



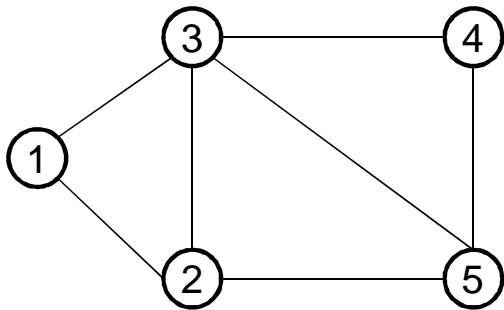
Veštačka inteligencija

CSP – Constraint Satisfaction Problems

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Vladan Mihajlović

Bojenje grafa

- Kako obojiti graf tako da ni jedna dva susedna čvora nemaju istu boju.
 - V (čvorovi grafa)
 - D (moguće boje za svaki čvor)
 - C (ni jedna dva susedna čvora nemaju istu boju)



Promenljive: $\{1,2,3,4,5\}$

Domeni: $\{D1,D2,D2,D4,D5\}$ $D_{i(1,5)}=\{R,G,B\}$

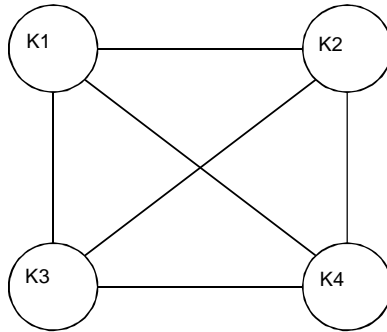
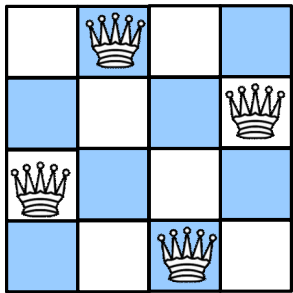
U ovom primeru domeni su isti za sve promenljive!

Ograničenja: $\{1 \neq 2, 1 \neq 3, 2 \neq 1, 2 \neq 3, 2 \neq 5, 3 \neq 2, 3 \neq 4, 3 \neq 5, 4 \neq 3, 4 \neq 5\}$



N Kraljica

- Kako rasporediti n kraljica na šahovskoj tabli dimenzija $n \times n$ tako da se ne napadaju
- $n=4$



Promenljive: $\{K1, K2, K3, K4\}$ $K_{i(1,4)}$ – kraljica u i-tom redu

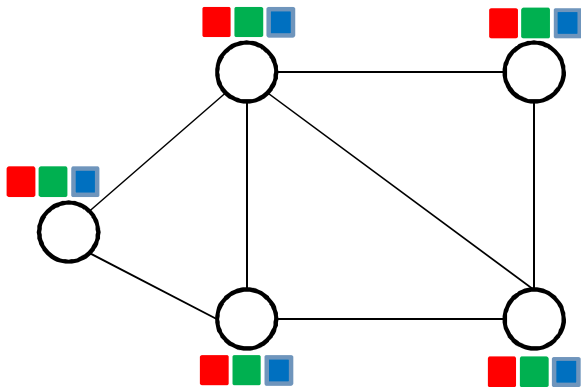
Domeni: $\{D1, D2, D3, D4\}$ $D_{i(1,4)} = \{1, 2, 3, 4\}$ opseg mogućih kolona za K_i kraljicu

Ograničenja: (K_i, K_j) ne mogu biti u istoj koloni ili na dijagonali



Backtracking (BT)

Polazno stanje

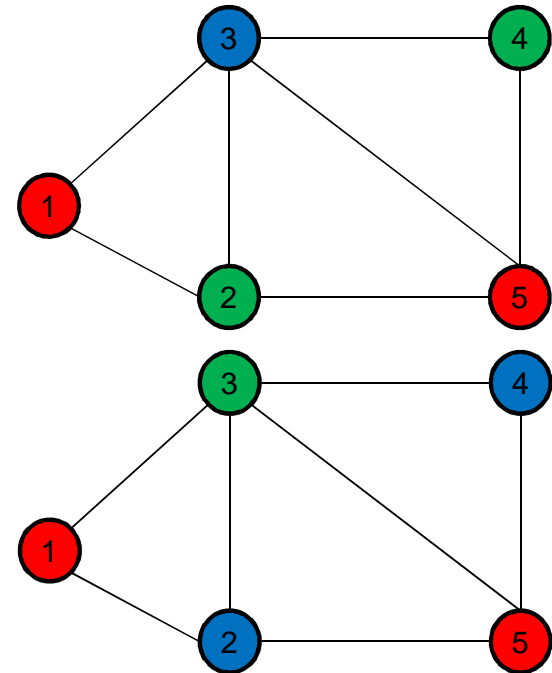


Promenljive: {1,2,3,4,5}

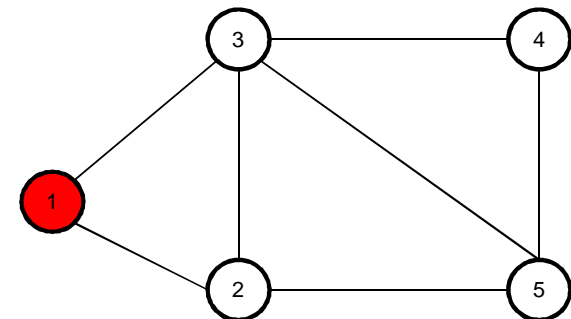
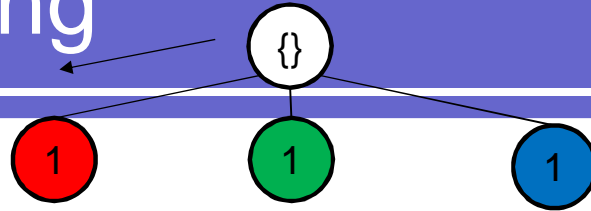
Domeni: {D1,D2,D2,D4,D5} $D_{i(1,5)} = \{R,G,B\}$

Ograničenja: {1≠2, 1≠3, 2≠1, 2≠3, 2≠5, 3≠2, 3≠4, 3≠5, 4≠3, 4≠5}

Ciljno stanje/a



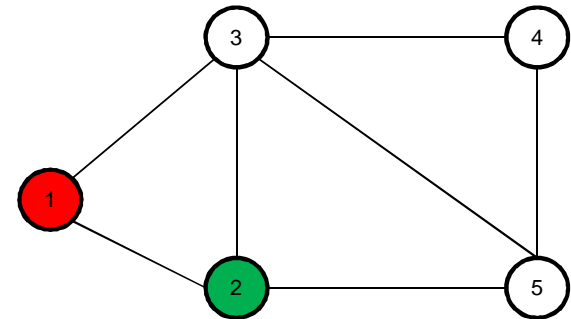
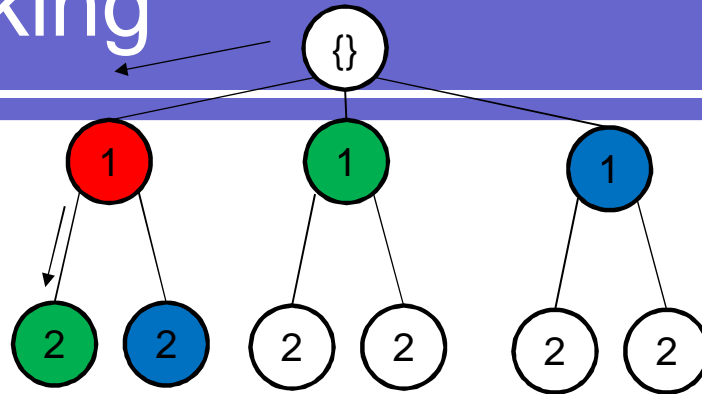
Backtracking



Obilazak: 1,2,5,4,3



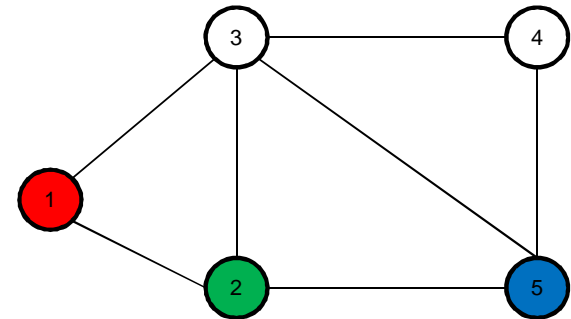
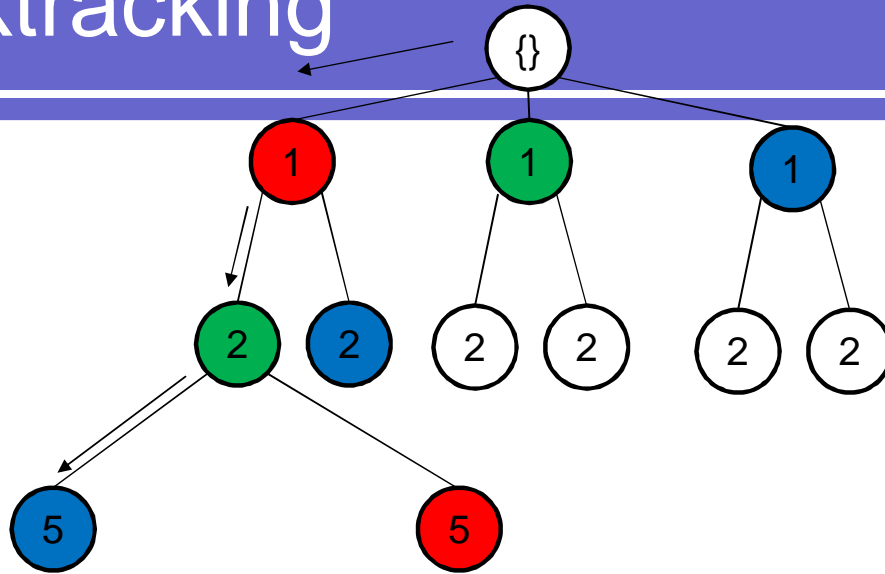
Backtracking



Obilazak: 1,2,5,4,3



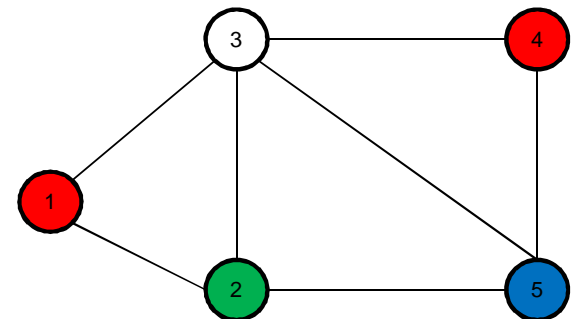
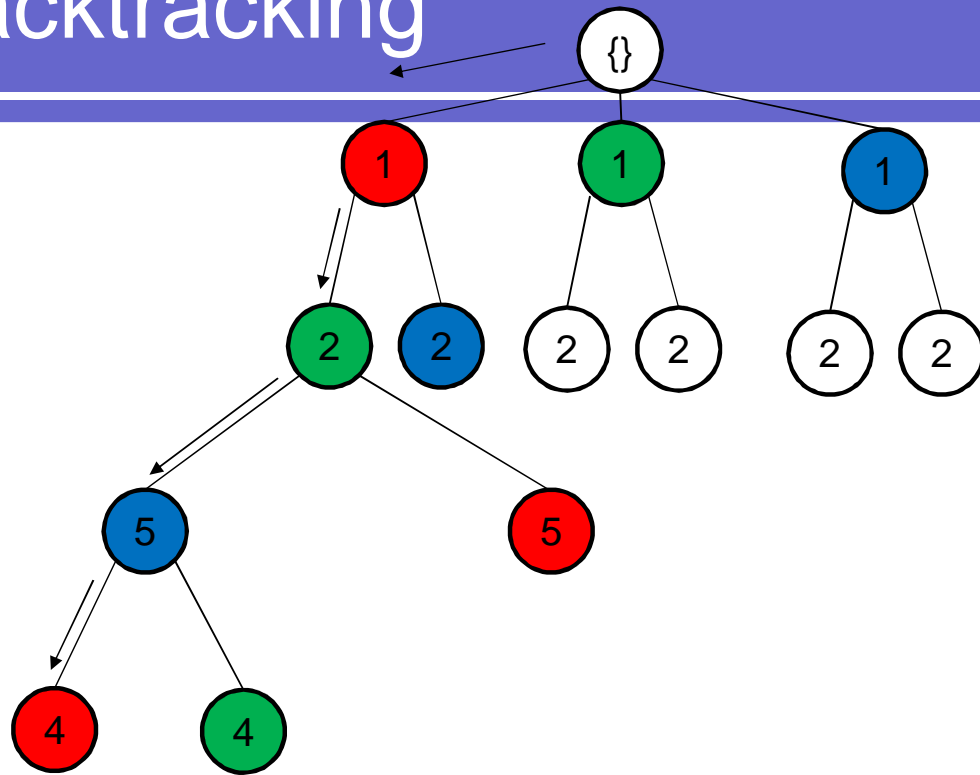
Backtracking



Obilazak: 1,2,5,4,3



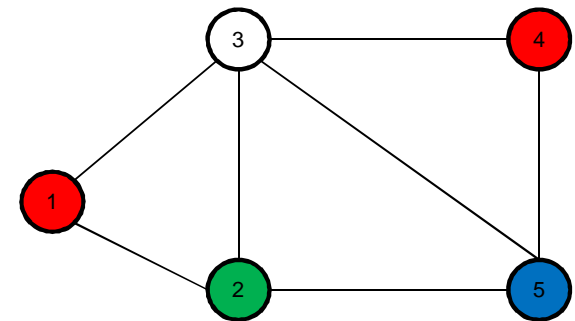
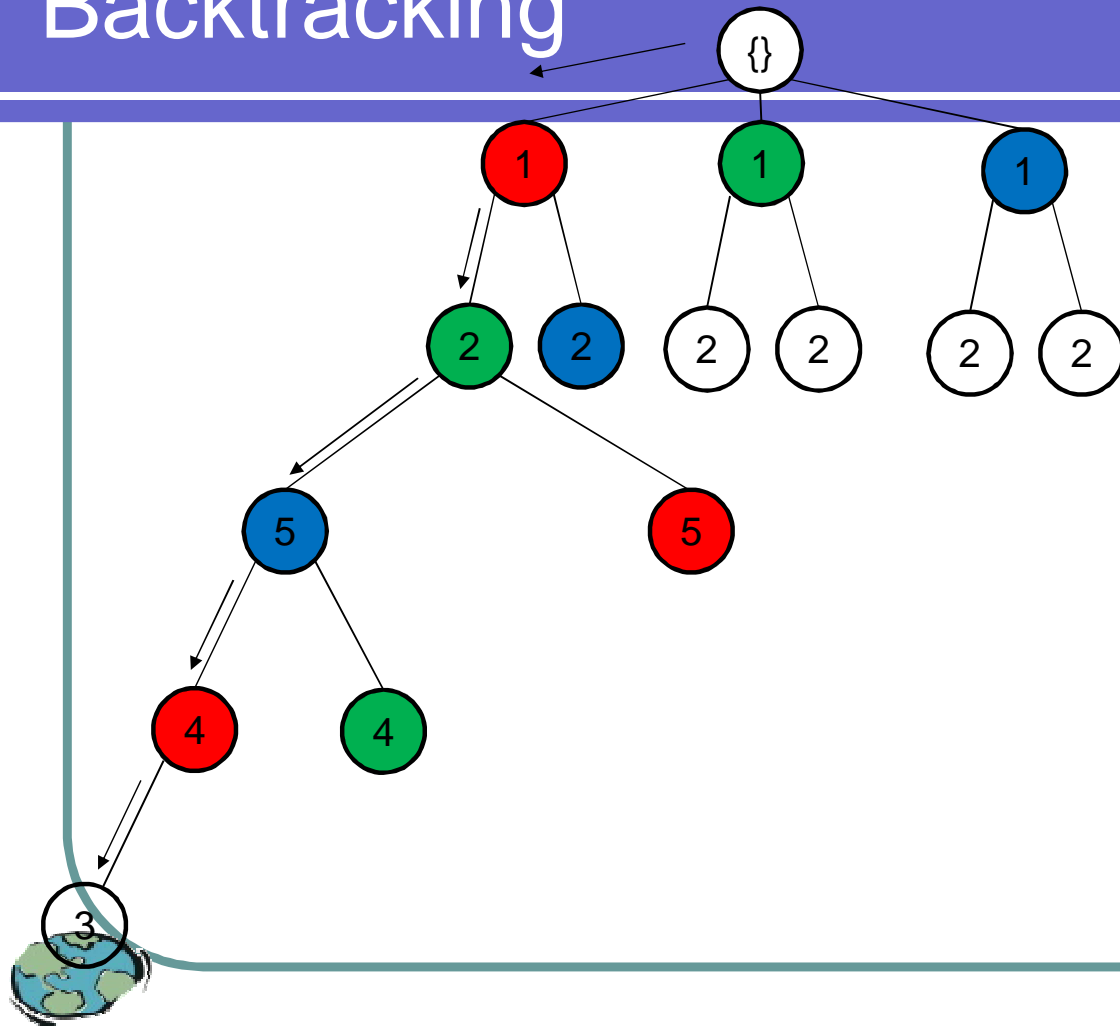
Backtracking



