Graph Shortest Path

Part 16

1

Dijkstra's Algorithm

Finding the best route!

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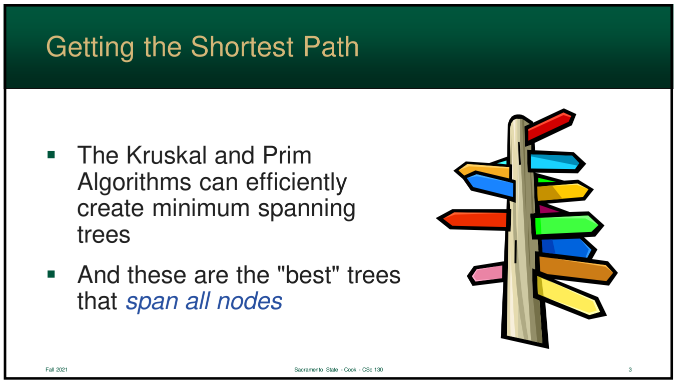

Getting the Shortest Path

- The Kruskal and Prim Algorithms can efficiently create minimum spanning trees
- And these are the "best" trees that *span all nodes*

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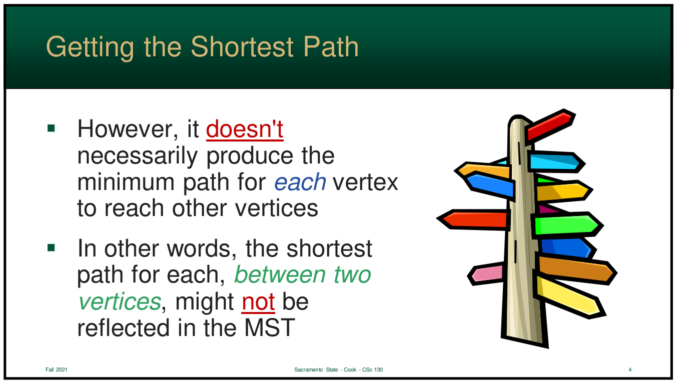

Getting the Shortest Path

- However, it doesn't necessarily produce the minimum path for *each* vertex to reach other vertices
- In other words, the shortest path for each, *between two vertices*, might not be reflected in the MST

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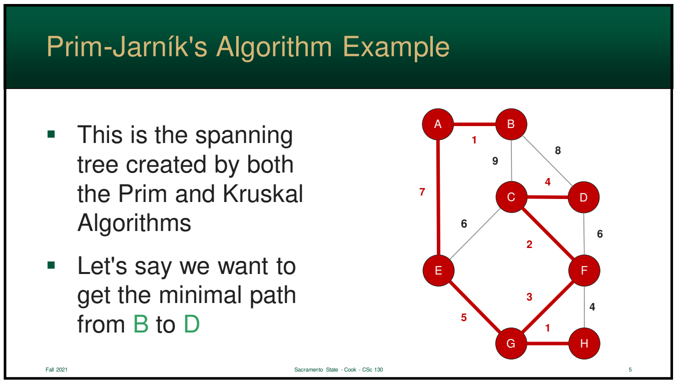

Prim-Jarník's Algorithm Example

- This is the spanning tree created by both the Prim and Kruskal Algorithms
- Let's say we want to get the minimal path from B to D

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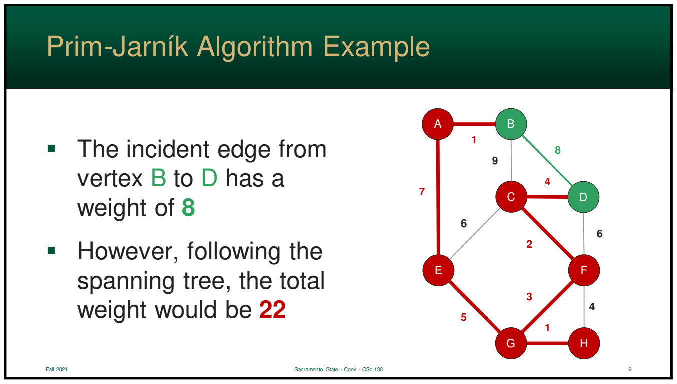

Prim-Jarník Algorithm Example

- The incident edge from vertex B to D has a weight of **8**
- However, following the spanning tree, the total weight would be **22**

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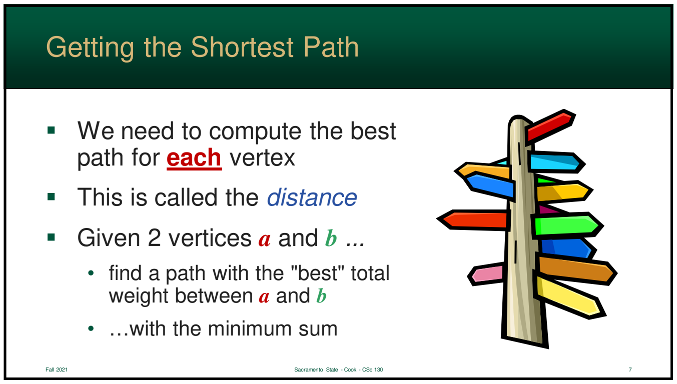

Getting the Shortest Path

- We need to compute the best path for **each** vertex
- This is called the *distance*
- Given 2 vertices ***a*** and ***b*** ...
  - find a path with the "best" total weight between ***a*** and ***b***
  - …with the minimum sum

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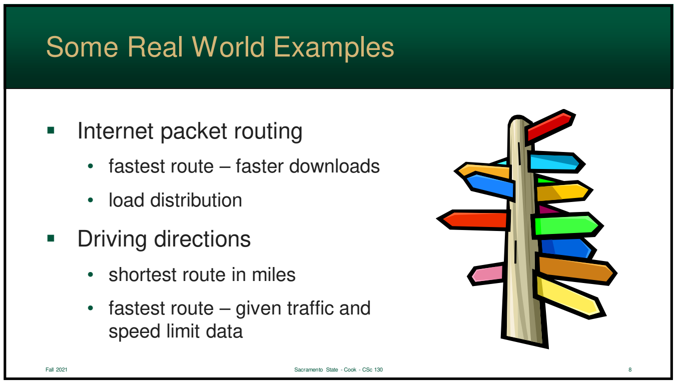

Some Real World Examples

- Internet packet routing
  - fastest route – faster downloads
  - load distribution
- Driving directions
  - shortest route in miles
  - fastest route – given traffic and speed limit data

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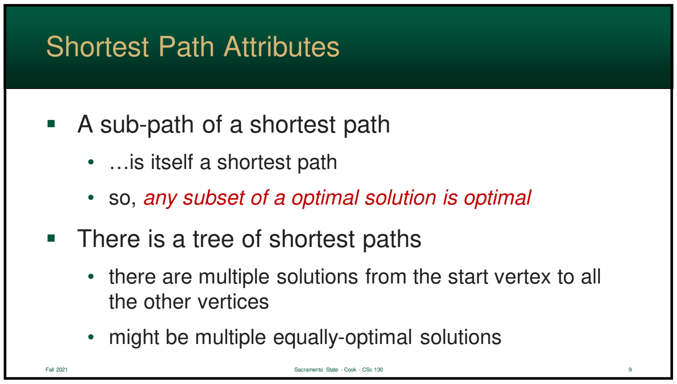

Shortest Path Attributes

- A sub-path of a shortest path
  - …is itself a shortest path
  - so, *any subset of a optimal solution is optimal*
- There is a tree of shortest paths
  - there are multiple solutions from the start vertex to all the other vertices
  - might be multiple equally-optimal solutions

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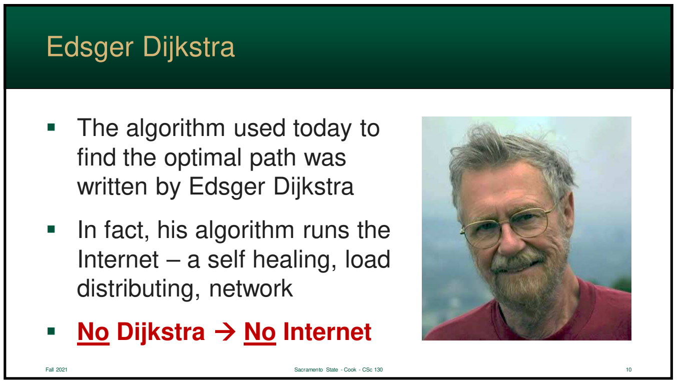

Edsger Dijkstra

- The algorithm used today to find the optimal path was written by Edsger Dijkstra
- In fact, his algorithm runs the Internet – a self healing, load distributing, network
- **No Dijkstra → No Internet**

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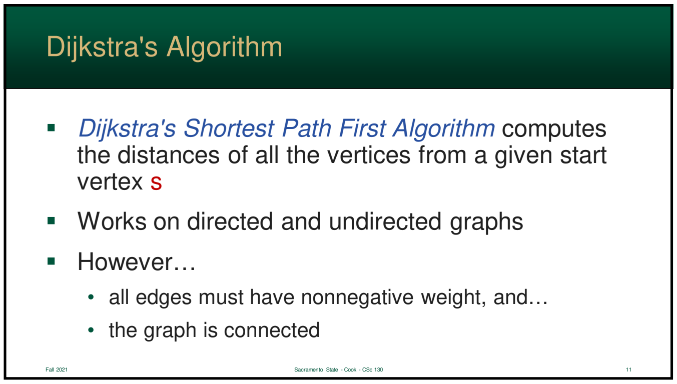

Dijkstra's Algorithm

- *Dijkstra's Shortest Path First Algorithm* computes the distances of all the vertices from a given start vertex s
- Works on directed and undirected graphs
- However…
  - all edges must have nonnegative weight, and…
  - the graph is connected

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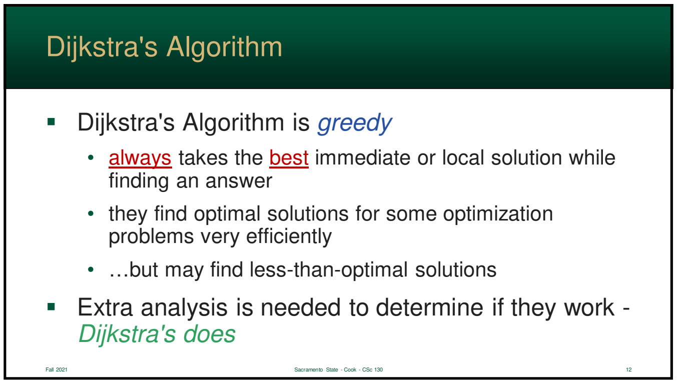

Dijkstra's Algorithm

- Dijkstra's Algorithm is *greedy*
  - always takes the best immediate or local solution while finding an answer
  - they find optimal solutions for some optimization problems very efficiently
  - …but may find less-than-optimal solutions
- Extra analysis is needed to determine if they work - *Dijkstra's does*

