

Heuristic

The globe has 3 rings and every ring has 12 tiles

Every 2 rings have 2 tiles in common

3 Axis are:

Longitude0/180

Longitude90/270

Equator

Common tiles:

[Longitude0/180, Longitude90/270] \rightarrow (0,0), (180,180)

[Longitude0/180, Equator] \rightarrow (90,0), (90,180)

[Equator, Longitude90/270] \rightarrow (90,90), (90,270)

The heuristic is calculated keeping in mind following 9 conditions

- If current tile position is in Longitude0/180 and goal tile position is in Longitude0/180
 - Number of moves is calculated to reach from current tile position to goal tile position
- If current tile position is in Longitude0/180 and goal tile position is in Longitude90/270
 - Number of moves is calculated to reach the common tile (0,0) or (180,180) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Longitude0/180 and goal tile position is in Equator
 - Number of moves is calculated to reach the common tile (90,0) or (90,180) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Longitude90/270 and goal tile position is in Longitude0/180
 - Number of moves is calculated to reach the common tile (0,0) or (180,180) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Longitude90/270 and goal tile position is in Longitude90/270
 - Number of moves is calculated to reach from current tile position to goal tile position
- If current tile position is in Longitude90/270 and goal tile position is in Equator
 - Number of moves is calculated to reach the common tile (90,90) or (90,270) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Equator and goal tile position is in Longitude0/180
 - Number of moves is calculated to reach the common tile (90,0) or (90,180) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Equator and goal tile position is in Longitude90/270
 - Number of moves is calculated to reach the common tile (90,90) or (90,270) and after that, number of moves is calculated from common tile to goal position
- If current tile position is in Equator and goal tile position is in Equator
 - Number of moves is calculated to reach from current tile position to goal tile position

Note:

Here in each condition minimum path is taken into consideration

There can be multiple paths because we can reach to goal tile position by increasing axis and decreasing axis also.

Also, the moves are taken in consideration that tiles in the other axis which does not have current tile or goal tile is does not affected.

Also, there are 2 common tiles when current tile position and goal tile position are in different axis. So, we can reach to goal tile position from any of the 2 common tiles. Minimum of both paths is taken in consideration.

Justification:

The above-mentioned heuristic work for the algorithm because:

- First it takes the total cost for all tiles to reach their goal position.
- The heuristic does not guarantee that the node it chooses to expand is correct one but this heuristic helps the algorithm not to choose other worst states.
- While solving the globe we are concerned that each tile should be in right position and so does the heuristic calculate cost.
- It chooses the best possible path to reach from source to destination and compute cost of that path for each tile.
- From this we can get to know how much moves each tile are at every state, so every time ASTAR or RBFS choose that in which maximum tiles are near to their goal state position.
- Here we can argue that while moving one tile to their goal position can make the cost of other tiles to reach their goal much high, but it does not affect the algorithm because even if it does, it will get to know at next few levels. So, it will again expand child of the node from which it made worst move.
- Basically, if heuristic fails at some level, algorithm behaves as BFS and best node cannot remain unexplored.
- So, this simple heuristic works well as it reduces the number of states to be explored before reaching goal.

$$h(n) \leq h(n') + c(n, a, n')$$

here $c(n, a, n') = 1$ taking n' as immediate next child of n

$$h(n) \leq h(n') + 1$$

For the heuristic defined above the maximum cost can be

Maximum number of moves required for one tile to reach the goal position is 6 considering every tile is in different axis from its goal position.

There are total 30 tiles.

So total cost is $30 \times 6 = 180$

So maximum heuristic cost is $180/8$ (Constant divided at the end) = 22.5

After rotating one axis maximum half tiles move near to the goal.

As we have considered maximum cost for each tile, it cannot be exceeded for other half tiles.

So approximated cost should be 18×6 (Other ring tiles) + 6×6 (tiles which moved away from goal) + 6×5 (tiles which move one step near to the goal) = 174

$h(n') = 174/8 = 21.75$

Therefore $h(n) \leq h(n') + 1$

The above explanation is based on the assumption for simplicity, The heuristic function mentioned above cannot be written as a function of state so estimated worst case is taken for explanation.

The code is run on local machine and not VCL image.

