COMP30030: Introduction to Artificial Intelligence

Neil Hurley

School of Computer Science
University College Dublin
neil.hurley@ucd.ie

September 25, 2018

A Quick Review…

- Search techniques are used in AI to find a sequence of steps that will get us from some initial state to some goal state(s).
- You can use various algorithms to do the search. We have looked at simple breadth-first and depth-first search.
- Both are **systematic, exhaustive** search techniques that will eventually try all the nodes in a finite search tree.
- The appropriate algorithm will depend on the problem you are trying to solve, such as whether you are looking for the shortest path.

A Quick Review…

- **Are you looking for the shortest path?**
  - If so, breadth-first search may be better as it will find the shortest path first.
- **Is memory likely to be a problem?**
  - Depth-first search generally requires much less memory.
- **Do you want to find a solution quickly?**
  - If so, the choice of algorithm gets complex!
    - Depth-first search may be faster if there are many paths that lead to solution states, but all are quite long.
    - Breadth-first search may be faster if there is one short path to the target, but within a large and deep search space.

A Quick Review

- You may be so ininformed about a search problem that you cannot rule out either a large branching factor or the possiblity of following very long useless paths.
- In such situations you may want to seek a **middle-ground between DFS and BFS.**
- $\Rightarrow$ **Random queuing** – *nondeterministic search*.

A Quick Review…

- There are **many variants** of breadth and depth-first that may be useful in certain situations.

- You can set a **depth-limit** in depth-limited search so it backs up when it gets to nodes further than the specified distance from the initial state.
  - Like DFS, but the search is limited to a predefined depth.
  - The depth of each state is recorded as it is generated. When picking the next state to expand, only those with depth less or equal than the current depth are expanded.
  - Once all the nodes of a given depth are explored, the current depth is incremented.

- A variant to this is **iterative deepening** which repeats depth-first search with gradually increasing depth limits.

A Quick Review…

- **In spite of the apparent waste in repeating bits of search iterative deepening is a very useful algorithm…**

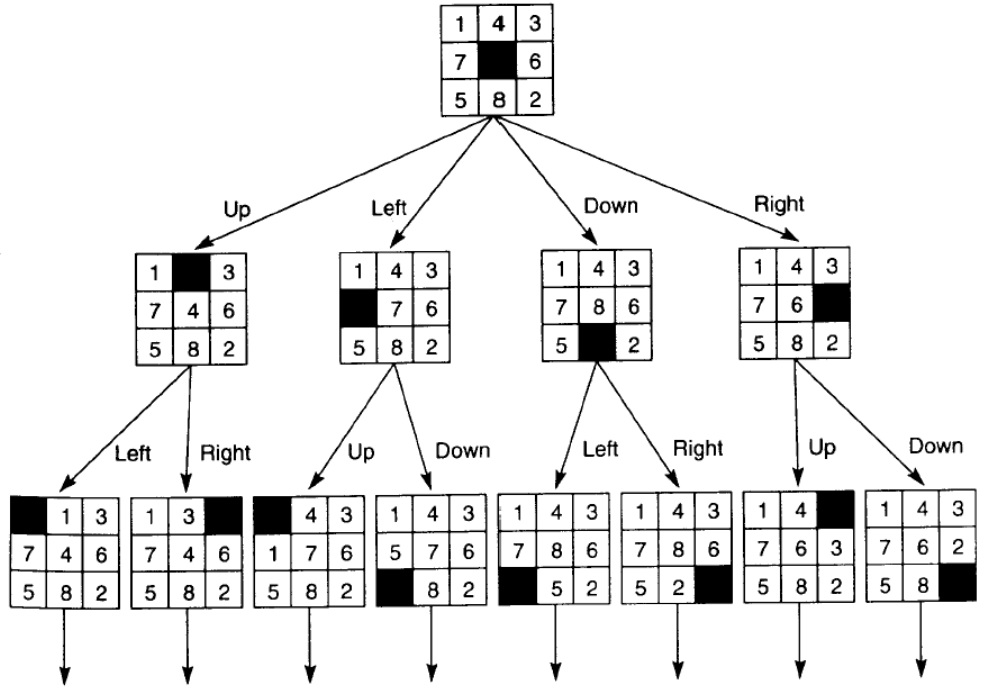
It **requires little memory** (like depth first),

and

it **finds the shortest path first** (like breadth first).

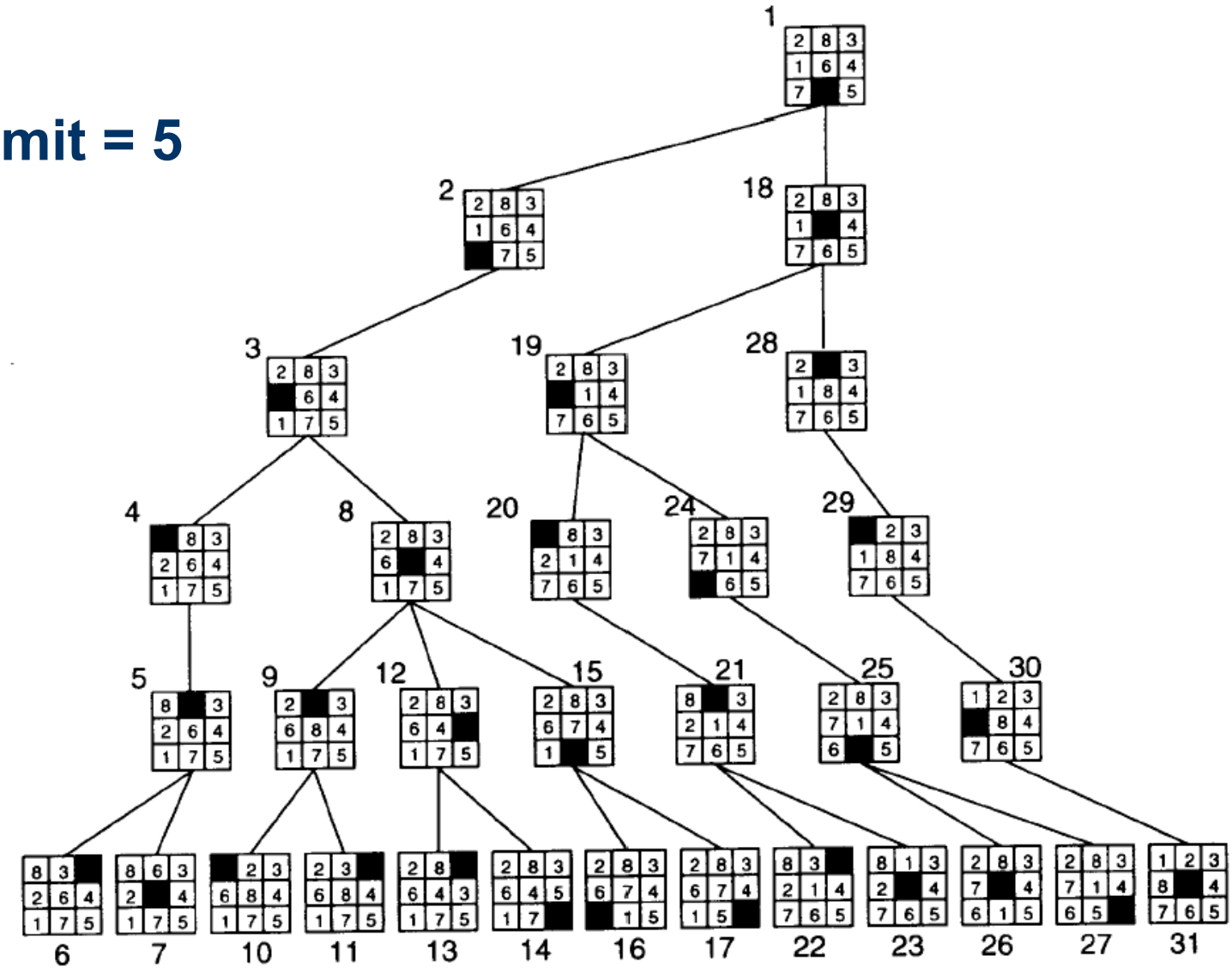
Another Example

- **The 8 Sliding Tile Puzzle**
  - Partial state space representation.
  - Generated by the **MoveBlank** operator
    - up, down, left, right

