U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Algoritmos para rotear Transportes Marítimos e Entregas Urbanas

Trabalho Prático 2 – Desenho de Algoritmos

André Santos(up202108658)
Diogo Silva(up202104794)
Samuel Maciel(up202108697)

Objetivo

- Este projeto, tem como objetivo analisar o TSP(Travelling Salesperson Problem) e projetar heurísticas para resolvê-lo, utilizando vários conjuntos de dados no contexto de transporte oceânico e entregas urbanas.

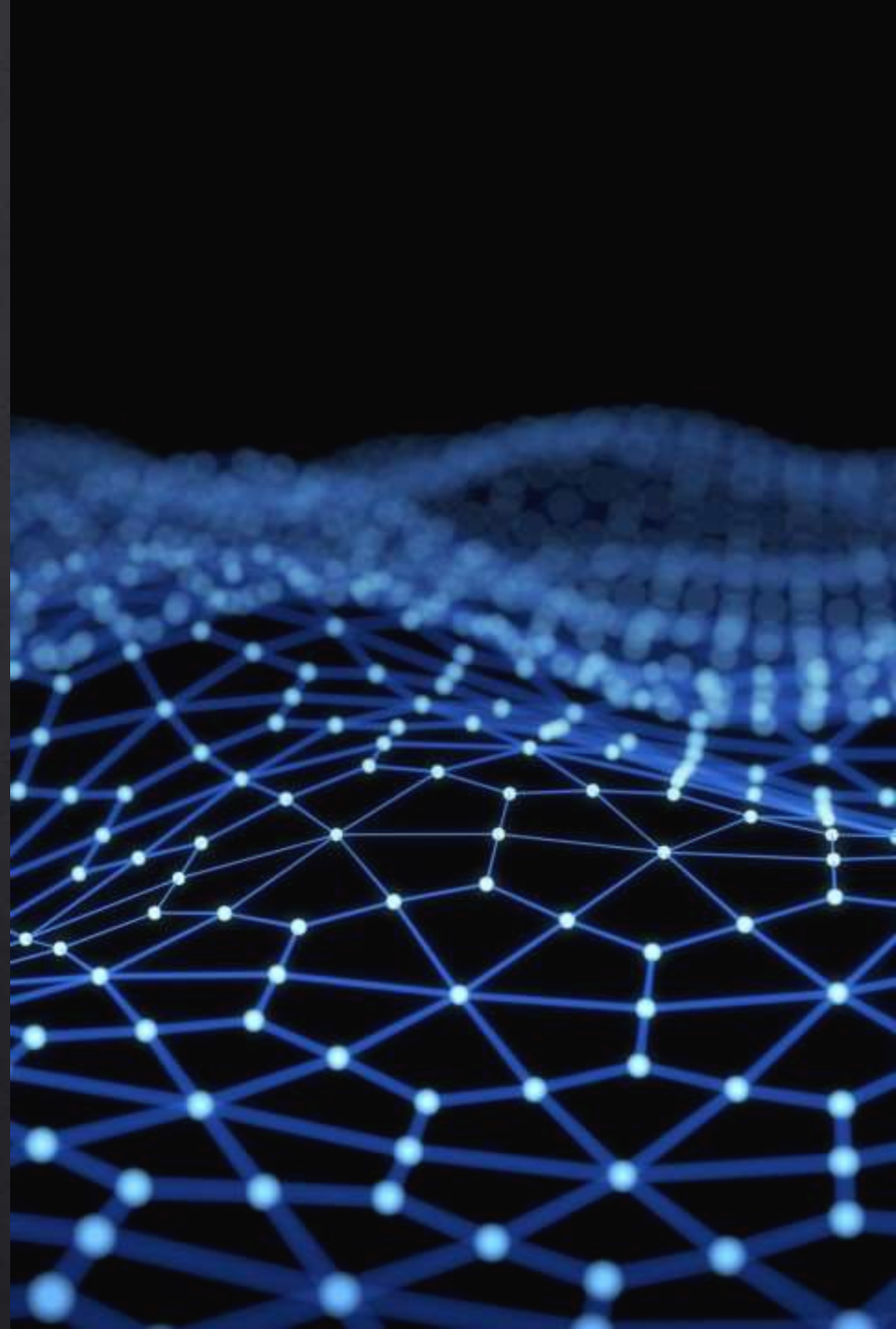
Dados

	origem	destino	distancia	label origem	label destino
1	0	1	1300	carmo	dLuis
2	0	2	1000	carmo	se
3	0	3	450	carmo	clerigos
4	0	4	750	carmo	bolsa
5	1	2	450	dLuis	se
6	1	3	950	dLuis	clerigos
7	1	4	450	dLuis	bolsa
8	2	3	500	se	clerigos
9	2	4	600	se	bolsa
10	3	4	750	clerigos	bolsa

	C1	C2	C3
1	0	1	38688.5
2	0	2	44944.4
3	0	3	63088.8
4	0	4	3088.5
5	0	5	16543.7
6	0	6	43275.0
7	0	7	8816.8
8	0	8	6350.4
9	0	9	17746.9
10	0	10	41883.1
11	0	11	8951.0
12	0	12	2454.3
13	0	13	31094.1
14	0	14	40728.8
15	0	15	18518.4
16	0	16	57994.3
17	0	17	5572.9
18	0	18	33593.4
19	0	19	46981.2
20	0	20	56278.7
21	0	21	32225.0
22	0	22	884.7
23	0	23	2891.7
24	0	24	5550.0
25	1	2	7460.9

Interface

- Menu;
- Inputs do utilizador;
- Algoritmos relevantes;



Classes

- Menu;
- Graph;
- Algorithms;
- Vertex;
- Edge;
- ReadData;

Funcionamento

```
=============== MENU ===============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangle 2-Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:
```

```
=============== GRAPH SELECTOR ===============
1. Toy Graphs
2. Medium Graphs
3. Real World Graphs
4. Return
Choose an option:
```

```
=============== TOY GRAPH SELECTOR ===============
1. Shipping Graph
2. Stadiums Graph
3. Tourism Graph
4. Return
Choose an option:
```

```
=============== MEDIUM GRAPH SELECTOR ===============
1. 25 vertices
2. 50 vertices
3. 75 vertices
4. 100 vertices
5. 200 vertices
6. 300 vertices
7. 400 vertices
8. 500 vertices
9. 600 vertices
10. 700 vertices
11. 800 vertices
12. 900 vertices
13. Return
Enter the number corresponding to the desired size:
```

```
=============== REAL WORLD GRAPH SELECTOR ===============
1. Graph 1
2. Graph 2
3. Graph 3
4. Return
Choose an option:
```