Obilazak: 1,2,5,4,3

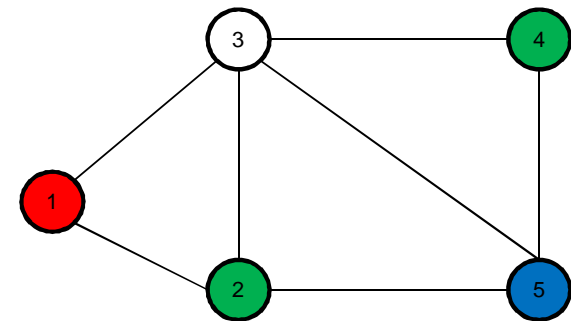
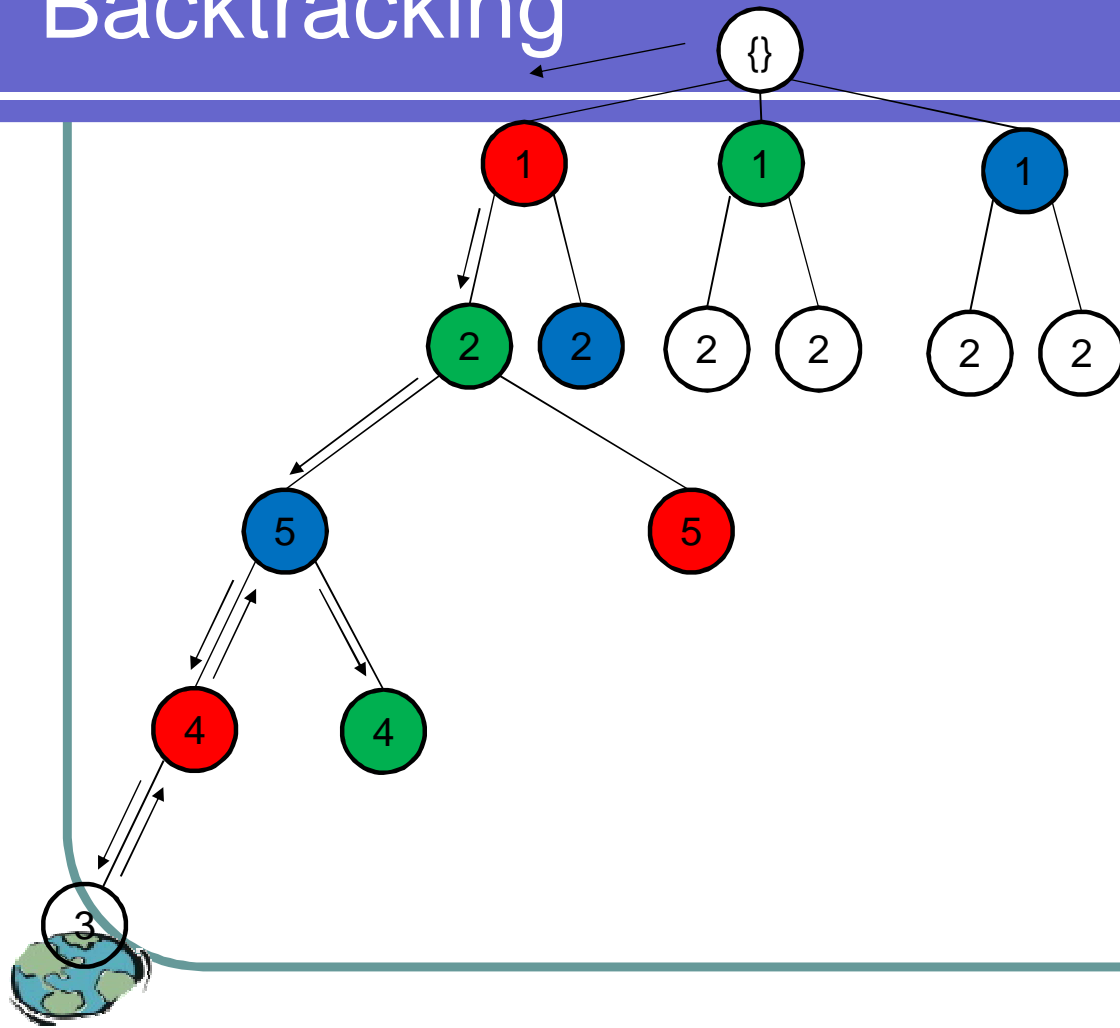


Backtracking



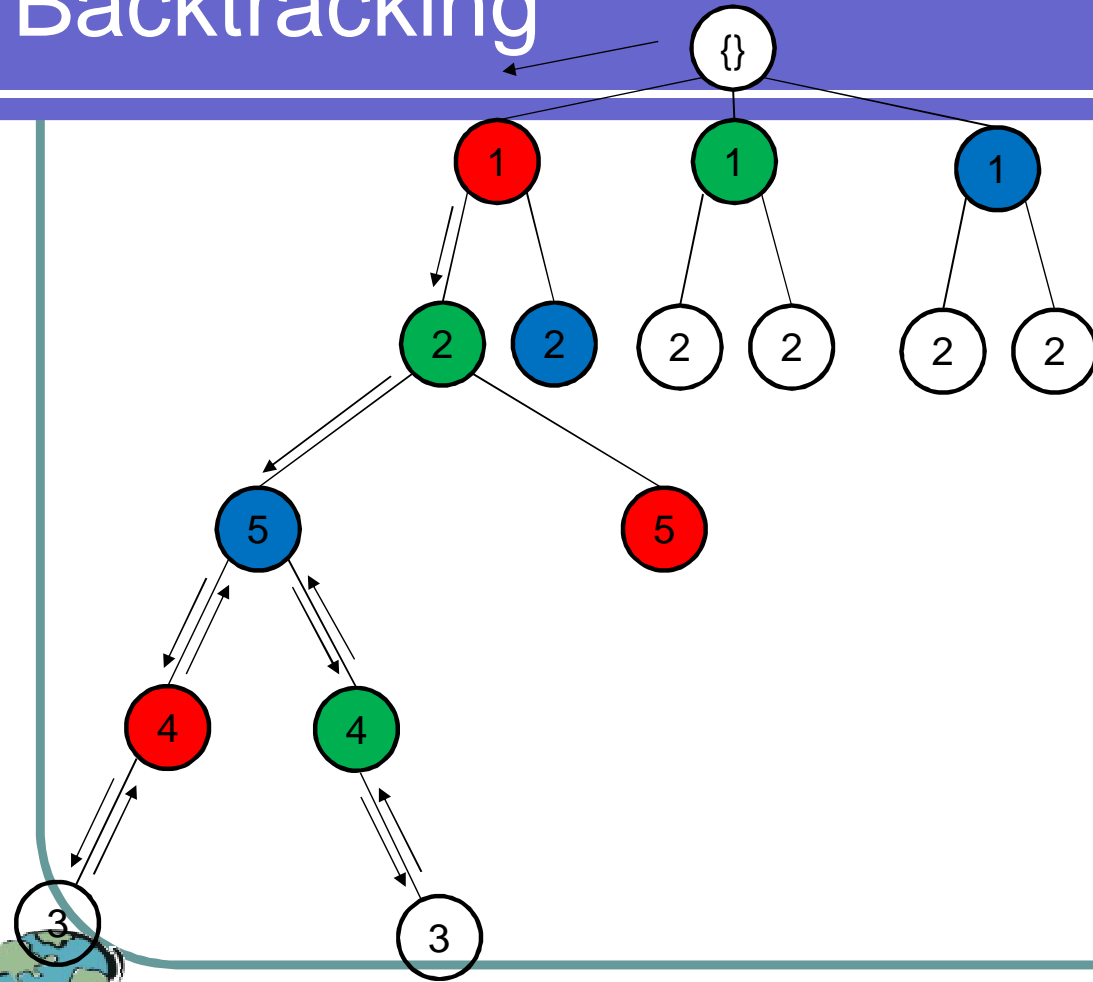
Obilazak: 1,2,5,4,3

Backtracking



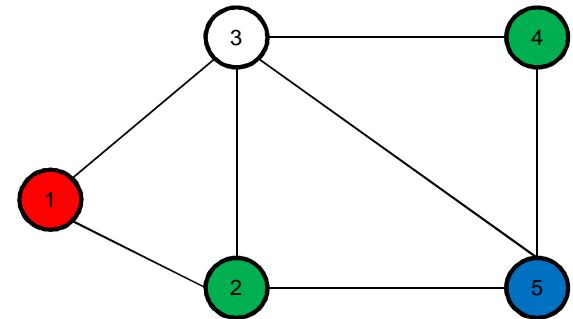
Obilazak: 1,2,5,4,3

Backtracking

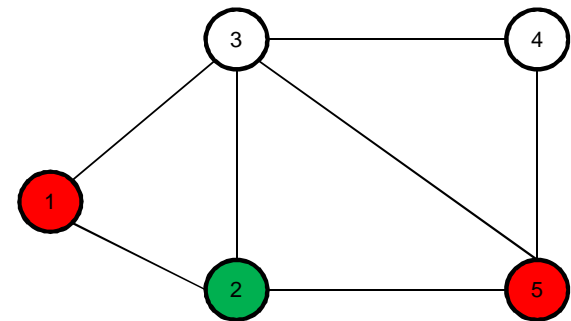
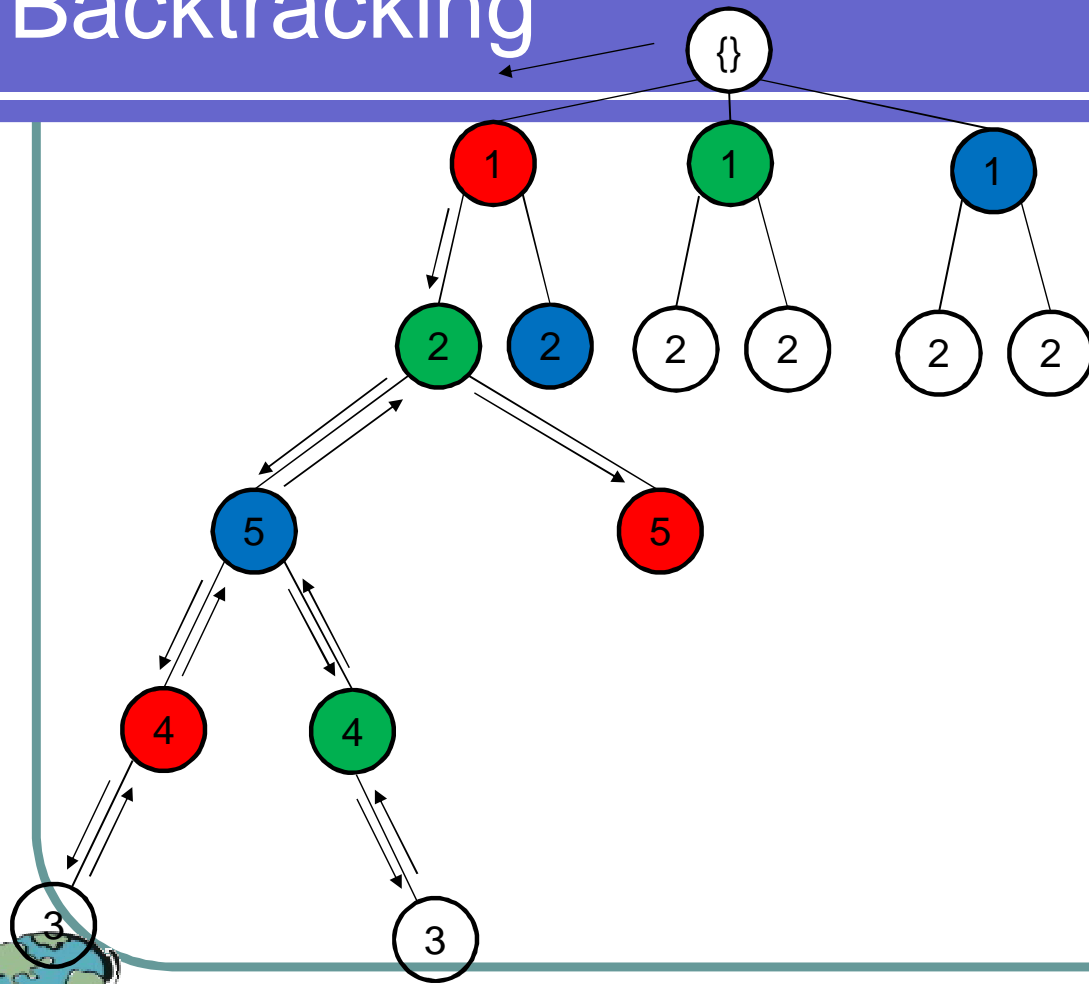


Backtrack:
 $3! = 5, 3! = 4, 3! = 2, 3! = 1$

Obilazak: 1,2,5,4,3

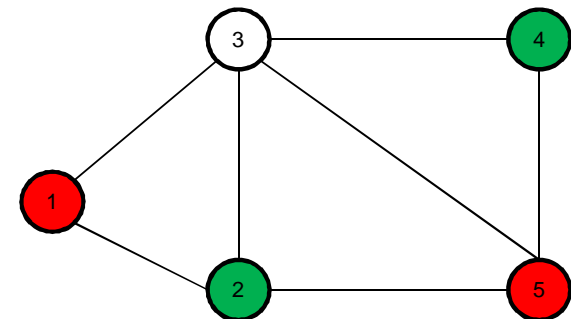
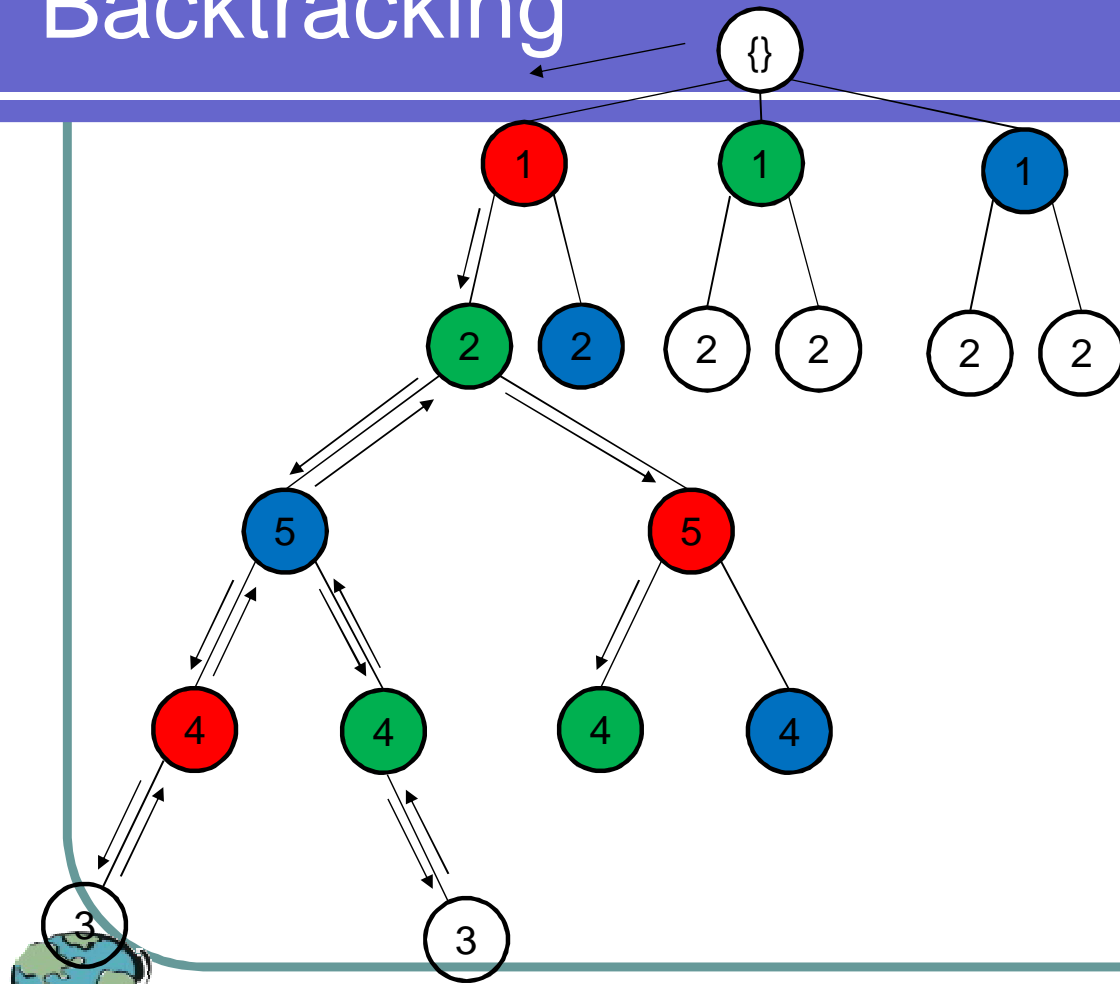