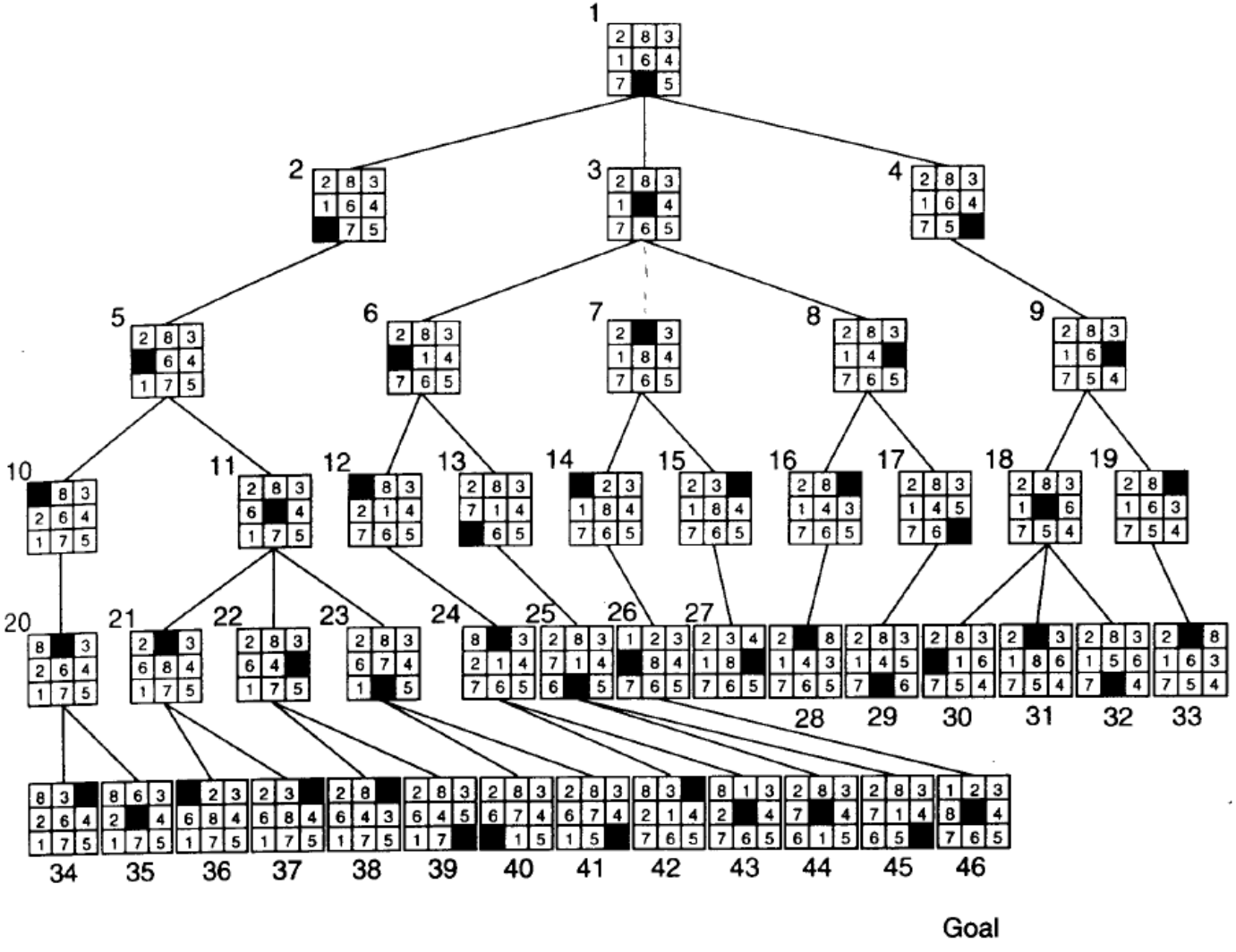


8-Puzzle: Depth First Search

- **Depth-limit = 5**

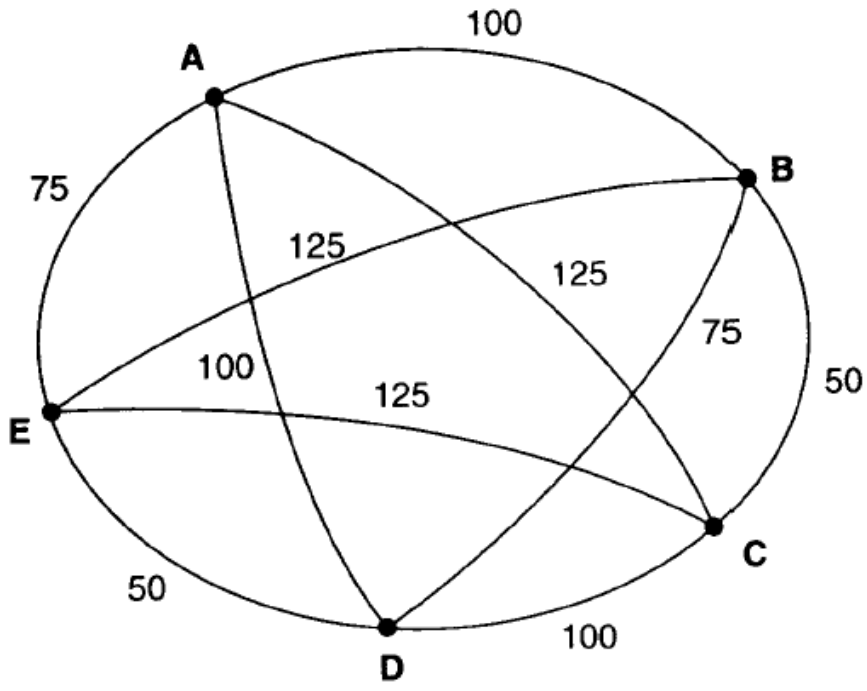


8-Puzzle: Breadth-First Search



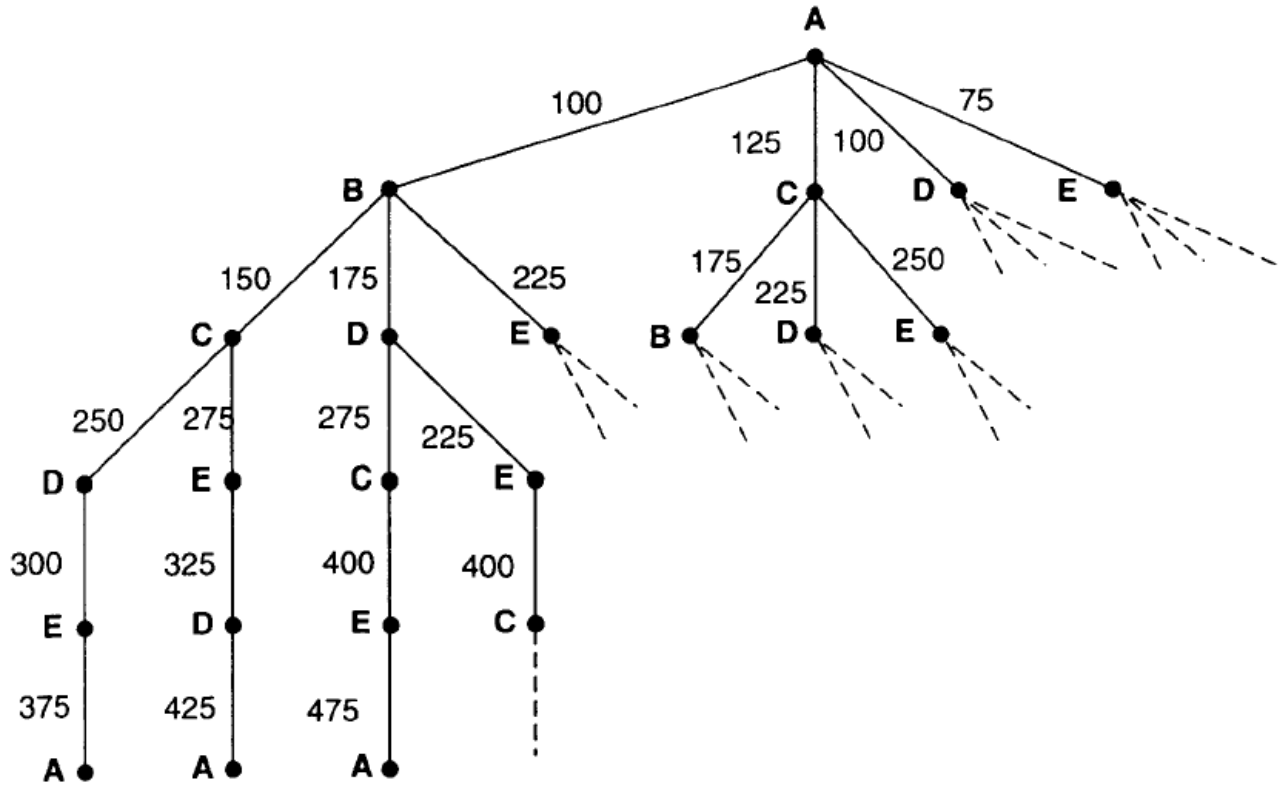
The TSP Example

- **The Travelling Salesman Problem**
  - Find the shortest path
  - Visit all cities
  - Return home



- **Representing the Problem**
  - Each arc is marked with the total weight of all paths from the start node (A) to its endpoint.

TSP – Partial State Space



Heuristic Search

- **Blind search methods** are simple but they are often **impractical**.
- The are **uninformed**. That is, they have no information about the state space and so are let to search blindly through it in a systematic fashion.
- **Heuristic search** methods, on the other hand, improve search efficiency by exploring **the most promising search paths first**.

Heuristic Search

To use heuristic search you need an **evaluation function** that scores a node in a search tree according to how close to the target/goal state it seems to be.

- NOTE: This will just be a **guess**, but it still should be a useful way of guiding the search.

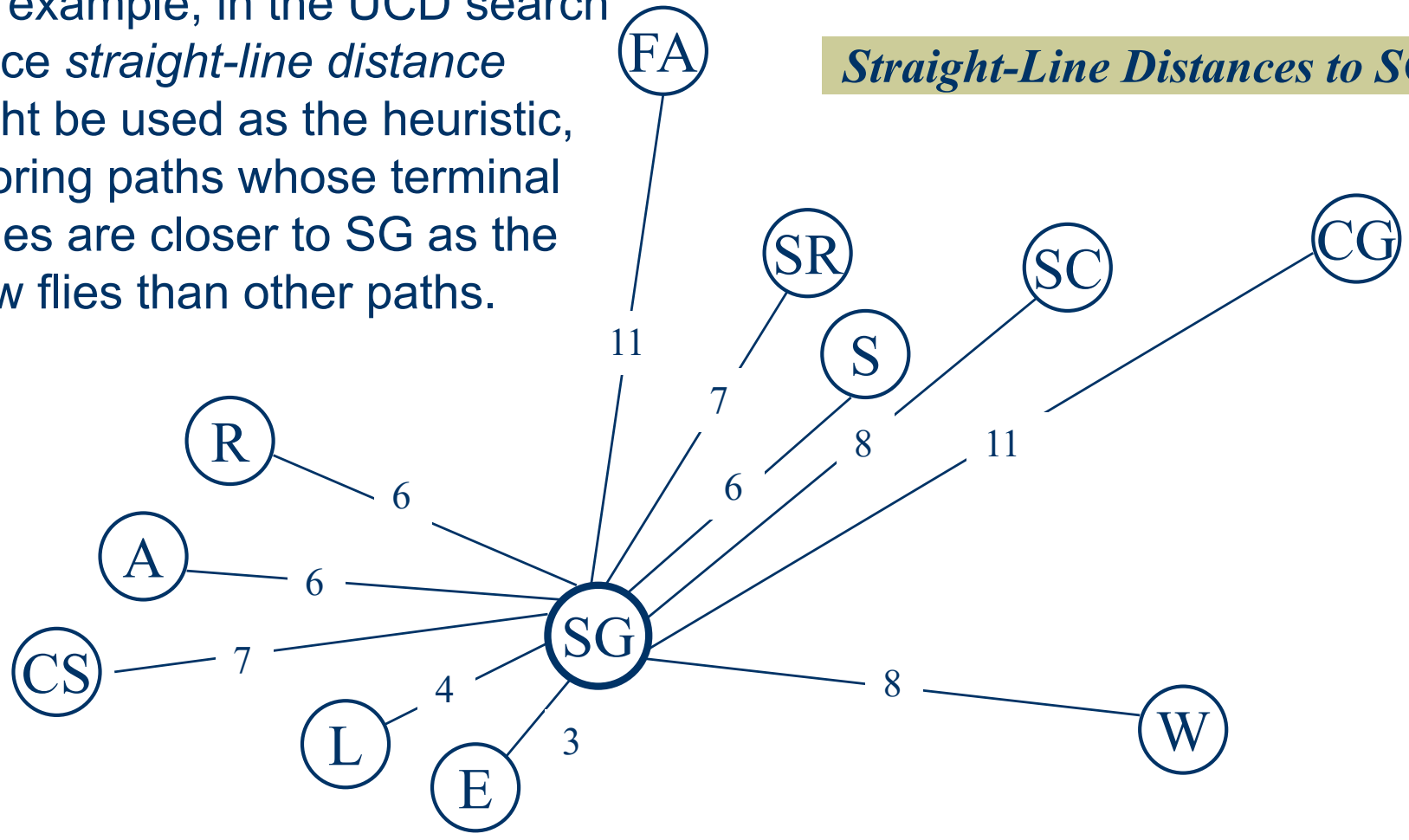
- Basic idea…
  - Rather than trying all possible search paths, you try to focus on paths that seem to be getting you nearer your target/goal state.

Heuristic Function Properties

- They are **problem specific**.
- The indicate the **promise of states**, not actions.
- They are **estimates** of the cheapest path to the goal
- ***h(n)=0*** if ***n*** is a goal node.