Funcionamento

Shipping

```
============== MENU ==============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangle 2-Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:2

The graph has a minimum distance of: 86.7.
The execution time was: 0 seconds.
The path is: 0 ==> 1 ==> 11 ==> 10 ==> 12 ==> 13 ==> 3 ==> 2 ==> 4 ==> 6 ==> 9 ==> 7 ==> 8 ==> 5
```

Tourism

```
=============== MENU ===============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangle 2-Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:2

The graph has a minimum distance of: 2600.
The execution time was: 0.001 seconds.
The path is: 0 ==> 3 ==> 2 ==> 1 ==> 4
```

Stadiums

```
=============== MENU ===============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangle 2-Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:2

The graph has a minimum distance of: 341.
The execution time was: 0 seconds.
The path is: 0 ==> 1 ==> 9 ==> 6 ==> 8 ==> 4 ==> 7 ==> 5 ==> 10 ==> 2 ==> 3
```

Funcionamento

```
=============== REAL WORLD GRAPH SELECTOR ===============
1. Graph 1
2. Graph 2
3. Graph 3
4. Return
Choose an option:1

=============== MENU ===============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangular Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:3
The execution time was: 0.075 seconds.
The path is: 0 ==> 496 ==> 878 ==> 221 ==> 98 ==> 134 ==> 7 ==> 152 ==> 728 ==> 87 ==> 928 ==> 654 ==> 411 ==> 327 ==> 266 ==> 835 ==> 601 ==> 723 ==> 106 ==> 980 ==> 92 ==> 362 ==> 632 ==> 662 ==> 161 ==> 521 ==> 378 ==> 842 ==>
 550 ==> 244 ==> 957 ==> 306 ==> 20 ==> 671 ==> 689 ==> 917 ==> 16 ==> 154 ==> 310 ==> 144 ==> 853 ==> 544 ==> 696 ==> 557 ==> 992 ==> 364 ==> 666 ==> 747 ==> 356 ==> 554 ==> 674 ==> 76 ==> 574 ==> 452 ==> 937 ==> 816 ==> 138 ==>
 984 ==> 645 ==> 926 ==> 646 ==> 317 ==> 177 ==> 343 ==> 919 ==> 125 ==> 252 ==> 490 ==> 958 ==> 911 ==> 176 ==> 150 ==> 360 ==> 43 ==> 358 ==> 943 ==> 2 ==> 196 ==> 110 ==> 848 ==> 639 ==> 857 ==> 23 ==> 377 ==> 236 ==> 858 ==>
594 ==> 69 ==> 751 ==> 349 ==> 586 ==> 660 ==> 972 ==> 332 ==> 533 ==> 767 ==> 619 ==> 995 ==> 656 ==> 295 ==> 757 ==> 803 ==> 927 ==> 719 ==> 921 ==> 502 ==> 780 ==> 146 ==> 224 ==> 109 ==> 268 ==> 337 ==> 10 ==> 446 ==> 53 ==>
79 ==> 530 ==> 61 ==> 207 ==> 497 ==> 34 ==> 379 ==> 461 ==> 312 ==> 844 ==> 520 ==> 298 ==> 615 ==> 888 ==> 77 ==> 94 ==> 898 ==> 259 ==> 864 ==> 435 ==> 834 ==> 718 ==> 886 ==> 389 ==> 48 ==> 227 ==> 929 ==> 57 ==> 441 ==> 308
==> 447 ==> 277 ==> 119 ==> 117 ==> 811 ==> 635 ==> 883 ==> 369 ==> 954 ==> 180 ==> 627 ==> 650 ==> 504 ==> 463 ==> 212 ==> 123 ==> 598 ==> 12 ==> 678 ==> 62 ==> 122 ==> 655 ==> 120 ==> 78 ==> 271 ==> 250 ==> 139 ==> 184 ==> 190
==> 536 ==> 492 ==> 321 ==> 201 ==> 996 ==> 895 ==> 675 ==> 668 ==> 27 ==> 322 ==> 410 ==> 242 ==> 445 ==> 50 ==> 270 ==> 909 ==> 116 ==> 64 ==> 693 ==> 89 ==> 216 ==> 300 ==> 529 ==> 46 ==> 291 ==> 22 ==> 516 ==> 140 ==> 501 ==>