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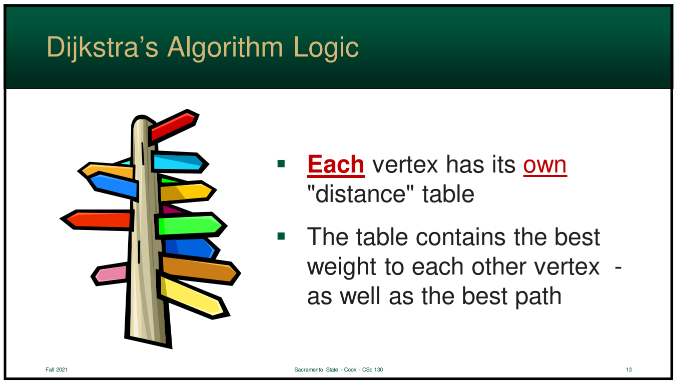
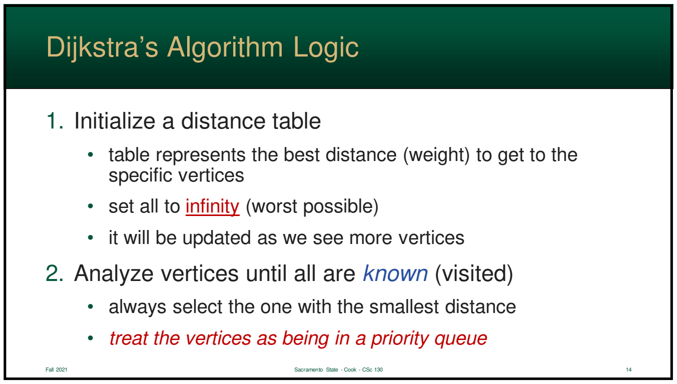


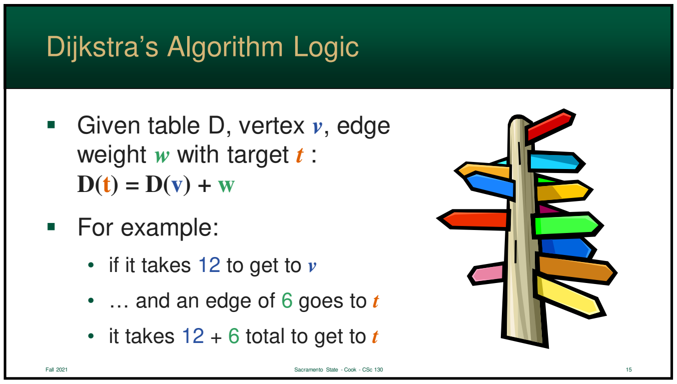
Dijkstra's Algorithm Logic

- **Each** vertex has its own "distance" table
- The table contains the best weight to each other vertex - as well as the best path



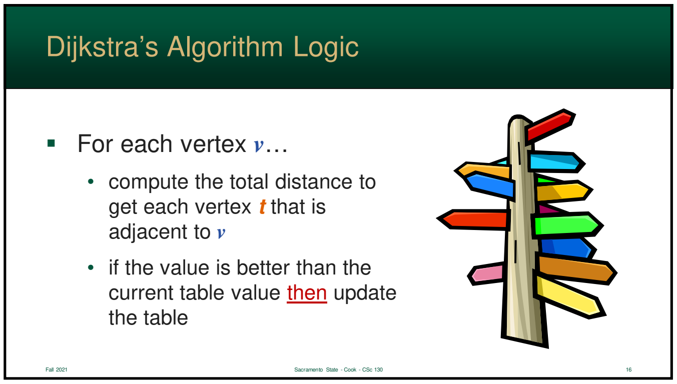
Dijkstra's Algorithm Logic

1. Initialize a distance table
   - table represents the best distance (weight) to get to the specific vertices
   - set all to infinity (worst possible)
   - it will be updated as we see more vertices
2. Analyze vertices until all are *known* (visited)
   - always select the one with the smallest distance
   - *treat the vertices as being in a priority queue*



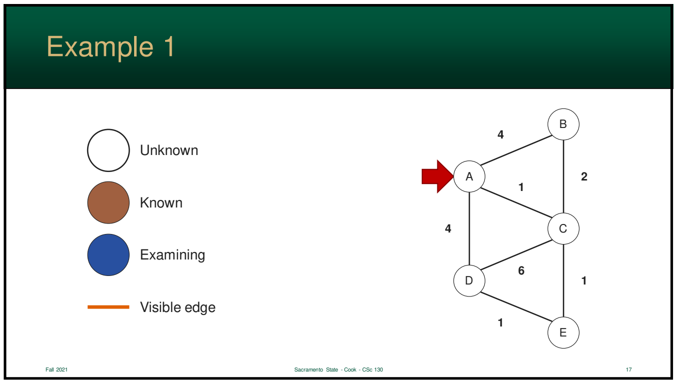
Dijkstra's Algorithm Logic

- Given table D, vertex v, edge weight w with target t : $\mathbf{D(t) = D(v) + w}$
- For example:
  - if it takes 12 to get to v
  - … and an edge of 6 goes to t
  - it takes 12 + 6 total to get to t



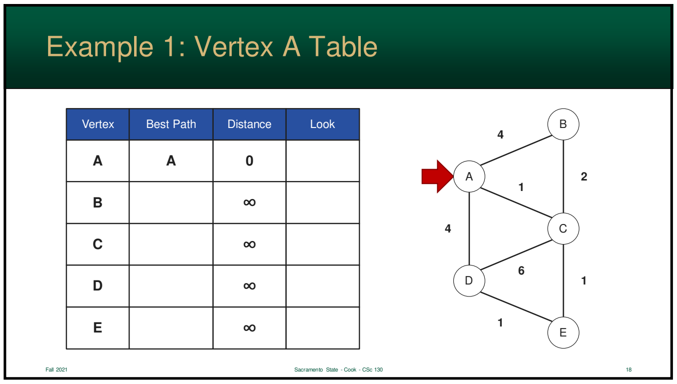
Dijkstra's Algorithm Logic

- For each vertex v…
  - compute the total distance to get each vertex t that is adjacent to v
  - if the value is better than the current table value then update the table



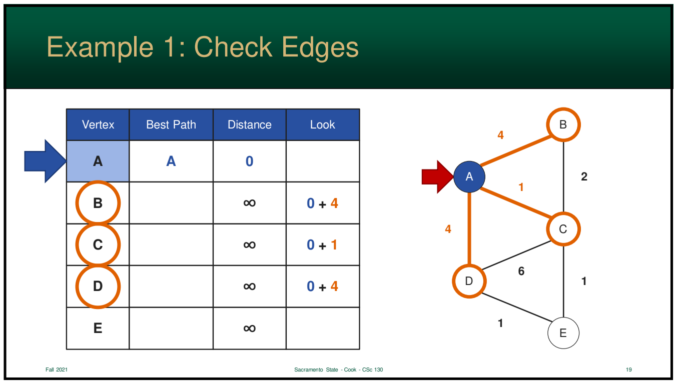
Example 1

- ○ Unknown
- ● Known
- ● Examining
- — Visible edge



Example 1: Vertex A Table

Vertex	Best Path	Distance	Look
A	A	0	
B		∞	
C		∞	
D		∞	
E		∞	



Example 1: Check Edges

Vertex	Best Path	Distance	Look
➡ A	A	0	
B		∞	0 + 4
C		∞	0 + 1
D		∞	0 + 4
E		∞	

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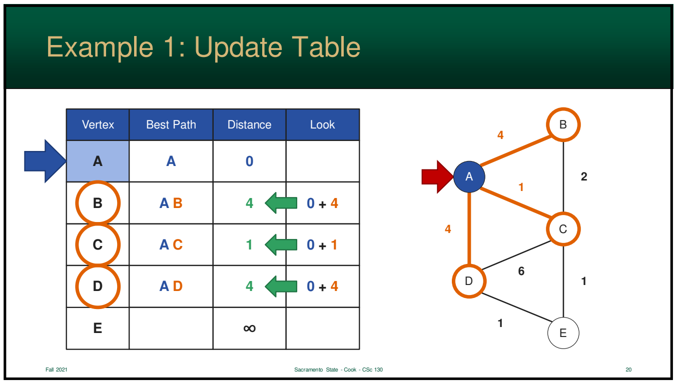

Example 1: Update Table

Vertex	Best Path	Distance	Look
➡ A	A	0	
B	A B	4 ⬅	0 + 4
C	A C	1 ⬅	0 + 1
D	A D	4 ⬅	0 + 4
E		∞	

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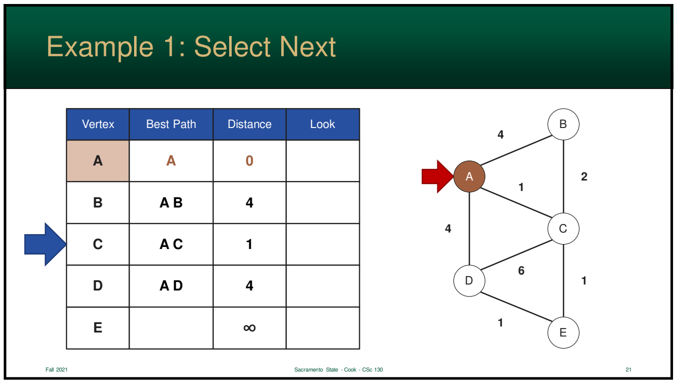

Example 1: Select Next

Vertex	Best Path	Distance	Look
A	A	0	
B	A B	4	
➡ C	A C	1	
D	A D	4	
E		∞	

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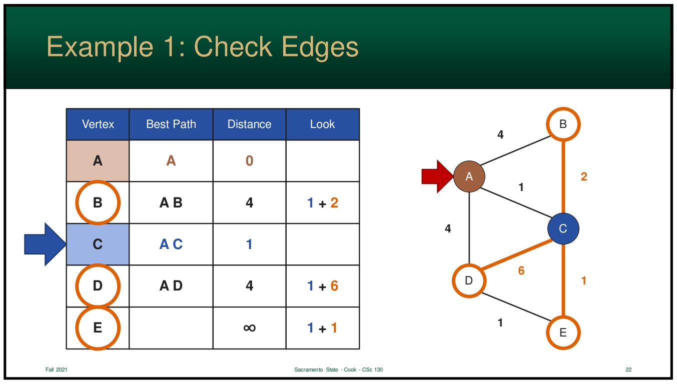

Example 1: Check Edges

Vertex	Best Path	Distance	Look
A	A	0	
B	A B	4	1 + 2
➡ C	A C	1	
D	A D	4	1 + 6
E		∞	1 + 1

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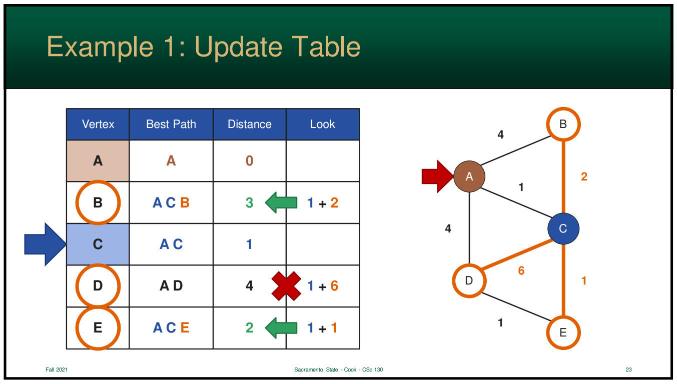

Example 1: Update Table

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3 ⬅	1 + 2
➡ C	A C	1	
D	A D	4 ✗	1 + 6
E	A C E	2 ⬅	1 + 1