Configuration of machine: 16 GB ram, 2.3 GHz Intel Core i9

Results for BFS

File: Puzzle2-0

Algorithm stopped at 8 level in time 1800.01723426677563seconds

Number of states expanded:209152

Maximum length of queue:796384

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> equa_inc -> long90_270_inc -> long90_270_inc -> equa_dec -> long0_180_inc -> long90_270_dec

File: Puzzle2-1

Algorithm stopped at 7 level in time 1800.0164522455522seconds

Number of states expanded:38923

Maximum length of queue:149881

Length of the path:7

Steps to goal:

start -> equa_dec -> long0_180_dec -> equa_dec -> long90_270_inc -> long0_180_inc -> long90_270_dec -> long0_180_inc

File: Puzzle2-2

Algorithm stopped at 8 level in time 1800.0167229175568seconds

Number of states expanded:261194

Maximum length of queue:994278

Length of the path:8

Steps to goal:

start -> equa_inc -> long90_270_inc -> equa_inc -> long90_270_dec -> equa_dec ->
long0_180_dec -> equa_dec -> equa_dec

File: Puzzle2-3

Algorithm stopped at 7 level in time 1800.0149225688440seconds

Number of states expanded:124741

Maximum length of queue:475982

Length of the path:7

Steps to goal:

start -> long0_180_inc -> long90_270_dec -> long90_270_dec -> equa_inc -> long0_180_inc ->
long0_180_inc -> long0_180_inc

File: Puzzle2-4

Algorithm stopped at 8 level in time 1800.0129424386633seconds

Number of states expanded:178701

Maximum length of queue:681353

Length of the path:8

Steps to goal:

start -> equa_dec -> long90_270_inc -> long90_270_inc -> long0_180_dec -> long90_270_dec -
> equa_dec -> long0_180_dec -> equa_inc

File: Puzzle2-5

Algorithm stopped at 8 level in time 1800.0172342765962seconds

Number of states expanded:219772

Maximum length of queue:836416

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> long0_180_inc -> long90_270_dec -> long0_180_inc ->
long0_180_inc -> long90_270_dec -> long90_270_dec

File: Puzzle2-6

Algorithm stopped at 8 level in time 1800.0172469139426seconds

Number of states expanded:219853

Maximum length of queue:836725

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> long0_180_inc -> long90_270_inc -> equa_dec ->
long90_270_inc -> long90_270_inc -> long0_180_inc

File: Puzzle2-7

Algorithm stopped at 8 level in time 1800.0146923585346seconds

Number of states expanded:221069

Maximum length of queue:841233

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> long0_180_inc -> long0_180_inc -> long90_270_inc ->
long0_180_inc -> equa_inc -> long90_270_inc

File: Puzzle2-8

Reached goal in 28.72718381881714seconds

Number of states expanded:41761

Maximum length of queue:160753

Length of the path:7

Steps to goal:

start -> equa_dec -> long0_180_dec -> long0_180_dec -> long90_270_dec -> long0_180_inc ->
long90_270_inc -> long0_180_inc -> goal

File: Puzzle2-9

Algorithm stopped at 8 level in time 1800.0185317587894seconds

Number of states expanded:221916

Maximum length of queue:844628

Length of the path:8

Steps to goal:

start -> equa_inc -> equa_inc -> equa_inc -> equa_inc -> long0_180_inc -> long90_270_inc ->
long0_180_dec -> long0_180_dec

File: Puzzle2-10

Algorithm stopped at 8 level in time 1800.0188572359906seconds

Number of states expanded:149679

Maximum length of queue:571139

Length of the path:8

Steps to goal:

start -> equa_dec -> equa_dec -> long0_180_inc -> long90_270_dec -> long90_270_dec ->
equa_dec -> long90_270_dec -> equa_inc

File: Puzzle2-11

Reached goal in 11.754987001419067seconds

Number of states expanded:28331

Maximum length of queue:109246

Length of the path:7

Steps to goal:

start -> equa_dec -> equa_dec -> long90_270_dec -> equa_dec -> long90_270_inc ->
long0_180_dec -> long90_270_inc -> goal

File: Puzzle2-12

Reached goal in 212.09317898750305seconds

Number of states expanded:106666

Maximum length of queue:407831

Length of the path:7

Steps to goal:

start -> long0_180_dec -> long90_270_dec -> equa_inc -> equa_inc -> long0_180_inc ->
equa_dec -> long90_270_dec -> goal

