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Tabu Search 禁忌搜索

- ❑ Tabu, indicates things that cannot be touched.
禁忌，指的是不能触及的事物。
- ❑ Tabu search is created by Fred Glover in 1986 and formalized in 1989.
禁忌搜索是由弗雷德·格洛夫于1986年提出，1989年加以形式化。
- ❑ It is a *meta-heuristic* algorithm, used for solving combinatorial optimization problems.
它是一种元启发式算法，用于解决组合优化问题。
- ❑ It uses a local or neighborhood search procedure, to iteratively move from one potential solution x to an improved neighborhood solution x' , until some stopping condition has been satisfied.
它使用一种局部搜索或邻域搜索过程，从一个潜在的解 x 到改进的相邻解 x' 之间反复移动，直到满足某些停止条件。
- ❑ The memory structure to determine the solutions is called **tabu list**.
用于确定解的数据结构被称为禁忌表。

Three Strategies of Tabu Search 禁忌搜索的三种策略

❑ Forbidding strategy 禁止策略

control what enters the tabu list.

控制何物进入该禁忌表。

❑ Freeing strategy 释放策略

control what exits the tabu list and when.

控制何物以及何时退出该禁忌表。

❑ Short-term strategy 短期策略

manage interplay between the forbidding strategy and freeing strategy to select trial solutions.

管理禁止策略和释放策略之间的相互作用来选择试验解。

Tabu Search Algorithm 禁忌搜索算法

```
function TABU-SEARCH ( $s'$ ) return a best candidate
   $sBest \leftarrow s \leftarrow s'$ 
   $tabuList \leftarrow$  null list
  while (not STOPPING-CONDITION())
     $candidateList \leftarrow$  null list
     $bestCandidate \leftarrow$  null
    for ( $sCandidate$  in  $sNeighborhood$ )
      if ((not  $tabuList.CONTAINS(sCandidate)$ )
        and ( $FITNESS(sCandidate) > FITNESS(bestCandidate)$ ))
        then  $bestCandidate \leftarrow sCandidate$ 
     $s \leftarrow bestCandidate$ 
    if ( $FITNESS(bestCandidate) > FITNESS(sBest)$ ) then  $sBest \leftarrow bestCandidate$ 
     $tabuList.PUSH(bestCandidate)$ 
    if ( $tabuList.SIZE > maxTabuSize$ ) then  $tabuList.REMOVE-FIRST()$ 
  return  $sBest$ 
```