Backtracking



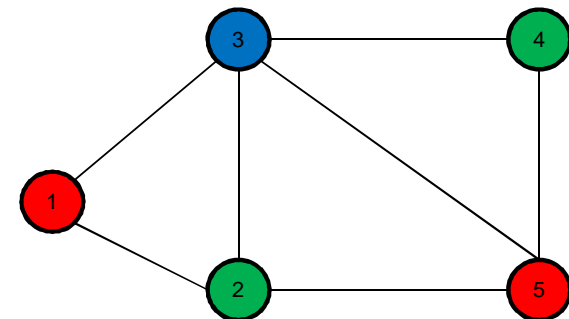
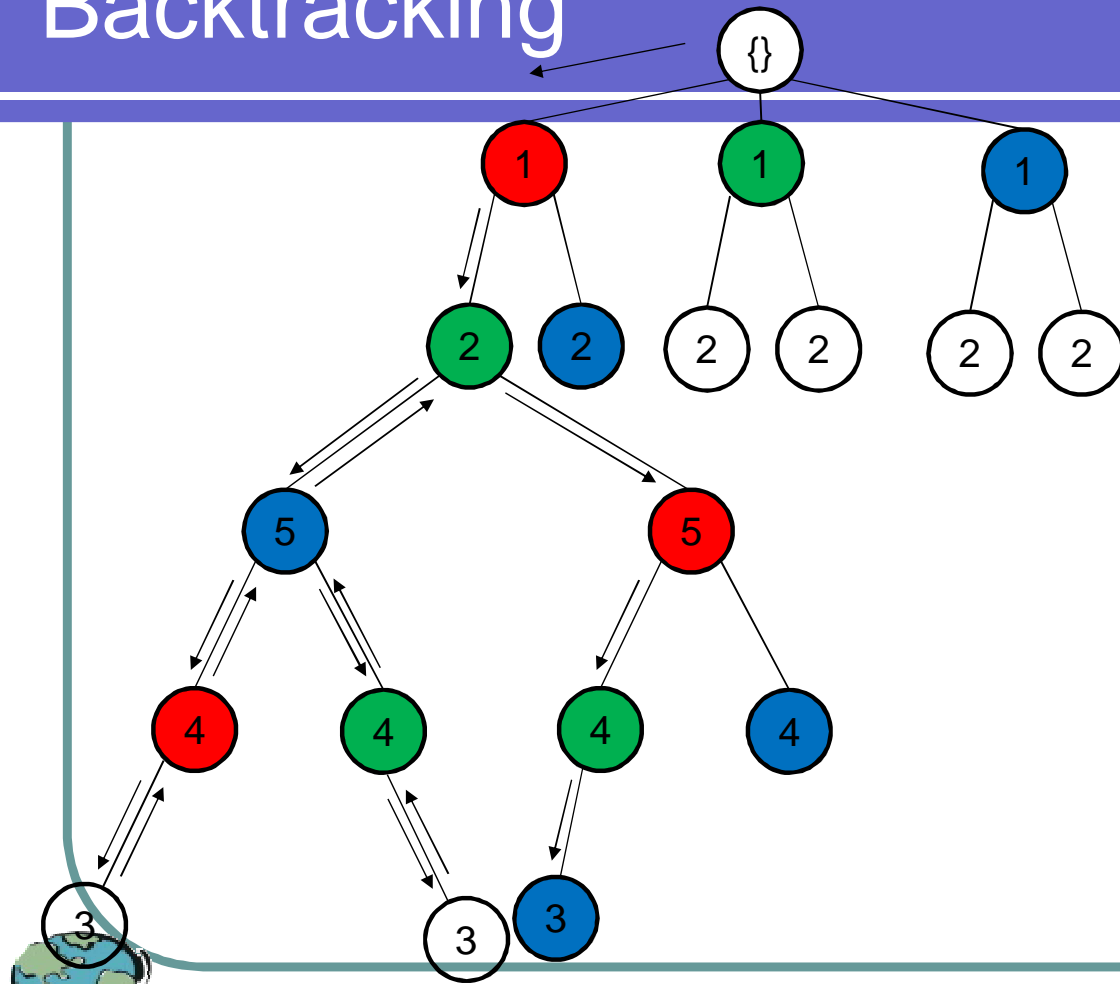
Obilazak: 1,2,5,4,3

Backtracking














Obilazak: 1,2,5,4,3

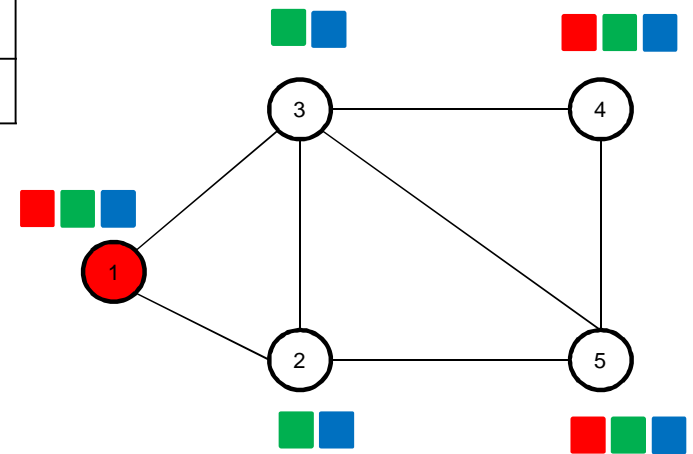
Backtracking



Obilazak: 1,2,5,4,3

Forward Checking (1)




















1	2	5	4	3
	 	  	  	 

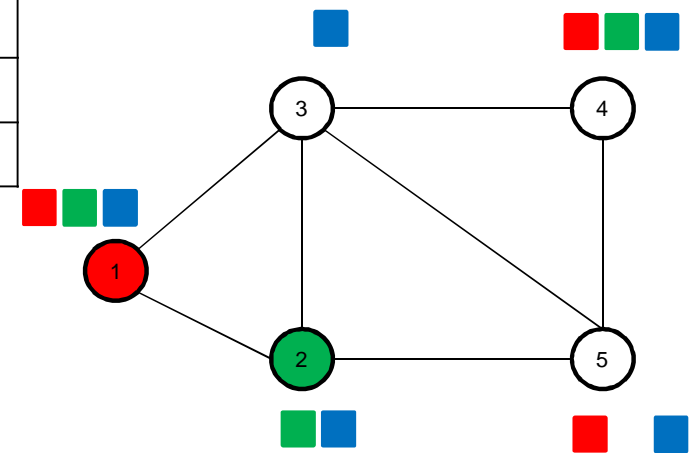


Order: 1,2,5,4,3



Forward Checking (2)




1	2	5	4	3
	 	  	  	 
		 	  	

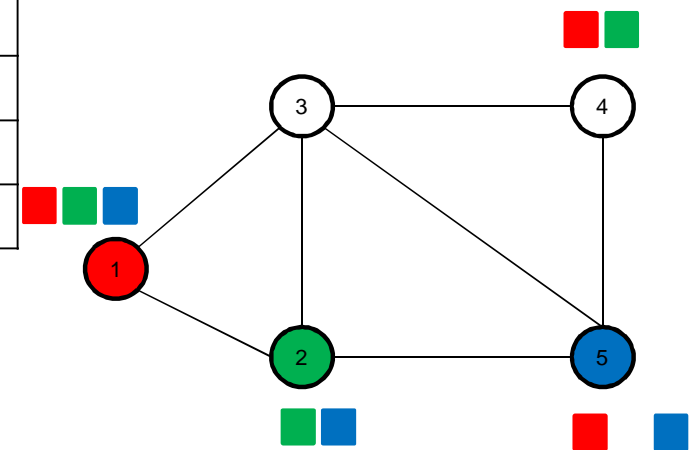


Order: 1,2,5,4,3



Forward Checking (3)



















1	2	5	4	3
	 	  	  	 
		 	  	
			 	/

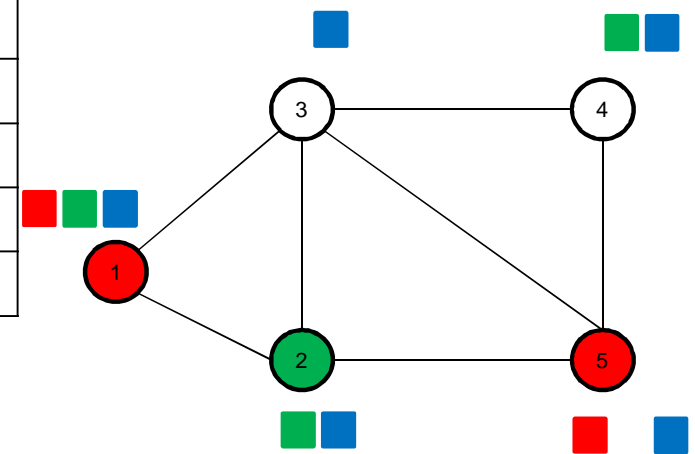


Order: 1,2,5,4,3



Forward Checking (4)
























1	2	5	4	3
				
				
				/
				

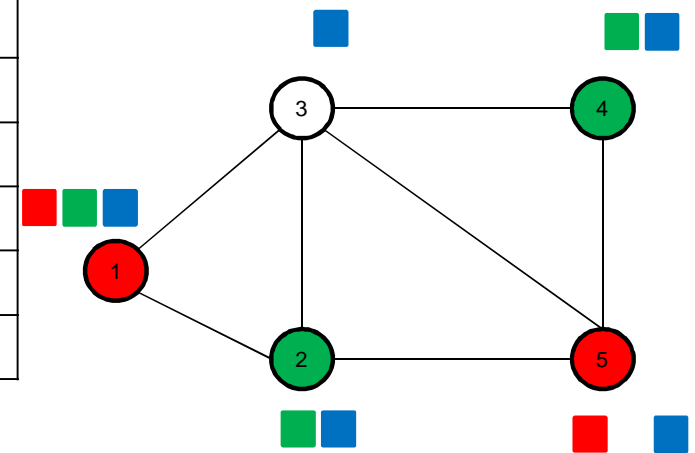


Order: 1,2,5,4,3



Forward Checking (5)





























1	2	5	4	3
				
				
				/
				
				

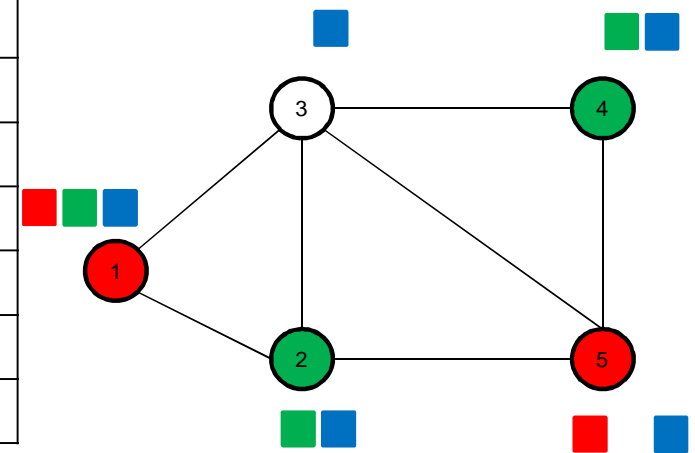


Order: 1,2,5,4,3



Forward Checking (6)

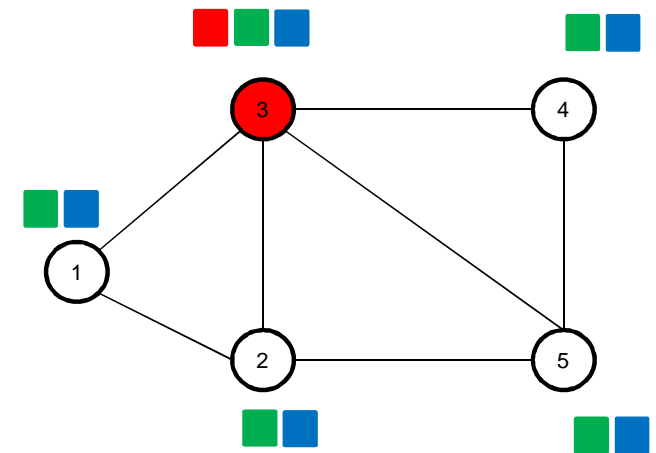
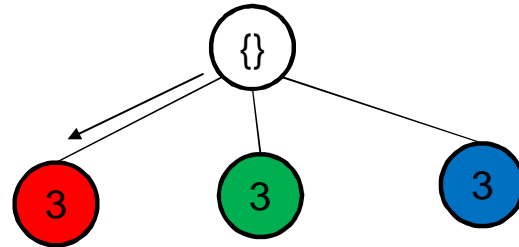
1	2	5	4	3
				
				
				/
				
				
				



Order: 1,2,5,4,3



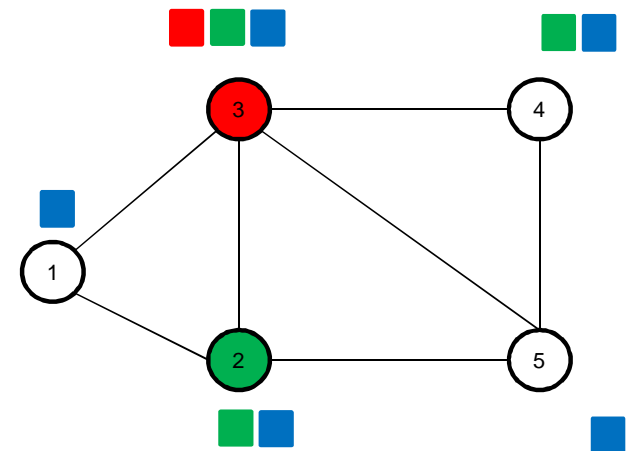
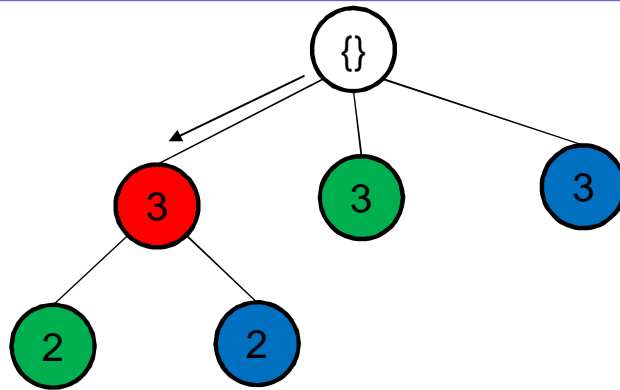
Forward checking & Degree Heuristics (1)



Order: 3,2,5,4,1



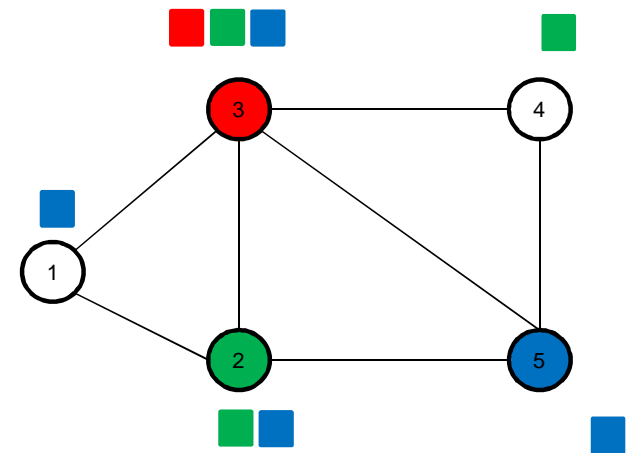
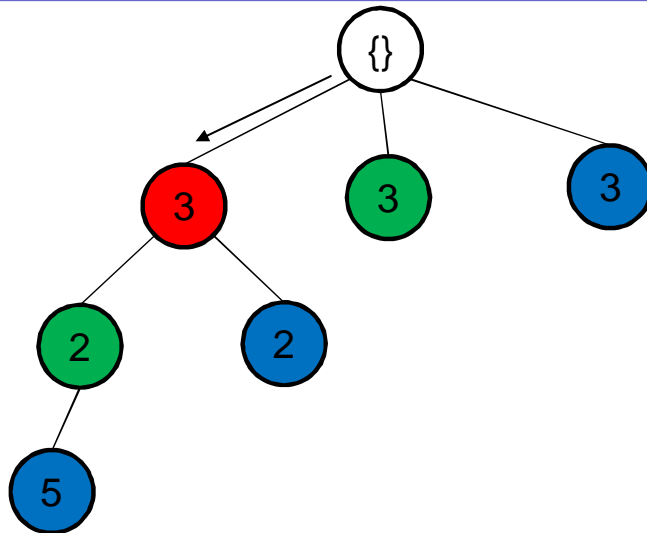
Forward checking & Degree Heuristics (2)