File: Puzzle2-13

Algorithm stopped at 8 level in time 1800.0189633674793seconds

Number of states expanded:188442

Maximum length of queue:718364

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_dec -> equa_dec -> long90_270_inc -> long90_270_inc ->
equa_dec -> long90_270_inc -> long0_180_dec

File: Puzzle2-14

Algorithm stopped at 8 level in time 1800.0194550797597seconds

Number of states expanded:217975

Maximum length of queue:829537

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> long0_180_inc -> equa_dec -> long90_270_inc ->
equa_dec -> equa_dec -> long0_180_inc

File: Puzzle2-15

Algorithm stopped at 8 level in time 1800.0180530548096seconds

Number of states expanded:267546

Maximum length of queue:1018298

Length of the path:8

Steps to goal:

start -> equa_inc -> long90_270_inc -> long0_180_dec -> equa_dec -> equa_dec ->
long90_270_dec -> equa_dec -> long0_180_dec

File: Puzzle2-16

Algorithm stopped at 8 level in time 1800.015722453664892seconds

Number of states expanded:241335

Maximum length of queue:918953

Length of the path:8

Steps to goal:

start -> equa_inc -> long90_270_dec -> equa_dec -> long90_270_inc -> long0_180_inc ->
equa_dec -> long90_270_dec -> equa_inc

File: Puzzle2-17

Algorithm stopped at 8 level in time 1800.0165740004511seconds

Number of states expanded:205787

Maximum length of queue:783795

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> equa_dec -> long90_270_inc -> long90_270_inc ->
long0_180_inc -> equa_inc -> long90_270_inc

File: Puzzle2-18

Algorithm stopped at 8 level in time 1800.0191264400102seconds

Number of states expanded:220555

Maximum length of queue:839359

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> long0_180_inc -> long0_180_inc -> equa_dec ->
long90_270_inc -> equa_dec -> long0_180_inc

File: Puzzle2-19

Algorithm stopped at 8 level in time 1800.0188694318269seconds

Number of states expanded:204464

Maximum length of queue:778788

Length of the path:8

Steps to goal:

start -> equa_dec -> long0_180_inc -> equa_dec -> equa_dec -> long0_180_dec -> equa_dec ->
long90_270_inc -> equa_dec

Minimum Number of states expanded = 28331 for Puzzle2-11

Maximum Number of states expanded = 106666 for Puzzle2-12

Average Number of states expanded = 58919.33

Minimum queue size = 109246 for Puzzle2-11

Maximum queue size = 407831 for Puzzle2-12

Average queue size = 225943.33

Hardest puzzle is puzzle2-12:

- Algorithm expands maximum number of states among all puzzles
- Maximum queue length during execution is also maximum this puzzle

- The time it takes high which is true because more computation is done

Due to above reasons Puzzle2-12 is the hardest puzzle for BFS algorithm

Not all puzzle ran till the goal is reached as it was taking very long time. The results are only based on those puzzles which reached goal.

Results for ASTAR

File: Puzzle2-0

Reached goal in 153.6475269794464seconds

Number of states expanded:219077

Maximum length of queue:760413

Length of the path:13

Steps to goal:

start -> long90_270_dec -> equa_inc -> long0_180_dec -> equa_dec -> equa_dec ->
long0_180_inc -> long90_270_inc -> long0_180_inc -> long90_270_inc -> long0_180_inc ->
long90_270_inc -> equa_inc -> long0_180_inc -> goal

File: Puzzle2-1

Reached goal in 1475.9863560199738seconds

Number of states expanded:141296

Maximum length of queue:555696

Length of the path:14

Steps to goal:

start -> long0_180_inc -> long0_180_inc -> long90_270_inc -> long0_180_dec ->
long90_270_inc -> equa_inc -> long0_180_inc -> equa_inc -> long0_180_inc -> long0_180_inc ->
> equa_inc -> long90_270_dec -> equa_inc -> long90_270_dec -> goal

File: Puzzle2-2

Reached goal in 0.017606019973754883seconds

Number of states expanded:29

Maximum length of queue:111

Length of the path:9

Steps to goal:

start -> long90_270_dec -> long90_270_dec -> equa_inc -> equa_inc -> equa_inc ->
long90_270_dec -> equa_inc -> long90_270_inc -> long0_180_dec -> goal