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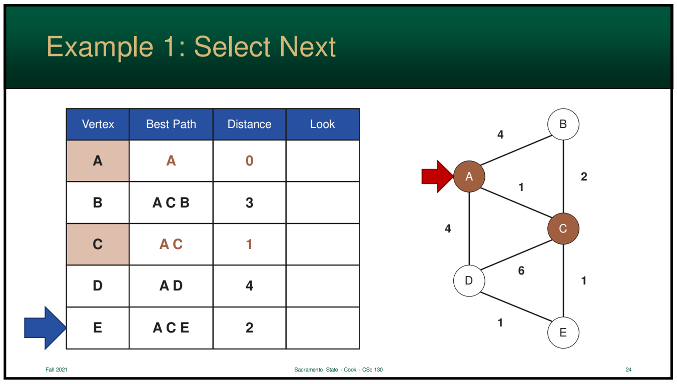

Example 1: Select Next

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A D	4	
➡ E	A C E	2	

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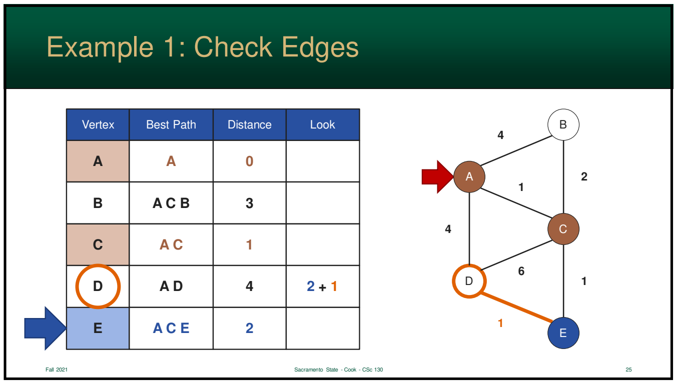

Example 1: Check Edges

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A D	4	2 + 1
E	A C E	2	

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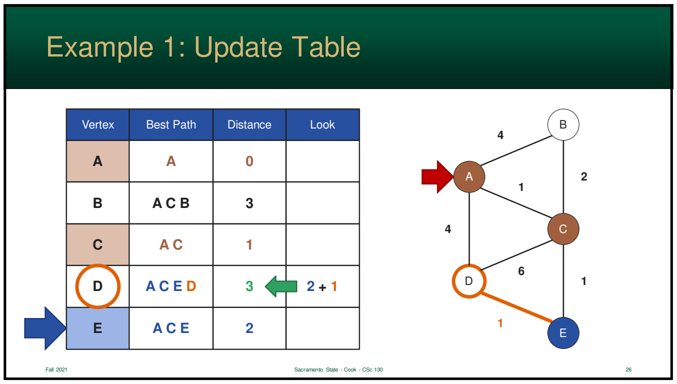

Example 1: Update Table

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A C E D	3	2 + 1
E	A C E	2	

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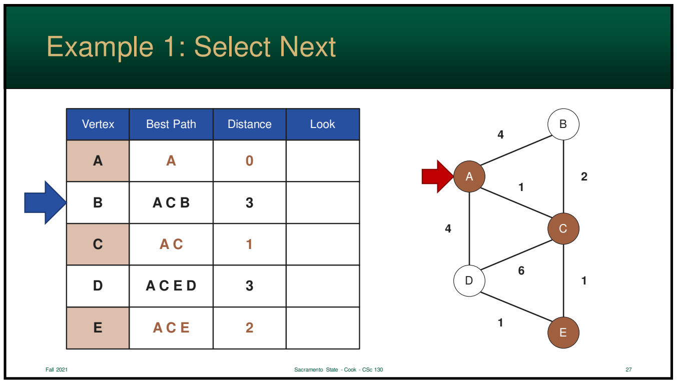

Example 1: Select Next

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A C E D	3	
E	A C E	2	

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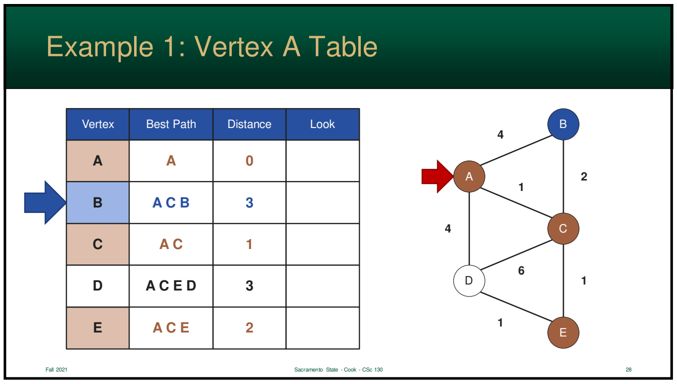

Example 1: Vertex A Table

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A C E D	3	
E	A C E	2	

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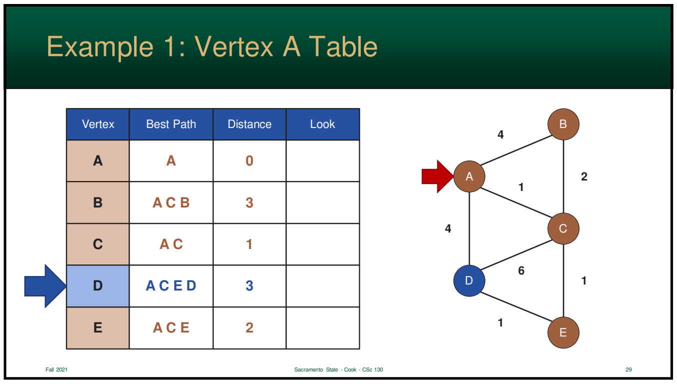

Example 1: Vertex A Table

Vertex	Best Path	Distance	Look
A	A	0	
B	A C B	3	
C	A C	1	
D	A C E D	3	
E	A C E	2	

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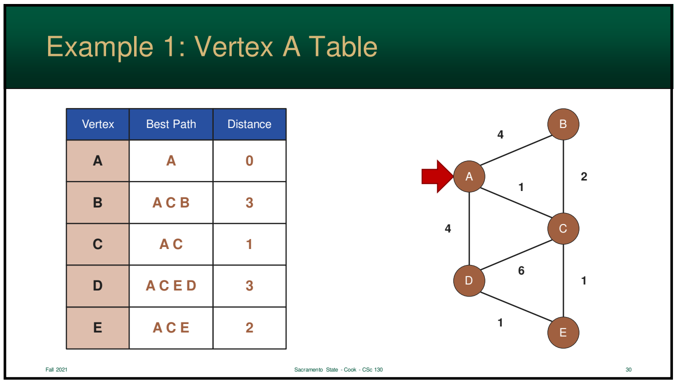

Example 1: Vertex A Table

Vertex	Best Path	Distance
A	A	0
B	A C B	3
C	A C	1
D	A C E D	3
E	A C E	2

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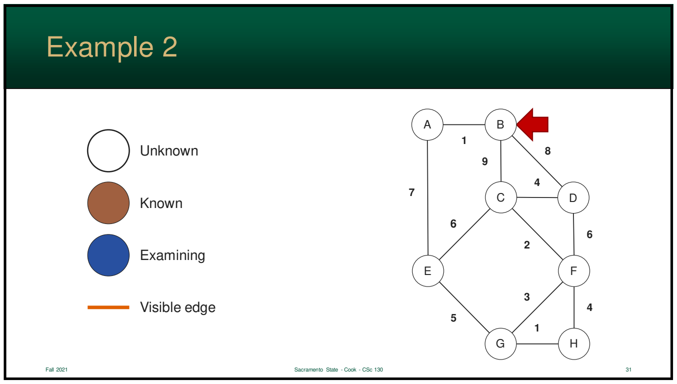

Example 2

- ○ Unknown
- ● Known
- ● Examining
- — Visible edge

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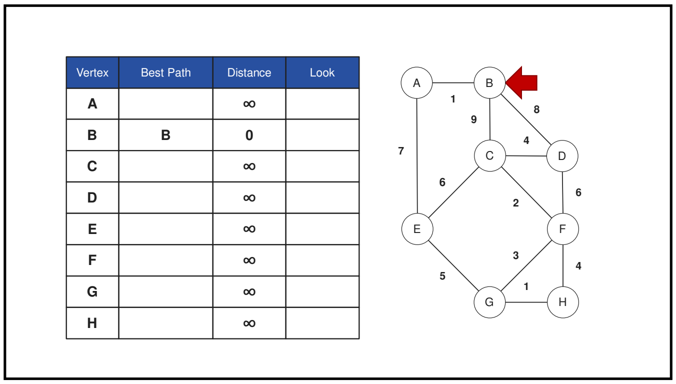

Vertex	Best Path	Distance	Look
A		∞	
B	B	0	
C		∞	
D		∞	
E		∞	
F		∞	
G		∞	
H		∞	

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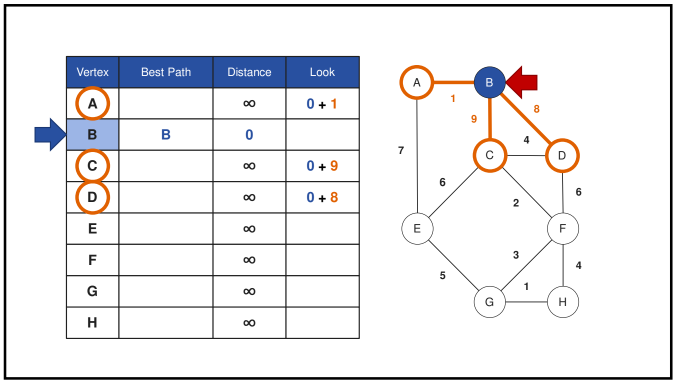

Vertex	Best Path	Distance	Look
A		∞	0 + 1
B	B	0	
C		∞	0 + 9
D		∞	0 + 8
E		∞	
F		∞	
G		∞	
H		∞	

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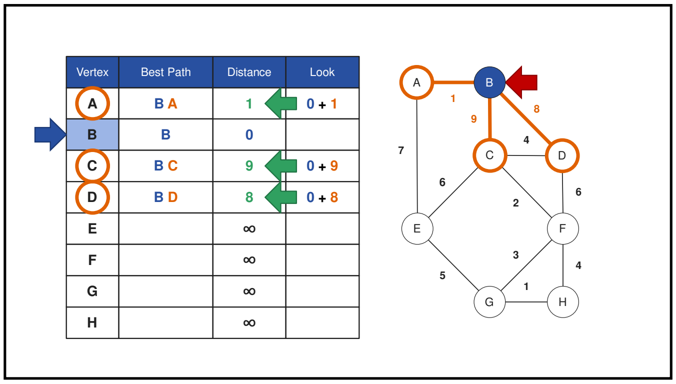

Vertex	Best Path	Distance	Look
A	B A	1	0 + 1
B	B	0	
C	B C	9	0 + 9
D	B D	8	0 + 8
E		∞	
F		∞	
G		∞	
H		∞	

