado que la mayoría de sus clientes se encuentra en Estados Unidos, deciden ubicar allí los datacenter con la idea de hacer mínima la latencia entre los datacenters y los clientes. Como en un principio no saben de dónde serán sus clientes (es decir, a qué estado pertenecerán) la empresa plantea reducir la latencia global del servicio definiéndolo de la siguiente manera:

"La latencia global del sistema es la suma de las latencias de cada estado. El cálculo de latencia de cada estado se hace considerando la distancia con el datacenter más próximo, estimándose 1 ms de latencia por cada milla de distancia."

Actualmente cuenta con 2 datacenters, uno en Oregon y otro en Florida. Por motivos económicos la empresa no puede agregar más de 3 datacenters nuevos.

Dado que no esperan clientes de Hawái y Alaska, estos estados no son tenidos en cuenta para calcular la latencia global.

¿Qué es lo mejor que puede hacer IngFraTech?



Part I

Descripción de la situación problemática

Se trata de un problema de combinatoria, en el que habrá que incluir variables continuas y booleanas.
En esta instancia podemos afirmar que habrá que considerar una variable *latencia* que deberá ser una variable continua; así como una variable booleana que indique si un determinado datacenter se encuentra instalado en un estado específico.

Part II

Objetivo

Determinar en qué estados van a estar los 3 nuevos datacenters (DB, DC, DD) durante un período de tiempo para minimizar la latencia global del sistema.

Part III

Hipótesis y supuestos

- Se instalarán los 3 datacenters puesto que cada datacenter agregado va a reducir la latencia.
- Se tomará un punto en cada estado. El mismo será referente para calcular las distancias entre estados y las respectivas latencias. No hay opción de instalar un datacenter en otro punto del estado que el mencionado.
- Para el cálculo se consideran únicamente las distancias, no la cantidad de usuarios por estado. O expresado de otra forma: para el modelo, la distribución de usuarios es uniforme a lo largo de todos los estados y en cada uno de los estados.
- No puede haber dos datacenters en un mismo estado.
- Los costos de instalación y mantenimiento de datacenters, así como cualquier otro costo que pueda implicar la instalación de los mismos, no serán tenidos en cuenta por el modelo.

Part IV

Definición de variables, incluyendo unidades

- L_i : variable continua que indica la latencia (en ms) correspondiente al estado i. $\forall i \in [1, 48]$
- DC_i : variable continua que indica la distancia (en millas) del datacenter C al estado i. (ídem para datacenters D y E. DA_i y DB_i son datos conocidos). $\forall i \in [1, 48]$
- YA_i : variable bivalente que vale 0 cuando el estado i tiene la menor latencia. (ídem B, C, D, E)
- YCe_i : variable bivalente que vale 1 cuando el datacenter C está en el Estado i. (ídem D, E)

Constantes

- D_{ij}: distancia entre estado i y estado j.
- M: valor mayor a cualquier distancia posible. Su valor se definirá al momento de pasar el modelo a software.

Part V

Modelo de Programación Lineal Continua

$$\sum_i YAi + YB_i + YC_i + YD_i + YE_i = 1 \tag{1}$$

1 Menor Distancia

Cada L_i tendrá como cota superior la distancia al datacenter más próximo, y como cota inferior esa misma distancia en el caso de que el estado i tenga la menor distancia.
$M \to \infty$

$$DA_i - M * YA_i \leq L_i \leq DA_i, \quad \forall i \in [1, 48] \tag{2}$$

$$DB_i - M * YB_i \leq L_i \leq DB_i, \quad \forall i \in [1, 48] \tag{3}$$

$$DC_i - M * YC_i \leq L_i \leq DC_i, \quad \forall i \in [1, 48] \tag{4}$$

$$DD_i - M * YD_i \leq L_i \leq DD_i, \quad \forall i \in [1, 48] \tag{5}$$

$$DE_i - M * YE_i \leq L_i \leq DE_i, \quad \forall i \in [1, 48] \tag{6}$$

2 Asociación de Datacenter a estado

Se asegura de que cada datacenter pueda ser asignado únicamente a un estado.