File: Puzzle2-3

Reached goal in 0.23533010482788086seconds

Number of states expanded:400

Maximum length of queue:1348

Length of the path:8

Steps to goal:

start -> equa_inc -> long0_180_inc -> long90_270_dec -> equa_dec -> long90_270_inc ->
long90_270_inc -> equa_dec -> long0_180_inc -> goal

File: Puzzle2-4

Reached goal in 2.560335874557495seconds

Number of states expanded:4088

Maximum length of queue:13422

Length of the path:11

Steps to goal:

start -> long0_180_inc -> long0_180_inc -> long90_270_inc -> long0_180_dec -> equa_inc ->
long90_270_dec -> equa_inc -> long90_270_inc -> equa_inc -> long0_180_dec ->
long0_180_dec -> goal

File: Puzzle2-5

Reached goal in 3.02296781539917seconds

Number of states expanded:4588

Maximum length of queue:17050

Length of the path:12

Steps to goal:

start -> long90_270_dec -> long90_270_dec -> equa_dec -> long90_270_inc -> equa_dec ->
equa_dec -> long0_180_inc -> long0_180_inc -> equa_inc -> long0_180_inc -> long0_180_inc ->
long0_180_inc -> goal

File: Puzzle2-6

Reached goal in 3.9793028831481934seconds

Number of states expanded:4597

Maximum length of queue:22039

Length of the path:16

Steps to goal:

start -> long90_270_inc -> equa_inc -> equa_inc -> long90_270_dec -> long90_270_dec ->
long90_270_dec -> long90_270_dec -> equa_inc -> equa_inc -> long0_180_inc -> equa_inc ->
long0_180_inc -> long90_270_dec -> equa_dec -> long90_270_dec -> long90_270_dec -> goal

File: Puzzle2-7

Reached goal in 17.00345015525818seconds

Number of states expanded:23370

Maximum length of queue:92420

Length of the path:16

Steps to goal:

start -> long0_180_inc -> equa_dec -> long0_180_inc -> long90_270_dec -> equa_inc ->
long0_180_inc -> long90_270_dec -> long0_180_inc -> long0_180_inc -> long0_180_inc ->
long0_180_inc -> long90_270_inc -> equa_inc -> long0_180_inc -> equa_dec -> long0_180_inc ->
> goal

File: Puzzle2-8

Reached goal in 0.24154901504516602seconds

Number of states expanded:490

Maximum length of queue:1456

Length of the path:7

Steps to goal:

start -> equa_dec -> long0_180_dec -> long0_180_dec -> long90_270_dec -> long0_180_inc -> long90_270_inc -> long0_180_inc -> goal

File: Puzzle2-9

Reached goal in 0.20784425735473633seconds

Number of states expanded:391

Maximum length of queue:1621

Length of the path:10

Steps to goal:

start -> long0_180_inc -> long90_270_inc -> long90_270_inc -> equa_inc -> long0_180_inc -> equa_dec -> equa_dec -> long90_270_inc -> long0_180_inc -> long0_180_inc -> goal

File: Puzzle2-10

Reached goal in 1730.614576101303seconds

Number of states expanded:453179

Maximum length of queue:1551141

Length of the path:16

Steps to goal:

start -> equa_inc -> long0_180_inc -> equa_inc -> long0_180_dec -> long90_270_dec -> long0_180_inc -> long0_180_inc -> long90_270_dec -> long90_270_dec -> long0_180_inc -> long90_270_inc -> equa_inc -> long90_270_inc -> long90_270_inc -> long0_180_inc -> equa_dec -> goal

File: Puzzle2-11

Reached goal in 0.04468989372253418seconds

Number of states expanded:93

Maximum length of queue:341

Length of the path:7

Steps to goal:

start -> equa_dec -> equa_dec -> long90_270_dec -> equa_dec -> long90_270_inc -> long0_180_dec -> long90_270_inc -> goal

File: Puzzle2-12

Reached goal in 0.09962320327758789seconds

Number of states expanded:175

Maximum length of queue:595

Length of the path:7

Steps to goal:

start -> long0_180_dec -> long90_270_dec -> equa_inc -> equa_inc -> long0_180_inc ->
equa_dec -> long90_270_dec -> goal