Order: 3,2,5,4,1



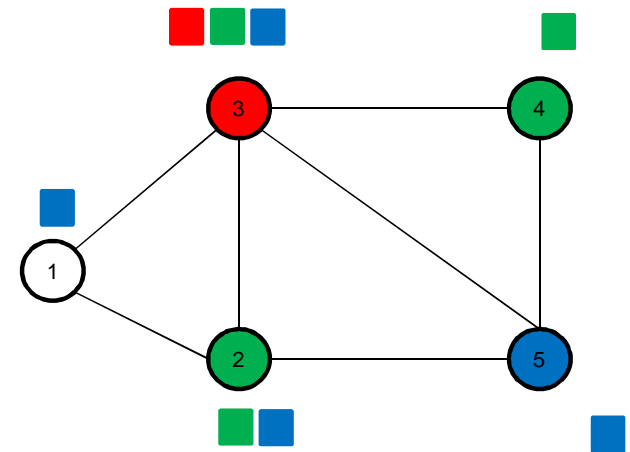
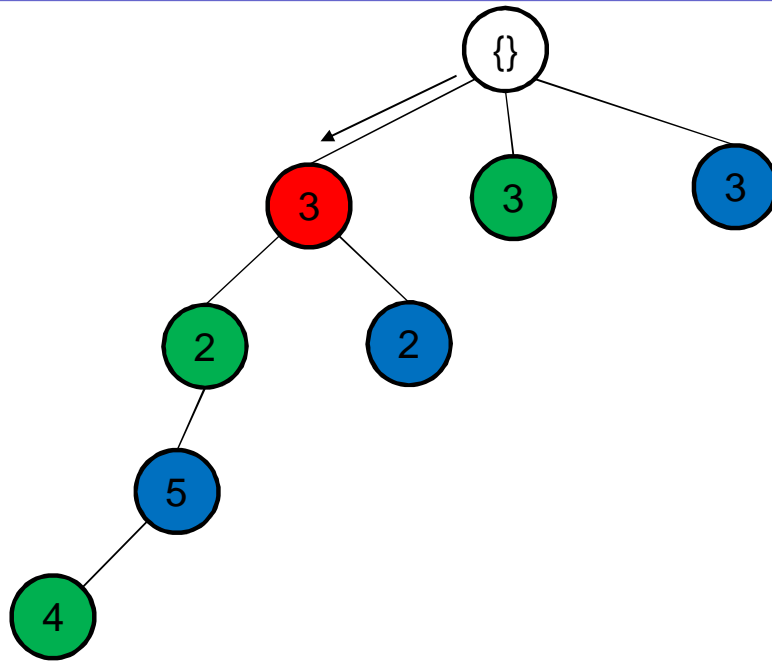
Forward checking & Degree Heuristics (3)



Order: 3,2,5,4,1



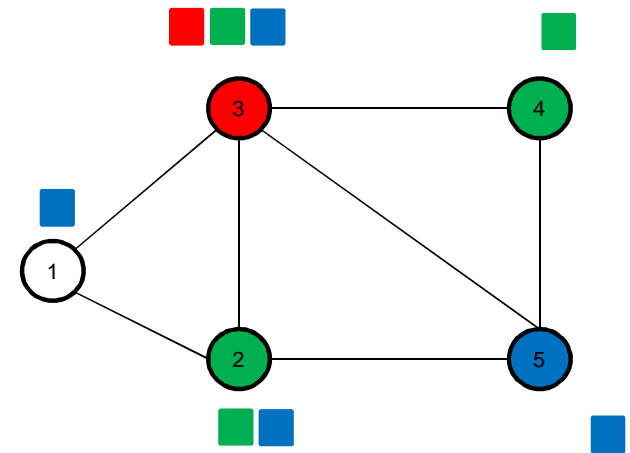
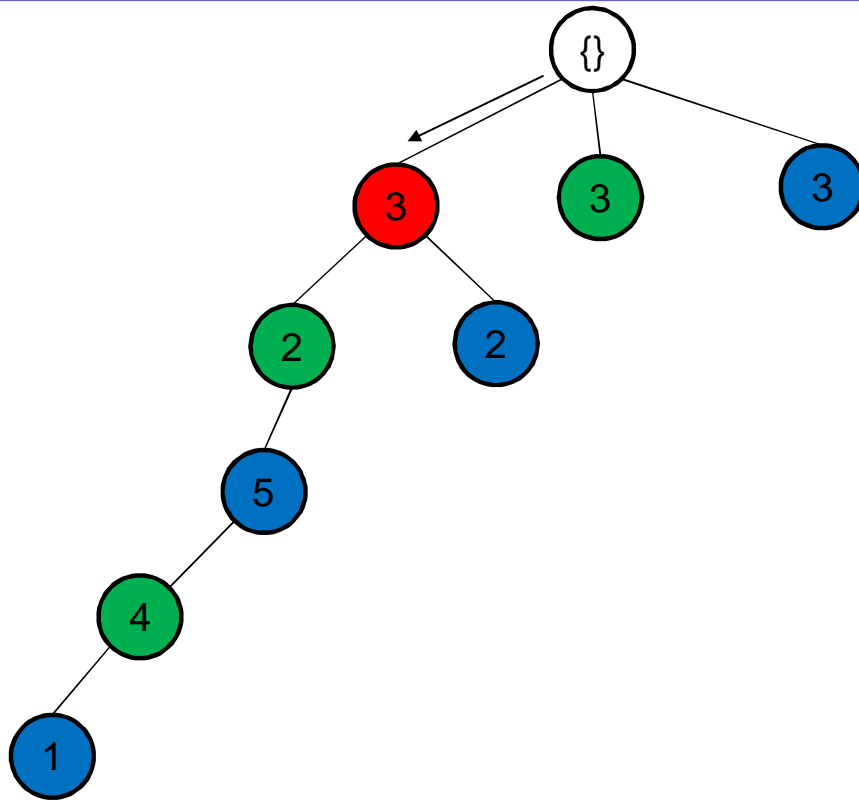
Forward checking & Degree Heuristics (4)



Order: 3,2,5,4,1














Forward checking & Degree Heuristics (5)

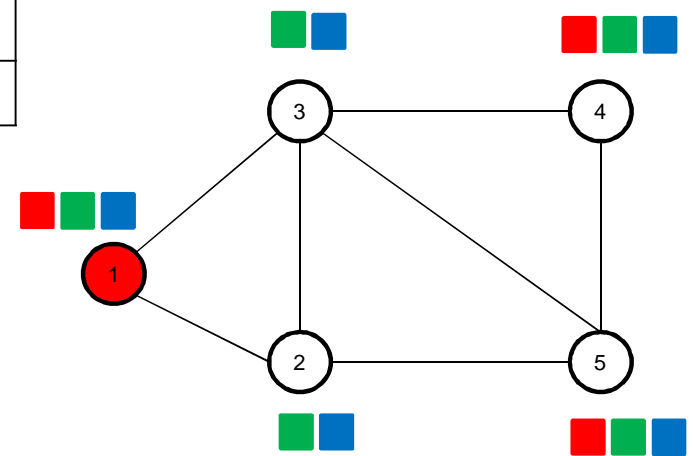


Order: 3,2,5,4,1



Forward checking & MRV (1)

1	2	5	4	3
	 	  	  	 






















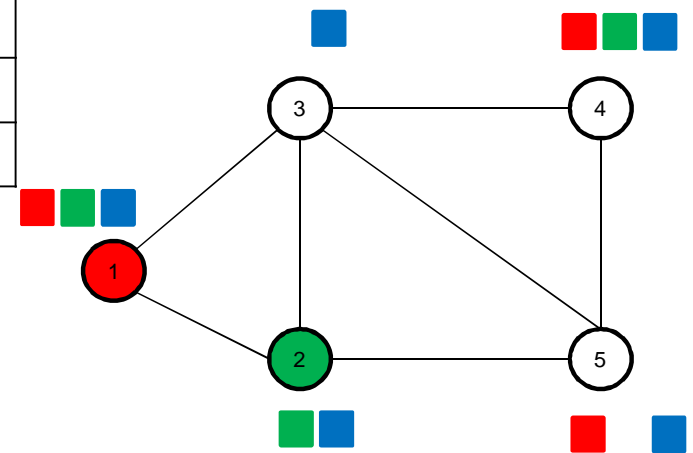
Start with order: 1,2,5,4,3

Order: 1,2,3,4,5





















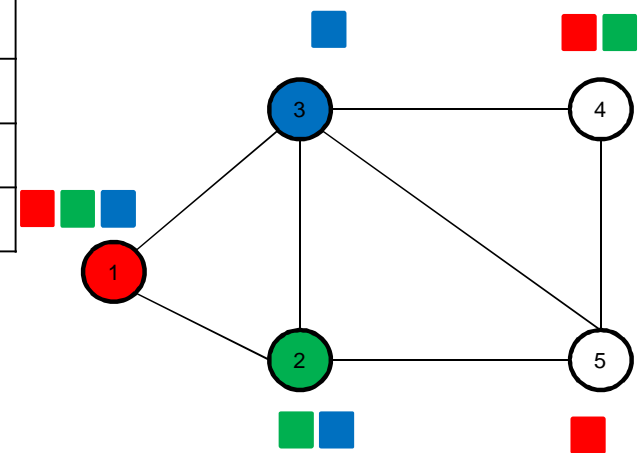
Forward checking & MRV (2)

1	2	5	4	3
	 	  	  	 
		 	  	



Forward checking & MRV (3)

























1	2	5	4	3
	 	  	  	 
		 	  	
			 	

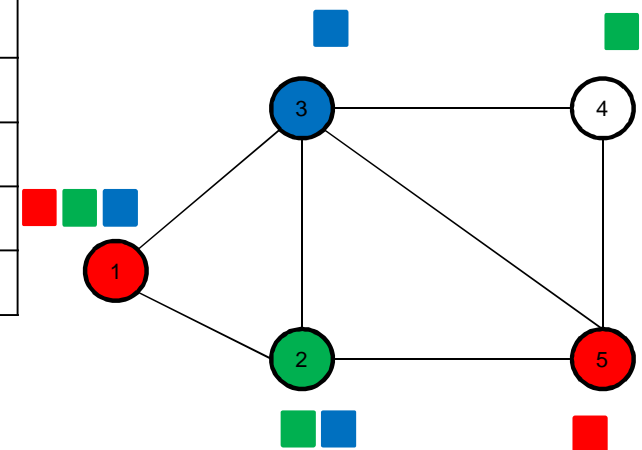


Order: 1,2,5,4,3



Forward checking & MRV (4)



































1	2	5	4	3
	 	  	  	 
		 	  	
			 	
				

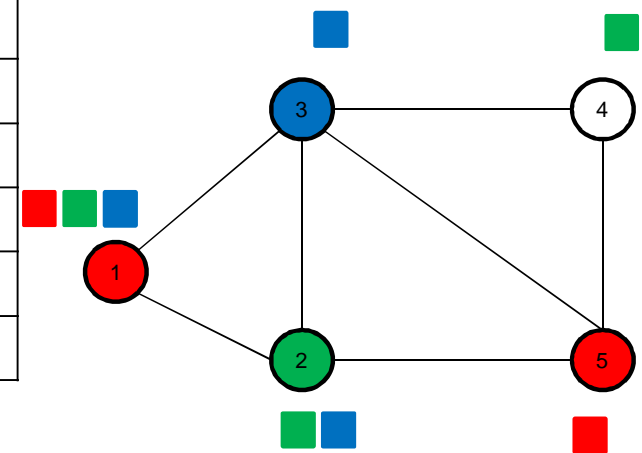


Order: 1,2,5,4,3








Forward checking & MRV (5)

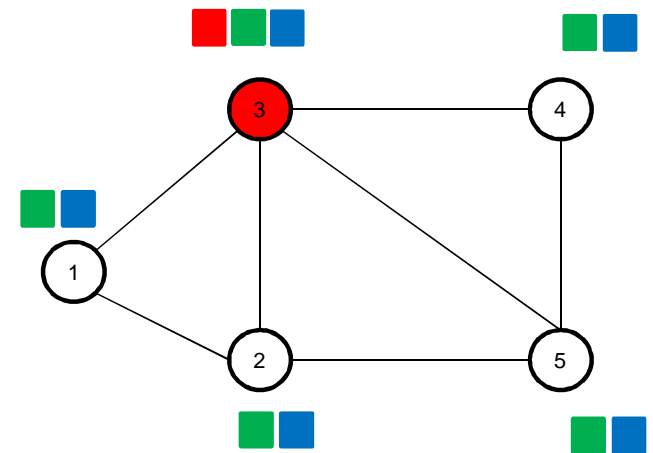
1	2	5	4	3
	 	  	  	 
		 	  	
			 	
				
				



Forward checking & MRV & DH (1)











Start: 3 (Degree Heuristics)

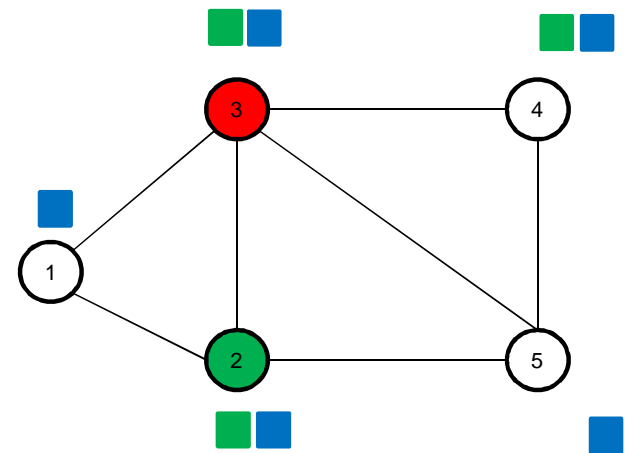
3	2	5	4	1
				



Forward checking & MRV & DH (2)
















Start: 3 (Degree Heuristics)

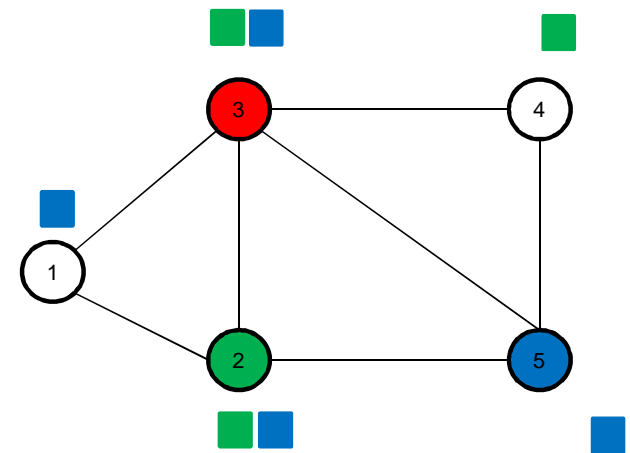
3	2	5	4	1
				
				



Forward checking & MRV & DH (3)





















Start: 3 (Degree Heuristics)

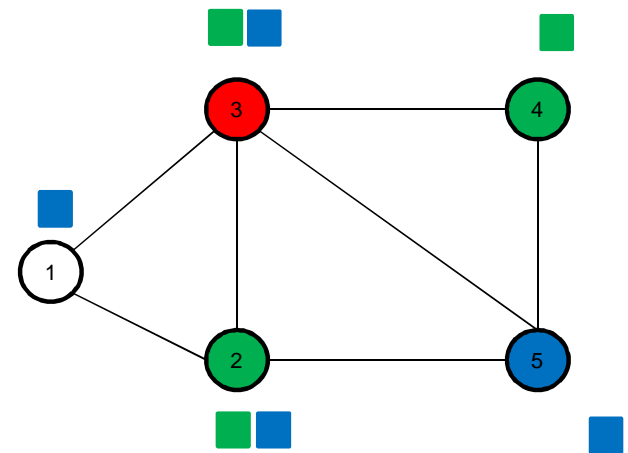
3	2	5	4	1
				
				
				



Forward checking & MRV & DH (4)


























Start: 3 (Degree Heuristics)

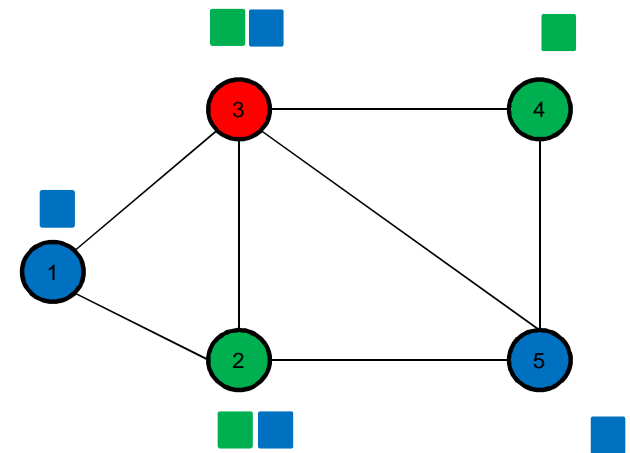
3	2	5	4	1
				
				
				
				








Forward checking & MRV & DH (5)

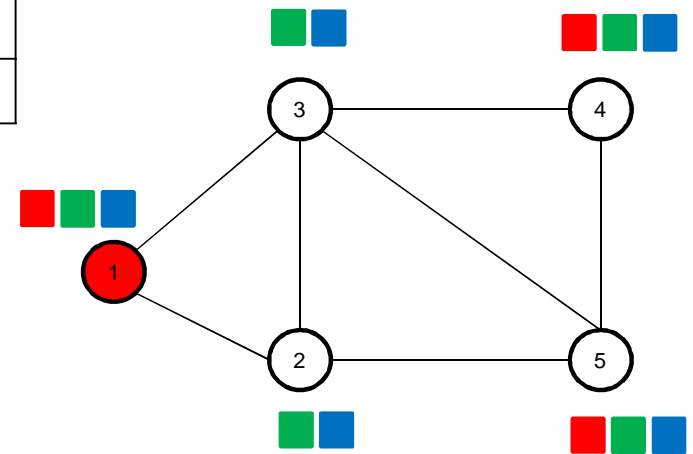
Start: 3 (Degree Heuristics)

3	2	5	4	1
				
				
				
				
				



Forward checking & LCV (1)




