 ==> 637 ==> 482 ==> 5 ==> 872 ==> 578 ==> 763 ==> 552 ==> 75 ==> 836 ==> 367 ==> 804 ==> 339 ==> 132 ==> 248 ==> 326 ==> 483 ==> 392 ==> 336 ==> 158 ==> 568 ==> 434 ==> 60 ==> 775 ==> 867 ==> 513 ==> 71 ==> 113 ==> 733 ==> 744 =
=> 630 ==> 91 ==> 706 ==> 983 ==> 791 ==> 229 ==> 243 ==> 669 ==> 532 ==> 714 ==> 866 ==> 640 ==> 930 ==> 614 ==> 585 ==> 228 ==> 771 ==> 580 ==> 584 ==> 426 ==> 625 ==> 913 ==> 743 ==> 286 ==> 613 ==> 831 ==> 828 ==> 17 ==> 313
==> 623 ==> 297 ==> 85 ==> 974 ==> 781 ==> 973 ==> 699 ==> 631 ==> 373 ==> 815 ==> 143 ==> 292 ==> 750 ==> 915 ==> 567 ==> 745 ==> 155 ==> 784 ==> 289 ==> 159 ==> 168 ==> 97 ==> 769 ==> 448 ==> 25 ==> 458 ==> 174 ==> 752 ==> 431
==> 3 ==> 875 ==> 709 ==> 861 ==> 414 ==> 54 ==> 935 ==> 990 ==> 764 ==> 198 ==> 629 ==> 45 ==> 165 ==> 391 ==> 896 ==> 135 ==> 673 ==> 698 ==> 774 ==> 294 ==> 942 ==> 56 ==> 559 ==> 556 ==> 468 ==> 944 ==> 910 ==> 171 ==> 357 ==
> 404 ==> 948 ==> 124 ==> 519 ==> 881 ==> 686 ==> 361 ==> 892 ==> 524 ==> 661 ==> 455 ==> 672 ==> 316 ==> 681 ==> 425 ==> 679 ==> 239 ==> 178 ==> 651 ==> 622 ==> 307 ==> 213 ==> 766 ==> 423 ==> 299 ==> 194 ==> 208 ==> 141 ==> 593
 ==> 565 ==> 754 ==> 323 ==> 451 ==> 818 ==> 29 ==> 442 ==> 82 ==> 820 ==> 579 ==> 30 ==> 67 ==> 432 ==> 890 ==> 753 ==> 823 ==> 634 ==> 28 ==> 217 ==> 537 ==> 783 ==> 475 ==> 467 ==> 355 ==> 794 ==> 717 ==> 74 ==> 371 ==> 535 ==
> 566 ==> 487 ==> 35 ==> 285 ==> 52 ==> 722 ==> 806 ==> 105 ==> 488 ==> 390 ==> 649 ==> 363 ==> 562 ==> 153 ==> 215 ==> 368 ==> 561 ==> 534 ==> 916 ==> 443 ==> 607 ==> 700 ==> 950 ==> 802 ==> 183 ==> 891 ==> 436 ==> 384 ==> 829 =
=> 715 ==> 206 ==> 24 ==> 871 ==> 232 ==> 905 ==> 66 ==> 707 ==> 375 ==> 677 ==> 840 ==> 827 ==> 517 ==> 724 ==> 320 ==> 226 ==> 960 ==> 786 ==> 315 ==> 156 ==> 422 ==> 354 ==> 478 ==> 885 ==> 514 ==> 628 ==> 427 ==> 526 ==> 899
==> 738 ==> 737 ==> 970 ==> 90 ==> 587 ==> 841 ==> 418 ==> 484 ==> 506 ==> 309 ==> 403 ==> 255 ==> 620 ==> 810 ==> 805 ==> 555 ==> 145 ==> 735 ==> 904 ==> 18 ==> 545 ==> 256 ==> 281 ==> 618 ==> 413 ==> 703 ==> 531 ==> 464 ==> 15
==> 690 ==> 386 ==> 817 ==> 982 ==> 560 ==> 945 ==> 419 ==> 602 ==> 778 ==> 238 ==> 169 ==> 472 ==> 473 ==> 279 ==> 421 ==> 981 ==> 70 ==> 643 ==> 192 ==> 710 ==> 481 ==> 359 ==> 32 ==> 494 ==> 348 ==> 151 ==> 499 ==> 160 ==> 597
 ==> 93 ==> 101 ==> 325 ==> 845 ==> 542 ==> 549 ==> 272 ==> 254 ==> 746 ==> 477 ==> 956 ==> 283 ==> 245 ==> 720 ==> 822 ==> 491 ==> 352 ==> 697 ==> 522 ==> 938 ==> 346 ==> 330 ==> 922 ==> 191 ==> 262 ==> 58 ==> 166 ==> 118 ==> 21
0 ==> 590 ==> 788 ==> 465 ==> 688 ==> 953 ==> 851 ==> 798 ==> 149 ==> 303 ==> 600 ==> 39 ==> 495 ==> 95 ==> 350 ==> 9 ==> 933 ==> 230 ==> 399 ==> 897 ==> 685 ==> 394 ==> 652 ==> 761 ==> 768 ==> 874 ==> 838 ==> 576 ==> 962 ==> 852
 ==> 382 ==> 263 ==> 366 ==> 932 ==> 564 ==> 621 ==> 680 ==> 466 ==> 807 ==> 865 ==> 182 ==> 704 ==> 776 ==> 148 ==> 0

The graph has a minimum distance of: 1.12185e+06 meters.
```