File: Puzzle2-13

Reached goal in 19.755154371261597seconds

Number of states expanded:38796

Maximum length of queue:115754

Length of the path:13

Steps to goal:

start -> long0_180_dec -> equa_dec -> long90_270_dec -> long0_180_dec -> equa_inc ->
equa_inc -> long0_180_inc -> long90_270_inc -> equa_dec -> equa_dec -> long0_180_inc ->
long90_270_inc -> long0_180_dec -> goal

File: Puzzle2-14

Reached goal in 1.5578548908233643seconds

Number of states expanded:2365

Maximum length of queue:9529

Length of the path:12

Steps to goal:

start -> long90_270_dec -> long0_180_inc -> long0_180_inc -> equa_dec -> long0_180_inc ->
long0_180_inc -> long90_270_dec -> long90_270_dec -> equa_dec -> long0_180_dec ->
long0_180_dec -> long90_270_dec -> goal

File: Puzzle2-15

Reached goal in 7.557093143463135seconds

Number of states expanded:15469

Maximum length of queue:45061

Length of the path:10

Steps to goal:

start -> long0_180_inc -> equa_dec -> long0_180_dec -> long0_180_dec -> long90_270_inc ->
equa_inc -> long90_270_dec -> long0_180_inc -> equa_dec -> long90_270_dec -> goal

File: Puzzle2-16

Reached goal in 0.22725510597229004seconds

Number of states expanded:362

Maximum length of queue:1602

Length of the path:8

Steps to goal:

start -> long0_180_inc -> long90_270_dec -> equa_inc -> long0_180_dec -> long0_180_dec ->
equa_inc -> long0_180_dec -> long90_270_inc -> goal

File: Puzzle2-17

Reached goal in 582.9676229953766seconds

Number of states expanded:526822

Maximum length of queue:1746160

Length of the path:15

Steps to goal:

start -> equa_inc -> equa_inc -> long0_180_dec -> long90_270_inc -> equa_inc ->
long90_270_dec -> long0_180_dec -> long90_270_dec -> equa_dec -> equa_dec ->
long0_180_inc -> long0_180_inc -> long0_180_inc -> long90_270_inc -> equa_inc -> goal

File: Puzzle2-18

Reached goal in 4.504258155822754seconds

Number of states expanded:8257

Maximum length of queue:27895

Length of the path:12

Steps to goal:

start -> equa_inc -> long90_270_inc -> equa_inc -> equa_inc -> equa_inc -> long90_270_dec ->
long90_270_dec -> long0_180_inc -> equa_dec -> long90_270_inc -> long90_270_inc ->
long0_180_dec -> goal

File: Puzzle2-19

Reached goal in 502.36737990379333seconds

Number of states expanded:94430

Maximum length of queue:282714

Length of the path:13

Steps to goal:

start -> equa_inc -> long0_180_dec -> long90_270_dec -> long0_180_inc -> equa_dec ->
long90_270_inc -> equa_dec -> long0_180_inc -> long0_180_inc -> long90_270_inc -> equa_inc
-> long90_270_dec -> equa_inc -> goal

Minimum Number of states expanded = 29 for Puzzle2-2

Maximum Number of states expanded = 526822 for Puzzle2-17

Average Number of states expanded = 76913.7

Minimum queue size = 111 for Puzzle2-2

Maximum queue size = 1746160 for Puzzle2-17

Average queue size = 262318.4

Hardest puzzle is puzzle2-17:

- Algorithm expands maximum number of states among all puzzles
- Maximum queue length during execution is also maximum this puzzle
- The time it takes high which is true because more computation is done

Due to above reasons Puzzle2-17 is the hardest puzzle for ASTAR algorithm

Results of RBFS

File: Puzzle2-0

Reached goal in 4247.841346025467seconds

Number of states expanded:2287525

Maximum length of queue:13725150

Length of the path:15

Steps to goal:

start -> long90_270_dec -> equa_inc -> long0_180_dec -> equa_dec -> equa_dec ->
long0_180_inc -> long90_270_inc -> long0_180_inc -> long90_270_inc -> long0_180_inc ->
long0_180_inc -> long0_180_dec -> long90_270_inc -> equa_inc -> long0_180_inc -> goal