$$\sum_{i=1}^{48} YCe_i = 1 \tag{7}$$

$$\sum_{i=1}^{48} YDe_i = 1 \tag{8}$$

$$\sum_{i=1}^{48} YEe_i = 1 \tag{9}$$

3 Asociación de distancia de un estado al datacenter correspondiente

$$DC_i = \sum_{j=1}^{48} D_{ij} * YCe_j \tag{10}$$

$$DD_i = \sum_{j=1}^{48} D_{ij} * YDe_j \tag{11}$$

$$DE_i = \sum_{j=1}^{48} D_{ij} * YEe_j, \quad \forall i \in [1, 48] \tag{12}$$

Part VI
Funcional

$$Z(min) = \sum_{i=1}^{48} L_i \tag{13}$$

Part VII
Modelo y salida

```
# conjuntos
##set ESTADOS := {1..48};
set ESTADOS;
set s dimen 2;
set s1;

# Parametros (constantes)
# Distancias entre ESTADOS
param Dij{i in ESTADOS, j in ESTADOS};

# DA i : variable continua que indica la distancia del datacenter A al estado
# i. (  dem para datacenter B)
param DAi{i in ESTADOS};
param DBi{i in ESTADOS};

# M : valor mayor a cualquier distancia posible.
param M := 10000;


# all distances
table tab_distances IN "CSV" "distances.csv" : s <- [state1, state2], Dij~distance;

# distances from datacenters A and B, which correspond to states
# of Florida and Oregon respectively.
table tab_florida_distances IN "CSV" "florida_distances.csv" : ESTADOS <- [state2], DAi~distance;
table tab_oregon_distances IN "CSV" "oregon_distances.csv" : s1 <- [state2], DBi~distance;

# Variables
# Li: variable continua que indica la latencia correspondiente al estado i
var Li{i in ESTADOS} >= 0;

# DC i : variable continua que indica la distancia del datacenter C
# al estado i. Idem para D y E.
var DCi{i in ESTADOS} >= 0;
var DDi{i in ESTADOS} >= 0;
var DEi{i in ESTADOS} >= 0;

# YAi: variable bivalente que vale 0 cuando la distancia del Datacenter
# A al Estado i es la menor respecto al resto de los Datacenters. (  dem
# B, C, D, E)
var YAi{i in ESTADOS} >= 0, binary;
var YBi{i in ESTADOS} >= 0, binary;
var YCi{i in ESTADOS} >= 0, binary;
var YDi{i in ESTADOS} >= 0, binary;
var YEi{i in ESTADOS} >= 0, binary;

# Y Ce i : variable bivalente que vale 1 cuando el datacenter C est  en el
# Estado i.
```

```
var YCei{i in ESTADOS} >= 0, binary;
var YDei{i in ESTADOS} >= 0, binary;
var YEei{i in ESTADOS} >= 0, binary;

# Restricciones
# Cada Li tendr  como cota superior la distancia al datacenter m s pr ximo, y
# como cota inferior esa misma distancia en el caso de que el estado i tenga la
# menor distancia.
s.t. cota_sup_dcA{i in ESTADOS}: Li[i] <= DAi[i];
s.t. cota_sup_dcB{i in ESTADOS}: Li[i] <= DBi[i];
s.t. cota_sup_dcC{i in ESTADOS}: Li[i] <= DCi[i];
s.t. cota_sup_dcD{i in ESTADOS}: Li[i] <= DDi[i];
s.t. cota_sup_dcE{i in ESTADOS}: Li[i] <= DEi[i];

s.t. cota_inf_dcA{i in ESTADOS}: Li[i] >= DAi[i] - M * YAi[i];
s.t. cota_inf_dcB{i in ESTADOS}: Li[i] >= DBi[i] - M * YBi[i];
s.t. cota_inf_dcC{i in ESTADOS}: Li[i] >= DCi[i] - M * YCi[i];
s.t. cota_inf_dcD{i in ESTADOS}: Li[i] >= DDi[i] - M * YDi[i];
s.t. cota_inf_dcE{i in ESTADOS}: Li[i] >= DEi[i] - M * YEi[i];

# sumatorioa de YXi debe ser 4
s.t. total_datacenters{i in ESTADOS}: YAi[i] + YBi[i] + YCi[i] + YDi[i] + YEi[i] = 4;

# Asociacion de datacenter a estado
s.t. asoc_dcC: sum{i in ESTADOS} YCei[i] = 1;
s.t. asoc_dcD: sum{i in ESTADOS} YDei[i] = 1;
s.t. asoc_dcE: sum{i in ESTADOS} YEei[i] = 1;

# Asociaci n de distancia de un estado al datacenter correspondiente
s.t. asoc_dist_dcC_estadoi{i in ESTADOS}: sum{(i,j) in s} Dij[i,j] * YCei[j] = DCi[i];
s.t. asoc_dist_dcD_estadoi{i in ESTADOS}: sum{(i,j) in s} Dij[i,j] * YDei[j] = DDi[i];
s.t. asoc_dist_dcE_estadoi{i in ESTADOS}: sum{(i,j) in s} Dij[i,j] * YEei[j] = DEi[i];

# funcional
minimize z: sum{i in ESTADOS} Li[i];

end;
```

```
Problem:    comb
Rows:       116
Columns:    96 (64 integer, 64 binary)
Non-zeros:  432
Status:     INTEGER OPTIMAL
Objective:  z = 1457.681632 (MINimum)

   No.   Row name         Activity     Lower bound   Upper bound
------ ------------    ------------- ------------- -------------
     1 cota_sup_dcA[Alabama]
                            223.749                      223.749
     2 cota_sup_dcA[Arizona]
                            817.982                      3090.64
     3 cota_sup_dcA[Arkansas]
                                  0                      895.532
     4 cota_sup_dcA[California]
                            415.951                      4130.54
     5 cota_sup_dcA[Colorado]
                                  0                       2296.9
     6 cota_sup_dcA[Connecticut]
                                  0                      1307.57
     7 cota_sup_dcA[Florida]
                                  0                           -0
     8 cota_sup_dcA[Oregon]
                                  0                       4291.9
     9 cota_sup_dcB[Alabama]
                            223.749                      4077.38
    10 cota_sup_dcB[Arizona]
                            817.982                      1348.72
    11 cota_sup_dcB[Arkansas]
                                  0                      3417.83
    12 cota_sup_dcB[California]
                            415.951                      415.951
    13 cota_sup_dcB[Colorado]
                                  0                      2018.37
    14 cota_sup_dcB[Connecticut]
                                  0                      5596.86
    15 cota_sup_dcB[Florida]
                                  0                       4291.9
    16 cota_sup_dcB[Oregon]
                                  0                           -0
    17 cota_sup_dcC[Alabama]
                            -1853.4                           -0