Heuristic Search

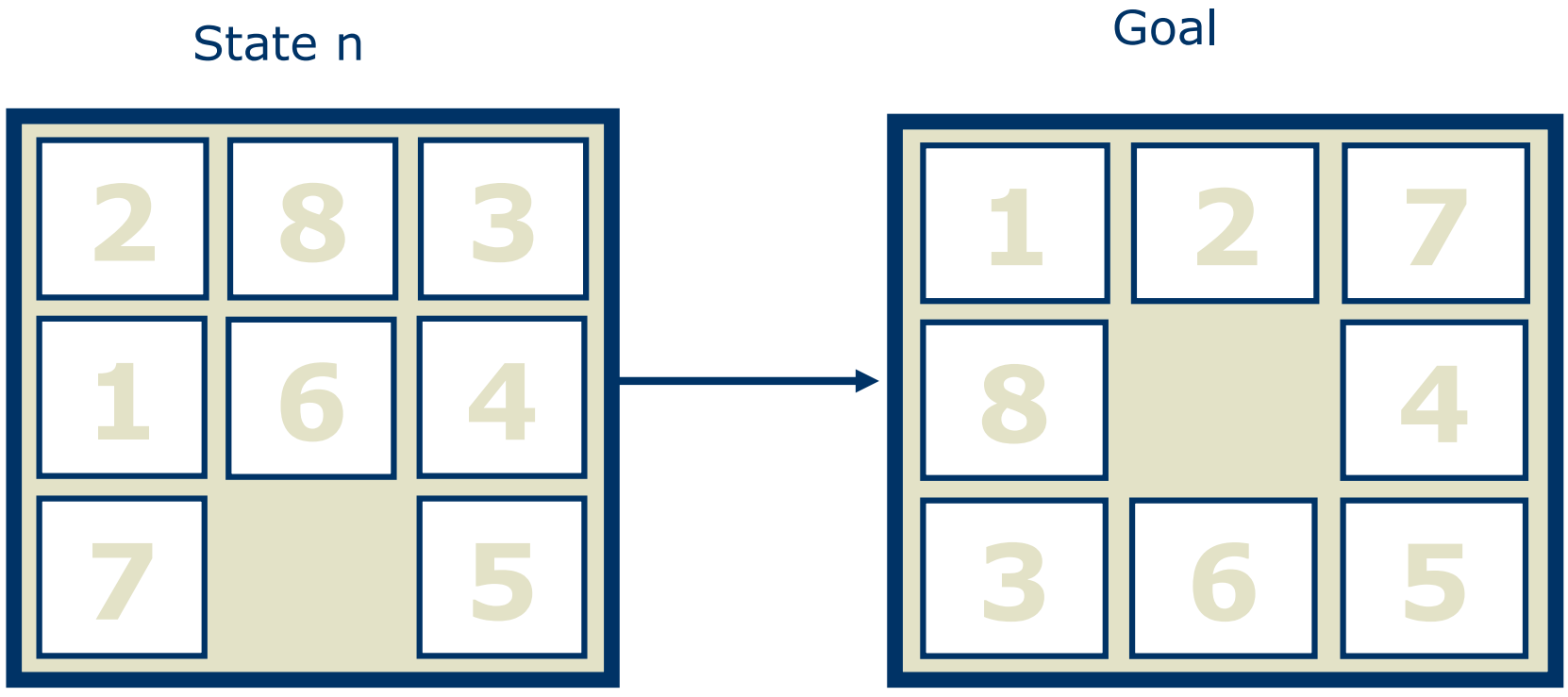
- For example, in the UCD search space *straight-line distance* might be used as the heuristic, favoring paths whose terminal nodes are closer to SG as the crow flies than other paths.



Heuristic Search

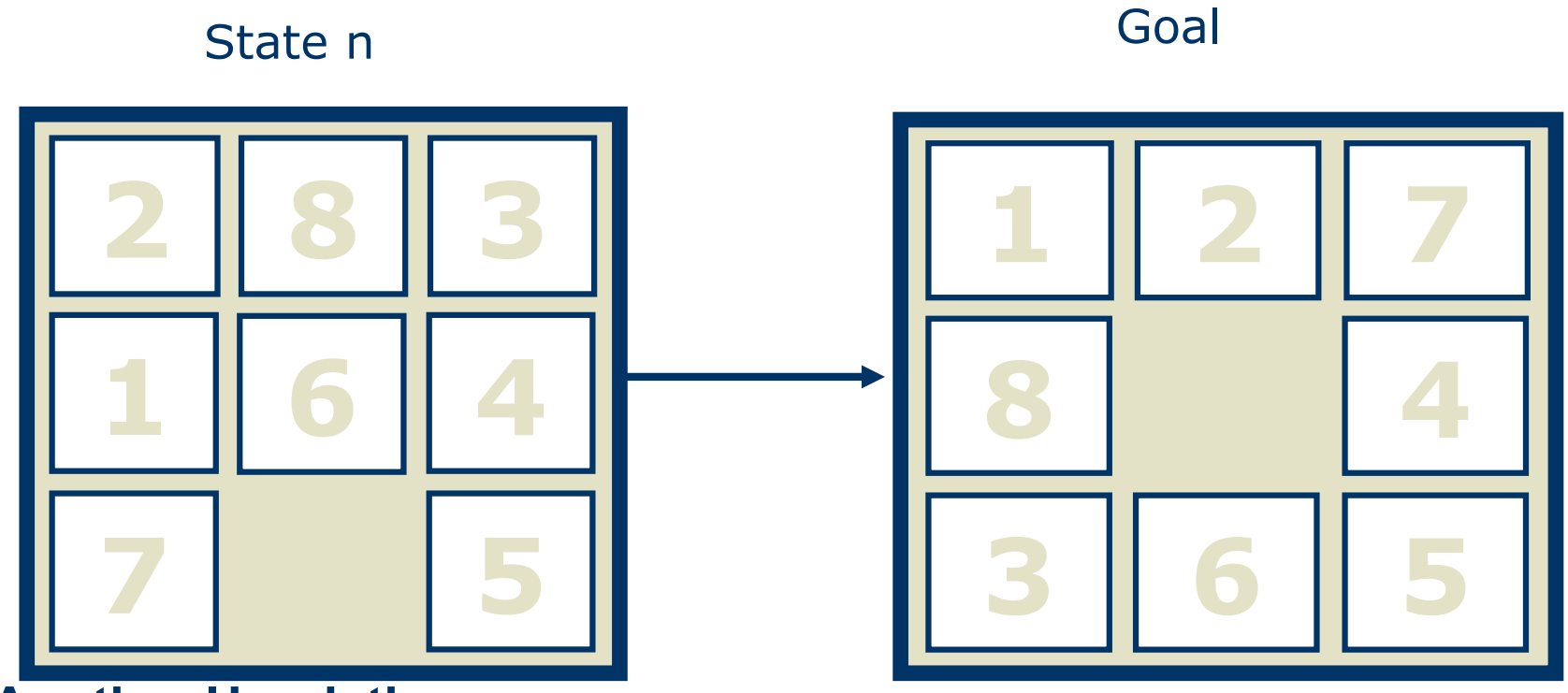
- In short, *heuristics* (heuristic evaluation functions) are simply just *rules of thumb*!
- They provide us with a means of ordering paths for exploration.
- They are not guaranteed to find one at all, but *if they are good*, then they help us find an adequate solution **faster!**

The 8-Puzzle – "Tiles-out-of-Place"



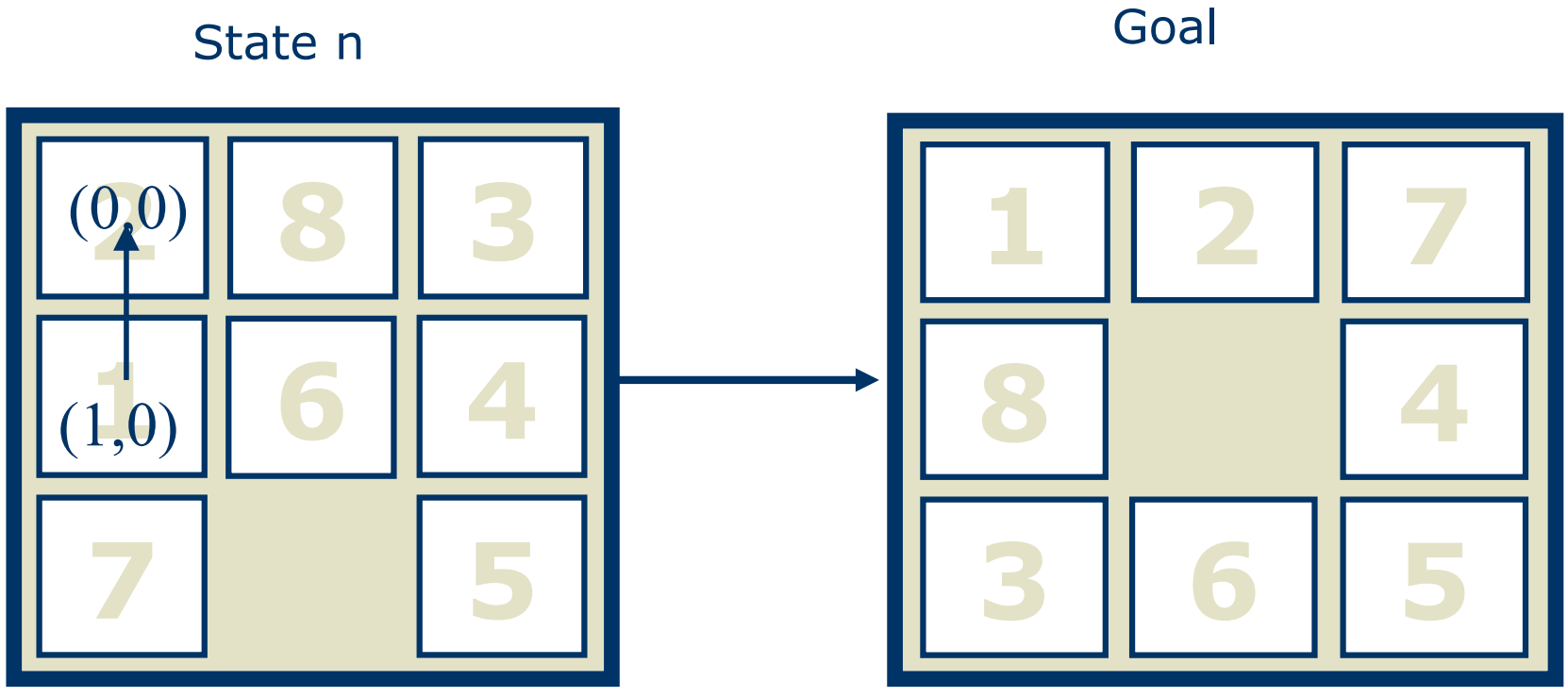
- **Possible Heuristic**
  - *h(n)* = number of tiles out of place in this state relative to the goal state.

The 8-Puzzle – "Manhattan Distance"



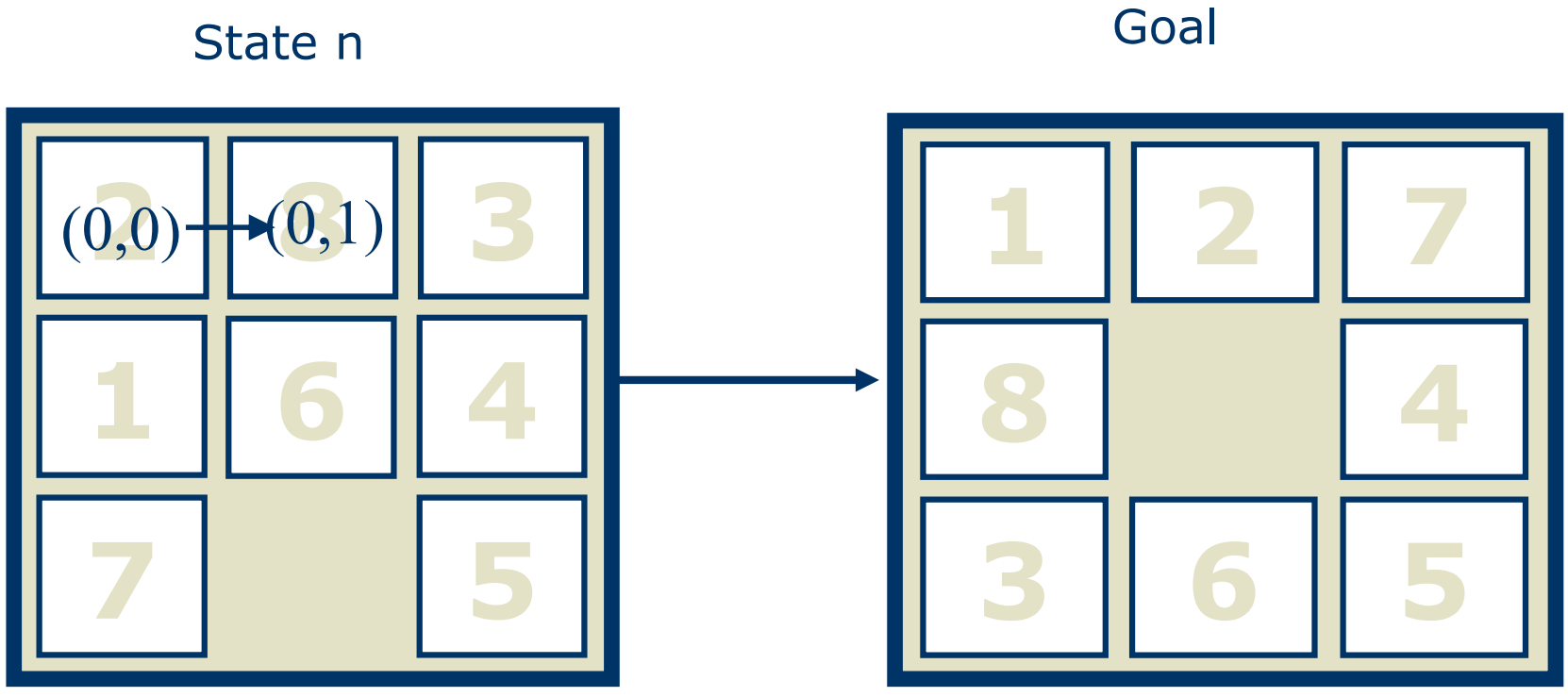
- **Another Heuristic**
  - *h(n)* = sum of **Manhattan distance** of each tile from its correct location.
    = sum over all tiles of *number of rows and number of columns* that tile is from correct position