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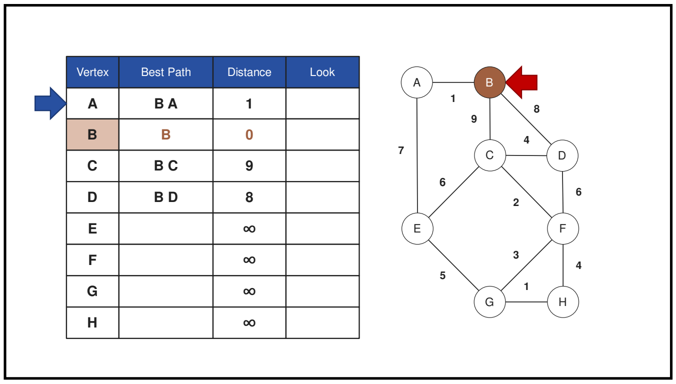

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E		∞	
F		∞	
G		∞	
H		∞	

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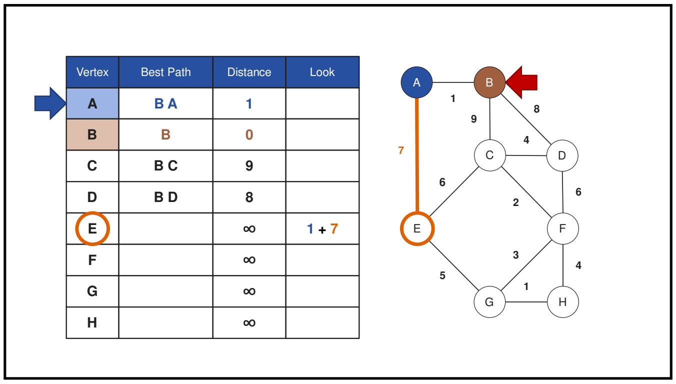

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E		∞	1 + 7
F		∞	
G		∞	
H		∞	

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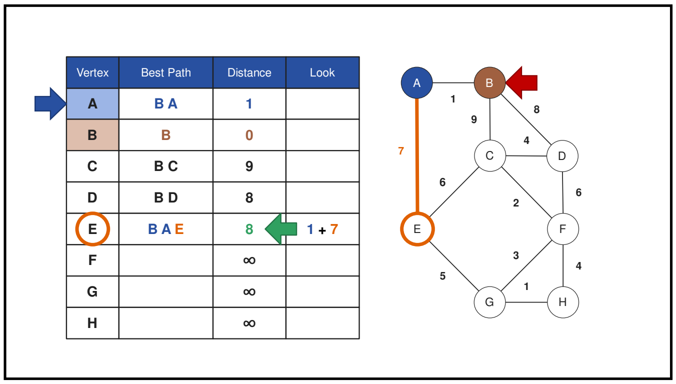

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	1 + 7
F		∞	
G		∞	
H		∞	

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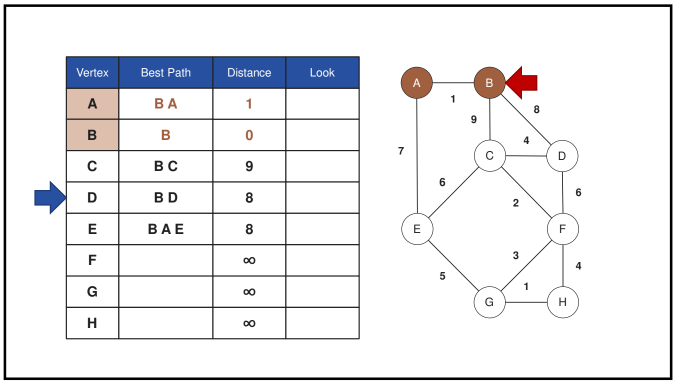

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F		∞	
G		∞	
H		∞	

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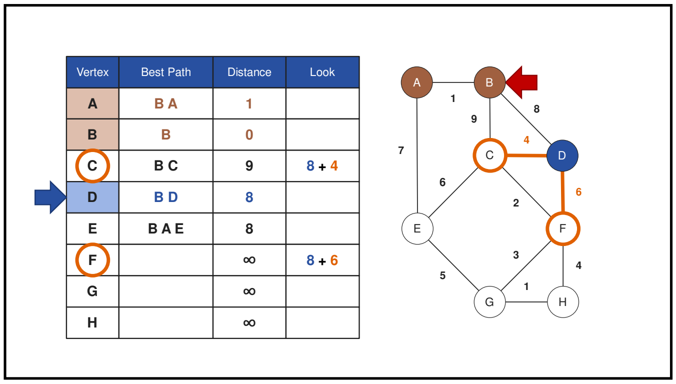

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	8 + 4
D	B D	8	
E	B A E	8	
F		∞	8 + 6
G		∞	
H		∞	

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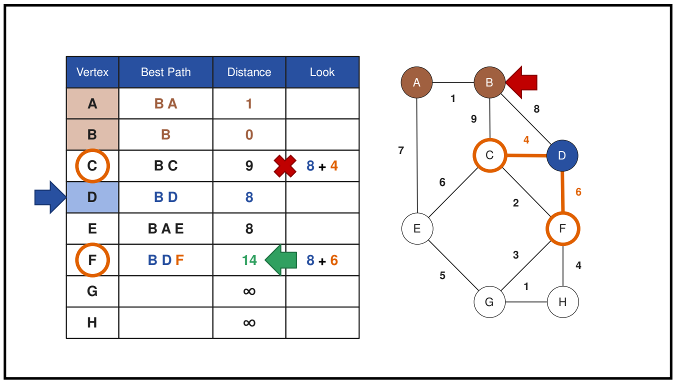

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	✖ 8 + 4
D	B D	8	
E	B A E	8	
F	B D F	14	8 + 6
G		∞	
H		∞	

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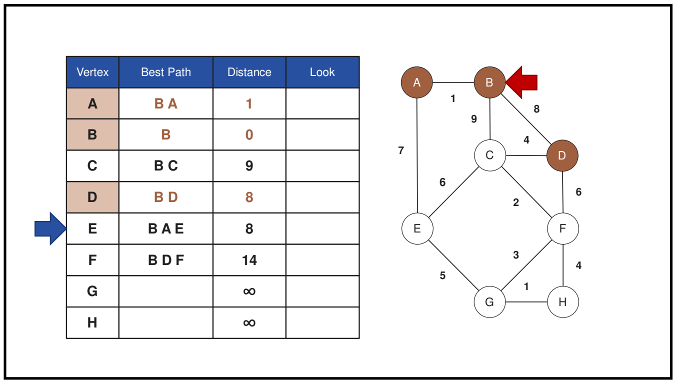

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B D F	14	
G		∞	
H		∞	

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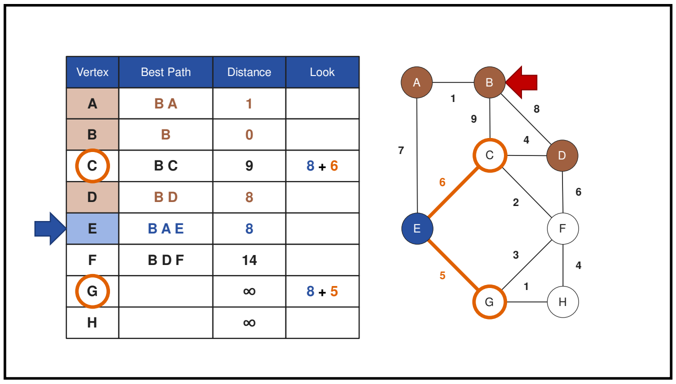

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	8 + 6
D	B D	8	
E	B A E	8	
F	B D F	14	
G		∞	8 + 5
H		∞	

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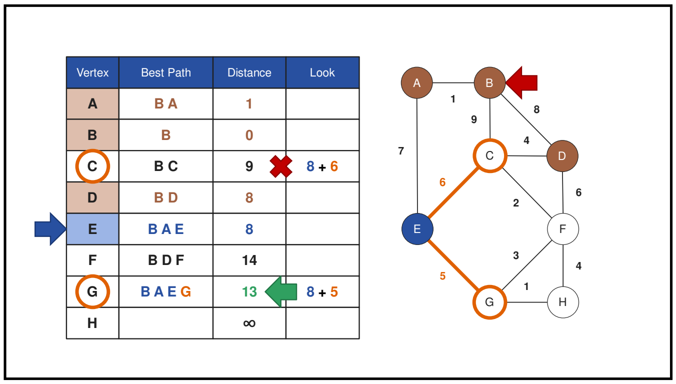

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9 ✖	8 + 6
D	B D	8	
E	B A E	8	
F	B D F	14	
G	B A E G	13	8 + 5
H		∞	

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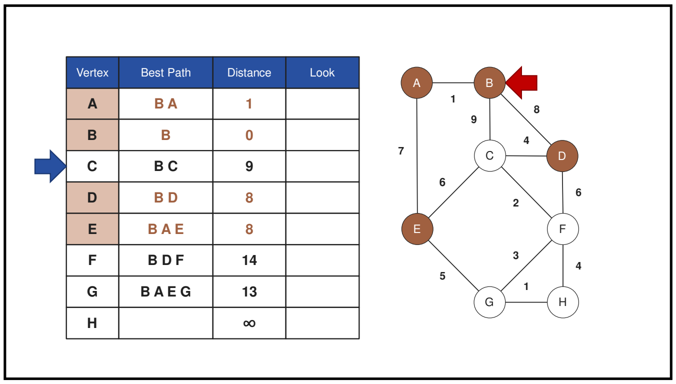

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B D F	14	
G	B A E G	13	
H		∞	

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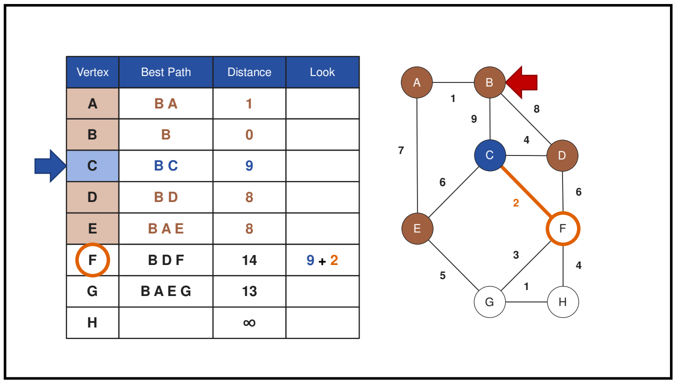

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B D F	14	9 + 2
G	B A E G	13	
H		∞	

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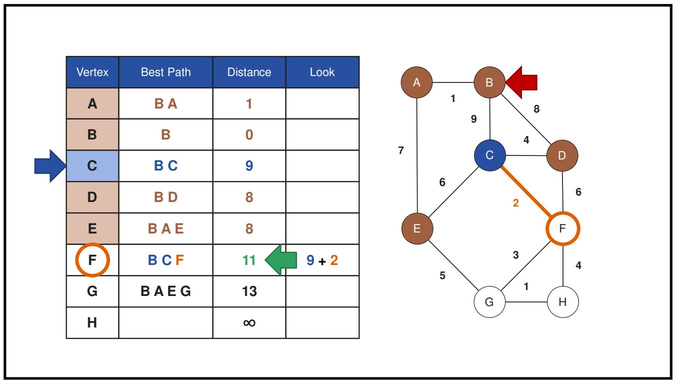

Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	9 + 2
G	B A E G	13	
H		∞	

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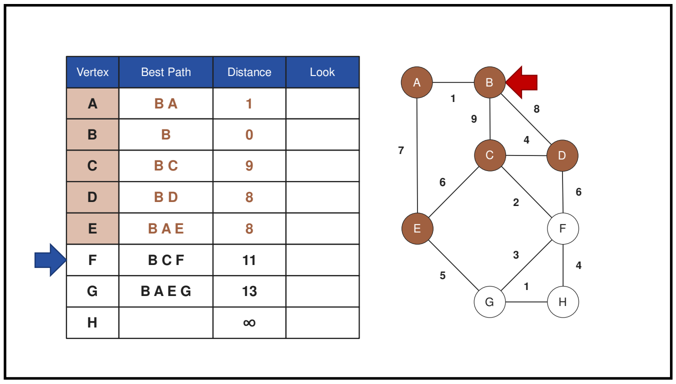
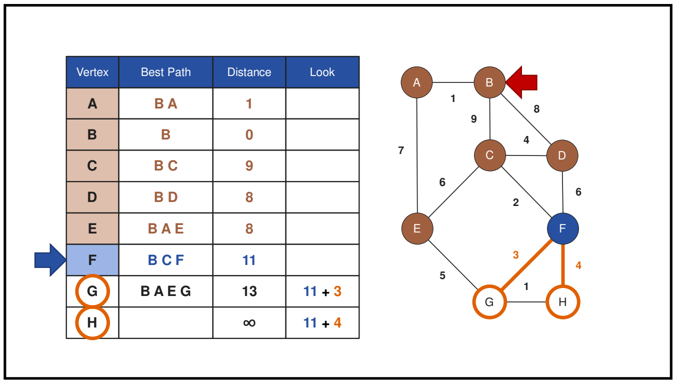


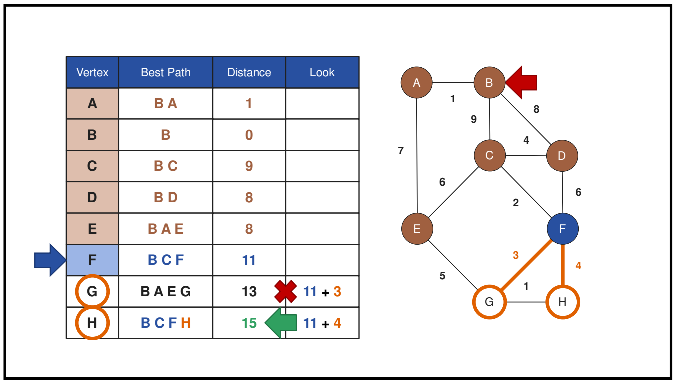
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	
H		∞	

47



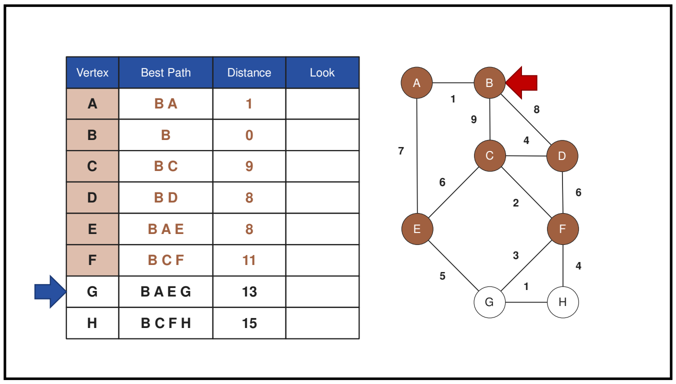
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	11 + 3
H		∞	11 + 4

48



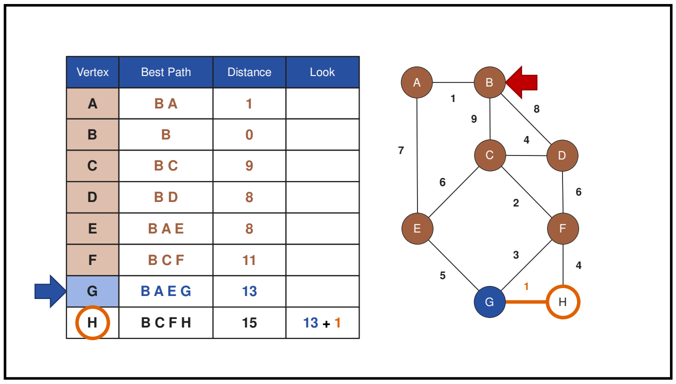
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13 ✖	11 + 3
H	B C F H	15 ⬅	11 + 4

49



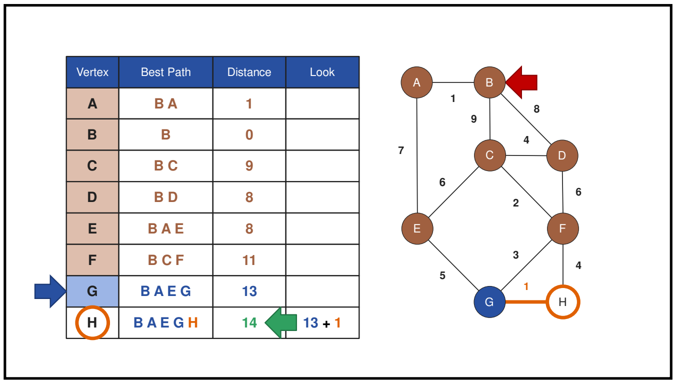
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	
H	B C F H	15	

50



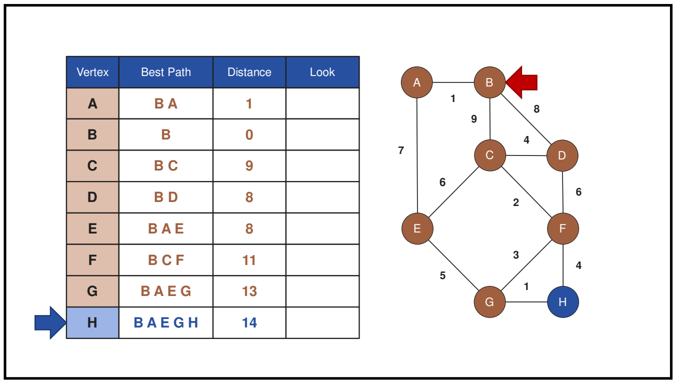
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	
H	B C F H	15	13 + 1

51



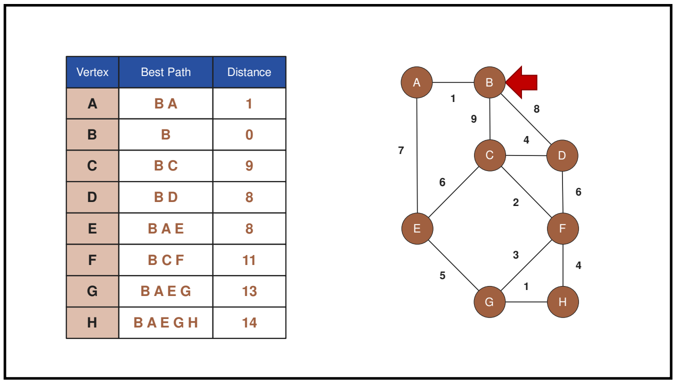
Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	
H	B A E G H	14 ⬅	13 + 1

52



Vertex	Best Path	Distance	Look
A	B A	1	
B	B	0	
C	B C	9	
D	B D	8	
E	B A E	8	
F	B C F	11	
G	B A E G	13	
H	B A E G H	14	

53



Vertex	Best Path	Distance
A	B A	1
B	B	0
C	B C	9
D	B D	8
E	B A E	8
F	B C F	11
G	B A E G	13
H	B A E G H	14

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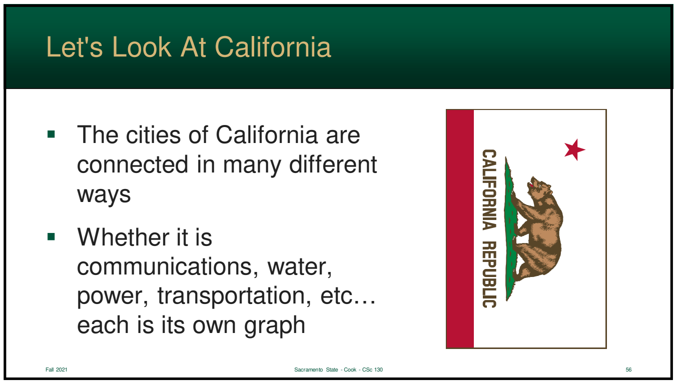
Let's Look at California

Driving Around the Golden State

55



Let's Look At California

- The cities of California are connected in many different ways
- Whether it is communications, water, power, transportation, etc… each is its own graph

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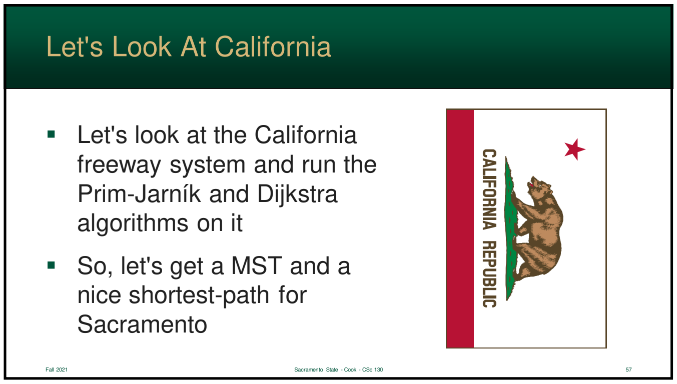

Let's Look At California

- Let's look at the California freeway system and run the Prim-Jarník and Dijkstra algorithms on it
- So, let's get a MST and a nice shortest-path for Sacramento

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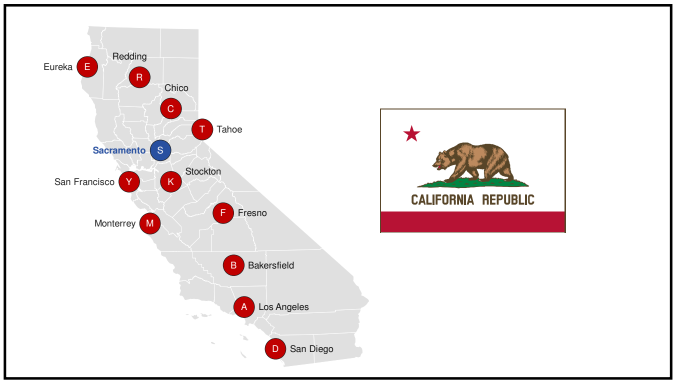
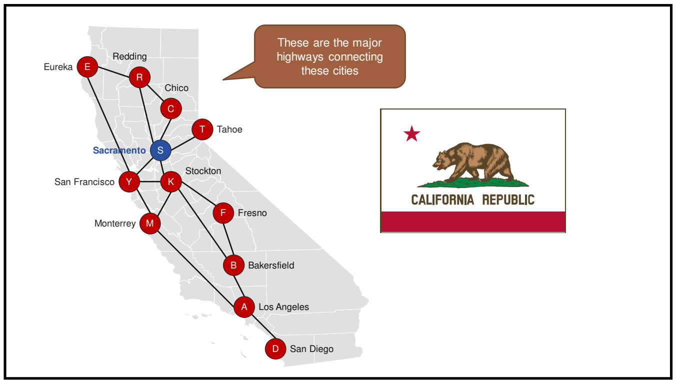
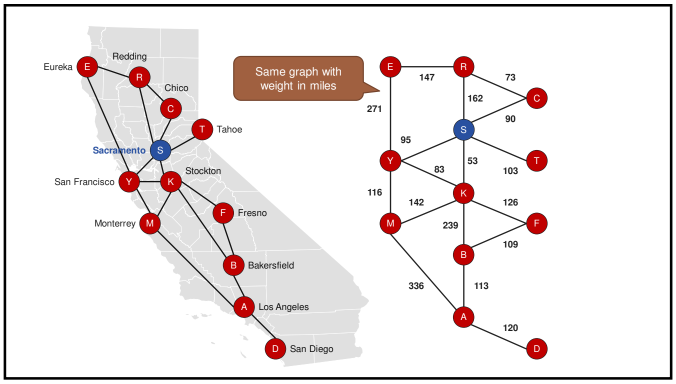