File: Puzzle2-1

Reached goal in 717.3583438396454seconds

Number of states expanded:815785

Maximum length of queue:4894710

Length of the path:16

Steps to goal:

start -> long0_180_inc -> long0_180_inc -> long90_270_inc -> long0_180_dec ->
long90_270_inc -> equa_inc -> long0_180_inc -> equa_inc -> long0_180_inc -> long0_180_inc ->
> long0_180_inc -> long0_180_dec -> equa_inc -> long90_270_dec -> equa_inc ->
long90_270_dec -> goal

File: Puzzle2-2

Reached goal in 0.24670815467834473seconds

Number of states expanded:246

Maximum length of queue:1476

Length of the path:9

Steps to goal:

start -> long90_270_dec -> long90_270_dec -> equa_inc -> equa_inc -> equa_inc ->
long90_270_dec -> equa_inc -> long90_270_inc -> long0_180_dec -> goal

File: Puzzle2-3

Reached goal in 1.3660609722137451seconds

Number of states expanded:1233

Maximum length of queue:7398

Length of the path:8

Steps to goal:

start -> equa_inc -> long0_180_inc -> long90_270_dec -> equa_dec -> long90_270_inc ->
long90_270_inc -> equa_dec -> long0_180_inc -> goal

File: Puzzle2-4

Reached goal in 34.25147223472595seconds

Number of states expanded:31514

Maximum length of queue:189084

Length of the path:11

Steps to goal:

start -> long0_180_inc -> long0_180_inc -> long90_270_inc -> long0_180_dec -> equa_inc ->
long90_270_dec -> equa_inc -> long90_270_inc -> equa_inc -> long0_180_dec ->
long0_180_dec -> goal

File: Puzzle2-5

Reached goal in 42.06346273422241seconds

Number of states expanded:38163

Maximum length of queue:228978

Length of the path:12

Steps to goal:

start -> long90_270_dec -> long90_270_dec -> equa_dec -> long90_270_inc -> equa_dec ->
equa_dec -> long0_180_inc -> long0_180_inc -> equa_inc -> long0_180_inc -> long0_180_inc ->
long0_180_inc -> goal

File: Puzzle2-6

Reached goal in 13.62032699584961seconds

Number of states expanded:12777

Maximum length of queue:76662

Length of the path:16

Steps to goal:

start -> long90_270_inc -> equa_inc -> equa_inc -> long90_270_dec -> long90_270_dec ->
long90_270_dec -> long90_270_dec -> equa_inc -> equa_inc -> long0_180_inc -> equa_inc ->
long0_180_inc -> long90_270_dec -> equa_dec -> long90_270_dec -> long90_270_dec -> goal

File: Puzzle2-7

Reached goal in 99.90949606895447seconds

Number of states expanded:131186

Maximum length of queue:787116

Length of the path:16

Steps to goal:

start -> long0_180_inc -> equa_dec -> long0_180_inc -> long90_270_dec -> equa_inc ->
long0_180_inc -> long90_270_dec -> long0_180_inc -> long0_180_inc -> long0_180_inc ->
long0_180_inc -> long90_270_inc -> equa_inc -> long0_180_inc -> equa_dec -> long0_180_inc ->
> goal

File: Puzzle2-8

Reached goal in 3.497126817703247seconds

Number of states expanded:3578

Maximum length of queue:21468

Length of the path:7

Steps to goal:

start -> equa_dec -> long0_180_dec -> long0_180_dec -> long90_270_dec -> long0_180_inc ->
long90_270_inc -> long0_180_inc -> goal

File: Puzzle2-9

Reached goal in 1.002436876296997seconds

Number of states expanded:1089

Maximum length of queue:6534

Length of the path:10

Steps to goal:

start -> long0_180_inc -> long90_270_inc -> long90_270_inc -> equa_inc -> long0_180_inc ->
equa_dec -> equa_dec -> long90_270_inc -> long0_180_inc -> long0_180_inc -> goal