The 8-Puzzle – "Manhattan Distance



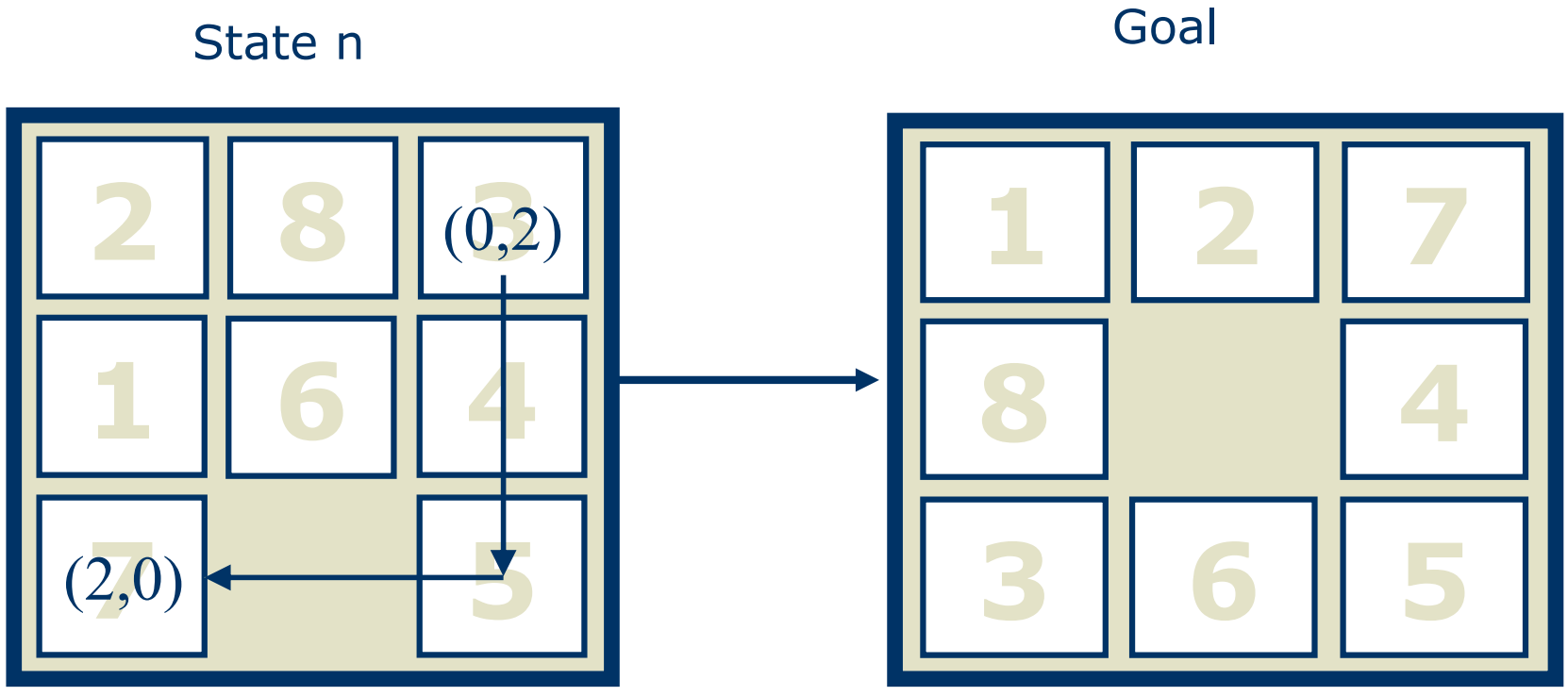
= 1

The 8-Puzzle – “Manhattan Distance



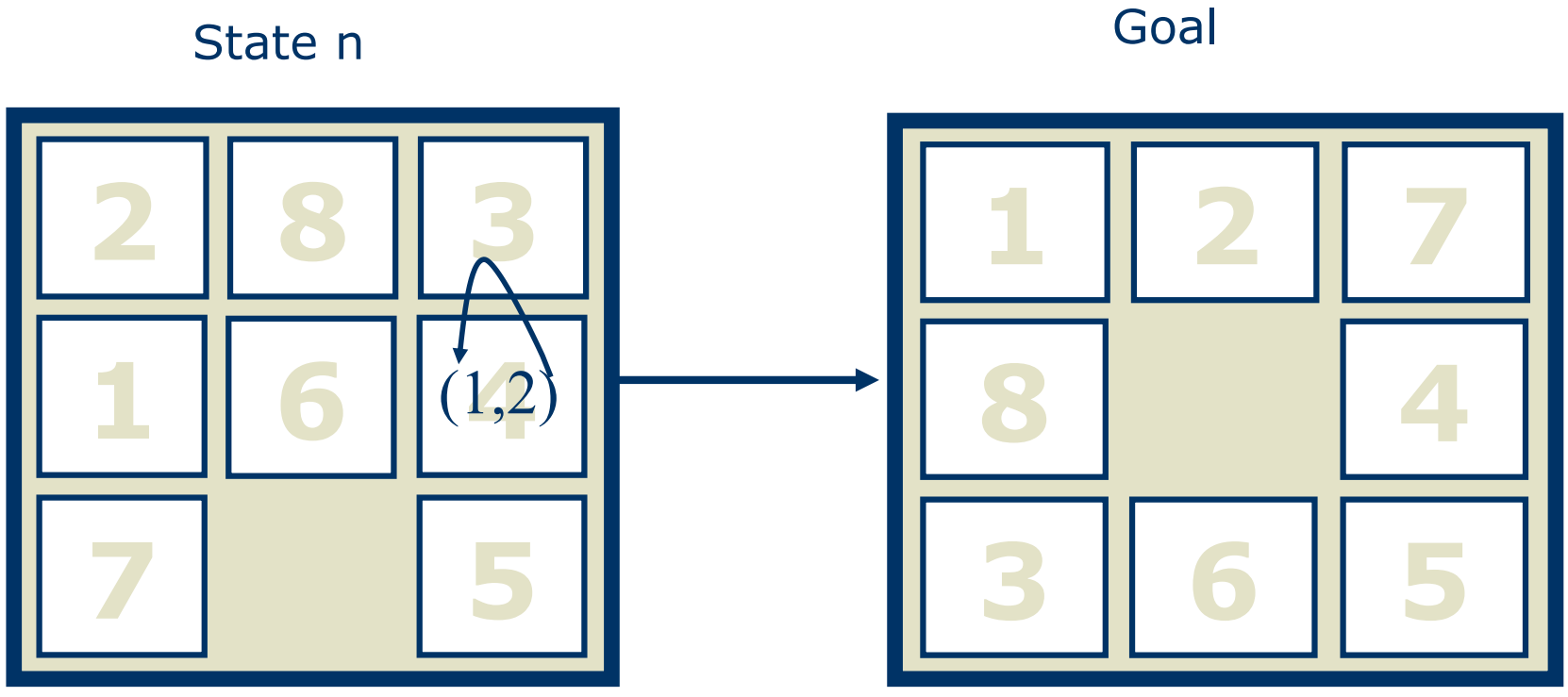
= 1 + 1

The 8-Puzzle – “Manhattan Distance



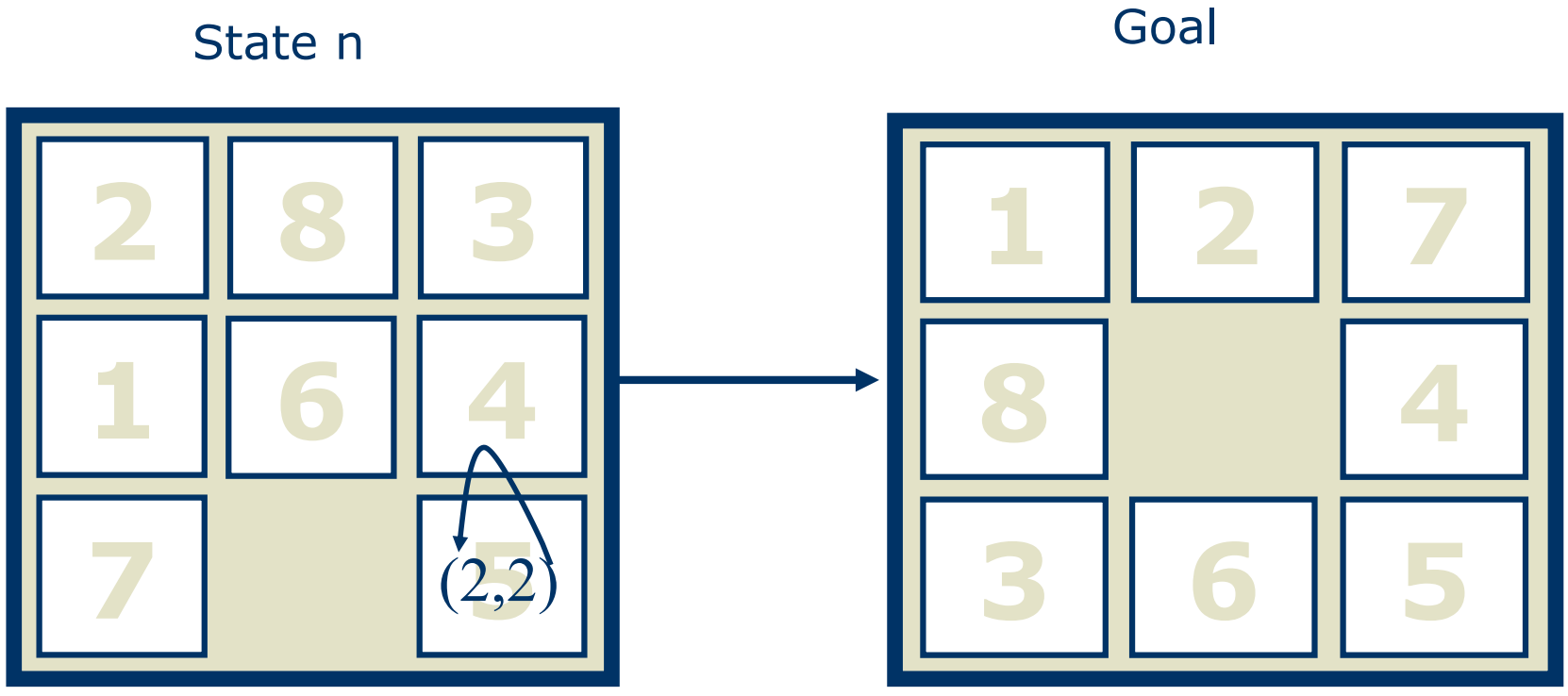
= 1 + 1 + 4

The 8-Puzzle – “Manhattan Distance



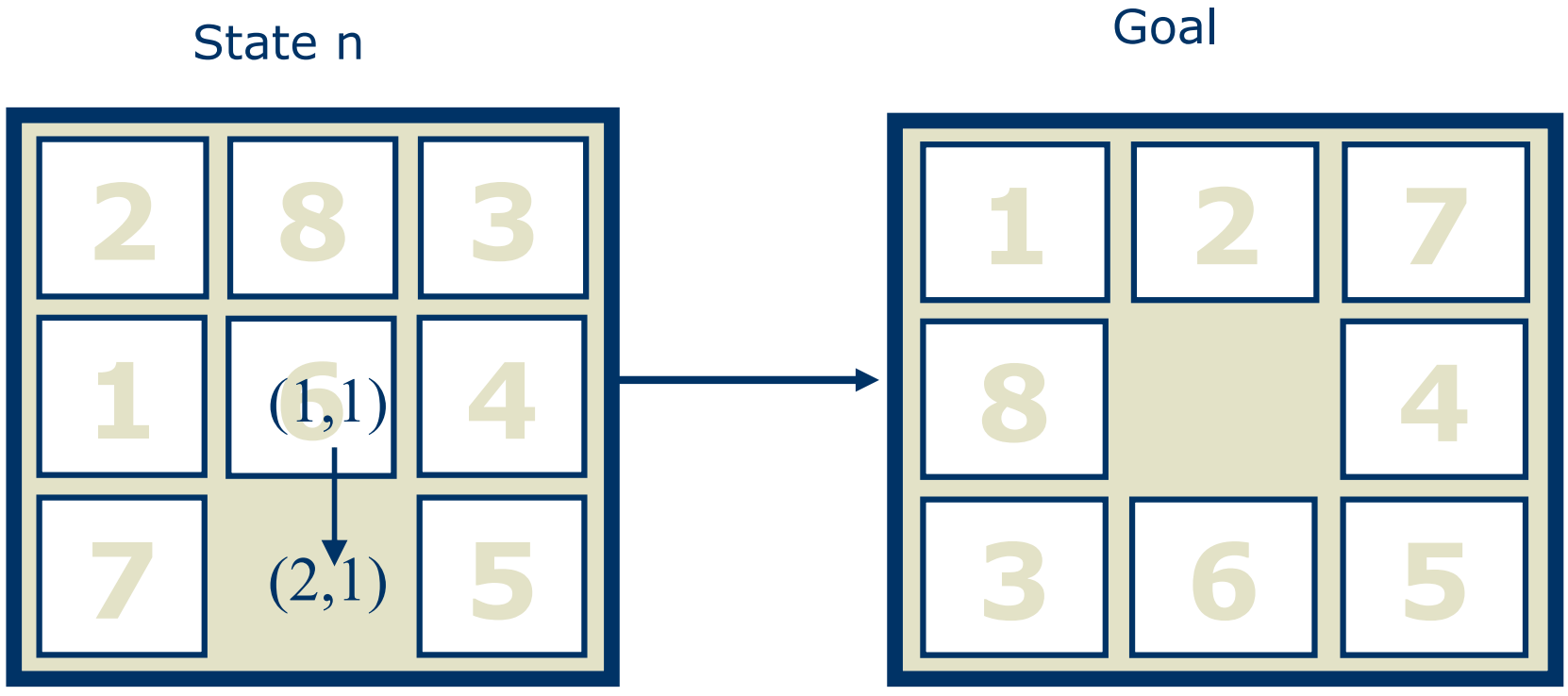
= 1 + 1 + 4 + 0

The 8-Puzzle – “Manhattan Distance



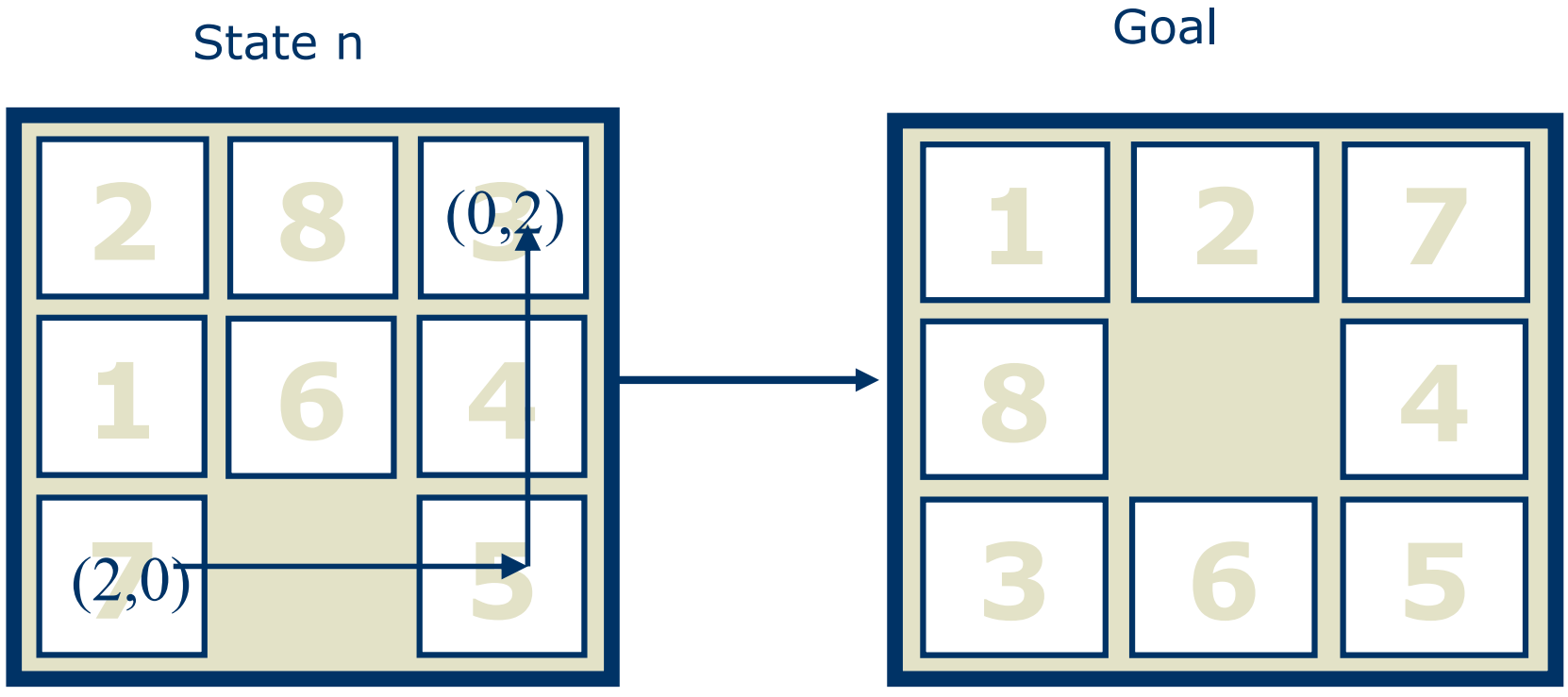
= 1 + 1 + 4 + 0 + 0

The 8-Puzzle – “Manhattan Distance



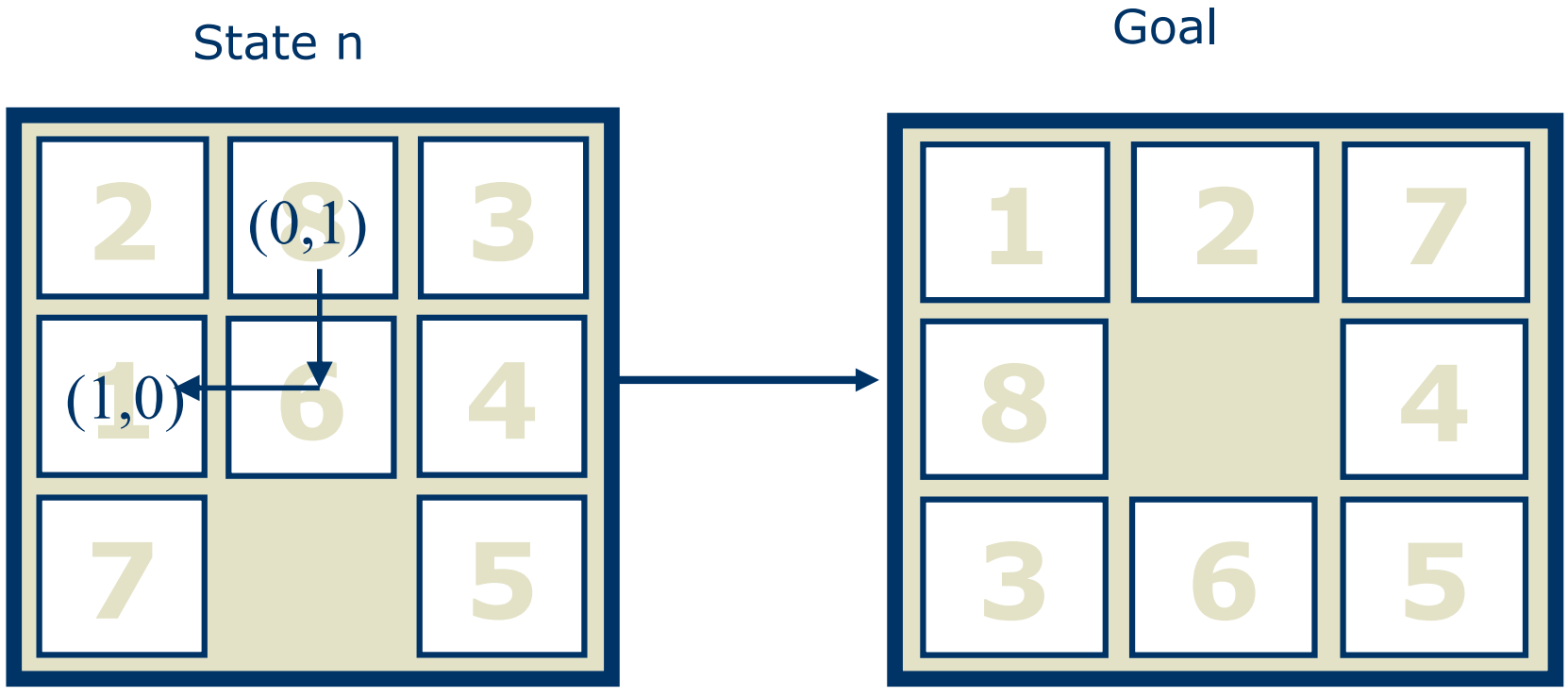
= 1 + 1 + 4 + 0 + 0 + 1

The 8-Puzzle – “Manhattan Distance



= 1 + 1 + 4 + 0 + 0 + 1 + 4

The 8-Puzzle – “Manhattan Distance



= 1 + 1 + 4 + 0 + 0 + 1 + 4 + 2 = 13

Admissible Heuristics I

- Notice that the two heuristics for the 8-puzzle are both optimistic.
- They *underestimate* the true distance to the goal – we must make *at least* the number of moves indicated by the heuristic.
- Such heuristics are called admissible.
- One way to arrive at such heuristics is to consider how to relax the original.
- Relaxation – removing some of the constraints of the original problem. With fewer constraints, the cost of the optimal solution for the relaxed problem will be at most equal to the cost of the optimal solution to the original problem.

Admissible Heuristics II

- For instance, we can arrive at the "Tiles out of Place" heuristic, by imagining a relaxed version of the 8-puzzle problem where a move consists of *any* two tiles swapping position, rather than just the blank and an adjacent tile.

