1 E.A.3.2

Implementazioni in `Rust` e esercizi
- https://github.com/CuriousCI/artificial-intelligence

1.1 Ricerca in profondità

DFS (depth first search);

NOTA: nella DFS viene **ignorato** l'ordine alfabetico per archi di pari merito; per come è stata definita l'interfaccia della frontiera i singoli inserimenti sono indipendenti… il problema si potrebbe aggirare trasformando la **stack** in una **priority-queue**, però non vale la pena sbattere la testa su questi dettagli, il concetto è chiaro.

NOTA: lo stesso problema c'è per l'**approfondimento iterativo**, perché non faccio altro che chiamare la versione iterativa della ricerca con la stessa frontiera del DFS.

#		**azioni**	**esplorati**	**frontiera**
0	∅		{}	(S, p: -, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
2	D	C	{D, S}	(C, p: D, g: 5, h: 14, f: 19, d: 2) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
3	C	S, G2	{D, C, S}	(G2, p: C, g: 23, h: 0, f: 23, d: 3) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
4	G2		{D, C, G2, S}	is goal

Percorso S → D → C → G2
Costo $3 + 2 + 18 = 23$
Iterazioni 4
Ottimalità il costo non è ottimale, e generalmente la DFS non garantisce ottimalità

1.2 Ricerca in ampiezza

BFS (breadth first search)

#		azioni	esplorati	frontiera
0	∅		{}	(S, p: -, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(A, p: S, g: 3, h: 16, f: 19, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
2	A	E, H	{A, S}	(B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1) (E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2)
3	B	C, I, J	{A, B, S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2)
4	D	C	{A, B, D, S}	(E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2)
5	E	D, H	{A, B, D, E, S}	(H, p: A, g: 11, h: 8, f: 19, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2)
6	H	G1	{A, B, D, E, H, S}	(C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (G1, p: H, g: 20, h: 0, f: 20, d: 3)
7	C	S, G2	{A, B, C, D, E, H, S}	(I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (G1, p: H, g: 20, h: 0, f: 20, d: 3) (G2, p: C, g: 23, h: 0, f: 23, d: 3)
8	I	A, H	{A, B, C, D, E, H, I, S}	(J, p: B, g: 8, h: 10, f: 18, d: 2) (G1, p: H, g: 20, h: 0, f: 20, d: 3) (G2, p: C, g: 23, h: 0, f: 23, d: 3)
9	J	G2	{A, B, C, D, E, H, I, J, S}	(G1, p: H, g: 20, h: 0, f: 20, d: 3) (G2, p: C, g: 23, h: 0, f: 23, d: 3)
10	G1		{A, B, C, D, E, G1, H I, J, S}	is goal

Percorso S $\rightarrow$ A $\rightarrow$ H $\rightarrow$ G1
Costo $3 + 8 + 9 = 20$
Iterazioni 10
Ottimalità il costo non è ottimale, generalmente la BFS garantisce ottimalità solo se il costo dei cammini aumenta monoticamente con la profondità

1.3 Ricerca a costi uniformi

Min cost search

#		azioni	esplorati	frontiera
0	∅		{}	(S, p: -, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(A, p: S, g: 3, h: 16, f: 19, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
2	A	E, H	{A, S}	(B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1) (E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2)
3	B	C, I, J	{A, B, S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (E, p: A, g: 4, h: 15, f: 19, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2)
4	D	C	{A, B, D, S}	(E, p: A, g: 4, h: 15, f: 19, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2)
5	E	D, H	{A, B, D, E, S}	(C, p: B, g: 5, h: 14, f: 19, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2)
6	C	S, G2	{A, B, C, D, E, S}	(I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2) (G2, p: C, g: 23, h: 0, f: 23, d: 3)
7	I	A, H	{A, B, C, D, E, I, S}	(J, p: B, g: 8, h: 10, f: 18, d: 2) (H, p: I, g: 10, h: 8, f: 18, d: 3) (G2, p: C, g: 23, h: 0, f: 23, d: 3)
8	J	G2	{A, B, C, D, E, I, J, S}	(H, p: I, g: 10, h: 8, f: 18, d: 3) (G2, p: J, g: 20, h: 0, f: 20, d: 3)
9	H	G1	{A, B, C, D, E, H, I, J, S}	(G1, p: H, g: 19, h: 0, f: 19, d: 4) (G2, p: J, g: 20, h: 0, f: 20, d: 3)
10	G1		{A, B, C, D, E, G1, H, I, J, S}	is goal

Percorso $S \to B \to I \to H \to G1$
Costo $3 + 3 + 4 + 9 = 19$
Iterazioni 10
Ottimalità il costo è ottimale, e generalmente il min-cost trova il cammino ottimale (si considera sempre il caso di un albero di ricerca finito)