58



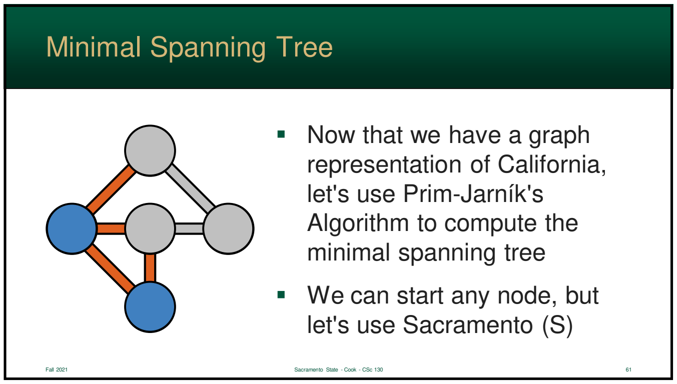
These are the major highways connecting these cities

59



Same graph with weight in miles

60



Minimal Spanning Tree

- Now that we have a graph representation of California, let's use Prim-Jarník's Algorithm to compute the minimal spanning tree
- We can start any node, but let's use Sacramento (S)

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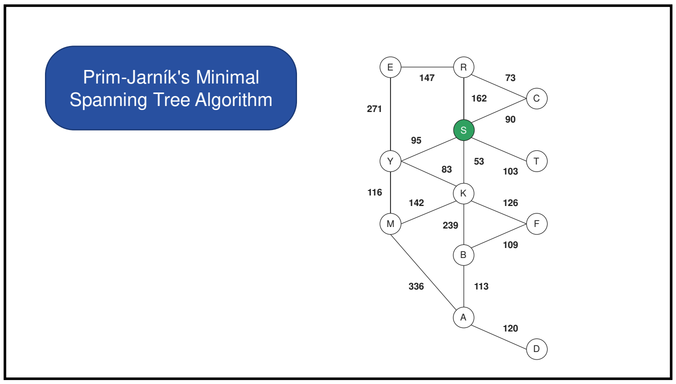
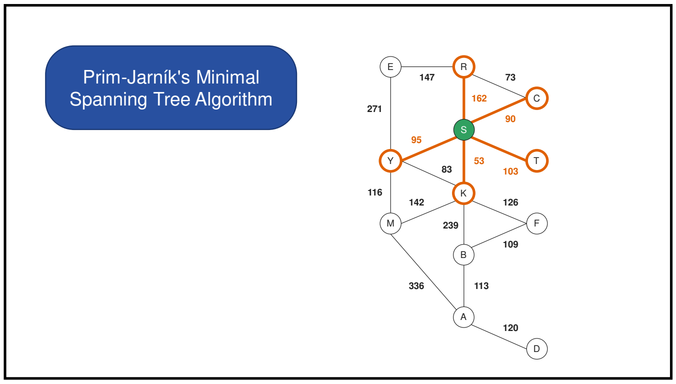


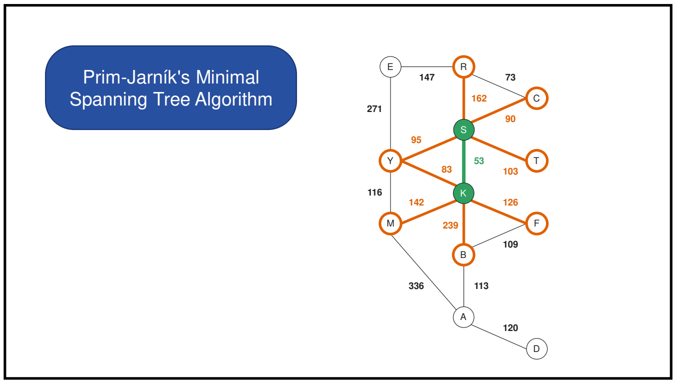
Prim-Jarník's Minimal Spanning Tree Algorithm

62



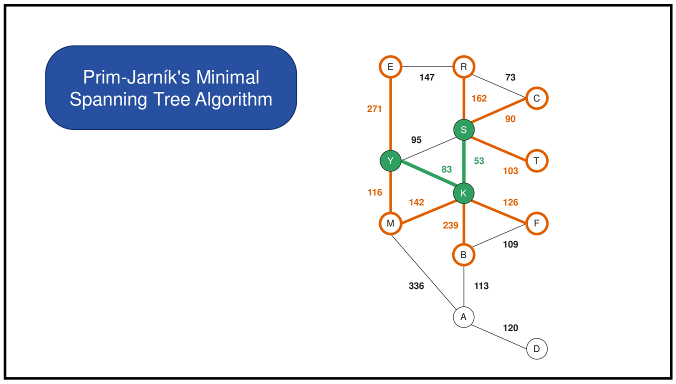
Prim-Jarník's Minimal Spanning Tree Algorithm

63



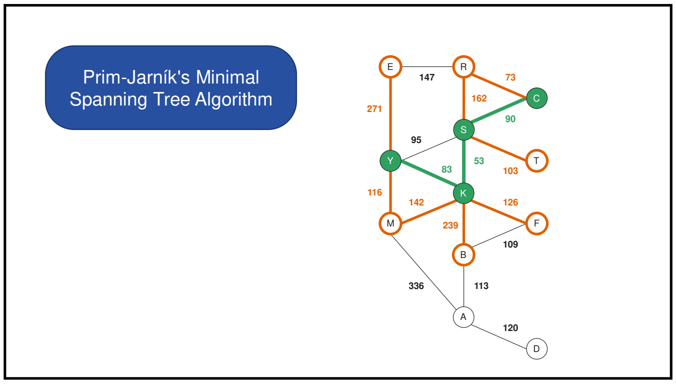
Prim-Jarník's Minimal Spanning Tree Algorithm

64



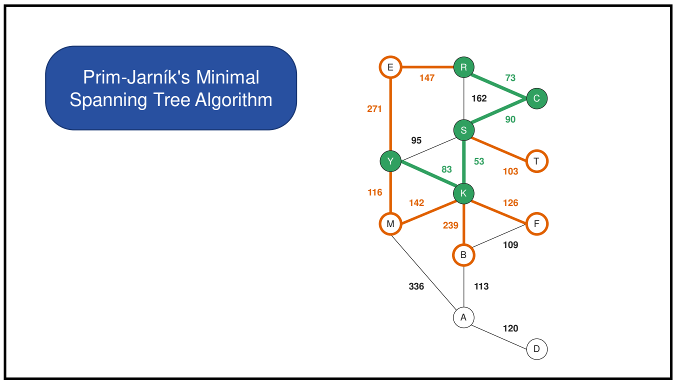
Prim-Jarník's Minimal Spanning Tree Algorithm

65



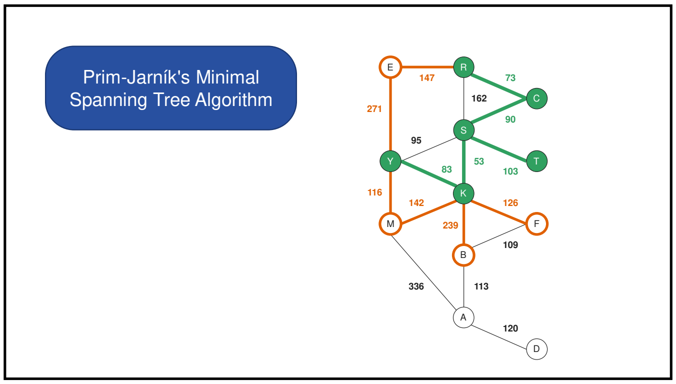
Prim-Jarník's Minimal Spanning Tree Algorithm

66



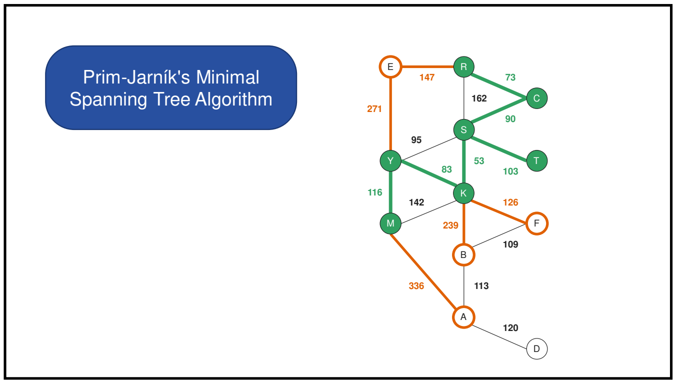
Prim-Jarník's Minimal Spanning Tree Algorithm

67



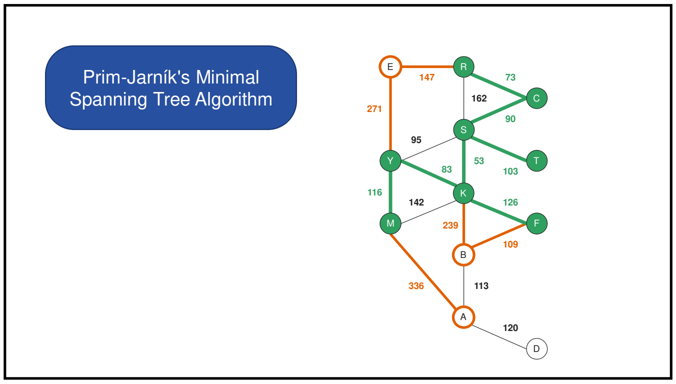
Prim-Jarník's Minimal Spanning Tree Algorithm

68



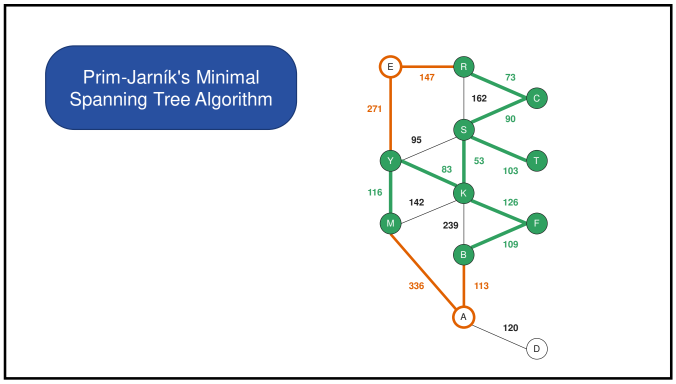
Prim-Jarník's Minimal Spanning Tree Algorithm