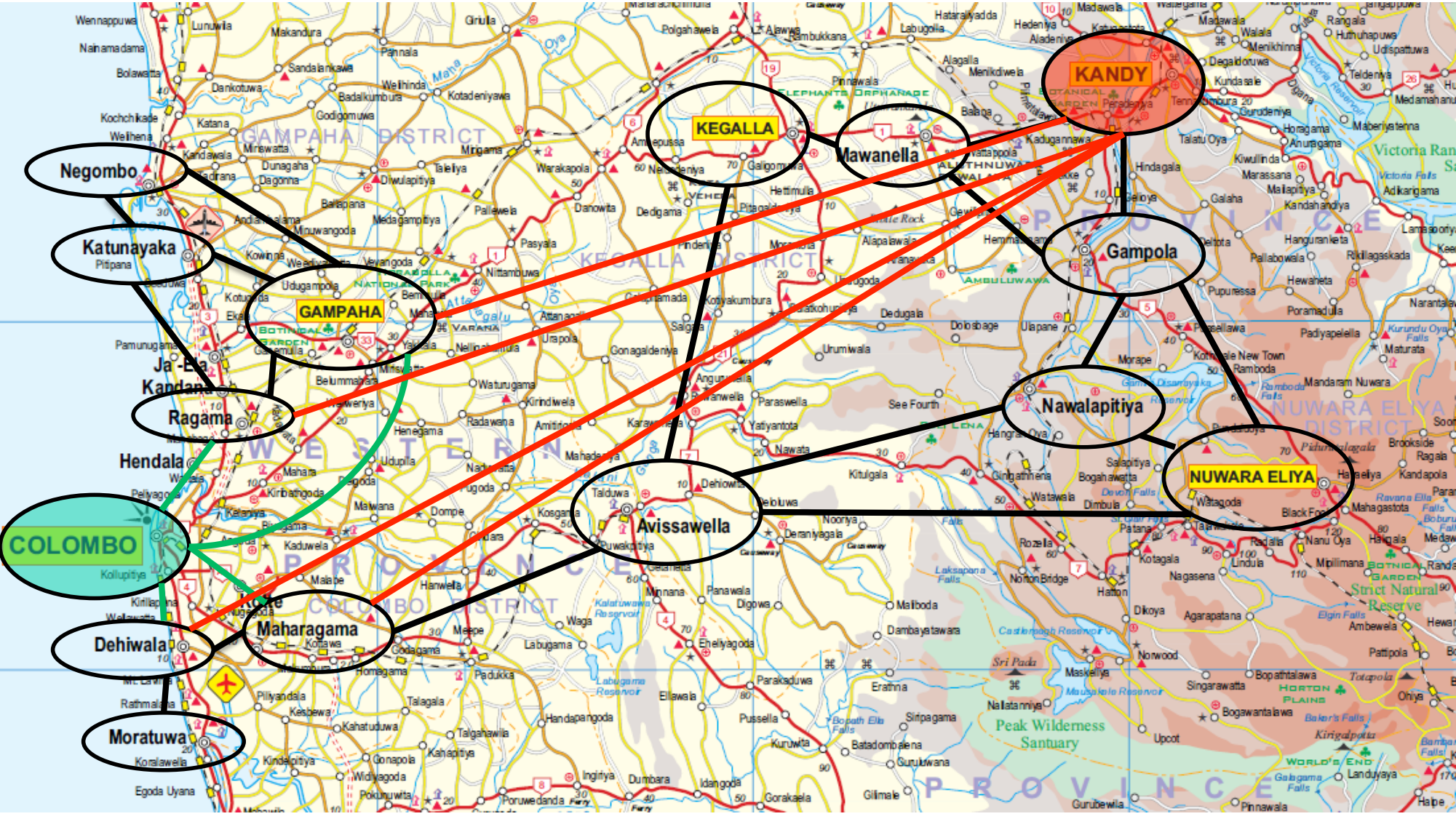
Greedy Best First Search I

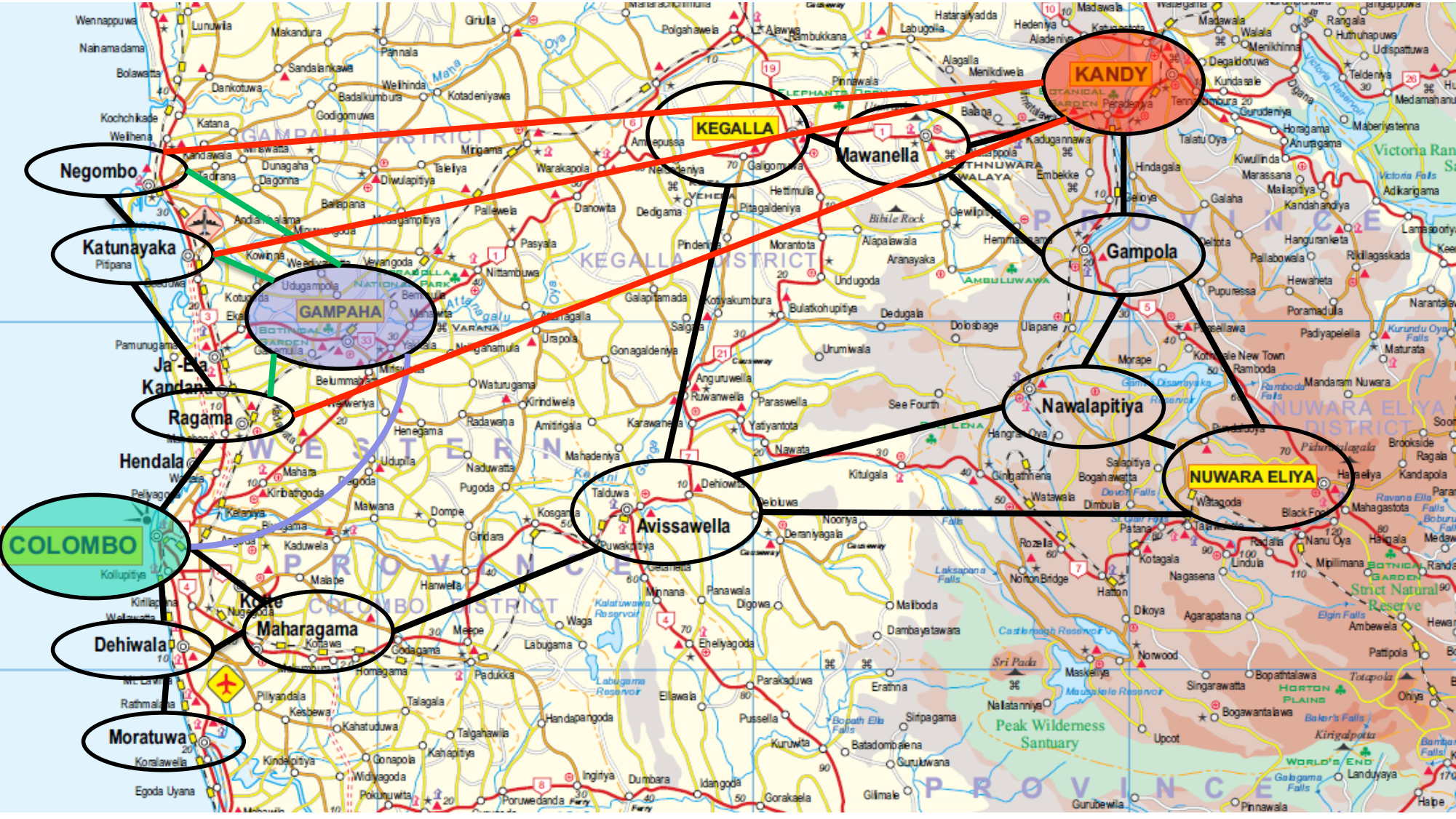
- In best-first search, a node, n, is chosen for expansion based on an evaluation function $f(n)$.
- $f(n)$ may depend on the description of the node, the description of the goal, the information gathered by the search up to that point, or any extra knowledge about the problem domain.
- A common approach is to use a heuristic that attempts to predict how close the end of a path is to a solution, so that paths which are judged to be closer to a solution are extended first.
- In this case, we will write $h(n)$ for the evaluation function.
- When the evaluation function is a heuristic measure of distance to the goal, the technique is referred to a greedy best first.

Greedy Best First Search II

- In reality we aren't expanding the best node first. We are expanding the one that appears to be the best.
- If we knew the best node, we would have the solution and there would not be any search.
- It resembles depth-first because it plunges in depth and ignores breadth.
- From the point-of-view of the queuing function, we use a priority queue for the open list, with the priority given by $h(n)$.

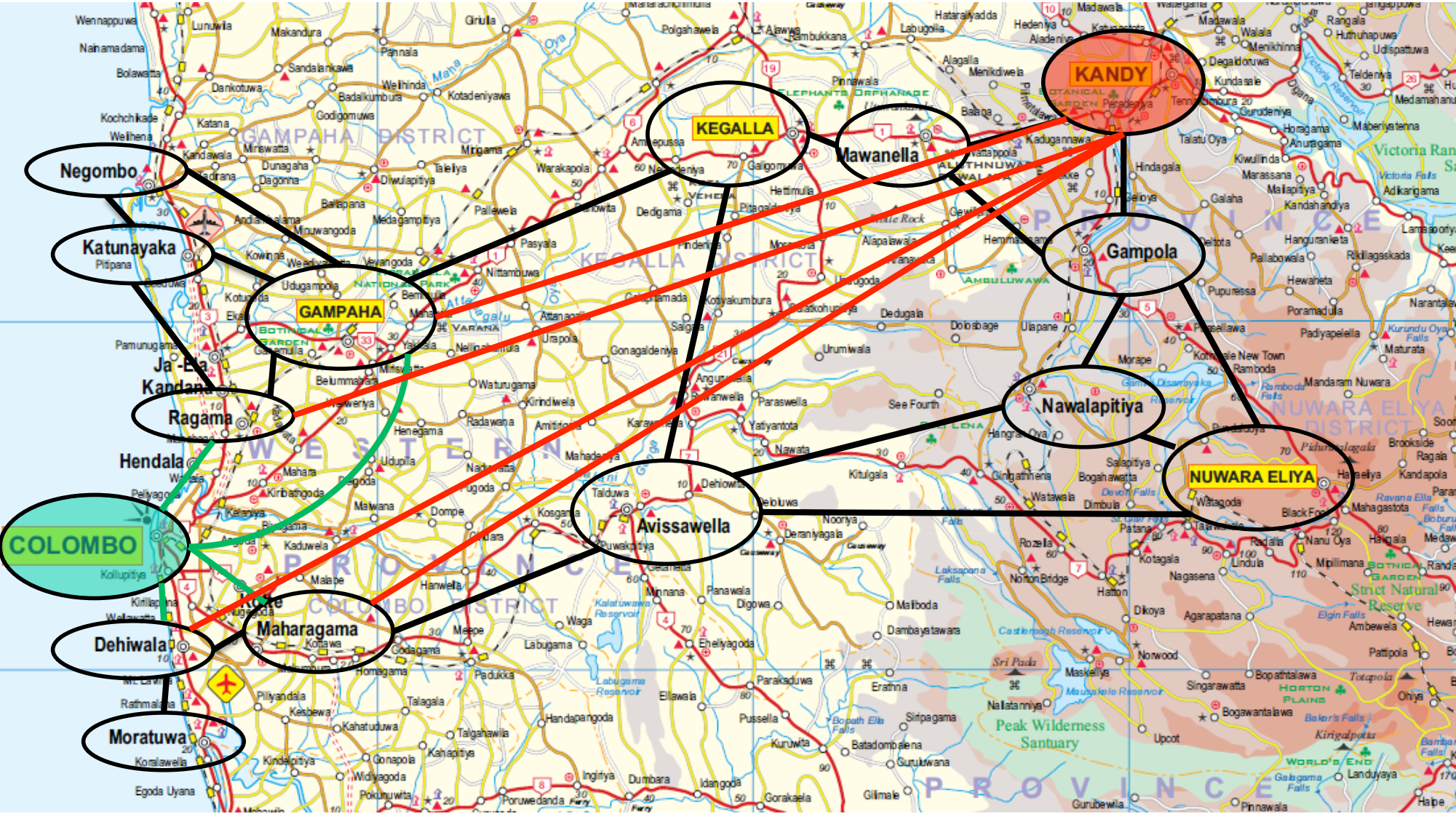
For example, route finding in Sri Lanka ...