Problems Can be Solved by Tabu Search 可用禁忌搜索解决的问题

Travelling Salesperson Problem ■ 旅行推销员问题

Traveling Tournament Problem ■ 旅行比赛问题

Job-shop Scheduling Problem ■ 作业车间调度问题

Network Loading Problem ■ 网络加载问题

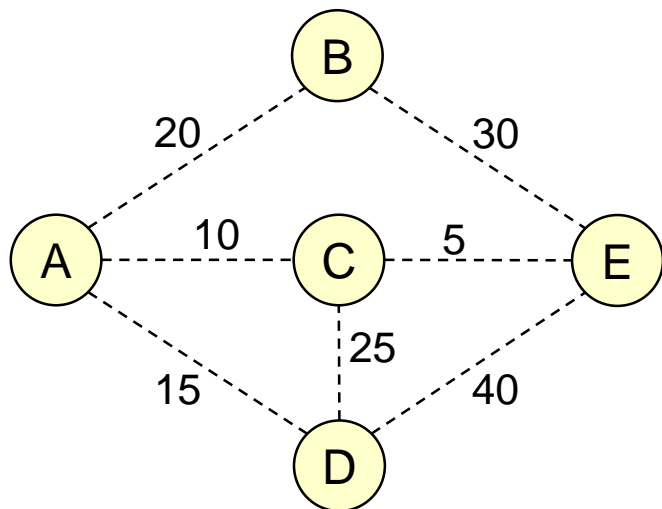
The Graph Coloring Problem ■ 图着色问题

Hardware/Software Partitioning ■ 硬件/软件划分

Minimum Spanning Tree Problem ■ 最小生成树问题

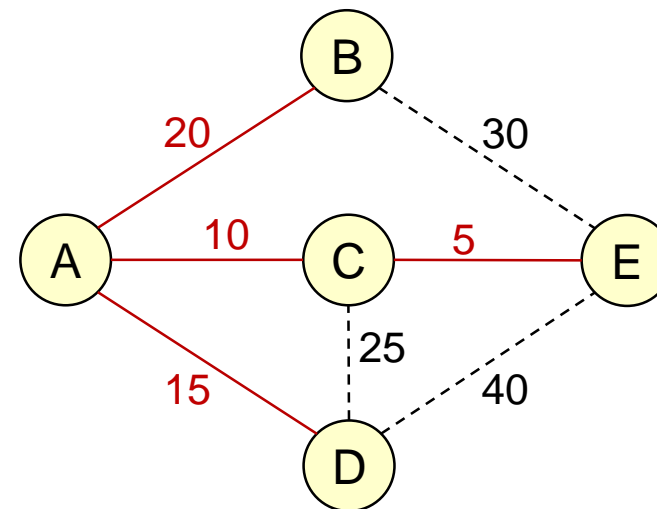
Minimum Spanning Tree Problem 最小生成树问题

□ Objective 目标



Connects all nodes with minimum cost

用最小代价连接所有节点



An optimal solution without constraints

一个无约束的最优解

Constraints 1: Link AD can be included only if link DE also is included. (Penalty:100)

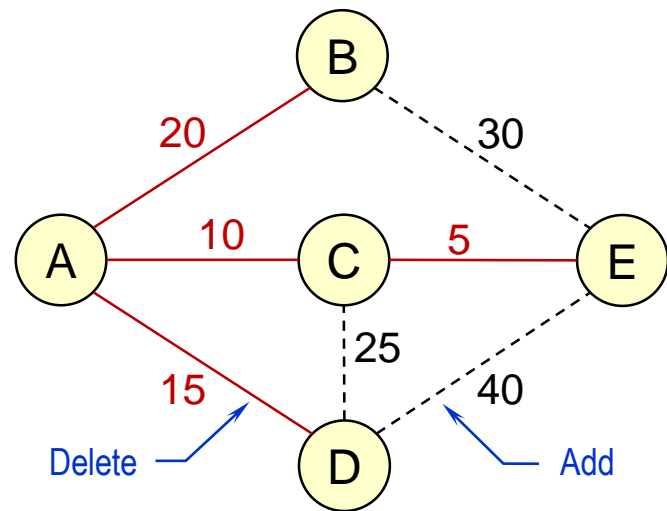
约束1: 仅当包含连接DE时, 才可以包含连接AD。(处罚: 100)

Constraints 2: At most one of the three links (AD, CD, and AB) can be included. (Penalty: 100 if selected two of the three, 200 if selected all three.)

约束2: 至多可以包含三个连接(AD, CD和AB)中的一个。(处罚: 若选择了三个中的两个则处罚100, 选择了全部三个则罚200)

Minimum Spanning Tree Problem 最小生成树问题

Iteration 1 迭代1



Cost = 50 + 200 (constraint penalty)
代价 = 50 + 200 (约束处罚)

Local optimum
局部最优

| Add | Delete | Cost |
|-----|--------|----------------|
| BE | CE | 75 + 200 = 275 |
| BE | AC | 70 + 200 = 270 |
| BE | AB | 60 + 100 = 160 |
| CD | AD | 60 + 100 = 160 |
| CD | AC | 65 + 300 = 365 |
| DE | CE | 85 + 100 = 185 |
| DE | AC | 80 + 100 = 180 |
| DE | AD | 75 + 0 = 75 |