1	2	5	4	3
				

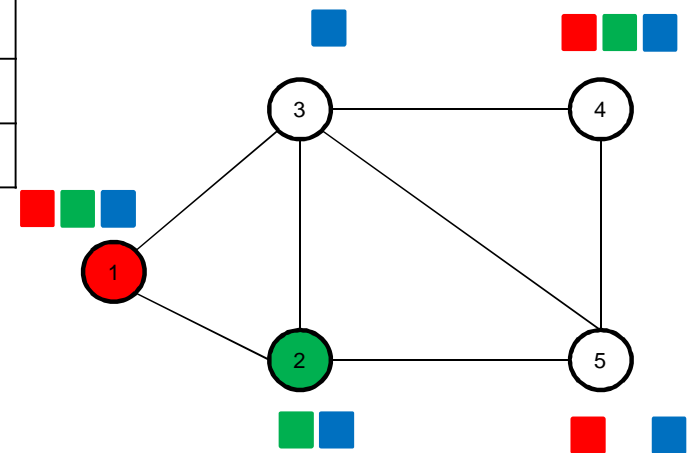


Order: 1,2,5,4,3



Forward checking & LCV (2)



























1	2	5	4	3
	 	  	  	 
		 	  	

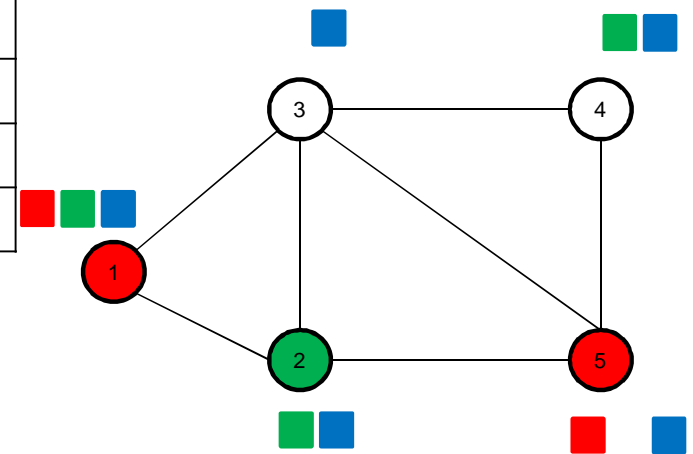


Order: 1,2,5,4,3



Forward checking & LCV (3)




















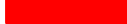

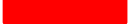








1	2	5	4	3
	 	  	  	 
		 	  	
			  	

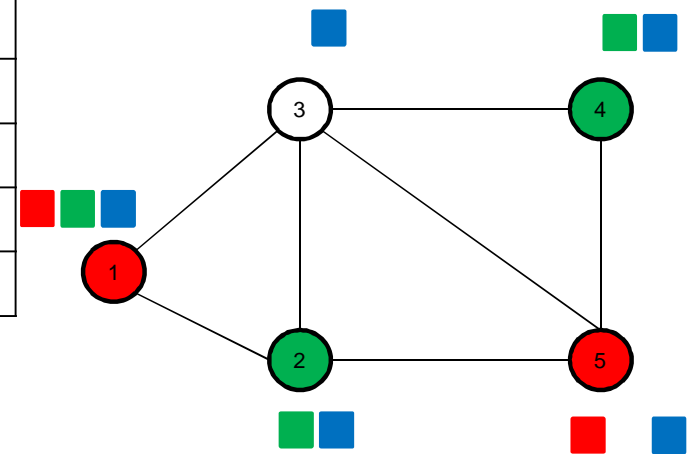


Order: 1,2,5,4,3



Forward checking & LCV (4)





































1	2	5	4	3
	 	  	  	 
		 	  	
			  	
				

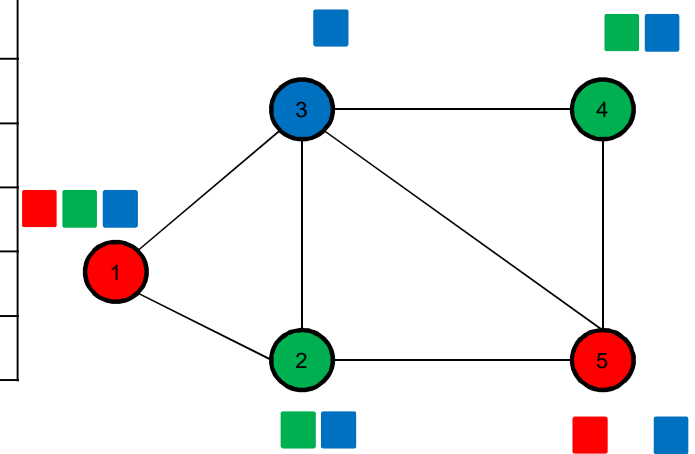


Order: 1,2,5,4,3



Forward checking & LCV (5)

1	2	5	4	3
	 	  	  	 
		 	  	
			  	
				
				

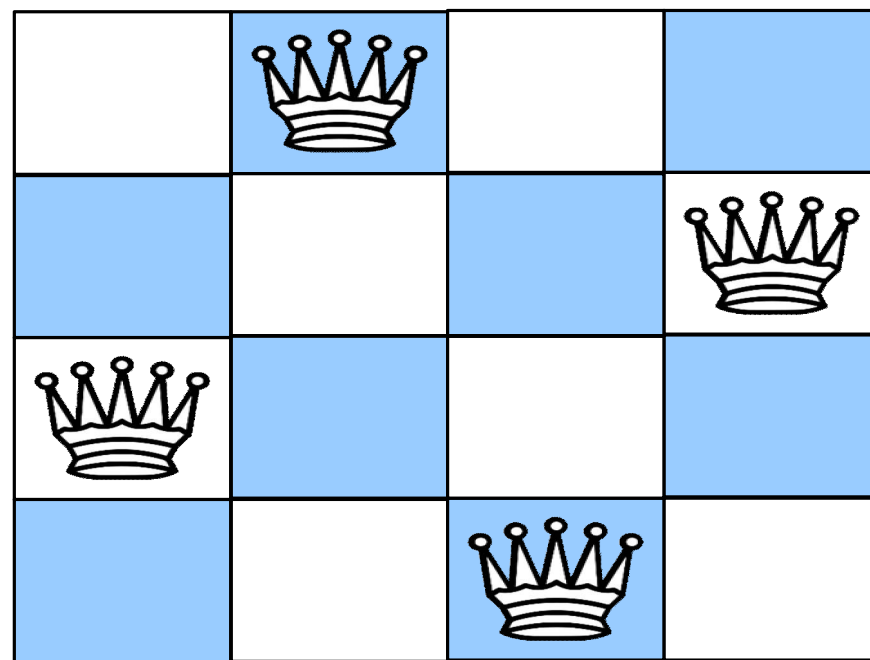
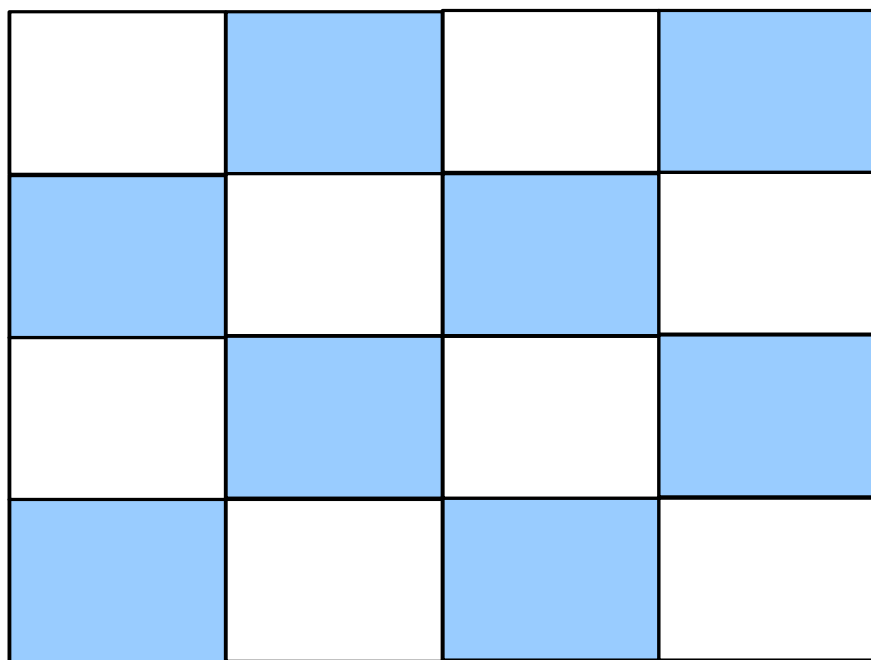


Order: 1,2,5,4,3

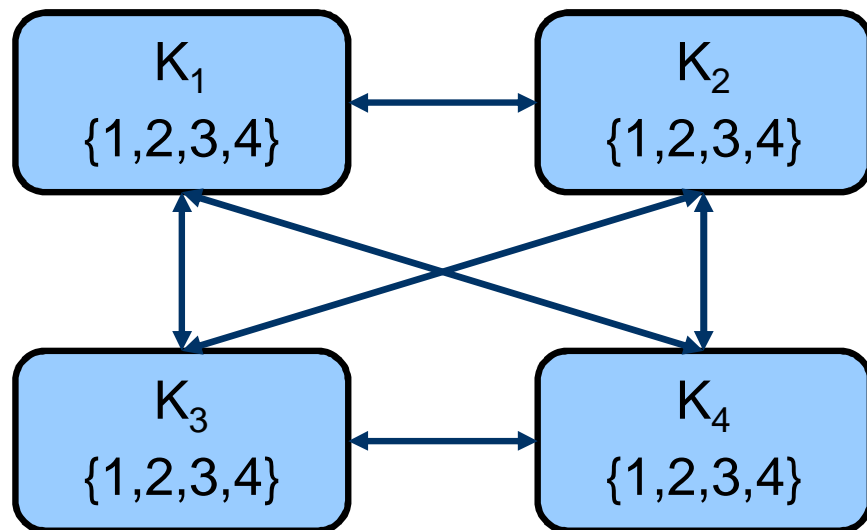


CSP za problem 4 kraljice

- Početno i ciljno stanje problema



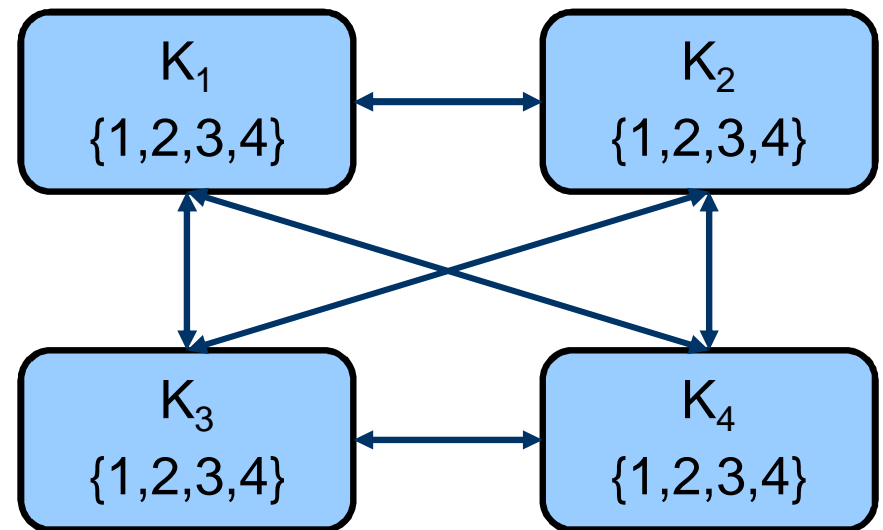
CSP za problem 4 kraljice



- Stanje problema odgovara dodeljivanju vrednosti jednoj od promenljivih, tj. izboru kolone u kojoj će se naći jedna od kraljica
- Redosled izbora kraljice kojoj treba dodeliti kolonu je proizvoljan



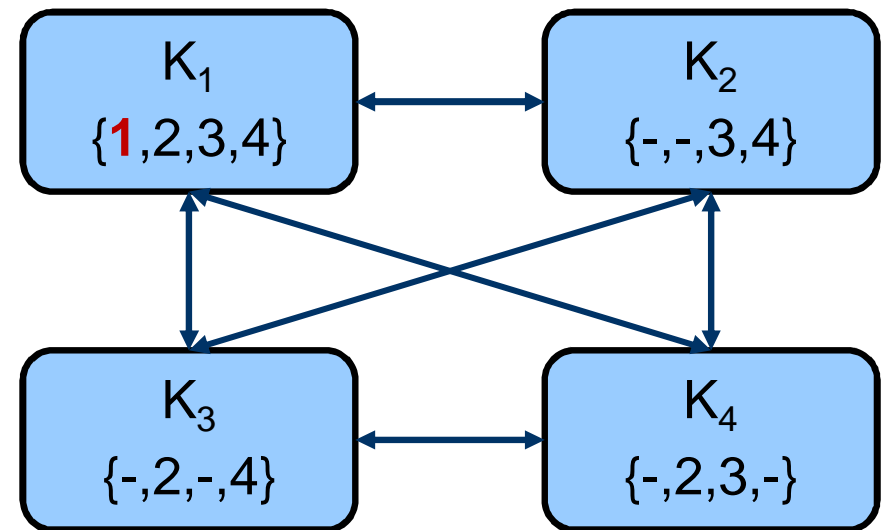
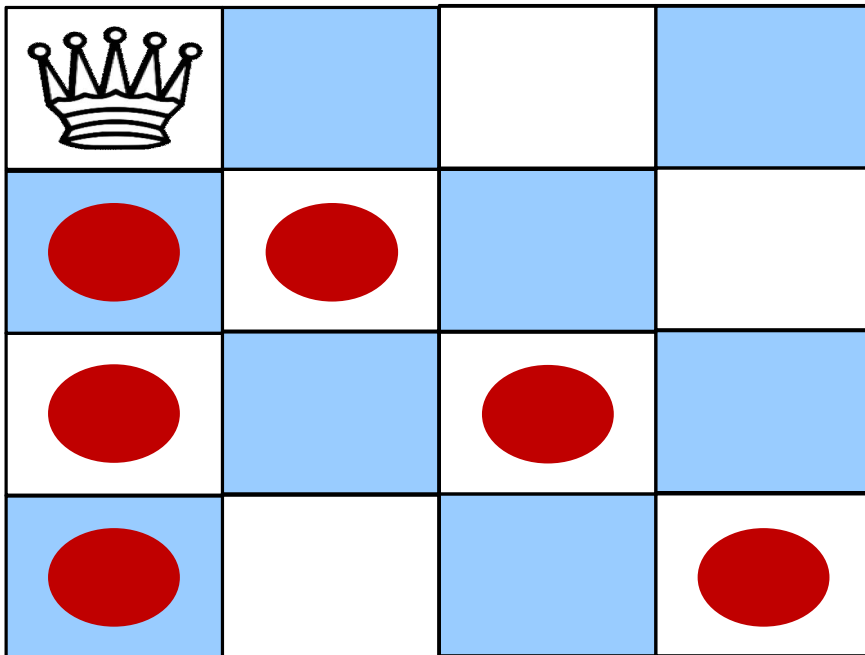
CSP FC MVR 4 kraljice



MRV: $K_1 K_2 K_3 K_4$



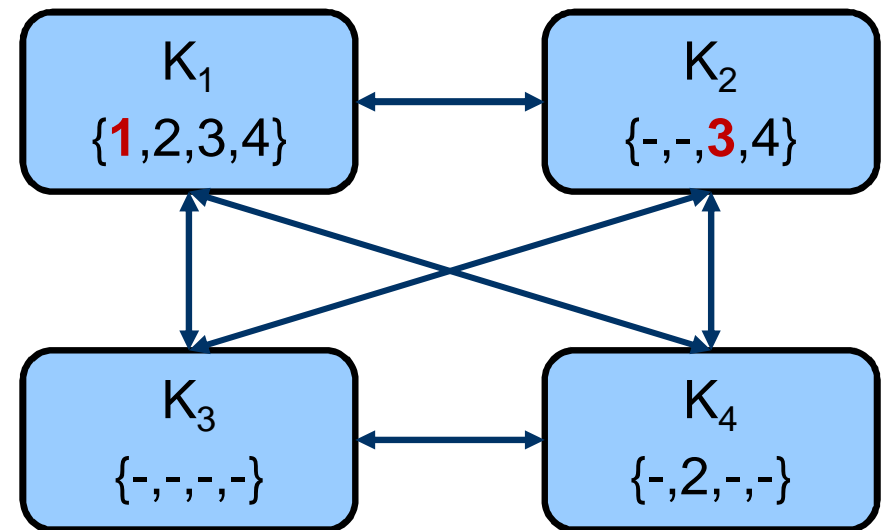
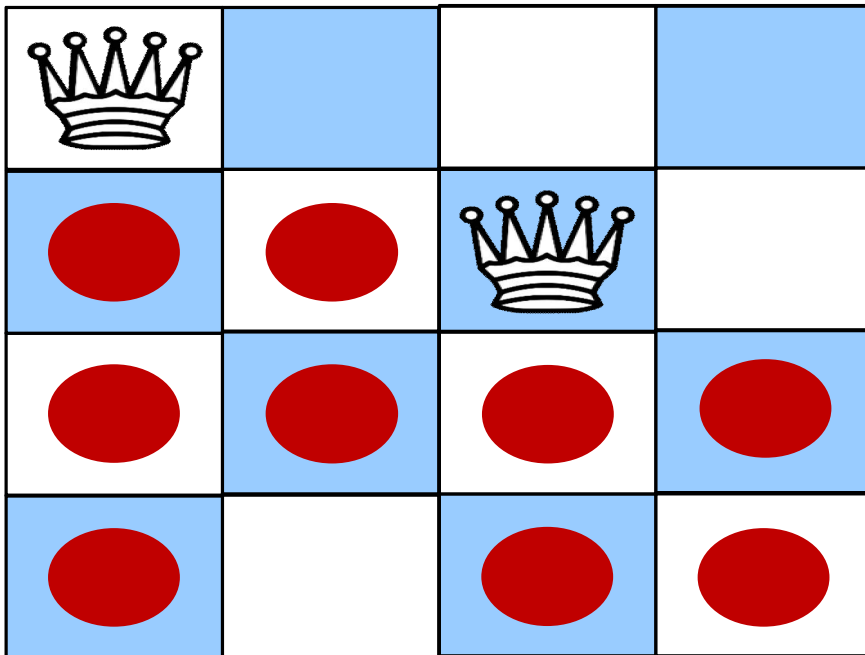
CSP FC MVR 4 kraljice (2)