    18 cota_sup_dcC[Arizona]
                                  0                           -0
    19 cota_sup_dcC[Arkansas]
                           -1408.12                           -0
    20 cota_sup_dcC[California]
                           -1417.72                           -0
    21 cota_sup_dcC[Colorado]
                                  0                           -0
    22 cota_sup_dcC[Connecticut]
                           -3591.82                           -0
    23 cota_sup_dcC[Florida]
                            -2296.9                           -0
    24 cota_sup_dcC[Oregon]
```

```
                                    -2018.37                              -0
  25 cota_sup_dcD[Alabama]
                                    -449.066                              -0
  26 cota_sup_dcD[Arizona]
                                    -1377.38                              -0
  27 cota_sup_dcD[Arkansas]
                                           0                              -0
  28 cota_sup_dcD[California]
                                    -2824.64                              -0
  29 cota_sup_dcD[Colorado]
                                    -1408.12                              -0
  30 cota_sup_dcD[Connecticut]
                                    -2183.71                              -0
  31 cota_sup_dcD[Florida]
                                    -895.532                              -0
  32 cota_sup_dcD[Oregon]
                                    -3417.83                              -0
  33 cota_sup_dcE[Alabama]
                                    -1295.76                              -0
  34 cota_sup_dcE[Arizona]
                                    -3550.92                              -0
  35 cota_sup_dcE[Arkansas]
                                    -2183.71                              -0
  36 cota_sup_dcE[California]
                                     -5007.4                              -0
  37 cota_sup_dcE[Colorado]
                                    -3591.82                              -0
  38 cota_sup_dcE[Connecticut]
                                           0                              -0
  39 cota_sup_dcE[Florida]
                                    -1307.57                              -0
  40 cota_sup_dcE[Oregon]
                                    -5596.86                              -0
  41 cota_inf_dcA[Alabama]
                                     223.749       223.749
  42 cota_inf_dcA[Arizona]
                                       10818       3090.64
  43 cota_inf_dcA[Arkansas]
                                       10000       895.532
  44 cota_inf_dcA[California]
                                       10416       4130.54
  45 cota_inf_dcA[Colorado]
                                       10000        2296.9
  46 cota_inf_dcA[Connecticut]
                                       10000       1307.57
  47 cota_inf_dcA[Florida]
                                           0            -0
  48 cota_inf_dcA[Oregon]
                                       10000        4291.9
  49 cota_inf_dcB[Alabama]
                                     10223.7       4077.38
  50 cota_inf_dcB[Arizona]
                                       10818       1348.72
  51 cota_inf_dcB[Arkansas]
                                       10000       3417.83
  52 cota_inf_dcB[California]
                                     415.951       415.951
```

```
      53 cota_inf_dcB[Colorado]
                                   10000         2018.37
      54 cota_inf_dcB[Connecticut]
                                   10000         5596.86
      55 cota_inf_dcB[Florida]
                                   10000          4291.9
      56 cota_inf_dcB[Oregon]
                                       0              -0
      57 cota_inf_dcC[Alabama]
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      60 cota_inf_dcC[California]
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      62 cota_inf_dcC[Connecticut]
                                 6408.18              -0
      63 cota_inf_dcC[Florida]
                                  7703.1              -0
      64 cota_inf_dcC[Oregon]
                                 7981.63              -0
      65 cota_inf_dcD[Alabama]
                                 9550.93              -0
      66 cota_inf_dcD[Arizona]
                                 8622.62              -0
      67 cota_inf_dcD[Arkansas]
                                       0              -0
      68 cota_inf_dcD[California]
                                 7175.36              -0
      69 cota_inf_dcD[Colorado]
                                 8591.88              -0
      70 cota_inf_dcD[Connecticut]
                                 7816.29              -0
      71 cota_inf_dcD[Florida]
                                 9104.47              -0
      72 cota_inf_dcD[Oregon]
                                 6582.17              -0
      73 cota_inf_dcE[Alabama]
                                 8704.24              -0
      74 cota_inf_dcE[Arizona]
                                 6449.08              -0
      75 cota_inf_dcE[Arkansas]
                                 7816.29              -0
      76 cota_inf_dcE[California]
                                  4992.6              -0
      77 cota_inf_dcE[Colorado]
                                 6408.18              -0