1.4 Ricerca ad approfondimento iterativo

Iterative deepening search

#		azioni	esplorati	frontiera
0	∅		{}	(S, p: –, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
2	D		{D, S}	(B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
3	B		{B, D, S}	(A, p: S, g: 3, h: 16, f: 19, d: 1)
4	A		{A, B, D, S}	
5	∅		{}	(S, p: –, g: 0, h: 20, f: 20, d: 0)
6	S	A, B, D	{S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
7	D	C	{D, S}	(C, p: D, g: 5, h: 14, f: 19, d: 2) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
7	C		{C, D, S}	(B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
8	B	C, I, J	{B, C, D, S}	(J, p: B, g: 8, h: 10, f: 18, d: 2) (I, p: B, g: 6, h: 12, f: 18, d: 2) (A, p: S, g: 3, h: 16, f: 19, d: 1)
9	J		{B, C, D, J, S}	(I, p: B, g: 6, h: 12, f: 18, d: 2) (A, p: S, g: 3, h: 16, f: 19, d: 1)
10	I		{B, C, D, I, J, S}	(A, p: S, g: 3, h: 16, f: 19, d: 1)
11	A	E, H	{A, B, C, D, J, S}	(H, p: A, g: 11, h: 8, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2)
12	H		{A, B, C, D, H, J, S}	(E, p: A, g: 4, h: 15, f: 19, d: 2)
13	E		{A, B, C, D, E, H, J, S}	
14	∅		{}	(S, p: –, g: 0, h: 20, f: 20, d: 0)
15	S	A, B, D	{S}	(D, p: S, g: 3, h: 17, f: 20, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
16	D	C	{D, S}	(C, p: D, g: 5, h: 14, f: 19, d: 2) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)

#		azioni	esplorati	frontiera
17	C	S, G2	{C, D, S}	(G2, p: C, g: 23, h: 0, f: 23, d: 3) (B, p: S, g: 3, h: 16, f: 19, d: 1) (A, p: S, g: 3, h: 16, f: 19, d: 1)
18	G2		{C, D, G2, S}	is goal

Percorso S → D → C → G2
Costo 3 + 2 + 18 = 23
Iterazioni 18
Ottimalità il cammino non è ottimale, e generalmente non è detto che la ricerca ad approfondimento iterativo trovi un cammino con costo ottimale

1.5 Ricerca best-first greedy

Best-first greedy search

#		azioni	esplorati	frontiera
0	∅		{}	(S, p: –, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(A, p: S, g: 3, h: 16, f: 19, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
2	A	E, H	{A, S}	(H, p: A, g: 11, h: 8, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
3	H	G1	{A, H, S}	(G1, p: H, g: 20, h: 0, f: 20, d: 3) (E, p: A, g: 4, h: 15, f: 19, d: 2) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
4	G1		{A, G1, H, S}	is goal

Percorso S → A → H → G1
Costo $3 + 8 + 9 = 20$
Iterazioni 4
Ottimalità il cammino non è ottimale, generalmente il best-first non trova l'algoritmo ottimale, a meno che l'euristica non è fedele al costo effettivo dei cammini

1.6 A*

A*

#		azioni	esplorati	frontiera
0	∅		{}	(S, p: -, g: 0, h: 20, f: 20, d: 0)
1	S	A, B, D	{S}	(A, p: S, g: 3, h: 16, f: 19, d: 1) (B, p: S, g: 3, h: 16, f: 19, d: 1) (D, p: S, g: 3, h: 17, f: 20, d: 1)
2	A	E, H	{A, S}	(B, p: S, g: 3, h: 16, f: 19, d: 1) (E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2) (D, p: S, g: 3, h: 17, f: 20, d: 1)
3	B	C, I, J	{A, B, S}	(I, p: B, g: 6, h: 12, f: 18, d: 2) (J, p: B, g: 8, h: 10, f: 18, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2) (H, p: A, g: 11, h: 8, f: 19, d: 2) (D, p: S, g: 3, h: 17, f: 20, d: 1)
4	I	A, H	{A, B, I, S}	(H, p: I, g: 10, h: 8, f: 18, d: 3) (J, p: B, g: 8, h: 10, f: 18, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2) (D, p: S, g: 3, h: 17, f: 20, d: 1)
5	H	G1	{A, B, H, I, S}	(J, p: B, g: 8, h: 10, f: 18, d: 2) (C, p: B, g: 5, h: 14, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2) (G1, p: H, g: 19, h: 0, f: 19, d: 4) (D, p: S, g: 3, h: 17, f: 20, d: 1)
5	J	G2	{A, B, H, I, J, S}	(C, p: B, g: 5, h: 14, f: 19, d: 2) (E, p: A, g: 4, h: 15, f: 19, d: 2) (G1, p: H, g: 19, h: 0, f: 19, d: 4) (D, p: S, g: 3, h: 17, f: 20, d: 1) (G2, p: J, g: 20, h: 0, f: 20, d: 3)
6	C	S, G2	{A, B, C, H, I, J, S}	(E, p: A, g: 4, h: 15, f: 19, d: 2) (G1, p: H, g: 19, h: 0, f: 19, d: 4) (D, p: S, g: 3, h: 17, f: 20, d: 1) (G2, p: J, g: 20, h: 0, f: 20, d: 3)
7	E	D, H	{A, B, C, E, H, I, J, S}	(G1, p: H, g: 19, h: 0, f: 19, d: 4) (D, p: S, g: 3, h: 17, f: 20, d: 1) (G2, p: J, g: 20, h: 0, f: 20, d: 3)
8	G1		{A, B, C, E, G1, H, I, J, S}	is goal

Percorso $S \to B \to I \to H \to G1$
Costo $3 + 3 + 8 + 9 = 23$
Iterazioni 8
Ottimalità il cammino non è ottimale, generalmente A^* trova il cammino ottimale solo se l'euristica è consistente

1.7 Euristica

Dato che h consistente $\implies$ A^* trova l'ottimo, e A^* non ha trovato l'ottimo, allora h non è consistente. Non è neanche ammissibile, dato che l'euristica di `S` è 20, ma il percorso ottimale ha costo 19.