MRV: K₂ K₃ K₄



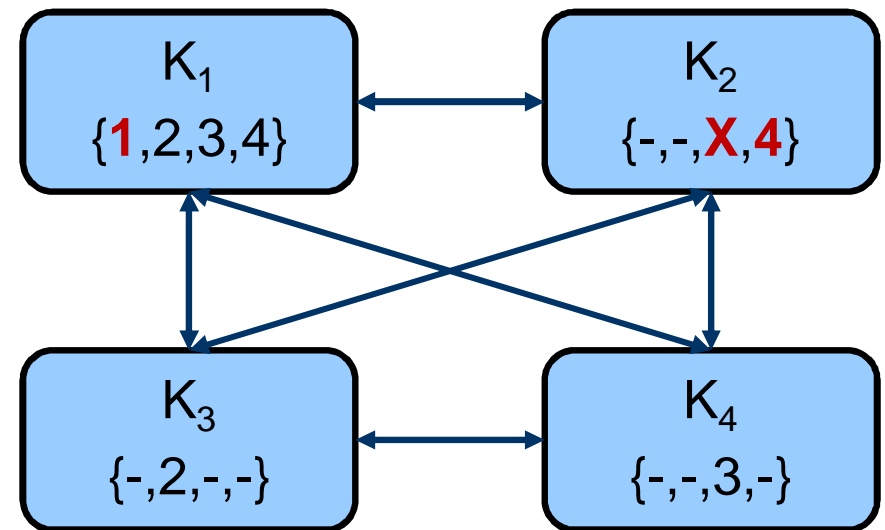
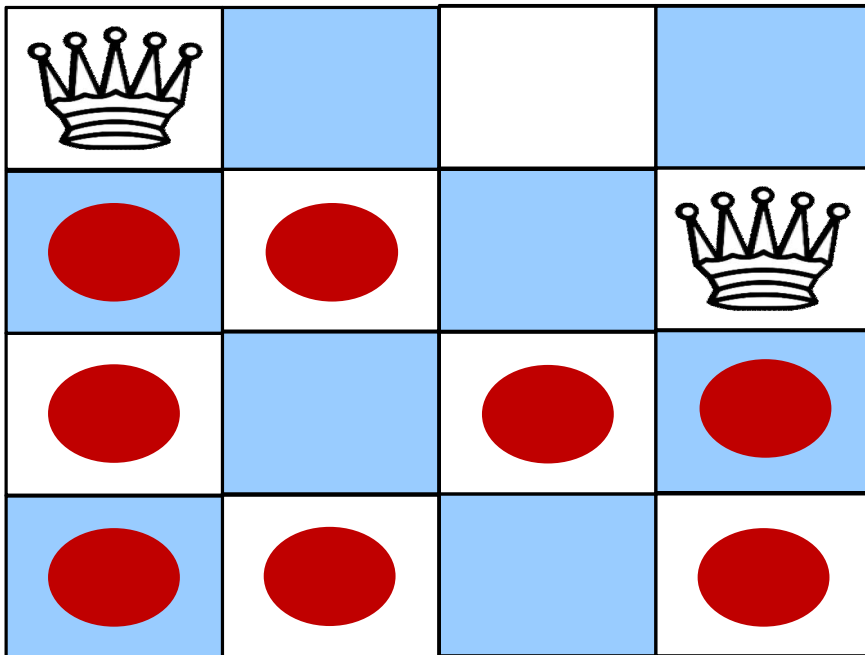
CSP FC MVR 4 kraljice (3)



FC: failure



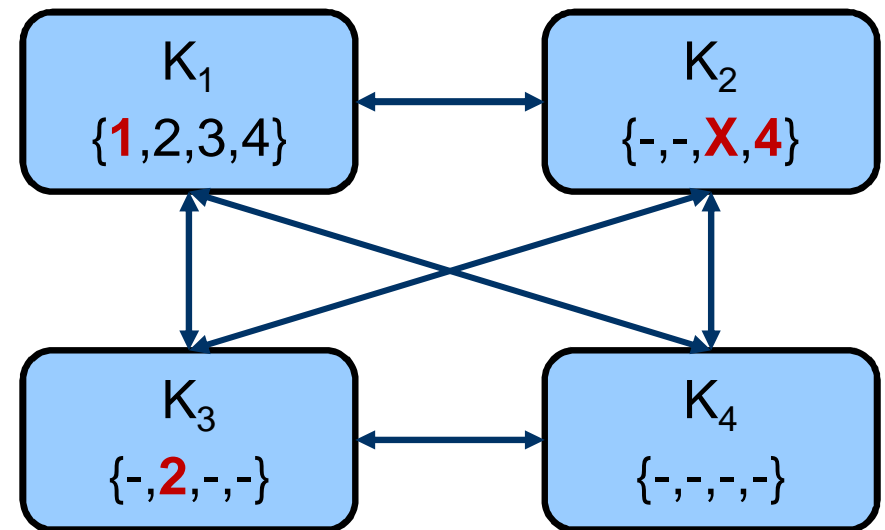
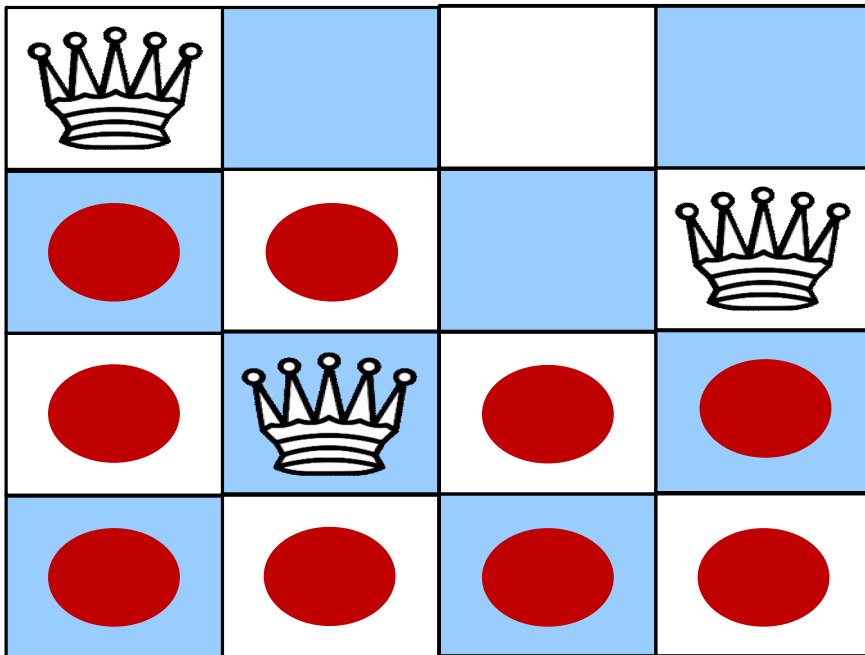
CSP FC MVR 4 kraljice (4)



MRV: K_3, K_4



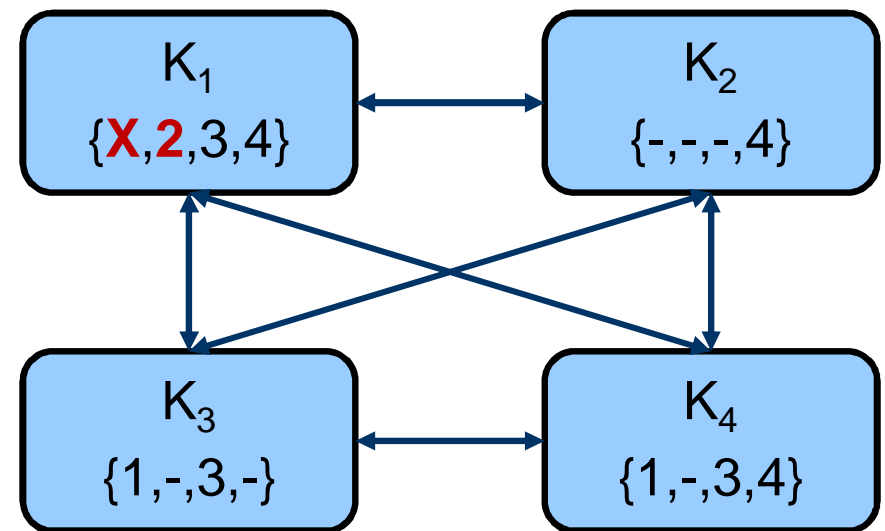
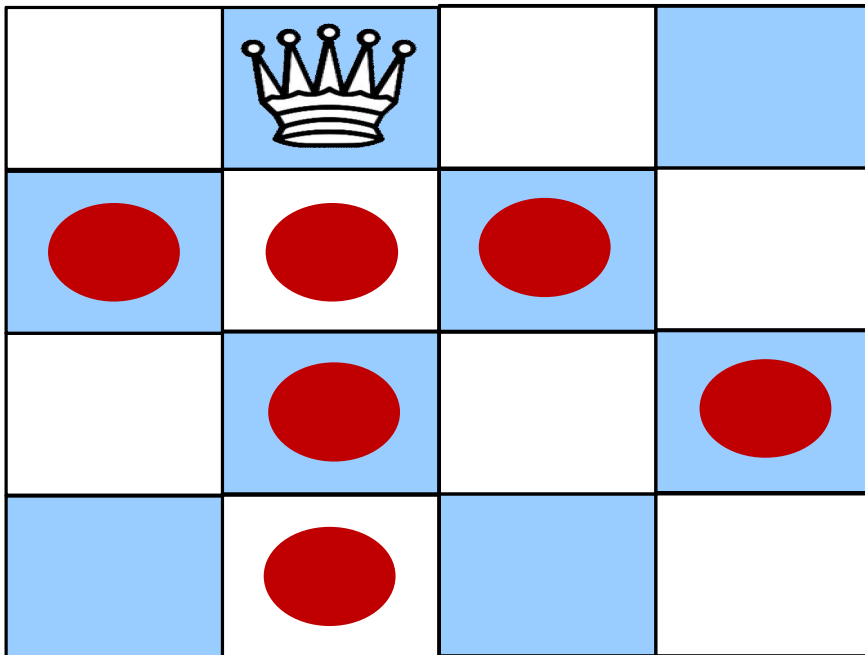
CSP FC MVR 4 kraljice (5)



FC: failure



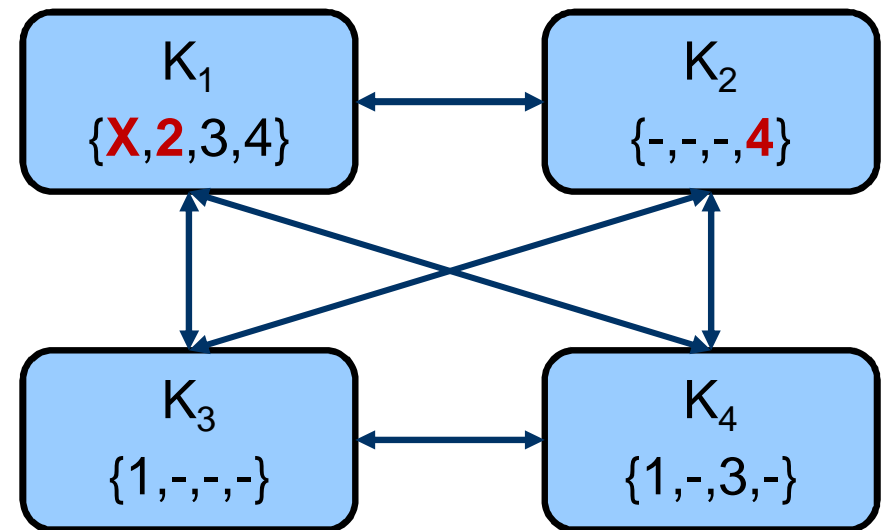
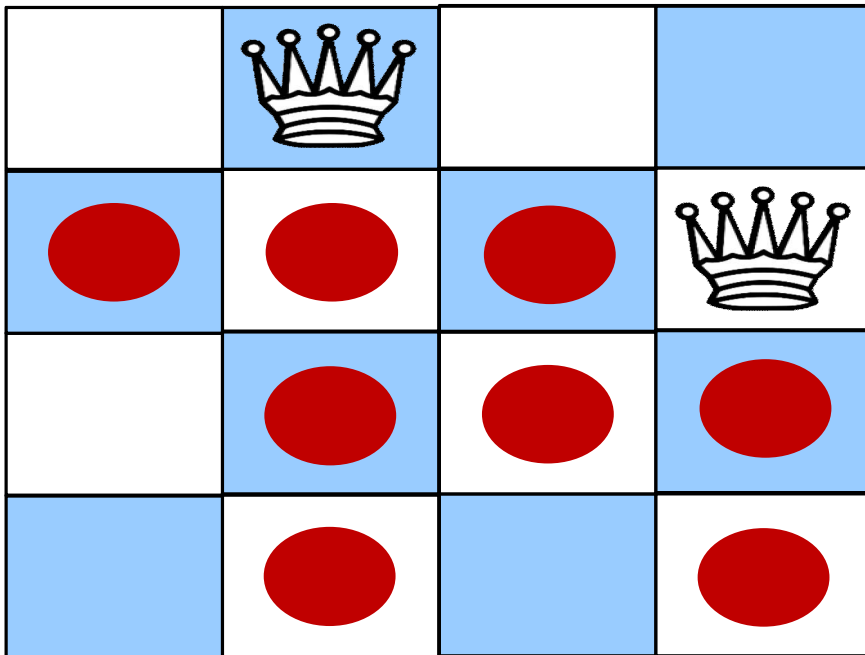
CSP FC MVR 4 kraljice (6)



MRV: K_2



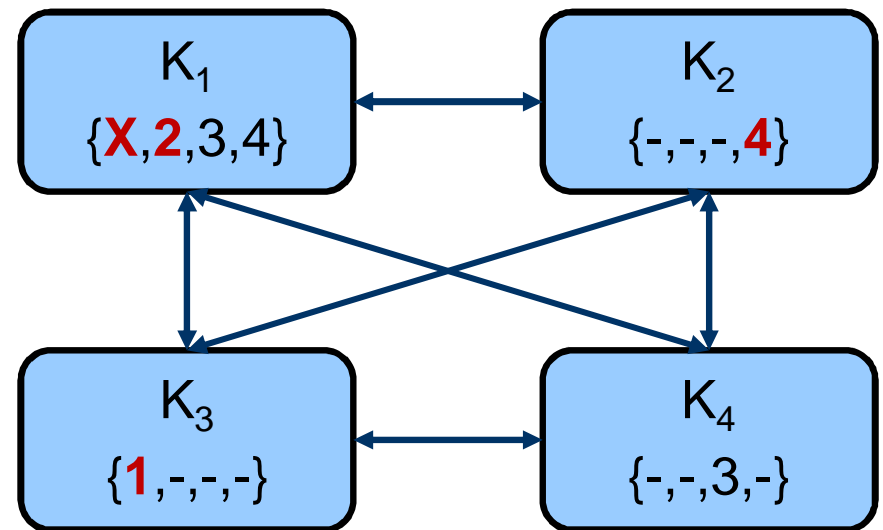
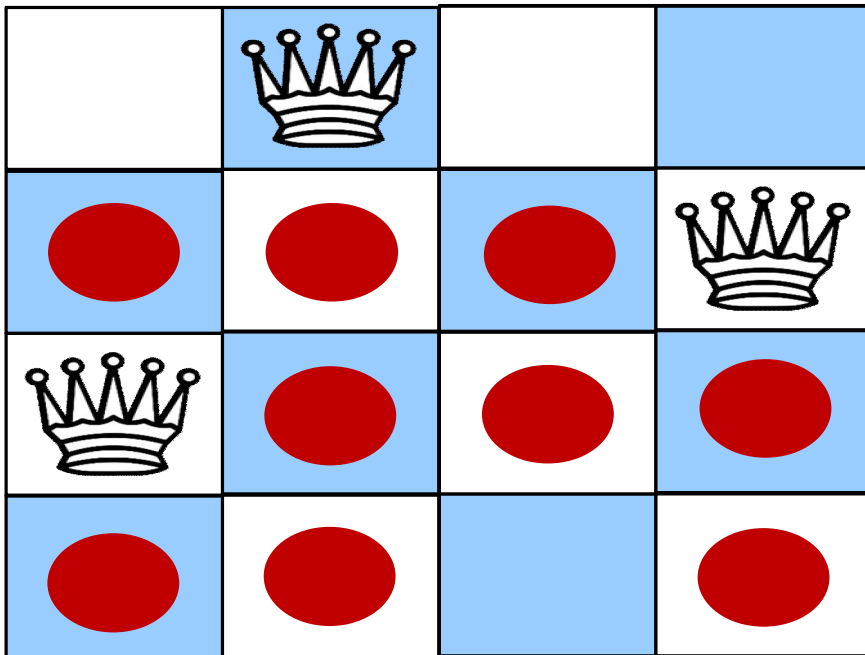
CSP FC MVR 4 kraljice (7)