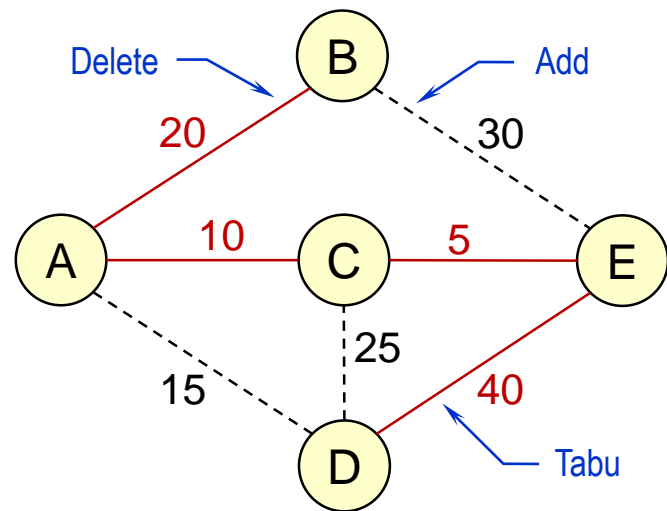
New Cost = 75
新代价 = 75

Constraints 1: Link AD can be included only if link DE also is included. (Penalty:100)
约束1: 仅当包含连接DE时, 才可以包含连接AD。(处罚: 100)

Constraints 2: At most one of the three links (AD, CD, and AB) can be included. (Penalty: 100 if selected two of the three, 200 if selected all three.)
约束2: 至多可以包含三个连接(AD, CD和AB)中的一个。(处罚: 若选择了三个中的两个则处罚100, 选择了全部三个则罚200)

Minimum Spanning Tree Problem 最小生成树问题

Iteration 2 迭代2



Cost = 75, Tabu list: DE
代价 = 75, 禁忌表: DE

Escape local optimum 溢出局部最优

| Add | Delete | Cost |
|-----|--------|----------------|
| AD | DE* | Tabu move |
| AD | CE | 85 + 100 = 185 |
| AD | AC | 80 + 100 = 180 |
| BE | CE | 100 + 0 = 100 |
| BE | AC | 95 + 0 = 95 |
| BE | AB | 85 + 0 = 85 |
| CD | DE* | Tabu move |
| CD | CE | 95 + 100 = 195 |

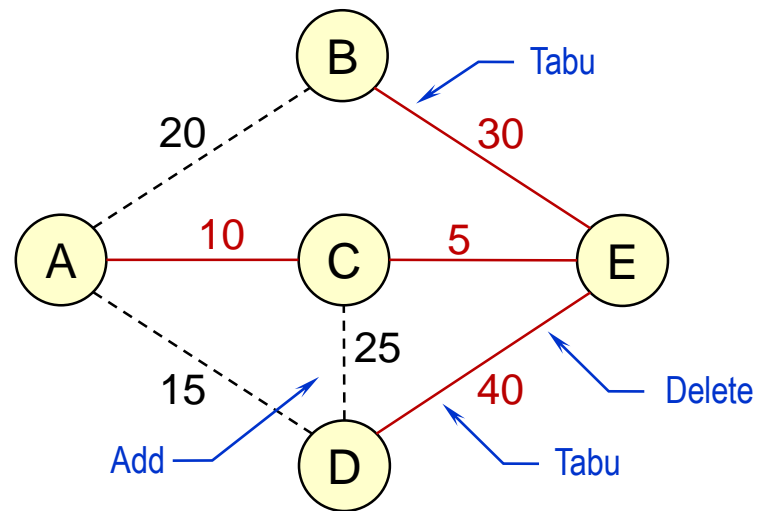
New Cost = 85
新代价 = 85

Constraints 1: Link AD can be included only if link DE also is included. (Penalty:100)
约束1: 仅当包含连接DE时, 才可以包含连接AD。(处罚: 100)

Constraints 2: At most one of the three links (AD, CD, and AB) can be included. (Penalty: 100 if selected two of the three, 200 if selected all three.)
约束2: 至多可以包含三个连接(AD, CD和AB)中的一个。(处罚: 若选择了三个中的两个则处罚100, 选择了全部三个则罚200)