      78 cota_inf_dcE[Connecticut]
                                       0              -0
      79 cota_inf_dcE[Florida]
                                 8692.43              -0
      80 cota_inf_dcE[Oregon]
                                 4403.14              -0
      81 total_datacenters[Alabama]
```

```
                                    4           4           =
    82 total_datacenters[Arizona]
                                    4           4           =
    83 total_datacenters[Arkansas]
                                    4           4           =
    84 total_datacenters[California]
                                    4           4           =
    85 total_datacenters[Colorado]
                                    4           4           =
    86 total_datacenters[Connecticut]
                                    4           4           =
    87 total_datacenters[Florida]
                                    4           4           =
    88 total_datacenters[Oregon]
                                    4           4           =
    89 asoc_dcC                     1           1           =
    90 asoc_dcD                     1           1           =
    91 asoc_dcE                     1           1           =
    92 asoc_dist_dcC_estadoi[Alabama]
                                    0          -0           =
    93 asoc_dist_dcC_estadoi[Arizona]
                                    0          -0           =
    94 asoc_dist_dcC_estadoi[Arkansas]
                                    0          -0           =
    95 asoc_dist_dcC_estadoi[California]
                                    0          -0           =
    96 asoc_dist_dcC_estadoi[Colorado]
                                    0          -0           =
    97 asoc_dist_dcC_estadoi[Connecticut]
                                    0          -0           =
    98 asoc_dist_dcC_estadoi[Florida]
                                    0          -0           =
    99 asoc_dist_dcC_estadoi[Oregon]
                                    0          -0           =
   100 asoc_dist_dcD_estadoi[Alabama]
                                    0          -0           =
   101 asoc_dist_dcD_estadoi[Arizona]
                                    0          -0           =
   102 asoc_dist_dcD_estadoi[Arkansas]
                                    0          -0           =
   103 asoc_dist_dcD_estadoi[California]
                                    0          -0           =
   104 asoc_dist_dcD_estadoi[Colorado]
                                    0          -0           =
   105 asoc_dist_dcD_estadoi[Connecticut]
                                    0          -0           =
   106 asoc_dist_dcD_estadoi[Florida]
                                    0          -0           =
   107 asoc_dist_dcD_estadoi[Oregon]
                                    0          -0           =
   108 asoc_dist_dcE_estadoi[Alabama]
                                    0          -0           =
   109 asoc_dist_dcE_estadoi[Arizona]
                                    0          -0           =
   110 asoc_dist_dcE_estadoi[Arkansas]
                                    0          -0           =
   111 asoc_dist_dcE_estadoi[California]
```

```
                                      0             −0             =
   112 asoc_dist_dcE_estadoi[Colorado]
                                      0             −0             =
   113 asoc_dist_dcE_estadoi[Connecticut]
                                      0             −0             =
   114 asoc_dist_dcE_estadoi[Florida]
                                      0             −0             =
   115 asoc_dist_dcE_estadoi[Oregon]
                                      0             −0             =
   116 z                        1457.68

   No. Column name          Activity     Lower bound   Upper bound
------ ------------       ------------- ------------- -------------
     1 Li[Alabama]          223.749             0
     2 Li[Arizona]          817.982             0
     3 Li[Arkansas]               0             0
     4 Li[California]
                            415.951             0
     5 Li[Colorado]               0             0
     6 Li[Connecticut]
                                  0             0
     7 Li[Florida]                0             0
     8 Li[Oregon]                 0             0
     9 DCi[Alabama]         2077.15             0
    10 DCi[Arizona]         817.982             0
    11 DCi[Arkansas]
                            1408.12             0
    12 DCi[California]
                            1833.67             0
    13 DCi[Colorado]
                                  0             0
    14 DCi[Connecticut]
                            3591.82             0
    15 DCi[Florida]          2296.9             0
    16 DCi[Oregon]          2018.37             0
    17 DDi[Alabama]         672.815             0
    18 DDi[Arizona]         2195.36             0
    19 DDi[Arkansas]
                                  0             0
    20 DDi[California]
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    21 DDi[Colorado]
                            1408.12             0
    22 DDi[Connecticut]
                            2183.71             0
    23 DDi[Florida]         895.532             0
    24 DDi[Oregon]          3417.83             0
    25 DEi[Alabama]         1519.51             0
    26 DEi[Arizona]          4368.9             0
    27 DEi[Arkansas]