Funcionamento

```
=============== MENU ===============
1. Load/Change Graph
2. Backtracking Algorithm
3. Triangular Approximation Algorithm
4. Other Heuristics
5. Exit
Choose an option:4
=============== Other Heuristics ===============
1. Cluster Based Algorithm
2. Christofides Algorithm
3. Nearest Neighbor Algorithm
4. Return
Choose an option:2
```

Funcionamento

```
Choose an option:4
=============== Other Heuristics ===============
1. Cluster Based Algorithm
2. Christofides Algorithm
3. Nearest Neighbor Algorithm
4. Return
Choose an option:1
Choose number of clusters (it must be a multiple of 4: 4,8,12, ... ):8
The Path is as followed: 351 ==> 287 ==> 701 ==> 599 ==> 4 ==> 412 ==> 457 ==> 548 ==> 370 ==> 748 ==> 730 ==> 121 ==> 795 ==> 249 ==> 941 ==> 73 ==> 163 ==> 231 ==> 612 ==> 894 ==> 755 ==> 459 ==> 903 ==> 99 ==> 546 ==> 727 ==>
636 ==> 670 ==> 716 ==> 329 ==> 994 ==> 204 ==> 721 ==> 107 ==> 523 ==> 759 ==> 571 ==> 847 ==> 409 ==> 773 ==> 257 ==> 440 ==> 33 ==> 130 ==> 340 ==> 172 ==> 199 ==> 173 ==> 302 ==> 47 ==> 976 ==> 456 ==> 211 ==> 540 ==> 808 ==>
 142 ==> 395 ==> 856 ==> 108 ==> 870 ==> 782 ==> 797 ==> 42 ==> 949 ==> 877 ==> 49 ==> 512 ==> 570 ==> 793 ==> 344 ==> 471 ==> 712 ==> 84 ==> 225 ==> 986 ==> 641 ==> 819 ==> 195 ==> 397 ==> 126 ==> 383 ==> 592 ==> 324 ==> 405 ==>
 541 ==> 290 ==> 760 ==> 606 ==> 304 ==> 264 ==> 185 ==> 493 ==> 694 ==> 912 ==> 417 ==> 882 ==> 777 ==> 967 ==> 539 ==> 975 ==> 653 ==> 42 ==> 393 ==> 334 ==> 489 ==> 971 ==> 347 ==> 388 ==> 988 ==> 237 ==> 814 ==> 188 ==> 365 =
=> 503 ==> 547 ==> 999 ==> 8 ==> 508 ==> 577 ==> 209 ==> 234 ==> 251 ==> 157 ==> 470 ==> 197 ==> 756 ==> 197 ==> 682 ==> 175 ==> 449 ==> 222 ==> 515 ==> 663 ==> 525 ==> 437 ==> 923 ==> 267 ==> 947 ==> 624 ==> 855 ==> 278 ==> 186
==> 979 ==> 925 ==> 318 ==> 749 ==> 736 ==> 380 ==> 964 ==> 991 ==> 170 ==> 538 ==> 770 ==> 772 ==> 14 ==> 940 ==> 998 ==> 167 ==> 68 ==> 989 ==> 333 ==> 202 ==> 608 ==> 977 ==> 884 ==> 868 ==> 240 ==> 843 ==> 44 ==> 966 ==> 11 =
=> 439 ==> 839 ==> 659 ==> 742 ==> 792 ==> 511 ==> 633 ==> 284 ==> 876 ==> 965 ==> 665 ==> 813 ==> 863 ==> 963 ==> 498 ==> 253 ==> 854 ==> 253 ==> 821 ==> 509 ==> 235 ==> 233 ==> 787 ==> 591 ==> 604 ==> 647 ==> 301 ==> 444 ==> 40
6 ==> 40 ==> 372 ==> 315 ==> 786 ==> 960 ==> 320 ==> 226 ==> 724 ==> 517 ==> 827 ==> 156 ==> 422 ==> 375 ==> 677 ==> 707 ==> 66 ==> 232 ==> 905 ==> 871 ==> 24 ==> 561 ==> 715 ==> 206 ==> 628 ==> 514 ==> 885 ==> 478 ==> 354 ==> 15
3 ==> 215 ==> 506 ==> 526 ==> 899 ==> 738 ==> 737 ==> 970 ==> 90 ==> 587 ==> 841 ==> 418 ==> 484 ==> 427 ==> 436 ==> 840 ==> 35 ==> 487 ==> 566 ==> 535 ==> 750 ==> 292 ==> 750 ==> 143 ==> 815 ==> 373 ==> 699 ==> 631 ==> 974 ==> 7
81 ==> 973 ==> 85 ==> 297 ==> 623 ==> 313 ==> 987 ==> 335 ==> 711 ==> 705 ==> 460 ==> 588 ==> 296 ==> 131 ==> 543 ==> 563 ==> 702 ==> 218 ==> 280 ==> 454 ==> 901 ==> 626 ==> 809 ==> 860 ==> 420 ==> 785 ==> 505 ==> 37 ==> 247 ==>
319 ==> 19 ==> 26 ==> 800 ==> 924 ==> 558 ==> 147 ==> 41 ==> 658 ==> 837 ==> 611 ==> 553 ==> 683 ==> 918 ==> 274 ==> 150 ==> 360 ==> 43 ==> 358 ==> 241 ==> 943 ==> 958 ==> 911 ==> 176 ==> 490 ==> 252 ==> 490 ==> 125 ==> 919 ==> 3
43 ==> 177 ==> 784 ==> 289 ==> 568 ==> 336 ==> 158 ==> 75 ==> 836 ==> 367 ==> 804 ==> 339 ==> 132 ==> 248 ==> 326 ==> 483 ==> 552 ==> 763 ==> 605 ==> 582 ==> 637 ==> 482 ==> 5 ==> 872 ==> 578 ==> 889 ==> 997 ==> 293 ==> 669 ==> 5
32 ==> 714 ==> 866 ==> 640 ==> 771 ==> 931 ==> 575 ==> 401 ==> 137 ==> 392 ==> 513 ==> 71 ==> 113 ==> 733 ==> 744 ==> 630 ==> 91 ==> 706 ==> 983 ==> 791 ==> 229 ==> 243 ==> 60 ==> 775 ==> 434 ==> 323 ==> 238 ==> 169 ==> 321 ==> 4
47 ==> 441 ==> 718 ==> 834 ==> 389 ==> 954 ==> 180 ==> 627 ==> 650 ==> 504 ==> 463 ==> 212 ==> 123 ==> 598 ==> 12 ==> 678 ==> 62 ==> 122 ==> 655 ==> 50 ==> 445 ==> 270 ==> 909 ==> 116 ==> 64 ==> 693 ==> 89 ==> 242 ==> 27 ==> 322
==> 410 ==> 668 ==> 675 ==> 978 ==> 732 ==> 31 ==> 112 ==> 120 ==> 78 ==> 271 ==> 250 ==> 61 ==> 207 ==> 497 ==> 34 ==> 379 ==> 461 ==> 312 ==> 844 ==> 520 ==> 298 ==> 615 ==> 888 ==> 674 ==> 138 ==> 845 ==> 542 ==> 816 ==> 77 ==
> 94 ==> 109 ==> 937 ==> 574 ==> 76 ==> 452 ==> 937 ==> 549 ==> 645 ==> 926 ==> 144 ==> 16 ==> 154 ==> 310 ==> 917 ==> 689 ==> 544 ==> 853 ==> 662 ==> 632 ==> 957 ==> 306 ==> 20 ==> 671 ==> 835 ==> 266 ==> 601 ==> 723 ==> 106 ==>
 221 ==> 521 ==> 161 ==> 45 ==> 764 ==> 198 ==> 629 ==> 990 ==> 494 ==> 348 ==> 151 ==> 499 ==> 160 ==> 597 ==> 93 ==> 101 ==> 325 ==> 165 ==> 391 ==> 896 ==> 135 ==> 178 ==> 651 ==> 481 ==> 359 ==> 32 ==> 565 ==> 686 ==> 881 ==>
 192 ==> 70 ==> 643 ==> 279 ==> 473 ==> 472 ==> 351

The graph has a minimum distance of: 701075 meters.
The execution time was: 0.032 seconds.
```