Minimum Spanning Tree Problem 最小生成树问题

Iteration 3 迭代3



Cost = 85, Tabu list: DE & BE
代价 = 85, 禁忌表: DE & BE

Override tabu status
覆盖禁忌状态

| Add | Delete | Cost |
|----------------|-----------------|--|
| AB AB AB | BE* CE AC | Tabu move 100 + 0 = 100 95 + 0 = 95 |
| AD AD AD | DE* CE AC | 60 + 100 = 160 95 + 0 = 95 90 + 0 = 90 |
| CD CD | DE* CE | 70 + 0 = 70 105 + 0 = 105 |

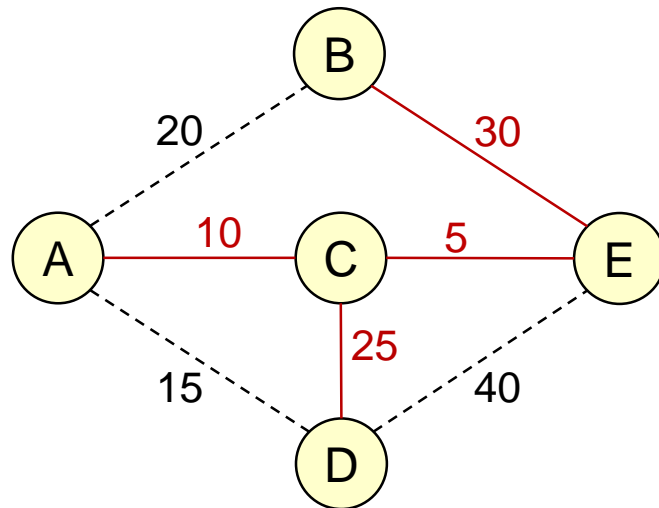
New Cost = 70
新代价 = 70

Constraints 1: Link AD can be included only if link DE also is included. (Penalty:100)
约束1: 仅当包含连接DE时, 才可以包含连接AD。(处罚: 100)

Constraints 2: At most one of the three links (AD, CD, and AB) can be included. (Penalty: 100 if selected two of the three, 200 if selected all three.)
约束2: 至多可以包含三个连接(AD, CD和AB)中的一个。(处罚: 若选择了三个中的两个则处罚100, 选择了全部三个则罚200)

Minimum Spanning Tree Problem 最小生成树问题

Iteration 4 迭代4



Cost = 70

代价 = 70

Optimal Solution

最优解

*Additional iterations only
find inferior solutions*

额外的迭代只会找到较差解

Constraints 1: Link AD can be included only if link DE also is included. (Penalty:100)

约束1: 仅当包含连接DE时, 才可以包含连接AD。(处罚: 100)

Constraints 2: At most one of the three links (AD, CD, and AB) can be included. (Penalty: 100 if selected two of the three, 200 if selected all three.)

约束2: 至多可以包含三个连接(AD, CD和AB)中的一个。(处罚: 若选择了三个中的两个则处罚100, 选择了全部三个则罚200)

Application Fields of Tabu Search 禁忌搜索的应用领域

| | | |
|----------------------------|---|--------|
| Resource planning | ■ | 资源规划 |
| Telecommunications | ■ | 通讯 |
| VLSI design | ■ | VLSI设计 |
| Financial analysis | ■ | 金融分析 |
| Scheduling | ■ | 调度 |
| Space planning | ■ | 空间规划 |
| Energy distribution | ■ | 能源分配 |
| Molecular engineering | ■ | 分子工程 |
| Logistics | ■ | 物流 |
| Flexible manufacturing | ■ | 柔性生产 |
| Waste management | ■ | 废物管理 |
| Mineral exploration | ■ | 矿产勘探 |
| Biomedical analysis | ■ | 生物医药分析 |
| Environmental conservation | ■ | 环境保护 |