File: Puzzle2-10

Algorithm stopped in 1953.6180038452148seconds

Number of states expanded:1262684

Maximum length of queue:7576104

File: Puzzle2-11

Reached goal in 0.18952107429504395seconds

Number of states expanded:187

Maximum length of queue:1122

Length of the path:7

Steps to goal:

start -> equa_dec -> equa_dec -> long90_270_dec -> equa_dec -> long90_270_inc ->
long0_180_dec -> long90_270_inc -> goal

File: Puzzle2-12

Reached goal in 0.5014219284057617seconds

Number of states expanded:524

Maximum length of queue:3144

Length of the path:7

Steps to goal:

start -> long0_180_dec -> long90_270_dec -> equa_inc -> equa_inc -> long0_180_inc ->
equa_dec -> long90_270_dec -> goal

File: Puzzle2-13

Reached goal in 6012.775228023529seconds

Number of states expanded:1590551

Maximum length of queue:9543306

Length of the path:13

Steps to goal:

start -> long0_180_dec -> equa_dec -> long0_180_dec -> long90_270_dec -> equa_inc ->
equa_inc -> long90_270_inc -> long0_180_inc -> equa_dec -> equa_dec -> long0_180_inc ->
long90_270_inc -> long0_180_dec -> goal

File: Puzzle2-14

Reached goal in 5.813715934753418seconds

Number of states expanded:6285

Maximum length of queue:37710

Length of the path:14

Steps to goal:

start -> long90_270_dec -> long0_180_inc -> long0_180_inc -> equa_dec -> long0_180_inc ->
long0_180_inc -> long90_270_dec -> long90_270_dec -> equa_dec -> long0_180_dec ->
long0_180_dec -> long0_180_inc -> long0_180_dec -> long90_270_dec -> goal

File: Puzzle2-15

Reached goal in 545.3642430305481seconds

Number of states expanded:560256

Maximum length of queue:3361536

Length of the path:10

Steps to goal:

start -> long0_180_inc -> equa_dec -> long0_180_dec -> long90_270_inc -> long0_180_dec ->
equa_inc -> long0_180_inc -> long90_270_dec -> equa_dec -> long90_270_dec -> goal

File: Puzzle2-16

Reached goal in 0.5277998447418213seconds

Number of states expanded:803

Maximum length of queue:4818

Length of the path:10

Steps to goal:

start -> long0_180_inc -> long90_270_dec -> equa_inc -> long0_180_dec -> long0_180_dec ->
equa_inc -> long0_180_dec -> long0_180_inc -> long0_180_dec -> long90_270_inc -> goal

File: Puzzle2-17

Reached goal in 1832.0003566741943seconds

Number of states expanded:1373234

Maximum length of queue:8239404

File: Puzzle2-18

Reached goal in 61.96150612831116seconds

Number of states expanded:67798

Maximum length of queue:406788

Length of the path:12

Steps to goal:

start -> equa_inc -> long90_270_inc -> equa_inc -> equa_inc -> equa_inc -> long90_270_dec ->
long90_270_dec -> long0_180_inc -> equa_dec -> long90_270_inc -> long90_270_inc ->
long0_180_dec -> goal

File: Puzzle2-19

Reached goal in 1932.0021427243323seconds

Number of states expanded:1537452

Maximum length of queue:8945372

Minimum Number of states expanded = 187 for Puzzle2-11

Maximum Number of states expanded = 1590551 for Puzzle2-13

Average Number of states expanded = 326441.176

Minimum queue size = 1122 for Puzzle2-11

Maximum queue size = 9543306 for Puzzle2-13

Average queue size = 1958647.059

Hardest puzzle is puzzle2-13:

- Algorithm expands maximum number of states among all puzzles
- Maximum queue length during execution is also maximum this puzzle
- The time it takes high which is true because more computation is done

Due to above reasons Puzzle2-13 is the hardest puzzle for RBFS algorithm

Note: Here not all puzzles ran till the goal is reached, some of them are stopped in between.
The results are based on only those puzzles which reached the goal.

Summary

The relative performance of all three algorithm says that AStar is best among 3. The time it takes to reach the goal is minimum. Most importantly AStar expands very few nodes to reach the goal than BFS and RBFS. The heuristics plays important role for efficiency of AStar. RBFS due to its different way of searching goal makes it less efficient for graph search problem like this. It goes into more depth sometimes and expands more nodes than AStar.

So final conclusion is AStar is best suited for graph searching algorithm like globe puzzle.