Funcionamento

```
=============== Other Heuristics ===============
1. Cluster Based Algorithm
2. Christofides Algorithm
3. Nearest Neighbor Algorithm
4. Return
Choose an option:2
The Path is as followed: 0 ==> 134 ==> 728 ==> 928 ==> 87 ==> 835 ==> 723 ==> 106 ==> 601 ==> 266 ==> 327 ==> 980 ==> 378 ==> 521 ==> 161 ==> 662 ==> 632 ==> 550 ==> 244 ==> 842 ==> 310 ==> 154 ==> 144 ==> 853 ==> 16 ==> 917 ==>
544 ==> 689 ==> 671 ==> 20 ==> 306 ==> 992 ==> 666 ==> 747 ==> 554 ==> 356 ==> 364 ==> 557 ==> 452 ==> 816 ==> 926 ==> 645 ==> 360 ==> 358 ==> 2 ==> 751 ==> 69 ==> 349 ==> 594 ==> 858 ==> 767 ==> 533 ==> 656 ==> 995 ==> 619 ==> 7
19 ==> 921 ==> 927 ==> 803 ==> 146 ==> 780 ==> 502 ==> 109 ==> 224 ==> 757 ==> 295 ==> 332 ==> 972 ==> 446 ==> 10 ==> 337 ==> 268 ==> 530 ==> 34 ==> 312 ==> 888 ==> 615 ==> 298 ==> 520 ==> 844 ==> 94 ==> 77 ==> 461 ==> 379 ==> 49
7 ==> 207 ==> 61 ==> 79 ==> 53 ==> 660 ==> 586 ==> 886 ==> 389 ==> 227 ==> 48 ==> 57 ==> 441 ==> 308 ==> 811 ==> 117 ==> 635 ==> 119 ==> 277 ==> 369 ==> 883 ==> 447 ==> 180 ==> 504 ==> 650 ==> 463 ==> 62 ==> 678 ==> 12 ==> 655 ==
> 122 ==> 271 ==> 78 ==> 492 ==> 201 ==> 321 ==> 895 ==> 996 ==> 536 ==> 190 ==> 184 ==> 139 ==> 250 ==> 120 ==> 598 ==> 123 ==> 212 ==> 410 ==> 322 ==> 50 ==> 909 ==> 270 ==> 89 ==> 300 ==> 291 ==> 22 ==> 516 ==> 140 ==> 46 ==>
856 ==> 395 ==> 211 ==> 456 ==> 976 ==> 163 ==> 459 ==> 755 ==> 894 ==> 612 ==> 636 ==> 670 ==> 546 ==> 302 ==> 173 ==> 716 ==> 329 ==> 721 ==> 107 ==> 523 ==> 797 ==> 33 ==> 130 ==> 440 ==> 257 ==> 773 ==> 409 ==> 393 ==> 847 ==
> 759 ==> 42 ==> 949 ==> 877 ==> 49 ==> 512 ==> 653 ==> 975 ==> 570 ==> 882 ==> 777 ==> 967 ==> 539 ==> 471 ==> 801 ==> 641 ==> 986 ==> 538 ==> 833 ==> 170 ==> 400 ==> 638 ==> 789 ==> 648 ==> 581 ==> 796 ==> 610 ==> 6 ==> 36 ==>
225 ==> 819 ==> 541 ==> 287 ==> 365 ==> 188 ==> 417 ==> 912 ==> 694 ==> 237 ==> 814 ==> 493 ==> 290 ==> 760 ==> 606 ==> 374 ==> 246 ==> 258 ==> 873 ==> 985 ==> 103 ==> 381 ==> 758 ==> 416 ==> 470 ==> 462 ==> 8 ==> 157 ==> 251 ==>
 234 ==> 209 ==> 577 ==> 508 ==> 999 ==> 547 ==> 503 ==> 862 ==> 832 ==> 128 ==> 179 ==> 63 ==> 260 ==> 880 ==> 988 ==> 388 ==> 347 ==> 971 ==> 489 ==> 334 ==> 304 ==> 264 ==> 185 ==> 126 ==> 324 ==> 405 ==> 592 ==> 383 ==> 397 =
=> 195 ==> 84 ==> 907 ==> 712 ==> 344 ==> 793 ==> 314 ==> 433 ==> 38 ==> 269 ==> 849 ==> 762 ==> 88 ==> 376 ==> 305 ==> 906 ==> 80 ==> 887 ==> 474 ==> 708 ==> 691 ==> 687 ==> 726 ==> 879 ==> 869 ==> 729 ==> 59 ==> 518 ==> 220 ==>
 684 ==> 223 ==> 569 ==> 136 ==> 644 ==> 407 ==> 104 ==> 667 ==> 551 ==> 902 ==> 923 ==> 267 ==> 525 ==> 437 ==> 826 ==> 175 ==> 197 ==> 756 ==> 682 ==> 14 ==> 940 ==> 998 ==> 989 ==> 868 ==> 240 ==> 284 ==> 965 ==> 665 ==> 963 =
=> 498 ==> 863 ==> 813 ==> 993 ==> 65 ==> 609 ==> 276 ==> 429 ==> 111 ==> 799 ==> 345 ==> 595 ==> 596 ==> 485 ==> 900 ==> 830 ==> 969 ==> 114 ==> 288 ==> 438 ==> 507 ==> 859 ==> 338 ==> 203 ==> 21 ==> 26 ==> 800 ==> 37 ==> 137 ==
> 812 ==> 13 ==> 5 ==> 482 ==> 637 ==> 578 ==> 872 ==> 582 ==> 483 ==> 326 ==> 248 ==> 132 ==> 392 ==> 339 ==> 804 ==> 367 ==> 836 ==> 158 ==> 867 ==> 775 ==> 60 ==> 434 ==> 568 ==> 336 ==> 75 ==> 552 ==> 113 ==> 91 ==> 630 ==> 7