                            2183.71             0
    28 DEi[California]
                            5423.35             0
    29 DEi[Colorado]
                            3591.82             0
    30 DEi[Connecticut]
                                  0             0
```

```
31 DEi[Florida]          1307.57          0
32 DEi[Oregon]           5596.86          0
33 YAi[Alabama]  *             0          0          1
34 YAi[Arizona]  *             1          0          1
35 YAi[Arkansas]
                 *             1          0          1
36 YAi[California]
                 *             1          0          1
37 YAi[Colorado]
                 *             1          0          1
38 YAi[Connecticut]
                 *             1          0          1
39 YAi[Florida]  *             0          0          1
40 YAi[Oregon]   *             1          0          1
41 YBi[Alabama]  *             1          0          1
42 YBi[Arizona]  *             1          0          1
43 YBi[Arkansas]
                 *             1          0          1
44 YBi[California]
                 *             0          0          1
45 YBi[Colorado]
                 *             1          0          1
46 YBi[Connecticut]
                 *             1          0          1
47 YBi[Florida]  *             1          0          1
48 YBi[Oregon]   *             0          0          1
49 YCi[Alabama]  *             1          0          1
50 YCi[Arizona]  *             0          0          1
51 YCi[Arkansas]
                 *             1          0          1
52 YCi[California]
                 *             1          0          1
53 YCi[Colorado]
                 *             0          0          1
54 YCi[Connecticut]
                 *             1          0          1
55 YCi[Florida]  *             1          0          1
56 YCi[Oregon]   *             1          0          1
57 YDi[Alabama]  *             1          0          1
58 YDi[Arizona]  *             1          0          1
59 YDi[Arkansas]
                 *             0          0          1
60 YDi[California]
                 *             1          0          1
61 YDi[Colorado]
                 *             1          0          1
62 YDi[Connecticut]
                 *             1          0          1
63 YDi[Florida]  *             1          0          1
64 YDi[Oregon]   *             1          0          1
65 YEi[Alabama]  *             1          0          1
66 YEi[Arizona]  *             1          0          1
67 YEi[Arkansas]
                 *             1          0          1
68 YEi[California]
                 *             1          0          1
69 YEi[Colorado]
```

```
                     *                1                0                1
    70  YEi[Connecticut]
                     *                0                0                1
    71  YEi[Florida] *                1                0                1
    72  YEi[Oregon]  *                1                0                1
    73  YCei[Alabama]
                     *                0                0                1
    74  YCei[Arizona]
                     *                0                0                1
    75  YCei[Arkansas]
                     *                0                0                1
    76  YCei[California]
                     *                0                0                1
    77  YCei[Colorado]
                     *                1                0                1
    78  YCei[Connecticut]
                     *                0                0                1
    79  YCei[Florida]
                     *                0                0                1
    80  YCei[Oregon] *                0                0                1
    81  YDei[Alabama]
                     *                0                0                1
    82  YDei[Arizona]
                     *                0                0                1
    83  YDei[Arkansas]
                     *                1                0                1
    84  YDei[California]
                     *                0                0                1
    85  YDei[Colorado]
                     *                0                0                1
    86  YDei[Connecticut]
                     *                0                0                1
    87  YDei[Florida]
                     *                0                0                1
    88  YDei[Oregon] *                0                0                1
    89  YEei[Alabama]
                     *                0                0                1
    90  YEei[Arizona]
                     *                0                0                1
    91  YEei[Arkansas]
                     *                0                0                1
    92  YEei[California]
                     *                0                0                1
    93  YEei[Colorado]
                     *                0                0                1
    94  YEei[Connecticut]
                     *                1                0                1
    95  YEei[Florida]
                     *                0                0                1
    96  YEei[Oregon] *                0                0                1

Integer feasibility conditions:

KKT.PE: max.abs.err = 1.82e-12 on row 74
        max.rel.err = 8.41e-17 on row 74
        High quality