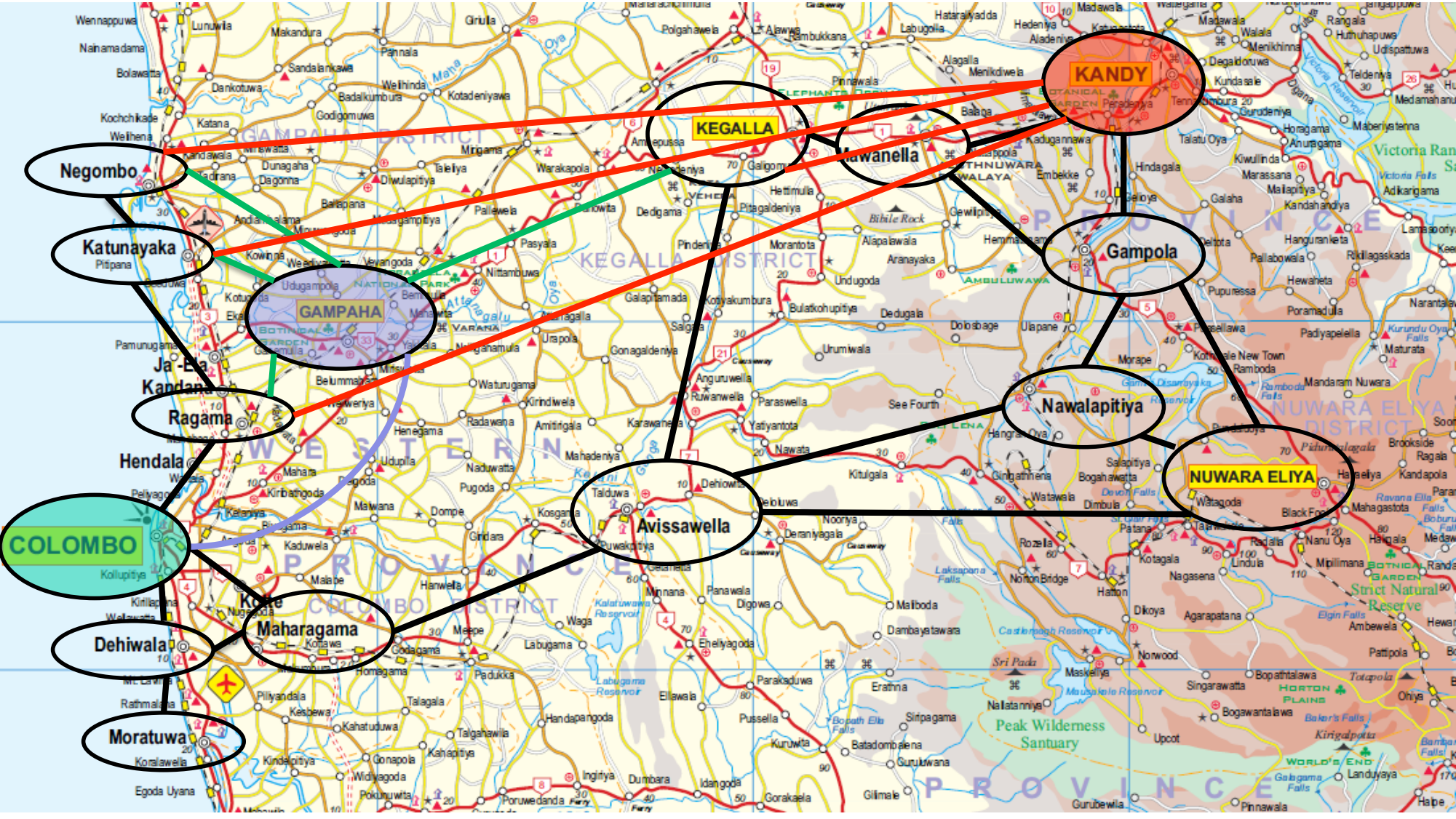

KANDY
KEGALLA
Mawanella
Negombo
Katunayaka
Gampola
GAMPAHA
Ja-Ela
Kandana
Ragama
Nawalapitiya
NUWARA ELIYA
Hendala
COLOMBO
Avissawella
Maharagama
Dehiwala
Moratuwa
WESTERN PROVINCE
COLOMBO DISTRICT
KEGALLA DISTRICT
NUWARA ELIYA DISTRICT
CENTRAL PROVINCE
SABARAGAMUWA PROVINCE
GAMPAHA DISTRICT
Peak Wilderness Santuary
Strict Natural Reserve

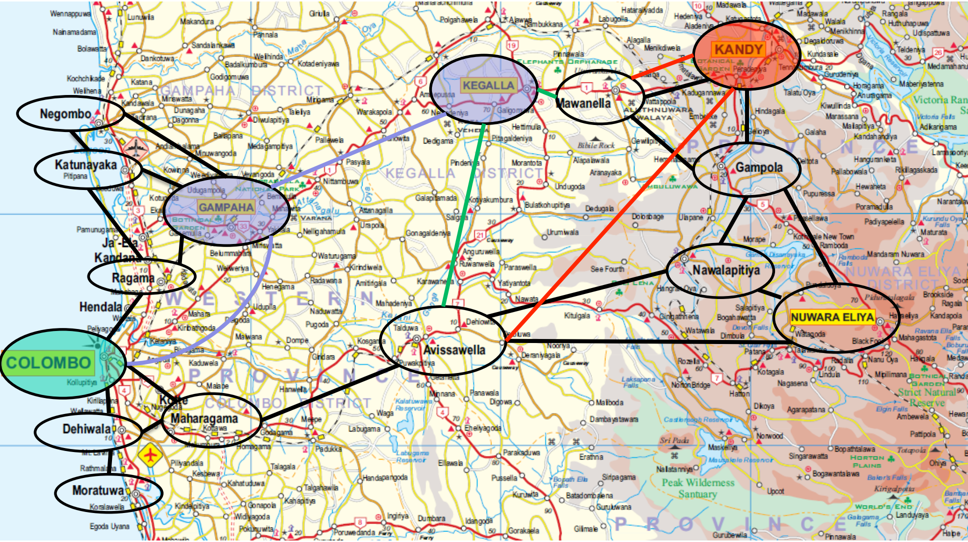

KANDY
KEGALLA
Mawanella
Negombo
Katunayaka
Gampola
GAMPAHA
Nawalapitiya
NUWARA ELIYA
COLOMBO
Avissawella
Ja-Ela
Kandana
Ragama
Hendala
Dehiwala
Maharagama
Moratuwa
Kotte
WESTERN PROVINCE
COLOMBO DISTRICT
KEGALLA DISTRICT
NUWARA ELIYA DISTRICT
CENTRAL PROVINCE
SABARAGAMUWA PROVINCE
Peak Wilderness Santuary
Strict Natural Reserve

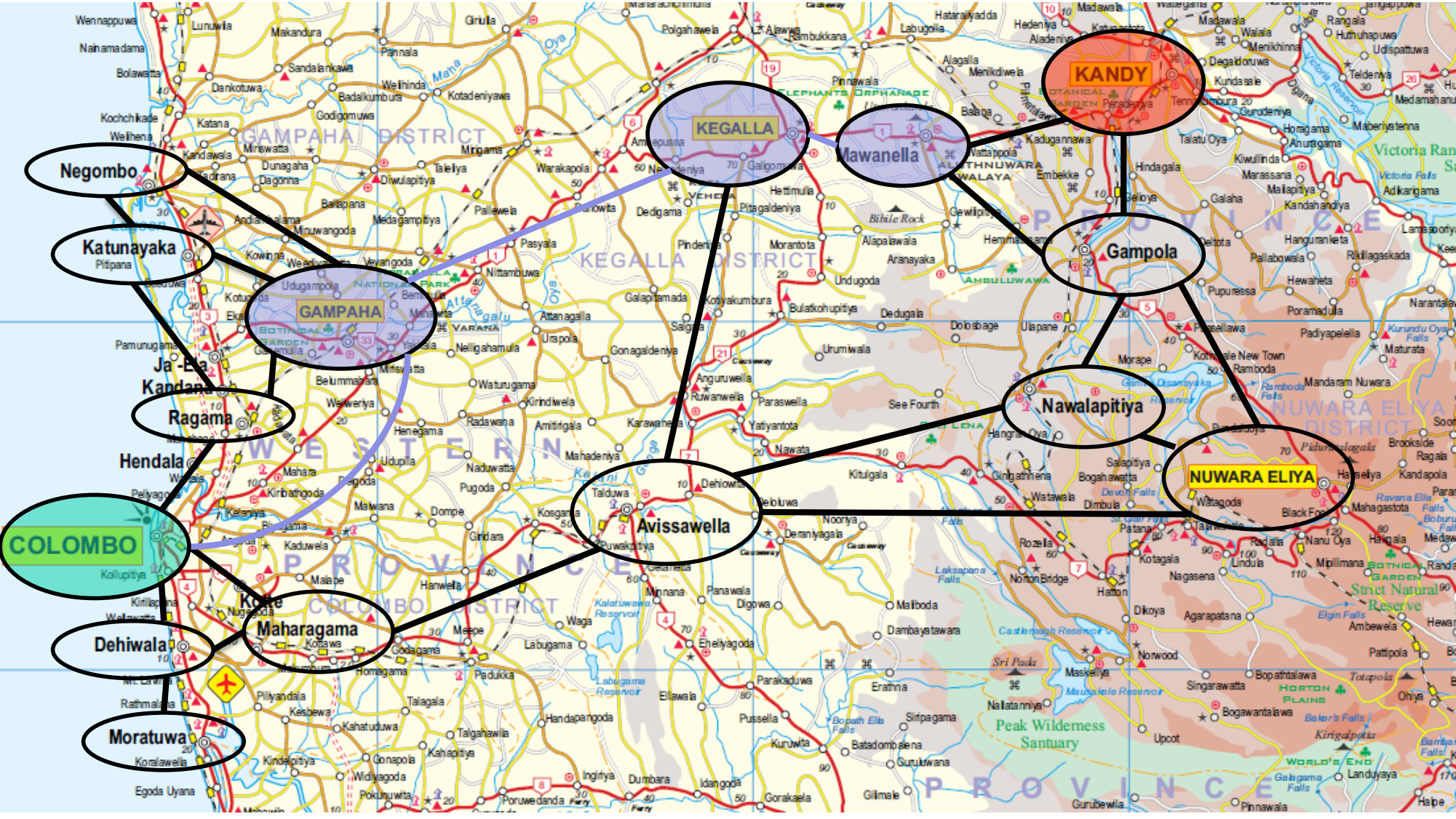
Greedy Best First Search I

- Best-first tells us to go from Colombo to Gampaha
- But there is no route from Gampaha, through its neighbours to Kandy).
- So, what seems the best, may not always be the best – sometimes we might run into dead ends.
- It will back up if it hits a dead end, but only a strategy to avoid repeated states will prevent it choosing Gampaha again.
- So, in general, it is not complete.
- Its performance depends crucially on the heuristic function.
- In our route-finding example, if there's a route from Gampaha to Kegalla, then it will work well...