44 ==> 791 ==> 983 ==> 706 ==> 243 ==> 229 ==> 733 ==> 71 ==> 513 ==> 763 ==> 605 ==> 889 ==> 997 ==> 228 ==> 585 ==> 614 ==> 930 ==> 640 ==> 866 ==> 771 ==> 714 ==> 532 ==> 669 ==> 293 ==> 931 ==> 575 ==> 401 ==> 19 ==> 319 ==>
387 ==> 247 ==> 951 ==> 580 ==> 785 ==> 420 ==> 860 ==> 809 ==> 901 ==> 286 ==> 743 ==> 913 ==> 613 ==> 625 ==> 828 ==> 831 ==> 17 ==> 426 ==> 584 ==> 454 ==> 280 ==> 218 ==> 583 ==> 296 ==> 588 ==> 460 ==> 705 ==> 335 ==> 973 ==
> 781 ==> 631 ==> 143 ==> 815 ==> 373 ==> 699 ==> 750 ==> 292 ==> 974 ==> 85 ==> 297 ==> 623 ==> 313 ==> 987 ==> 150 ==> 176 ==> 911 ==> 958 ==> 490 ==> 252 ==> 155 ==> 745 ==> 567 ==> 915 ==> 125 ==> 919 ==> 289 ==> 784 ==> 343
==> 177 ==> 317 ==> 97 ==> 168 ==> 448 ==> 431 ==> 861 ==> 709 ==> 875 ==> 3 ==> 752 ==> 414 ==> 174 ==> 458 ==> 25 ==> 54 ==> 198 ==> 629 ==> 165 ==> 135 ==> 698 ==> 56 ==> 942 ==> 468 ==> 556 ==> 559 ==> 294 ==> 774 ==> 686 ==>
 881 ==> 519 ==> 124 ==> 948 ==> 316 ==> 672 ==> 681 ==> 455 ==> 661 ==> 524 ==> 425 ==> 892 ==> 361 ==> 404 ==> 679 ==> 357 ==> 239 ==> 171 ==> 910 ==> 944 ==> 673 ==> 896 ==> 391 ==> 651 ==> 307 ==> 141 ==> 208 ==> 194 ==> 299
==> 423 ==> 766 ==> 451 ==> 579 ==> 753 ==> 823 ==> 890 ==> 432 ==> 634 ==> 67 ==> 217 ==> 390 ==> 649 ==> 488 ==> 562 ==> 443 ==> 802 ==> 891 ==> 183 ==> 436 ==> 950 ==> 700 ==> 607 ==> 916 ==> 829 ==> 384 ==> 534 ==> 206 ==> 71
5 ==> 905 ==> 226 ==> 315 ==> 786 ==> 960 ==> 320 ==> 724 ==> 517 ==> 156 ==> 827 ==> 840 ==> 677 ==> 422 ==> 375 ==> 707 ==> 66 ==> 232 ==> 871 ==> 24 ==> 561 ==> 368 ==> 215 ==> 427 ==> 737 ==> 587 ==> 90 ==> 970 ==> 484 ==> 41
8 ==> 841 ==> 738 ==> 899 ==> 526 ==> 628 ==> 514 ==> 885 ==> 478 ==> 354 ==> 506 ==> 153 ==> 363 ==> 105 ==> 806 ==> 722 ==> 52 ==> 285 ==> 35 ==> 487 ==> 620 ==> 810 ==> 904 ==> 735 ==> 145 ==> 18 ==> 703 ==> 413 ==> 618 ==> 28
1 ==> 256 ==> 531 ==> 545 ==> 15 ==> 464 ==> 690 ==> 555 ==> 805 ==> 255 ==> 560 ==> 982 ==> 817 ==> 386 ==> 403 ==> 309 ==> 566 ==> 535 ==> 371 ==> 74 ==> 717 ==> 794 ==> 355 ==> 467 ==> 475 ==> 945 ==> 783 ==> 778 ==> 602 ==> 4
19 ==> 537 ==> 28 ==> 30 ==> 820 ==> 169 ==> 238 ==> 82 ==> 442 ==> 29 ==> 981 ==> 421 ==> 643 ==> 70 ==> 279 ==> 473 ==> 472 ==> 818 ==> 323 ==> 192 ==> 754 ==> 565 ==> 593 ==> 710 ==> 213 ==> 622 ==> 178 ==> 45 ==> 481 ==> 32 =
=> 359 ==> 764 ==> 499 ==> 151 ==> 348 ==> 597 ==> 325 ==> 101 ==> 93 ==> 160 ==> 494 ==> 990 ==> 935 ==> 769 ==> 159 ==> 646 ==> 984 ==> 845 ==> 542 ==> 138 ==> 549 ==> 937 ==> 574 ==> 76 ==> 674 ==> 696 ==> 957 ==> 477 ==> 283
==> 245 ==> 956 ==> 746 ==> 352 ==> 491 ==> 822 ==> 720 ==> 254 ==> 522 ==> 697 ==> 262 ==> 191 ==> 922 ==> 330 ==> 346 ==> 58 ==> 465 ==> 788 ==> 590 ==> 39 ==> 600 ==> 9 ==> 230 ==> 933 ==> 350 ==> 95 ==> 495 ==> 303 ==> 149 ==
> 685 ==> 897 ==> 652 ==> 852 ==> 962 ==> 576 ==> 838 ==> 874 ==> 768 ==> 761 ==> 394 ==> 399 ==> 798 ==> 851 ==> 953 ==> 263 ==> 621 ==> 564 ==> 932 ==> 865 ==> 807 ==> 466 ==> 182 ==> 680 ==> 366 ==> 382 ==> 688 ==> 210 ==> 776
 ==> 148 ==> 704 ==> 118 ==> 166 ==> 938 ==> 272 ==> 362 ==> 92 ==> 411 ==> 654 ==> 152 ==> 7 ==> 98 ==> 221 ==> 878 ==> 496 ==> 0

The graph has a minimum distance of: 1.1151ó6e+06 meters.
The execution time was: 0.123 seconds.
```