69



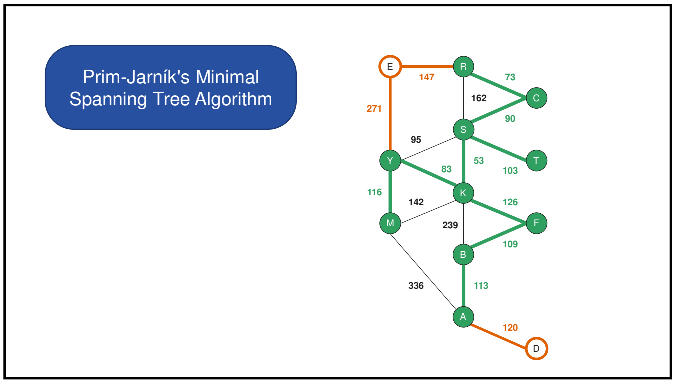
Prim-Jarník's Minimal Spanning Tree Algorithm

70



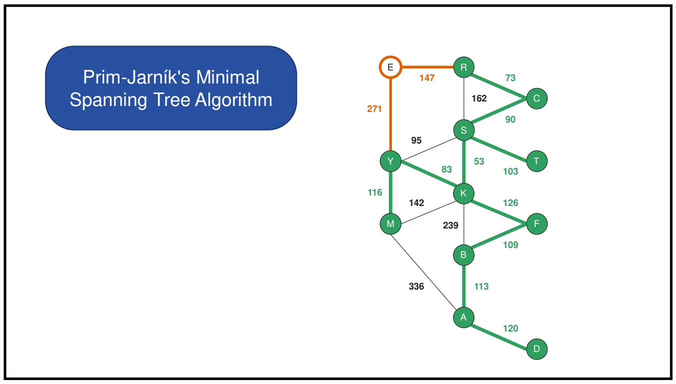
Prim-Jarník's Minimal Spanning Tree Algorithm

71



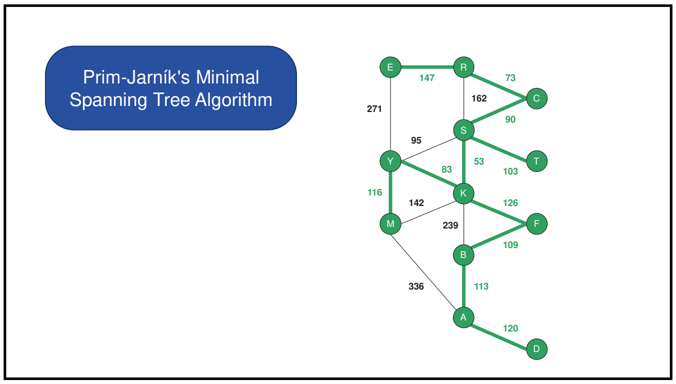
Prim-Jarník's Minimal Spanning Tree Algorithm

72



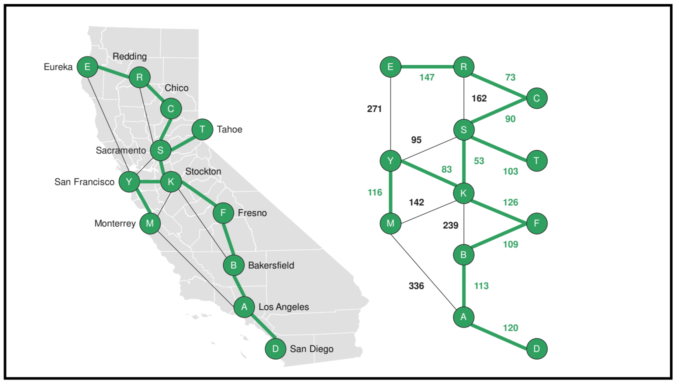
Prim-Jarník's Minimal Spanning Tree Algorithm

73

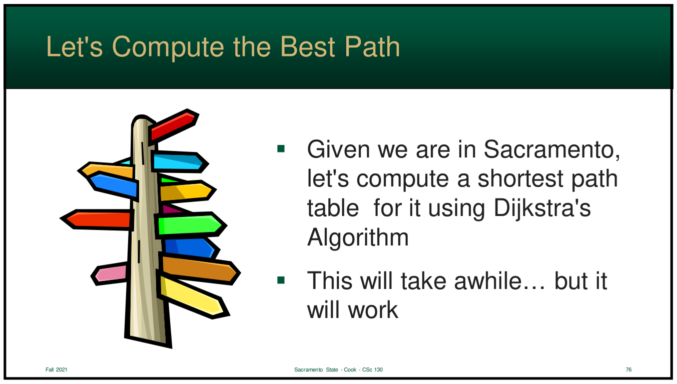


Prim-Jarník's Minimal Spanning Tree Algorithm

74



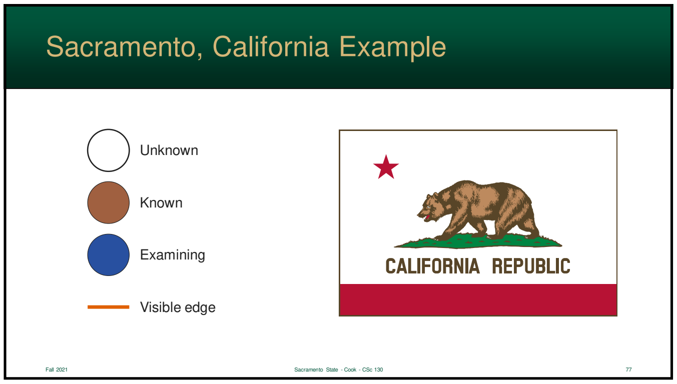
75



Let's Compute the Best Path

- Given we are in Sacramento, let's compute a shortest path table for it using Dijkstra's Algorithm
- This will take awhile… but it will work

76



Sacramento, California Example

○ Unknown

● Known

● Examining

— Visible edge

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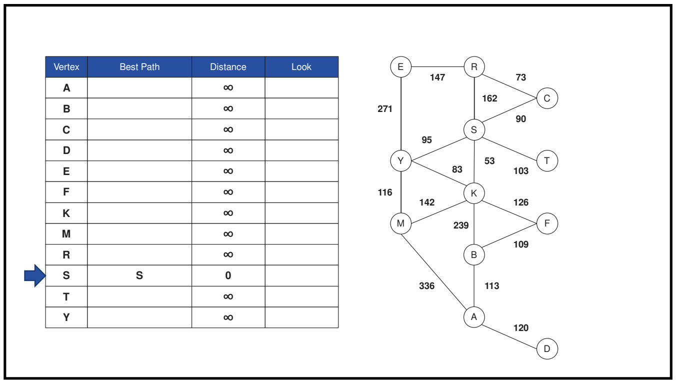
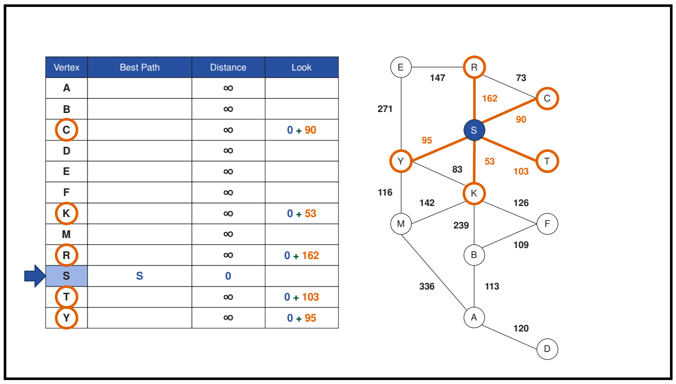


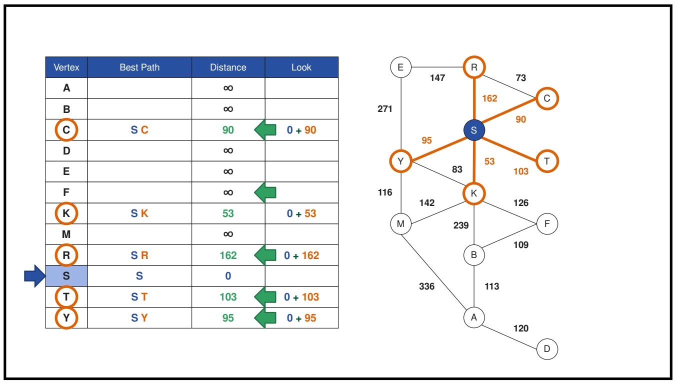
Vertex	Best Path	Distance	Look
A		∞	
B		∞	
C		∞	
D		∞	
E		∞	
F		∞	
K		∞	
M		∞	
R		∞	
S	S	0	
T		∞	
Y		∞	

78



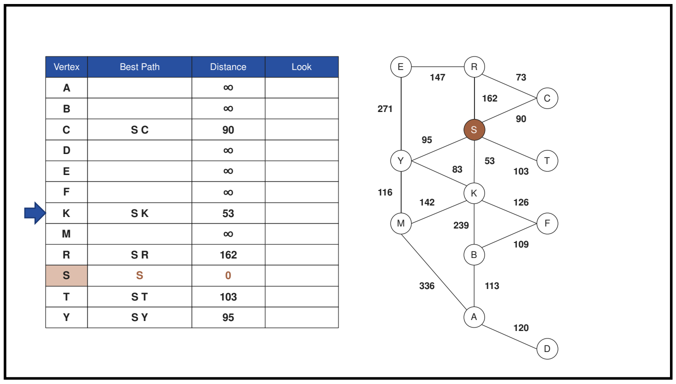
Vertex	Best Path	Distance	Look
A		∞	
B		∞	
C		∞	0 + 90
D		∞	
E		∞	
F		∞	
K		∞	0 + 53
M		∞	
R		∞	0 + 162
S	S	0	
T		∞	0 + 103
Y		∞	0 + 95

79



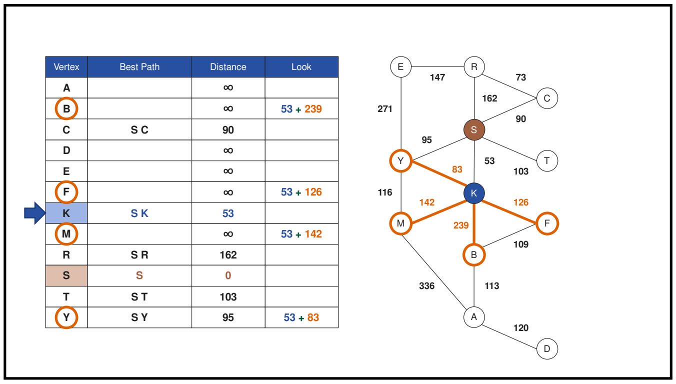
Vertex	Best Path	Distance	Look
A		∞	
B		∞	
C	S C	90	0 + 90
D		∞	
E		∞	
F		∞	
K	S K	53	0 + 53
M		∞	
R	S R	162	0 + 162
S	S	0	
T	S T	103	0 + 103
Y	S Y	95	0 + 95