MRV: K_3



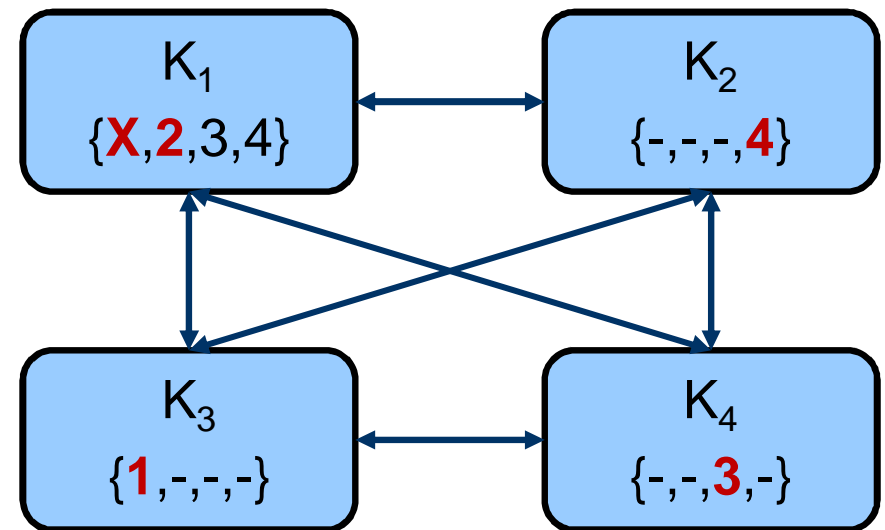
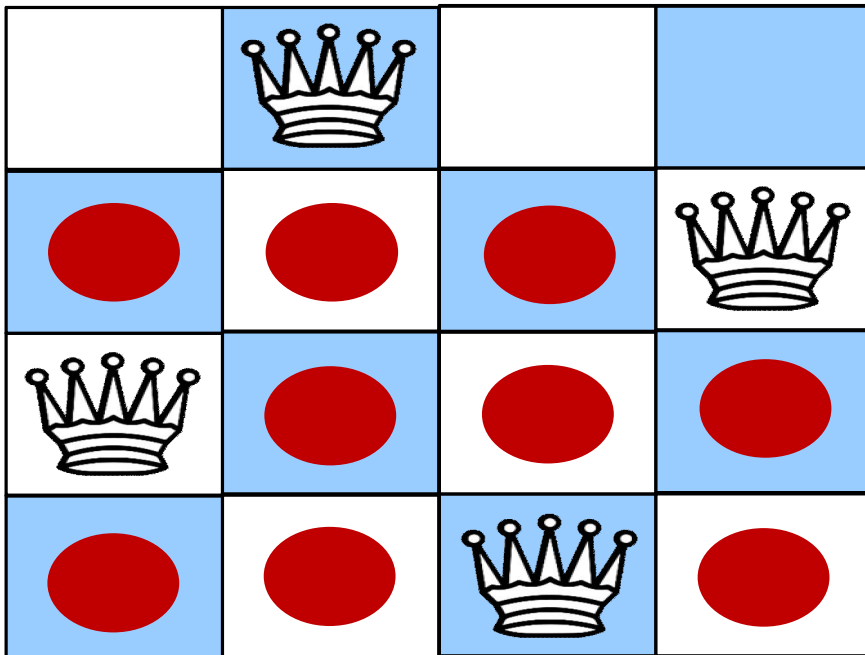
CSP FC MVR 4 kraljice (8)



MVR: K_4



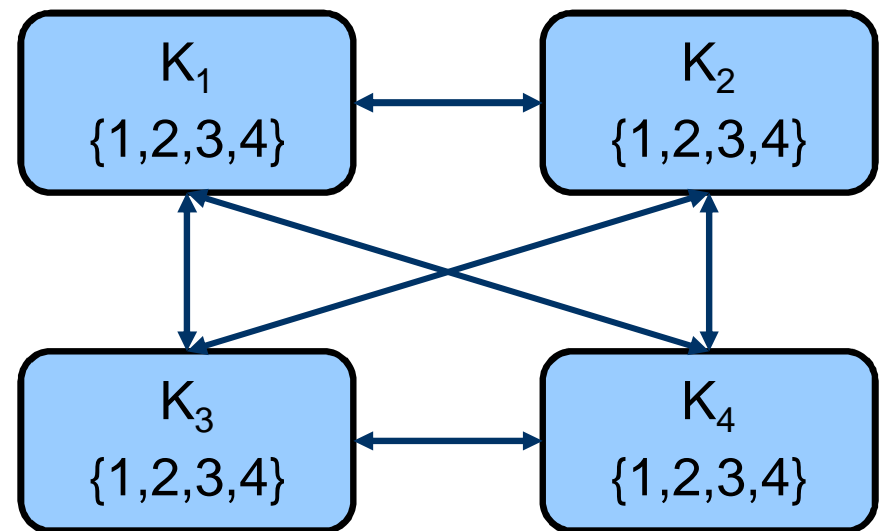
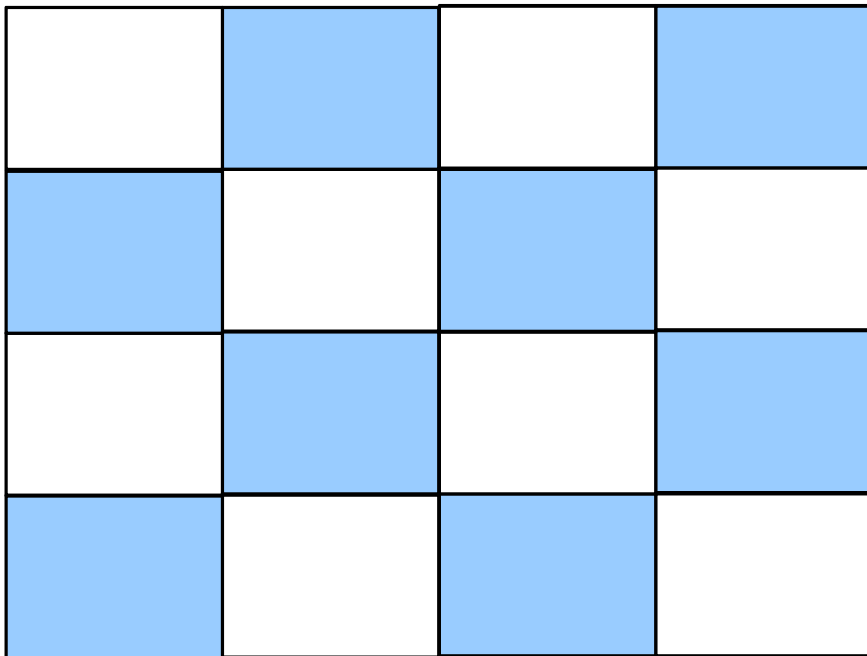
CSP FC MVR 4 kraljice (9)



$(K_1, K_2, K_3, K_4) = (2, 4, 1, 3)$



CSP FC LCV 4 kraljice

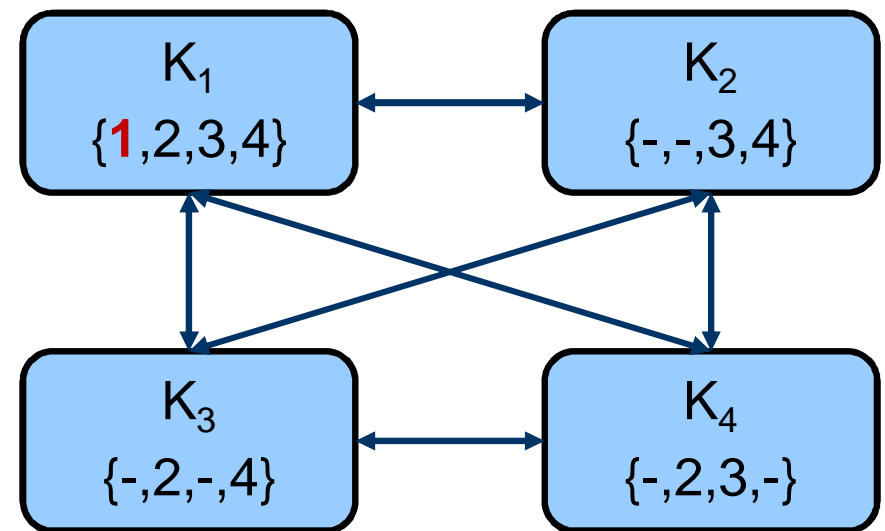
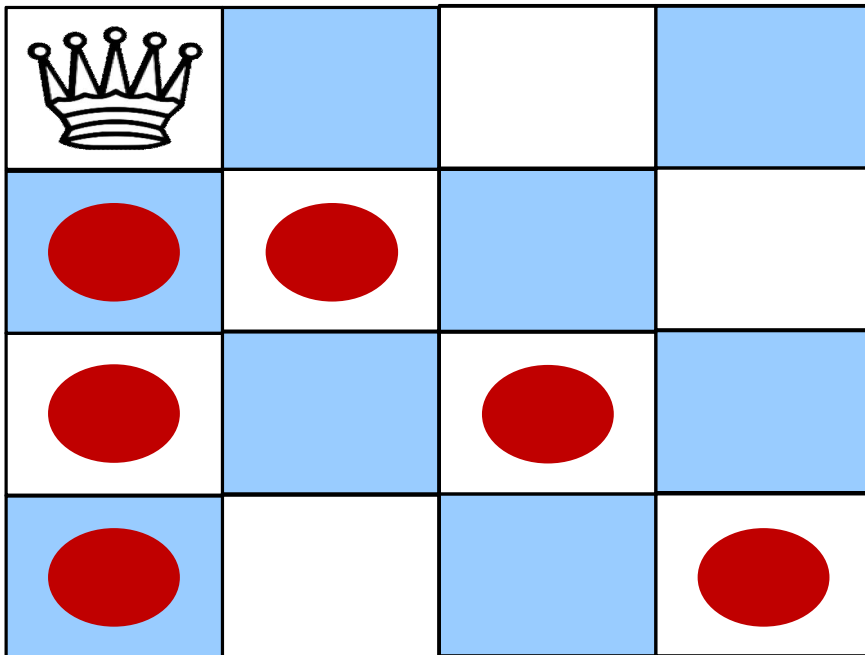


LCV: $K_1 - 1$

Obilazak: $K_1 K_2 K_3 K_4$



CSP FC LCV 4 kraljice (2)

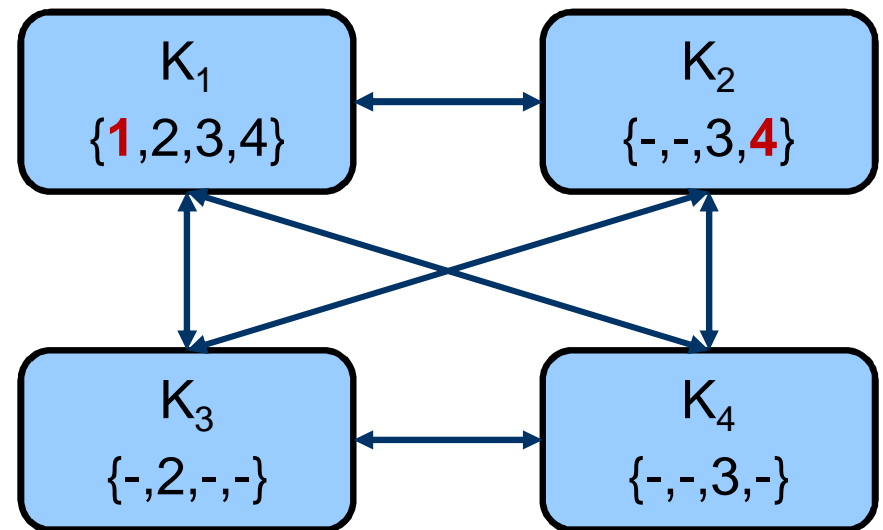
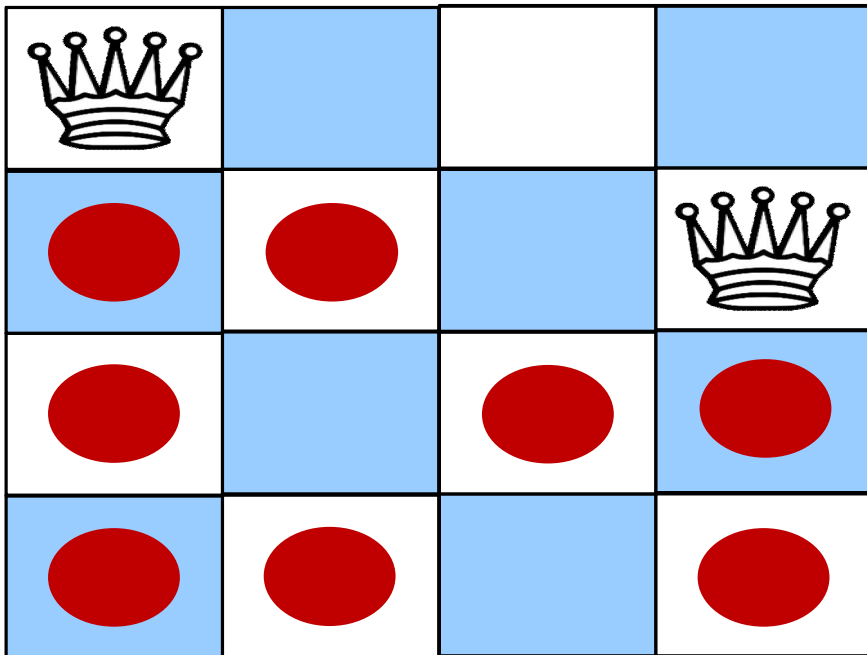


LCV: $K_2 - 4$

Obilazak: $K_1 K_2 K_3 K_4$



CSP FC LCV 4 kraljice (3)

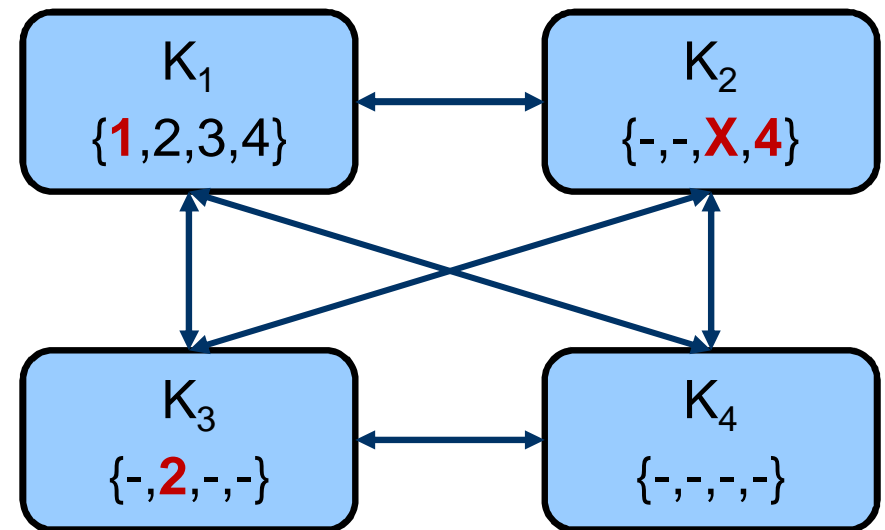
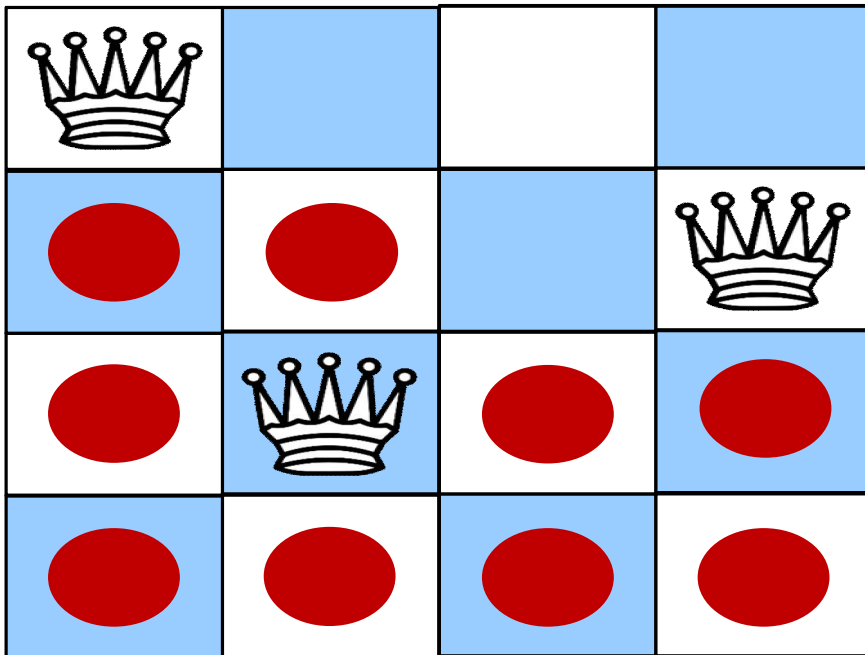