```

```
KKT.PB: max.abs.err = 0.00e+00 on row 0
        max.rel.err = 0.00e+00 on row 0
        High quality

End of output
```

Part VIII
Conclusiones

Se decidió realizar la corrida sobre los siguientes estados:

Alabama, Arizona, Arkansas, California, Colorado, Connecticut, Florida, Oregon

Fuera de Florida (Datacenter A) y Oregon (Datacenter B), las 3 nuevas datacenters son las siguientes

Datacenter C: Colorado (77 YCei[Colorado] 1)

Datacenter D: Arkansas (83 YDei[Arkansas] 1)

Datacenter E: Connecticut (94 YEei[Connecticut] 1)

La latencia global del sistema es: 1457.681632

Las latencias de cada estado son las siguientes:

Li[Alabama] 223.749

Li[Arizona] 817.982

Li[Arkansas] 0

Li[California] 415.951

Li[Colorado] 0

Li[Connecticut] 0

Li[Florida] 0

Li[Oregon] 0

Esto tiene sentido pues solo Alabama, Arizona y California no tienen un datacenter en el estado.

El datacenter C de Colorado es el mas cercano a Arizona (la distancia del datacenter al estado es la misma que su latencia mínima):

DCi[Arizona] 817.982

El datacenter A de Florida es el mas cercano a Alabama (define la cota inferior a la latencia del estado)

cota_inf_dcA[Alabama] 223.749

El datacenter B de Oregon es el mas cercano a California (define la cota inferior a la latencia del estado)

cota_inf_dcB[California] 415.951

Part IX
Heurística

```
compilar: g++ -std=c++11 heuristic.cpp -o heuristic
correr: cat distances.csv  | ./heuristic
```