Funcionamento

```
Choose an option:3
The Path is as followed: 0 ==> 496 ==> 878 ==> 221 ==> 98 ==> 134 ==> 7 ==> 152 ==> 728 ==> 654 ==> 411 ==> 327 ==> 266 ==> 835 ==> 601 ==> 723 ==> 106 ==> 980 ==> 92 ==> 362 ==> 632 ==> 957 ==> 306 ==> 20 ==> 671 ==> 696 ==> 557
 ==> 992 ==> 554 ==> 356 ==> 364 ==> 666 ==> 747 ==> 842 ==> 550 ==> 244 ==> 87 ==> 928 ==> 272 ==> 254 ==> 746 ==> 477 ==> 720 ==> 822 ==> 491 ==> 352 ==> 283 ==> 956 ==> 245 ==> 697 ==> 522 ==> 938 ==> 346 ==> 330 ==> 922 ==> 1
91 ==> 262 ==> 58 ==> 263 ==> 382 ==> 366 ==> 932 ==> 564 ==> 621 ==> 680 ==> 466 ==> 807 ==> 865 ==> 851 ==> 953 ==> 688 ==> 210 ==> 118 ==> 590 ==> 788 ==> 465 ==> 704 ==> 776 ==> 148 ==> 166 ==> 149 ==> 798 ==> 600 ==> 303 ==>
 495 ==> 95 ==> 39 ==> 350 ==> 9 ==> 933 ==> 230 ==> 182 ==> 662 ==> 161 ==> 310 ==> 154 ==> 16 ==> 144 ==> 917 ==> 689 ==> 544 ==> 853 ==> 937 ==> 816 ==> 138 ==> 984 ==> 845 ==> 542 ==> 549 ==> 574 ==> 76 ==> 452 ==> 674 ==> 84
4 ==> 461 ==> 312 ==> 379 ==> 497 ==> 34 ==> 207 ==> 61 ==> 79 ==> 530 ==> 53 ==> 660 ==> 972 ==> 332 ==> 533 ==> 767 ==> 295 ==> 757 ==> 803 ==> 927 ==> 719 ==> 921 ==> 848 ==> 110 ==> 196 ==> 639 ==> 857 ==> 23 ==> 377 ==> 236
==> 858 ==> 594 ==> 69 ==> 751 ==> 586 ==> 268 ==> 337 ==> 10 ==> 446 ==> 619 ==> 995 ==> 656 ==> 502 ==> 780 ==> 146 ==> 224 ==> 109 ==> 908 ==> 943 ==> 2 ==> 958 ==> 911 ==> 176 ==> 150 ==> 360 ==> 43 ==> 358 ==> 987 ==> 335 ==
> 711 ==> 705 ==> 460 ==> 588 ==> 297 ==> 623 ==> 313 ==> 85 ==> 974 ==> 781 ==> 973 ==> 699 ==> 631 ==> 373 ==> 815 ==> 143 ==> 750 ==> 292 ==> 241 ==> 296 ==> 131 ==> 543 ==> 563 ==> 702 ==> 218 ==> 280 ==> 454 ==> 901 ==> 626
==> 809 ==> 860 ==> 420 ==> 785 ==> 505 ==> 951 ==> 21 ==> 247 ==> 37 ==> 800 ==> 26 ==> 401 ==> 19 ==> 319 ==> 387 ==> 137 ==> 812 ==> 13 ==> 203 ==> 338 ==> 859 ==> 100 ==> 507 ==> 438 ==> 114 ==> 282 ==> 102 ==> 115 ==> 453 ==
> 408 ==> 415 ==> 398 ==> 946 ==> 193 ==> 311 ==> 914 ==> 331 ==> 955 ==> 510 ==> 55 ==> 893 ==> 450 ==> 585 ==> 614 ==> 930 ==> 640 ==> 866 ==> 714 ==> 532 ==> 669 ==> 293 ==> 997 ==> 889 ==> 605 ==> 582 ==> 637 ==> 482 ==> 5 ==
> 552 ==> 763 ==> 75 ==> 836 ==> 367 ==> 804 ==> 339 ==> 132 ==> 248 ==> 326 ==> 483 ==> 568 ==> 336 ==> 158 ==> 513 ==> 71 ==> 113 ==> 733 ==> 744 ==> 630 ==> 91 ==> 706 ==> 983 ==> 791 ==> 229 ==> 243 ==> 289 ==> 784 ==> 343 ==
> 919 ==> 125 ==> 252 ==> 490 ==> 915 ==> 567 ==> 745 ==> 155 ==> 177 ==> 317 ==> 646 ==> 159 ==> 168 ==> 97 ==> 769 ==> 448 ==> 25 ==> 458 ==> 174 ==> 752 ==> 431 ==> 414 ==> 3 ==> 875 ==> 709 ==> 861 ==> 54 ==> 935 ==> 990 ==>
764 ==> 198 ==> 629 ==> 45 ==> 165 ==> 391 ==> 896 ==> 135 ==> 494 ==> 348 ==> 151 ==> 499 ==> 160 ==> 597 ==> 93 ==> 101 ==> 325 ==> 32 ==> 359 ==> 651 ==> 178 ==> 622 ==> 307 ==> 213 ==> 766 ==> 423 ==> 299 ==> 194 ==> 208 ==>
141 ==> 593 ==> 565 ==> 754 ==> 323 ==> 451 ==> 818 ==> 29 ==> 472 ==> 473 ==> 279 ==> 421 ==> 981 ==> 70 ==> 643 ==> 82 ==> 442 ==> 820 ==> 579 ==> 30 ==> 67 ==> 432 ==> 634 ==> 890 ==> 753 ==> 823 ==> 618 ==> 413 ==> 703 ==> 53
1 ==> 545 ==> 555 ==> 145 ==> 735 ==> 904 ==> 464 ==> 15 ==> 18 ==> 805 ==> 255 ==> 620 ==> 403 ==> 309 ==> 566 ==> 487 ==> 35 ==> 535 ==> 371 ==> 74 ==> 717 ==> 794 ==> 355 ==> 467 ==> 475 ==> 783 ==> 945 ==> 419 ==> 602 ==> 778
 ==> 537 ==> 390 ==> 488 ==> 105 ==> 806 ==> 722 ==> 52 ==> 285 ==> 690 ==> 810 ==> 386 ==> 817 ==> 982 ==> 560 ==> 281 ==> 256 ==> 649 ==> 829 ==> 384 ==> 534 ==> 916 ==> 443 ==> 183 ==> 950 ==> 700 ==> 607 ==> 561 ==> 368 ==> 2
15 ==> 153 ==> 354 ==> 478 ==> 885 ==> 514 ==> 628 ==> 427 ==> 871 ==> 24 ==> 206 ==> 715 ==> 232 ==> 905 ==> 436 ==> 802 ==> 891 ==> 363 ==> 562 ==> 506 ==> 526 ==> 899 ==> 738 ==> 737 ==> 970 ==> 90 ==> 587 ==> 841 ==> 418 ==>
484 ==> 422 ==> 375 ==> 677 ==> 707 ==> 66 ==> 840 ==> 827 ==> 517 ==> 156 ==> 724 ==> 320 ==> 226 ==> 960 ==> 786 ==> 315 ==> 28 ==> 217 ==> 238 ==> 169 ==> 192 ==> 944 ==> 673 ==> 698 ==> 556 ==> 468 ==> 559 ==> 294 ==> 942 ==>
 774 ==> 524 ==> 892 ==> 361 ==> 404 ==> 948 ==> 124 ==> 519 ==> 881 ==> 686 ==> 171 ==> 357 ==> 679 ==> 910 ==> 239 ==> 661 ==> 455 ==> 672 ==> 681 ==> 316 ==> 56 ==> 425 ==> 481 ==> 77 ==> 94 ==> 516 ==> 46 ==> 291 ==> 529 ==>