LCV: $K_3 - 2$

Obilazak: $K_1 K_2 K_3 K_4$



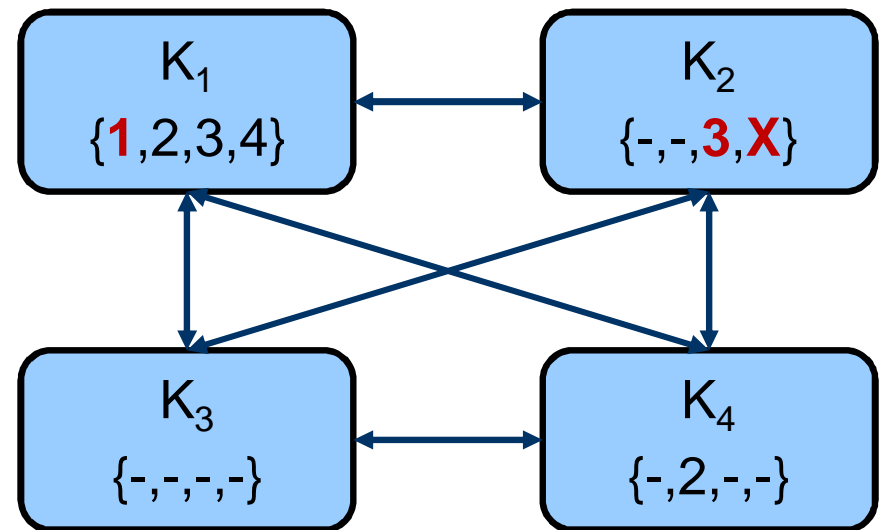
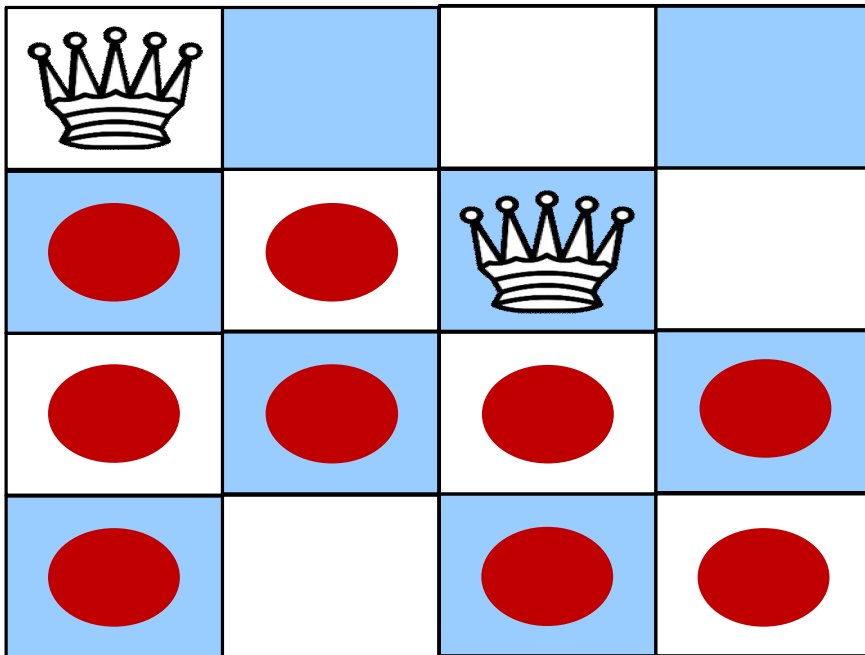
CSP FC LCV 4 kraljice (4)



FC: failure



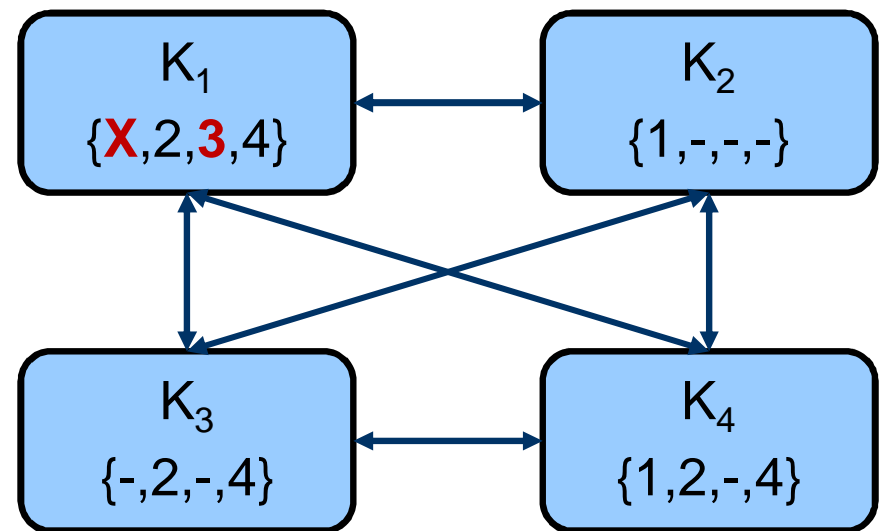
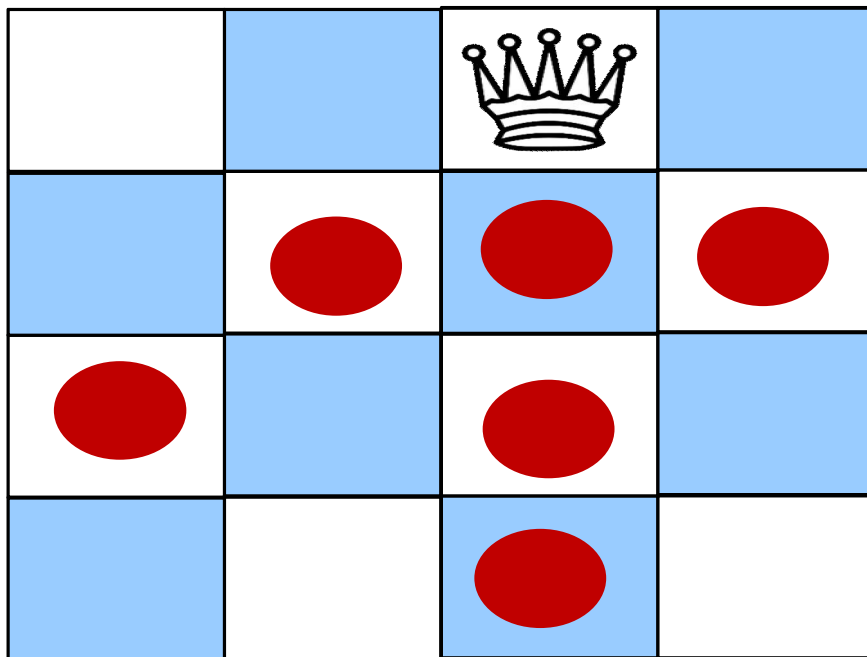
CSP FC LCV 4 kraljice (5)



FC: failure



CSP FC LCV 4 kraljice (6)

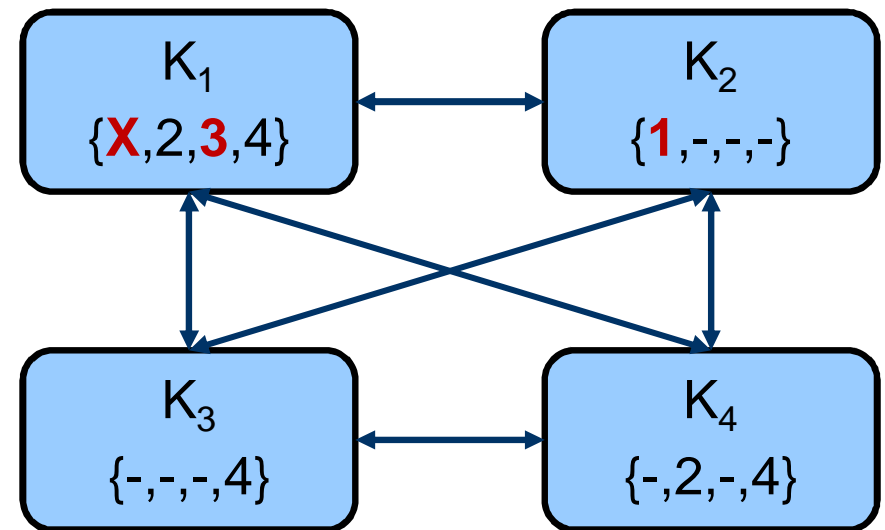
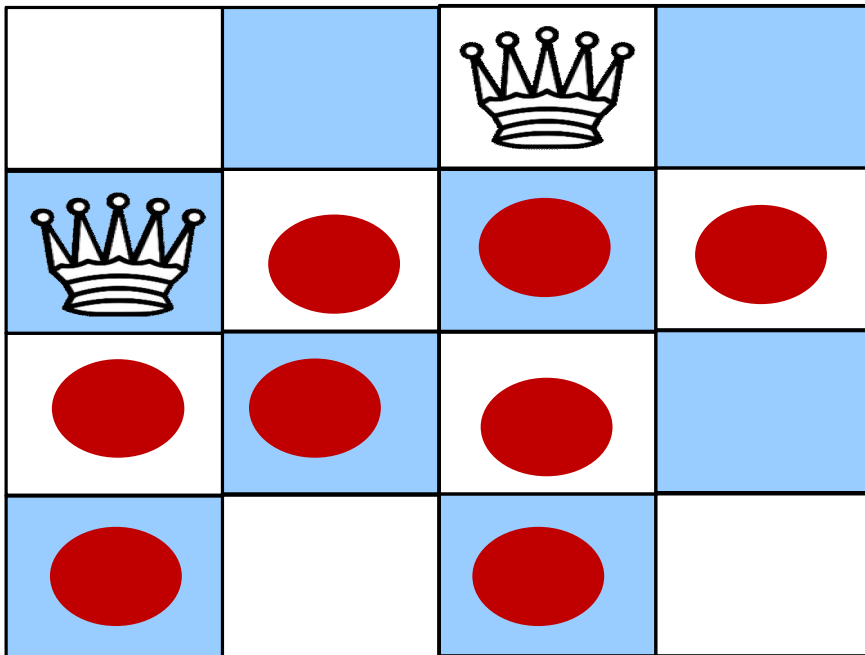


LCV: K₁ - 3

Obilazak: K₁ K₂ K₃ K₄



CSP FC LCV 4 kraljice (7)

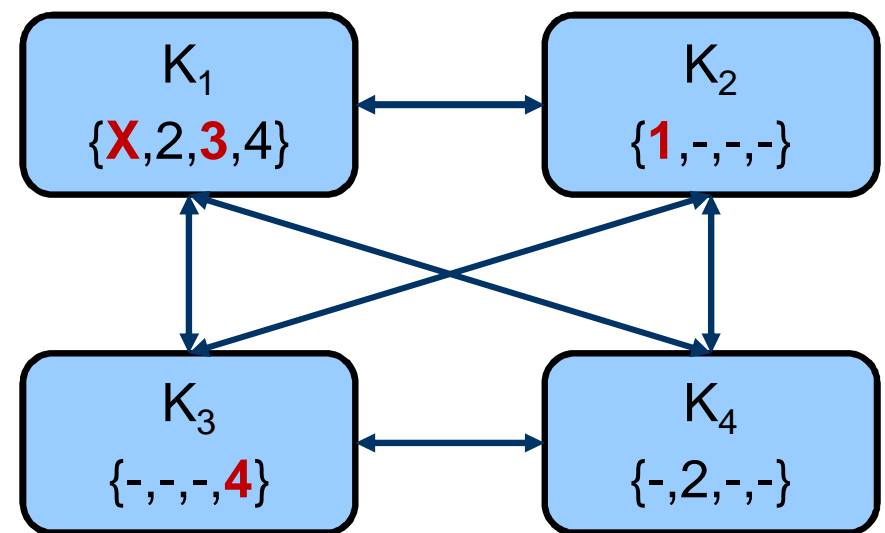
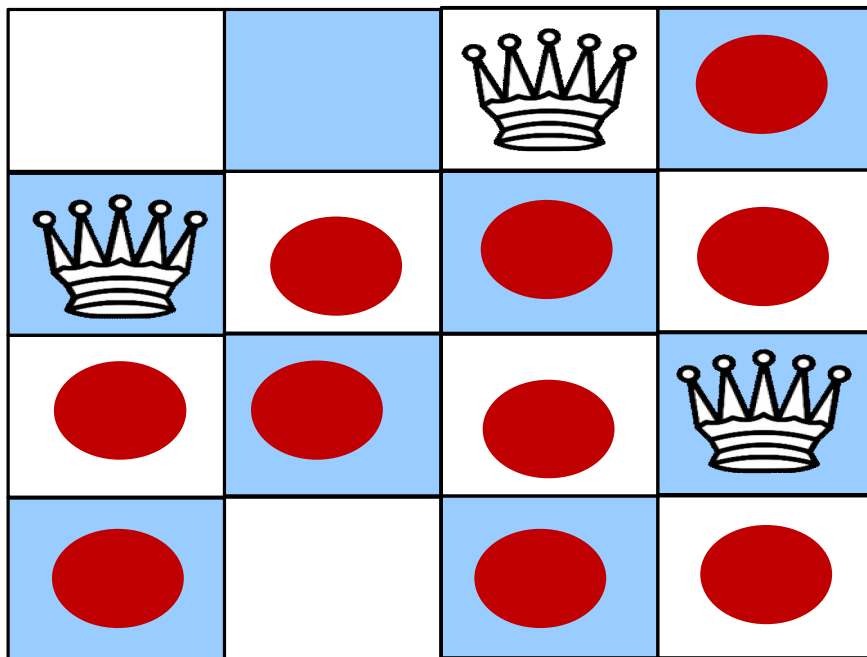


LCV: $K_2 - 1$

Obilazak: $K_1 K_2 K_3 K_4$



CSP FC LCV 4 kraljice (8)

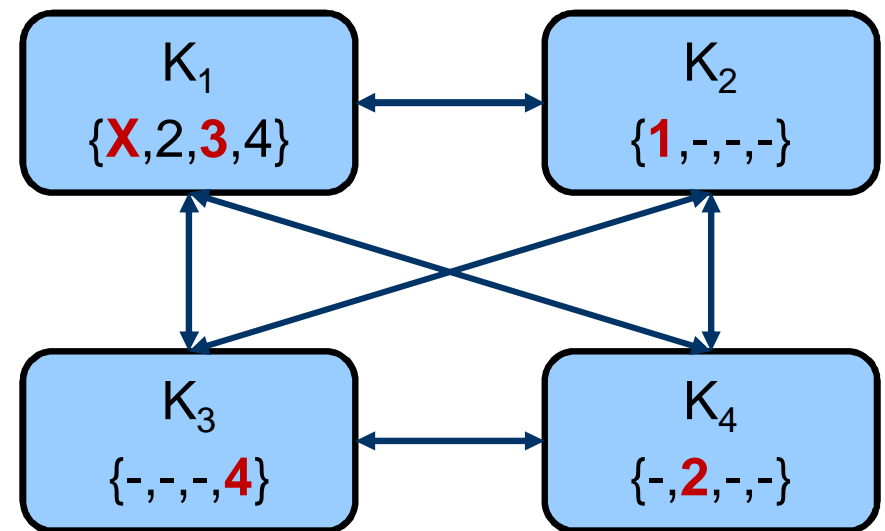
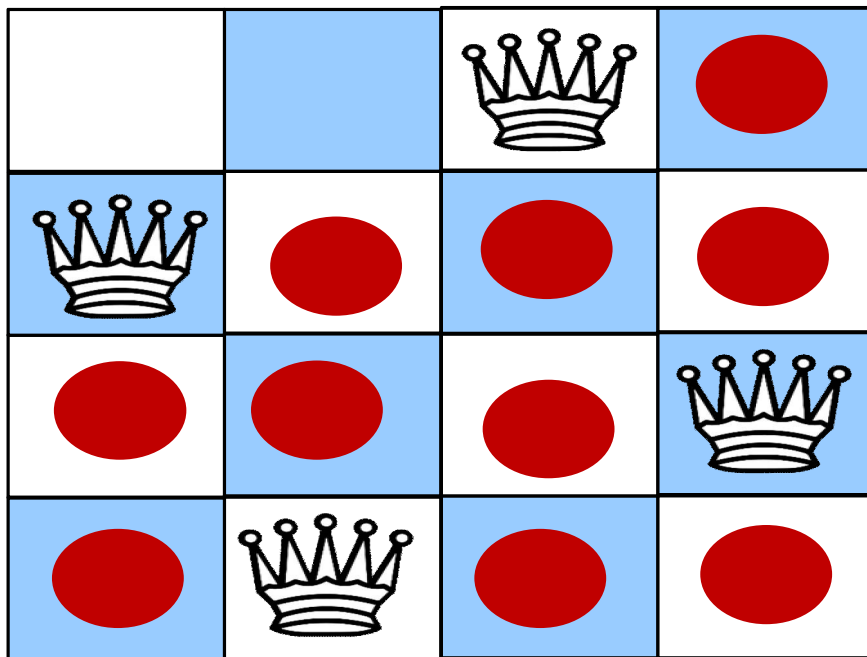


LCV: $K_3 - 4$

Obilazak: $K_1 K_2 K_3 K_4$



CSP FC LCV 4 kraljice (9)



LCV: $K_4 - 2$

$(K_1, K_2, K_3, K_4) = (3, 1, 4, 2)$