heuristic.cpp

```cpp
#include <iostream>
#include <map>
#include <cfloat>

void get_problem_values(int &num_of_states, int &num_of_datacenters){
    std::cout << "Insert number of states" << std::endl;
    std::cin >> num_of_states;
    std::cout << "Insert number of datacenters" << std::endl;
    std::cin >> num_of_datacenters;
}

void fill_distances_matrix(int num_of_states,
                           std::map<int, std::map<int, double> > &distances){
    for(int i = 1; i <= num_of_states; ++i){
        for(int j = i + 1; j <= num_of_states; ++j){
            double current_distance;
            std::cout << "insert distance between state "
                      << i << " and " << j << std::endl;
            std::cin >> current_distance;
            distances[i][j] = current_distance;
            distances[j][i] = current_distance;
        }
        /* distance from a state to itself is 0 */
        distances[i][i] = 0;
    }
}

double calculate_current_latency(int num_of_states,
                                 const std::map<int, int> &datacenters,
                                 const std::map<int, std::map<int, double> >
                                 &distances){
    double total_latency = 0;
    /* for each state, check the minimum distance to each datacenter */
    for(int i = 1; i <= num_of_states; ++i){
        double this_state_lat = DBL_MAX;
        for(auto it = datacenters.begin(); it != datacenters.end(); ++it){
            double read_lat = distances.at(i).at(it->second);
            if (read_lat < this_state_lat){
                this_state_lat = read_lat;
            }
        }
        total_latency += this_state_lat;
    }
    return total_latency;
}

void manage_manually_allocated_dataceneters(
```

```cpp
        int num_of_states, int &num_of_manually_allocated_datacenters,
        std::map<int, int> &datacenters,
        std::map<int, std::map<int, double> > &distances){
    std::cout << "How many datacenters are manually allocated?" << std::endl;
    std::cin >> num_of_manually_allocated_datacenters;

    for (int i = 1; i <= num_of_manually_allocated_datacenters; ++i){
        int state;
        std::cout << "Insert number of state where datacenter " << i
                  << " should be." << std::endl;
        std::cin >> state;
        datacenters[i] = state;
        /* display current latency */
        std::cout << "latency after datacenter " << i
                  << " was allocated: "
                  << calculate_current_latency(num_of_states, datacenters,
                                               distances) << std::endl;
    }
}

bool state_already_has_datacenter(int state,
                                  const std::map<int, int> &datacenters){
    for (auto it = datacenters.begin(); it != datacenters.end(); ++it){
        if (it->second == state){
            return true;
        }
    }
    return false;
}

int locate_new_datacenter(int num_of_datacenter,
                          int num_of_states, std::map<int, int> &datacenters,
                          const std::map<int, std::map<int, double> >
                          &distances){
    /* returns number of state which minimizes latency */
    double current_lat = DBL_MAX;
    int state_that_minimizes_lat;
    for(int i = 1; i <= num_of_states; ++i){
        if (!state_already_has_datacenter(i, datacenters)){
            datacenters[num_of_datacenter] = i;
            if (calculate_current_latency(num_of_states, datacenters,
                distances)
                < current_lat){
                state_that_minimizes_lat = i;
            }
        }
    }
    return state_that_minimizes_lat;
}

void locate_remaining_datacenters(int num_of_states, int num_of_datacenters,
                                  int num_of_manually_allocated_datacenters,
                                  std::map<int, int> &datacenters,
                                  std::map<int, std::map<int, double> >
                                  &distances){
    for (int i = num_of_manually_allocated_datacenters + 1;
         i <= num_of_datacenters; ++i){
```

```
        datacenters[i] = locate_new_datacenter(i, num_of_states,
                                               datacenters, distances);
        /* display current latency */
        std::cout << "latency after datacenter " << i << " located: " <<
                 calculate_current_latency(
                         num_of_states, datacenters, distances) << std::endl;
    }
}

void inform_datacenter_positions(const std::map<int, int> &datacenters){
    for (auto it = datacenters.begin(); it != datacenters.end(); ++it){
        std::cout << "datacenter\t" << it->first <<
                 "\tlocated in state\t" << it->second << std::endl;
    }
}

int main(){
    int num_of_states;
    int num_of_datacenters;

    /* A map is used to store de distance matrix.
     * States are identified with numbers from 1 to n,
     * where n is the number of states to consider. */
    std::map<int, std::map<int, double> > distances;

    /* A map is used to link each datacenter to a state.
     * K = datacenter.
     * V = state.  */
    std::map<int, int> datacenters;

    get_problem_values(num_of_states, num_of_datacenters);

    fill_distances_matrix(num_of_states, distances);

    int num_of_manually_allocated_datacenters;
    manage_manually_allocated_dataceneters(
            num_of_states, num_of_manually_allocated_datacenters, datacenters,
            distances);

    locate_remaining_datacenters(num_of_states, num_of_datacenters,
                                 num_of_manually_allocated_datacenters,
                                 datacenters, distances);

    /* inform results */
    std::cout << "*** Final datacenter positions ****" << std::endl;
    inform_datacenter_positions(datacenters);
    return 0;
}
```