KANDY
KEGALLA
Mawanella
Negombo
Katunayaka
Gampola
GAMPAHA
Ja-Ela
Kandana
Ragama
Nawalapitiya
NUWARA ELIYA
Hendala
COLOMBO
Avissawella
Maharagama
Dehiwala
Moratuwa
WESTERN PROVINCE
COLOMBO DISTRICT
KEGALLA DISTRICT
NUWARA ELIYA DISTRICT
CENTRAL PROVINCE
SABARAGAMUWA PROVINCE
GAMPAHA DISTRICT
Peak Wilderness Santuary
Strict Natural Reserve


KANDY
KEGALLA
Negombo
Katunayaka
GAMPAHA
Gampola
Nawalapitiya
NUWARA ELIYA
COLOMBO
Avissawella
Ja-Ela
Kandana
Ragama
Hendala
Kotte
Maharagama
Dehiwala
Moratuwa
WESTERN PROVINCE
COLOMBO DISTRICT
KEGALLA DISTRICT
NUWARA ELIYA DISTRICT
CENTRAL PROVINCE
SABARAGAMUWA PROVINCE
Peak Wilderness Santuary
Strict Natural Reserve


KANDY
KEGALLA
Mawanella
Negombo
Katunayaka
GAMPAHA
Ragama
Hendala
COLOMBO
Dehiwala
Moratuwa
Kotte
Maharagama
Avissawella
Gampola
Nawalapitiya
NUWARA ELIYA
GAMPAHA DISTRICT
KEGALLA DISTRICT
COLOMBO DISTRICT
NUWARA ELIYA DISTRICT
WESTERN PROVINCE
Peak Wilderness Santuary
Horton Plains
World's End


Negombo
Katunayaka
Ja-Ela
Kandana
Ragama
Hendala
COLOMBO
Dehiwala
Moratuwa
GAMPAHA
KEGALLA
Mawanella
KANDY
Gampola
Nawalapitiya
NUWARA ELIYA
Avissawella
Maharagama
Kotte
WESTERN PROVINCE
COLOMBO DISTRICT
GAMPAHA DISTRICT
KEGALLA DISTRICT
NUWARA ELIYA DISTRICT
SABARAGAMUWA PROVINCE
CENTRAL PROVINCE
Peak Wilderness Santuary
Strict Natural Reserve
Victoria Ran
Victoria Falls
Adikarigama
Kurundu Oya Falls
Ravana Ella Falls
Bopath Ella Falls
Baker's Falls
Kirigalpotta
Gal oya
Kelani Ganga
Attanagalu Oya
Maha Oya
Mee Oya
Kalatuwawa Reservoir
Laksapana Falls
Castlereagh Reservoir
Mausakele Reservoir
Labugama Reservoir
Victoria Reservoir
Bibile Rock
Sri Pada
Bopath Ella Falls
Galagama Falls
Gilimale
Egoda Uyana
Kolonnawa
Kollupitiya
Wennappuwa
Nainamadama
Bolawatta
Kochchikade
Welihena
Lunuwila
Makandura
Giriula
Polgahawela
Alawwa
Rambukkana
Labugoda
Hataraliyadda
Hedeniya
Aladeniya
Madawala
Walala
Menikhinna
Degaldoruwa
Kundasale
Rangala
Huthuhapuwa
Udispattuwa
Teldeniya
Medamahanuwara
Danikotuwa
Sandalankawa
Pannala
Wellahinda
Badalkumbura
Kotadeniyawa
Godigamuwa
Alagalla
Menikdiwela
Pinnawala
Elephants Orphanage
Balana
Kadugannawa
Wattappola
Embekke
Hindagala
Talatu Oya
Gurudeniya
Horagama
Anuragama
Kiwulinda
Marassana
Mailapitiya
Kandahandiya
Galaha
Gelioya
Katana
Kandawala
Minuwatta
Dunagaha
Dagonna
Mirigama
Warakapola
Amunugama
Pitagaldeniya
Hettimulla
Dedigama
Pallewela
Diwulapitiya
Talelya
Baliapana
Andiambalama
Minuwangoda
Medagampitiya
Kowinna
Weedagama
Veyangoda
Nittambuwa
Pasyala
Udugampola
Kotugoda
Ekala
Mahara
Kiribathgoda
Kelaniya
Peliyagoda
Kaduwela
Malabe
Kirillapone
Nugegoda
Kohawa
Meepe
Godagama
Homagama
Padukka
Piliyandala
Kesbewa
Kahatuduwa
Talagala
Talgahawila
Kahapitiya
Kindalapitiya
Gonapola
Widiyagoda
Pokunuwita
Ingiriya
Dumbara
Idangoda
Poruwedanda
Gorakaela
Yatiyantota
Ruwanwella
Anguruwella
Kotiyakumbura
Bulatkohupitiya
Galapitamada
Attanagalla
Urapola
Nelligahamula
Waturugama
Kirindiwela
Radawana
Amitirigala
Henegama
Belummahara
Minuwatta
Weiweriya
Udupila
Naduwatta
Pugoda
Mahadeniya
Karawanella
Talduwa
Dehiowita
Kosgama
Dompe
Malwana
Gindara
Puwakpitiya
Deraniyagala
Nooriya
Delioluwa
Kitulgala
Urumiwala
Dedugala
Saliya
Gonagaldeniya
Dolosbage
Ulapane
Morape
Kotmale New Town
Ramboda
Ramboda Falls
Mandaram Nuwara
Padiyapelella
Maturata
Pupuressa
Hewaheta
Poramadulla
Pussellawa
Hanguranketa
Pallebowala
Rikillagaskada
Lamasoriya
Narantala
Kandapola
Ragala
Brookside
Hasseliya
Pidurutalagala
Nanu Oya
Radella
Lindula
Mipillimana
Hanguala
Medawa
Mahagastota
Boburu Fall
Watagoda
Black Fo
Dimbula
Watawala
Ginigathhena
Bogahawatta
Salapitiya
Hangra Oya
Sri Lena
See Fourth
Nawata
Paraswella
Yatiyantota
Kotagala
Patana
Rozella
Norton Bridge
Nagasena
Hatton
Dikoya
Agarapatana
Ambewela
Pattipola
Norwood
Maskeliya
Nallatanniya
Bogawantalawa
Upcot
Bopaththalawa
Singarawatta
Horton Plains
Ohiya
Totapola
Belihuloya
Noriya
Deraniyagala
Gelanigama
Minnana
Panawala
Digowa
Maliboda
Dambayatawara
Waga
Labugama
Ehaliyagoda
Parakaduwa
Ellawala
Pussella
Kuruwita
Siripagama
Batadombaena
Guruluwana
Erathna
Handapangoda
Talgahawila
Padukka
Homagama
Godagama
Meepe
Kohawa
Nugegoda
Kollupitiya
Kirillapone
Welawatta
Rathmalana
Mt Lavinia
Koralawella
Egoda Uyana
Mahawila
Gurubewila
Pinnawala
Halpe
Landuyaya
World's End
Idalgashinna
Kuruwita
Ratnapura
Kalawana
Eheliyagoda
Kahawatta
Kolonna
Embilipitiya
Balangoda
Weligepola
Pelmadulla
Rakwana
Bulathsinhala
Agalawatta
Millaniya
Kalutara
Panadura
Horana
Ingiriya
Matugama
Aluthgama
Beruwala
Kalutara South
Wadduwa
Moratuwa
Dehiwala
Mt Lavinia
Colombo
Kollupitiya
Bambalapitiya
Wellawatta
Kirillapone
Nugegoda
Maharagama
Kotte
Kaduwela
Malabe
Battaramulla
Pelawatta
Thalawathugoda
Kolonnawa
Peliyagoda
Kelaniya
Mahara
Kiribathgoda
Ja-Ela
Kandana
Ragama
Hendala
Wattala
Negombo
Katunayaka
Pitipana
Seeduwa
Andiambalama
Minuwangoda
Kowinna
Weedagama
Veyangoda
Udugampola
Gampaha
Botanical Garden
Kotugoda
Ekala
Pamunugama
Belummahara
Minuwatta
Weiweriya
Udupila
Naduwatta
Pugoda
Mahara
Kiribathgoda
Kelaniya
Peliyagoda
Kaduwela
Malabe
Kirillapone
Nugegoda
Kohawa
Meepe
Godagama
Homagama
Padukka
Piliyandala
Kesbewa
Kahatuduwa
Talagala
Talgahawila
Kahapitiya
Kindalapitiya
Gonapola
Widiyagoda
Pokunuwita
Ingiriya
Dumbara
Idangoda
Poruwedanda
Gorakaela
Yatiyantota
Ruwanwella
Anguruwella
Kotiyakumbura
Bulatkohupitiya
Galapitamada
Attanagalla
Urapola
Nelligahamula
Waturugama
Kirindiwela
Radawana
Amitirigala
Henegama
Belummahara
Minuwatta
Weiweriya
Udupila
Naduwatta
Pugoda
Mahadeniya
Karawanella
Talduwa
Dehiowita
Kosgama
Dompe
Malwana
Gindara
Puwakpitiya
Deraniyagala
Nooriya
Delioluwa
Kitulgala
Urumiwala
Dedugala
Saliya
Gonagaldeniya
Dolosbage
Ulapane
Morape
Kotmale New Town
Ramboda
Ramboda Falls
Mandaram Nuwara
Padiyapelella
Maturata
Pupuressa
Hewaheta
Poramadulla
Pussellawa
Hanguranketa
Pallebowala
Rikillagaskada
Lamasoriya
Narantala
Kandapola
Ragala
Brookside
Hasseliya
Pidurutalagala
Nanu Oya
Radella
Lindula
Mipillimana
Hanguala
Medawa
Mahagastota
Boburu Fall
Watagoda
Black Fo
Dimbula
Watawala
Ginigathhena
Bogahawatta
Salapitiya
Hangra Oya
Sri Lena
See Fourth
Nawata
Paraswella
Yatiyantota
Kotagala
Patana
Rozella
Norton Bridge
Nagasena
Hatton
Dikoya
Agarapatana
Ambewela
Pattipola
Norwood
Maskeliya
Nallatanniya
Bogawantalawa
Upcot
Bopaththalawa
Singarawatta
Horton Plains
Ohiya
Totapola
Belihuloya
Noriya
Deraniyagala
Gelanigama
Minnana
Panawala
Digowa
Maliboda
Dambayatawara
Waga
Labugama
Ehaliyagoda
Parakaduwa
Ellawala
Pussella
Kuruwita
Siripagama
Batadombaena
Guruluwana
Erathna
Handapangoda
Talgahawila
Padukka
Homagama
Godagama
Meepe
Kohawa
Nugegoda
Kollupitiya
Kirillapone
Welawatta
Rathmalana
Mt Lavinia
Koralawella
Egoda Uyana
Mahawila
Gurubewila
Pinnawala
Halpe
Landuyaya
World's End
Idalgashinna
Kuruwita
Ratnapura
Kalawana
Eheliyagoda
Kahawatta
Kolonna
Embilipitiya
Balangoda
Weligepola
Pelmadulla
Rakwana
Bulathsinhala
Agalawatta
Millaniya
Kalutara
Panadura
Horana
Ingiriya
Matugama
Aluthgama
Beruwala
Kalutara South
Wadduwa
Moratuwa
Dehiwala
Mt Lavinia
Colombo
Kollupitiya
Bambalapitiya
Wellawatta
Kirillapone
Nugegoda
Maharagama
Kotte
Kaduwela
Malabe
Battaramulla
Pelawatta
Thalawathugoda
Kolonnawa
Peliyagoda
Kelaniya
Mahara
Kiribathgoda
Ja-Ela
Kandana
Ragama
Hendala
Wattala
Negombo
Katunayaka
Pitipana
Seeduwa
Andiambalama
Minuwangoda
Kowinna
Weedagama
Veyangoda
Udugampola
Gampaha
Botanical Garden
Kotugoda
Ekala
Pamunugama