216 ==> 300 ==> 501 ==> 22 ==> 572 ==> 693 ==> 89 ==> 64 ==> 116 ==> 445 ==> 50 ==> 270 ==> 909 ==> 242 ==> 27 ==> 322 ==> 410 ==> 668 ==> 675 ==> 627 ==> 650 ==> 504 ==> 463 ==> 954 ==> 180 ==> 598 ==> 12 ==> 678 ==> 62 ==> 122
==> 655 ==> 123 ==> 212 ==> 978 ==> 732 ==> 31 ==> 936 ==> 939 ==> 112 ==> 140 ==> 139 ==> 250 ==> 120 ==> 78 ==> 271 ==> 277 ==> 447 ==> 883 ==> 369 ==> 929 ==> 57 ==> 441 ==> 718 ==> 834 ==> 389 ==> 886 ==> 48 ==> 227 ==> 308 =
=> 435 ==> 864 ==> 259 ==> 898 ==> 117 ==> 811 ==> 119 ==> 635 ==> 664 ==> 349 ==> 918 ==> 274 ==> 924 ==> 558 ==> 147 ==> 392 ==> 931 ==> 575 ==> 228 ==> 771 ==> 872 ==> 578 ==> 60 ==> 775 ==> 867 ==> 434 ==> 658 ==> 837 ==> 611
 ==> 553 ==> 683 ==> 41 ==> 580 ==> 17 ==> 426 ==> 625 ==> 913 ==> 743 ==> 286 ==> 613 ==> 584 ==> 831 ==> 583 ==> 288 ==> 969 ==> 589 ==> 528 ==> 527 ==> 240 ==> 843 ==> 44 ==> 966 ==> 11 ==> 439 ==> 839 ==> 659 ==> 742 ==> 792
==> 511 ==> 633 ==> 284 ==> 876 ==> 965 ==> 665 ==> 429 ==> 813 ==> 863 ==> 963 ==> 498 ==> 65 ==> 609 ==> 276 ==> 993 ==> 111 ==> 799 ==> 345 ==> 341 ==> 595 ==> 900 ==> 830 ==> 485 ==> 596 ==> 868 ==> 989 ==> 333 ==> 68 ==> 998
 ==> 167 ==> 940 ==> 14 ==> 181 ==> 301 ==> 647 ==> 604 ==> 591 ==> 444 ==> 202 ==> 608 ==> 977 ==> 884 ==> 253 ==> 854 ==> 821 ==> 509 ==> 235 ==> 233 ==> 787 ==> 406 ==> 40 ==> 372 ==> 828 ==> 926 ==> 645 ==> 520 ==> 298 ==> 61
5 ==> 888 ==> 521 ==> 378 ==> 710 ==> 685 ==> 897 ==> 399 ==> 394 ==> 652 ==> 761 ==> 768 ==> 874 ==> 838 ==> 576 ==> 962 ==> 852 ==> 184 ==> 190 ==> 536 ==> 492 ==> 321 ==> 201 ==> 996 ==> 895 ==> 397 ==> 126 ==> 383 ==> 195 ==>
 819 ==> 185 ==> 264 ==> 304 ==> 606 ==> 760 ==> 290 ==> 541 ==> 493 ==> 694 ==> 912 ==> 417 ==> 882 ==> 777 ==> 967 ==> 539 ==> 471 ==> 344 ==> 712 ==> 907 ==> 84 ==> 225 ==> 986 ==> 641 ==> 801 ==> 36 ==> 6 ==> 610 ==> 796 ==>
400 ==> 833 ==> 538 ==> 682 ==> 175 ==> 449 ==> 222 ==> 515 ==> 663 ==> 525 ==> 437 ==> 902 ==> 923 ==> 267 ==> 551 ==> 947 ==> 624 ==> 855 ==> 278 ==> 186 ==> 979 ==> 925 ==> 318 ==> 749 ==> 736 ==> 380 ==> 964 ==> 991 ==> 476 =
=> 214 ==> 219 ==> 424 ==> 616 ==> 402 ==> 725 ==> 740 ==> 642 ==> 734 ==> 824 ==> 96 ==> 617 ==> 104 ==> 667 ==> 846 ==> 657 ==> 407 ==> 644 ==> 187 ==> 731 ==> 765 ==> 80 ==> 887 ==> 474 ==> 906 ==> 88 ==> 762 ==> 849 ==> 342 =
=> 385 ==> 961 ==> 952 ==> 433 ==> 273 ==> 83 ==> 38 ==> 269 ==> 376 ==> 305 ==> 708 ==> 687 ==> 879 ==> 869 ==> 480 ==> 691 ==> 726 ==> 695 ==> 428 ==> 573 ==> 518 ==> 850 ==> 200 ==> 603 ==> 692 ==> 825 ==> 790 ==> 205 ==> 486
==> 676 ==> 741 ==> 133 ==> 164 ==> 136 ==> 569 ==> 223 ==> 684 ==> 220 ==> 729 ==> 59 ==> 479 ==> 86 ==> 162 ==> 755 ==> 459 ==> 894 ==> 612 ==> 163 ==> 231 ==> 73 ==> 976 ==> 340 ==> 172 ==> 199 ==> 716 ==> 329 ==> 994 ==> 204
==> 721 ==> 107 ==> 523 ==> 759 ==> 571 ==> 42 ==> 847 ==> 409 ==> 773 ==> 257 ==> 440 ==> 33 ==> 130 ==> 99 ==> 546 ==> 727 ==> 636 ==> 670 ==> 903 ==> 47 ==> 173 ==> 302 ==> 653 ==> 975 ==> 570 ==> 512 ==> 49 ==> 793 ==> 314 ==
> 877 ==> 949 ==> 797 ==> 782 ==> 870 ==> 108 ==> 856 ==> 395 ==> 211 ==> 540 ==> 808 ==> 142 ==> 456 ==> 730 ==> 748 ==> 370 ==> 548 ==> 457 ==> 412 ==> 4 ==> 795 ==> 121 ==> 249 ==> 941 ==> 701 ==> 599 ==> 500 ==> 934 ==> 353 =
=> 72 ==> 275 ==> 396 ==> 430 ==> 129 ==> 469 ==> 127 ==> 920 ==> 261 ==> 51 ==> 1 ==> 189 ==> 328 ==> 779 ==> 713 ==> 81 ==> 393 ==> 592 ==> 324 ==> 405 ==> 814 ==> 237 ==> 188 ==> 365 ==> 334 ==> 489 ==> 971 ==> 347 ==> 388 ==>
 988 ==> 880 ==> 260 ==> 374 ==> 258 ==> 246 ==> 873 ==> 985 ==> 103 ==> 381 ==> 758 ==> 179 ==> 63 ==> 581 ==> 638 ==> 170 ==> 648 ==> 789 ==> 832 ==> 128 ==> 862 ==> 503 ==> 547 ==> 999 ==> 8 ==> 508 ==> 577 ==> 209 ==> 234 ==>
 251 ==> 157 ==> 470 ==> 416 ==> 462 ==> 287 ==> 351 ==> 265 ==> 739 ==> 968 ==> 959 ==> 756 ==> 197 ==> 826 ==> 770 ==> 0

The graph has a minimum distance of: 1.00488e+06 meters.
The execution time was: 0.25 seconds.
```

Dificuldades Encontradas

- Doxyfile;
- Gestão do tempo;
- Esforço de cada elemento;

Bibliografia

- https://es.linkedin.com/pulse/aprendizaje-profundo-sobre-grafos-julio-bonis-sanz
- https://sigarra.up.pt/feup/pt/web_base.gera_pagina?p_pagina=*variantes%20do%20log%c3%b3tipo
- https://itforum.com.br/noticias/faca-a-teoria-dos-grafos-trabalhar-para-sua-empresa/