distances.csv

```
48
5
2868.1784177465
672.8151726255
3910.7411305068
2077.1452377083
1519.5077579655
```

```
1199.4986222794
223.7493394677
210.4252102536
3324.1942219342
375.2257089259
56.4357710091
813.7155779585
1044.7398456498
165.0340299937
540.4773059684
1847.1499908138
1091.0322829094
1703.4547303348
212.816842606
753.2459183061
436.760545128
656.2792698469
2852.0588142381
1153.1140642009
3719.6061504499
1647.0895439219
1286.3997375109
2188.3611696487
1398.2602236424
850.7371193588
1599.6208068671
372.2093675161
1251.1843173346
4077.3821775963
1051.0725631423
1658.9964185501
583.4074521691
1556.4006060984
61.6660433356
1275.3164983935
2844.2698934059
1535.3683688696
983.0281549644
4058.9796061032
520.6289399976
346.722732452
2055.7517642547
2195.3633128392
1074.6564829771
817.9816362195
4368.8983013915
4058.8562357351
3090.6378199187
3078.2955554998
652.9574510614
2493.1423425089
2880.6046484923
2056.6878450176
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3024.0858609986
2327.8933566076
4682.3639246028
```

```
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547.8271383216
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897.0547741451
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4142.2868098361
683.9429951775
4243.9969329672
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1335.176983076
3228.9139729094
1617.4340416483
1348.7170068791
3907.1834067229
4507.7632004432
3451.3284563862
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2811.7489989948
1594.7492824989
304.6040016489
4372.3388621472
3846.5508340495
1383.7138875033
3382.3197560766
2522.0070767663
851.0210240327
3240.5930582521
1408.1193462358
2183.7128516647
1867.8921975774
895.5322444057
882.9858748922
2661.6694918504
297.9545644178
686.9378827219
148.5196443215
374.724802599
830.0793441766
133.1107231847
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1759.60566892
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100.1013188851
236.2140420465
23.0538798924
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2308.321592842
1953.2153440986
1516.0107427025
```

```
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1388.6180685584
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3157.4969452398
3476.3045536175
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1122.1693629777
2757.6338063377
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5193.7171224844
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4761.4435405175
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415.9506567564
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```

```
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1498.1971567642
2328.8500611693
2558.3839762036
```

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```

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```

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4415.123611807
5026.7659657486
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```

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1768.3006914047
3272.3837865658
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763.3098168329
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3711.3963033762
1420.4899404651
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900.125209431
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29.7180307086
```

```
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360.0448799892
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2512.2461498969
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```

```
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507.682524458
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2741.5796964907
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292.6355375731
609.8458434683
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111.5837197317
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2683.042000756
2327.6403801501
1144.1664996257
2435.1884600521
1895.4052420326
584.881261015
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210.0535847952
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1013.9006060591
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1683.1245155173
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913.7400968134
594.0971288437
814.6295959333
```

```
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1371.20676542
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2373.2798868679
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730.7640664565
223.5442431313
103.7851766124
119.2687749474
2327.7558272547
617.9587449396
3183.204812454
2175.473004539
1820.1153509532
1648.9548448082
1927.5375700966
1389.6886758486
1078.9637993687
903.5812348985
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3550.036229175
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1123.4350998294
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734.9738304061
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```

```
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Part X
Resultados de Heurística

Se corrió la heurística con los 8 estados y se consiguieron los siguientes resultados:

```
Insert number of state where datacenter 1 should be.
latency after datacenter 1 was allocated: 16236.8
Insert number of state where datacenter 2 should be.
latency after datacenter 2 was allocated: 6209.89
latency after datacenter 3 located: 4902.32
latency after datacenter 4 located: 2353.21
latency after datacenter 5 located: 1937.26
*** Final datacenter positions ****
datacenter 1 located in state 7
datacenter 2 located in state 8
datacenter 3 located in state 6
datacenter 4 located in state 5
datacenter 5 located in state 4
```

Los datacenters seleccionador quedaron en los estados California Colorado y Conetticut (4, 5 y 6) dejando la latencia en 1937.26 Este resultado es peor comparado con el modelo de GLPK que dejó la latencia en 1457

Se corrió la heurística con los 48 estados y se consiguieron los siguientes resultados:

```
Insert number of state where datacenter 1 should be.
latency after datacenter 1 was allocated: 68827.2
Insert number of state where datacenter 2 should be.
latency after datacenter 2 was allocated: 44071.9
latency after datacenter 3 located: 32303.7
latency after datacenter 4 located: 27360.3
latency after datacenter 5 located: 22764.1
*** Final datacenter positions ****
datacenter 1 located in state 8
datacenter 2 located in state 35
datacenter 3 located in state 48
datacenter 4 located in state 47
datacenter 5 located in state 46
```

Los datacenters seleccionador quedaron en los estados Wyoming, Wisconsin y west virginia dejando la latencia en 22764.1