80



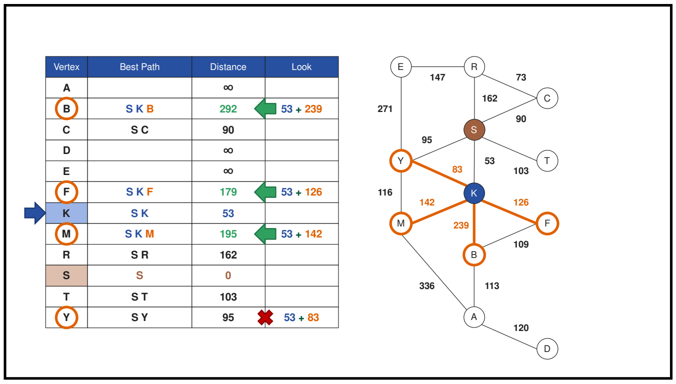
Vertex	Best Path	Distance	Look
A		∞	
B		∞	
C	S C	90	
D		∞	
E		∞	
F		∞	
K	S K	53	
M		∞	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

81



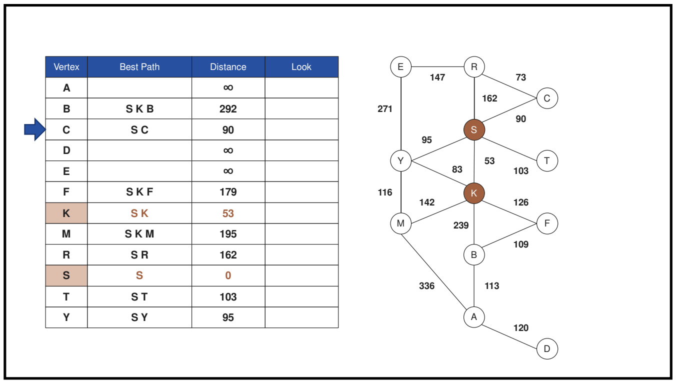
Vertex	Best Path	Distance	Look
A		∞	
B		∞	53 + 239
C	S C	90	
D		∞	
E		∞	
F		∞	53 + 126
K	S K	53	
M		∞	53 + 142
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	53 + 83

82



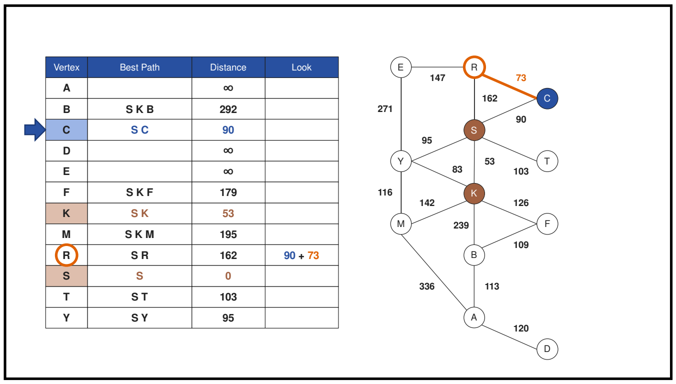
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	53 + 239
C	S C	90	
D		∞	
E		∞	
F	S K F	179	53 + 126
K	S K	53	
M	S K M	195	53 + 142
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	✖ 53 + 83

83



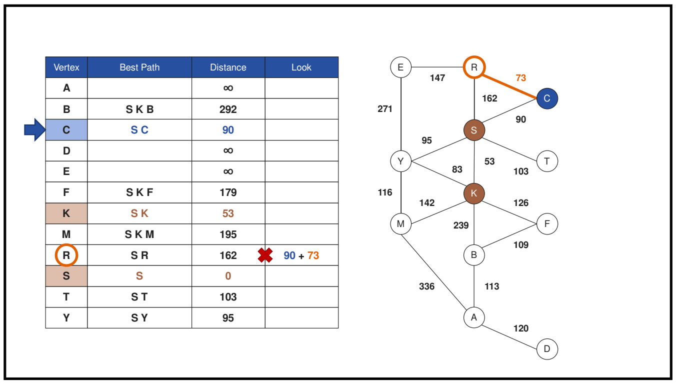
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E		∞	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

84



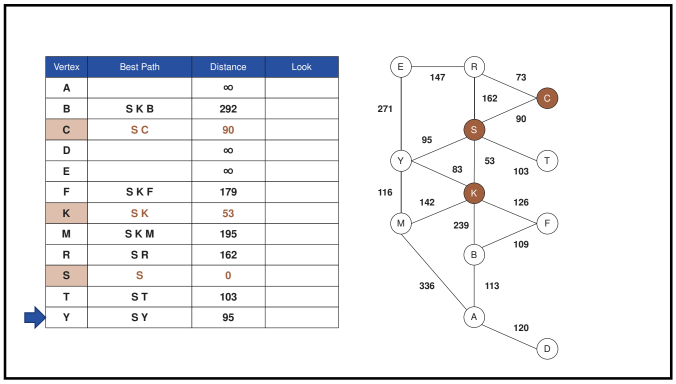
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E		∞	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	90 + 73
S	S	0	
T	S T	103	
Y	S Y	95	

85



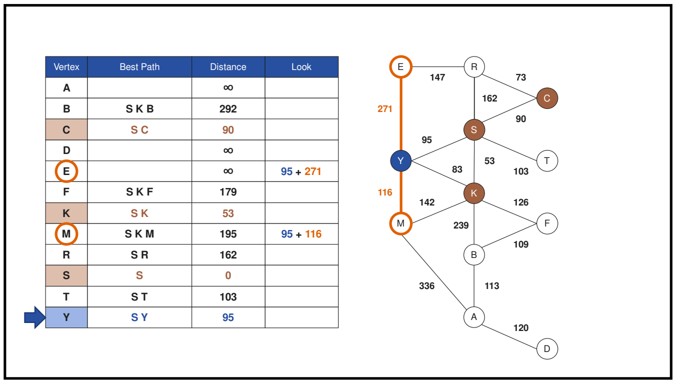
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E		∞	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	✗ 90 + 73
S	S	0	
T	S T	103	
Y	S Y	95	

86



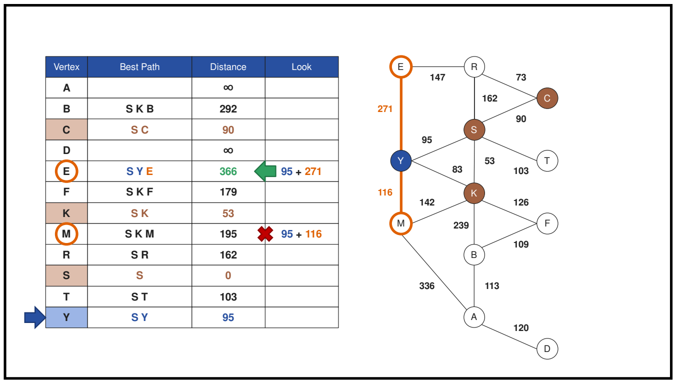
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E		∞	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

87



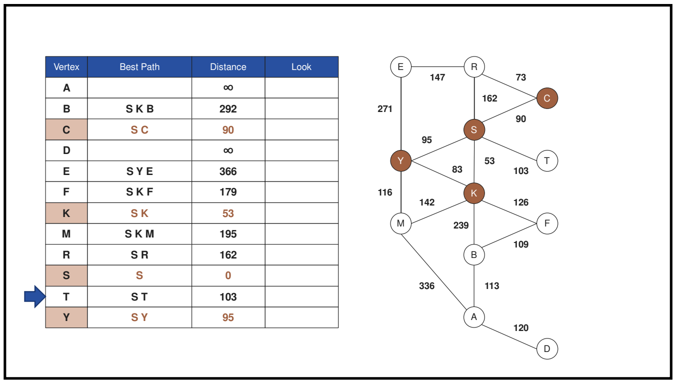
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E		∞	95 + 271
F	S K F	179	
K	S K	53	
M	S K M	195	95 + 116
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

88



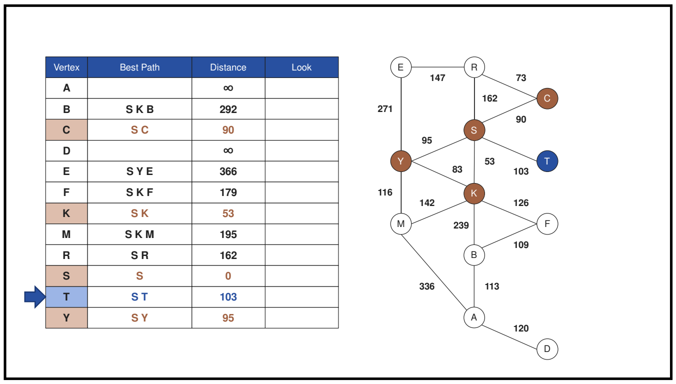
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S Y E	366	⬅ 95 + 271
F	S K F	179	
K	S K	53	
M	S K M	195	✗ 95 + 116
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

89



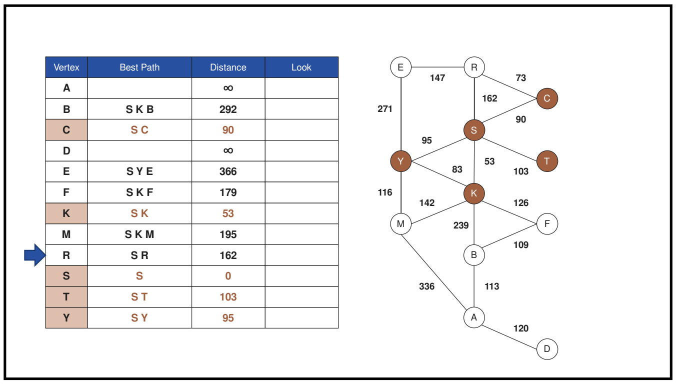
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S Y E	366	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

90



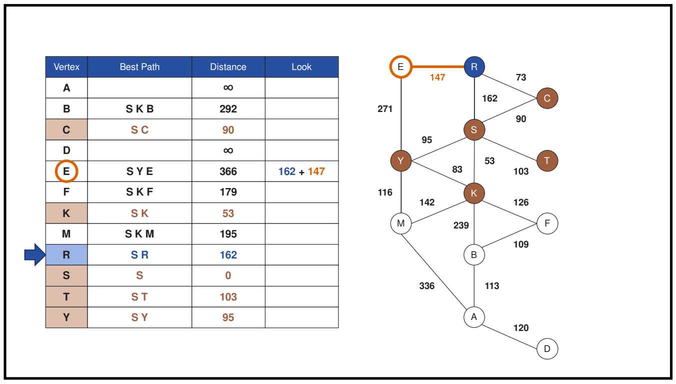
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S Y E	366	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

91



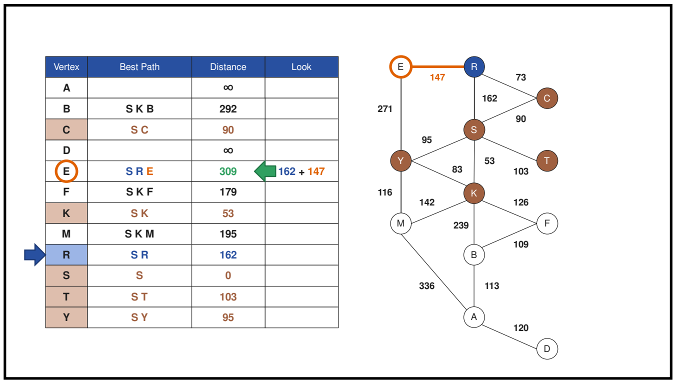
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S Y E	366	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

92



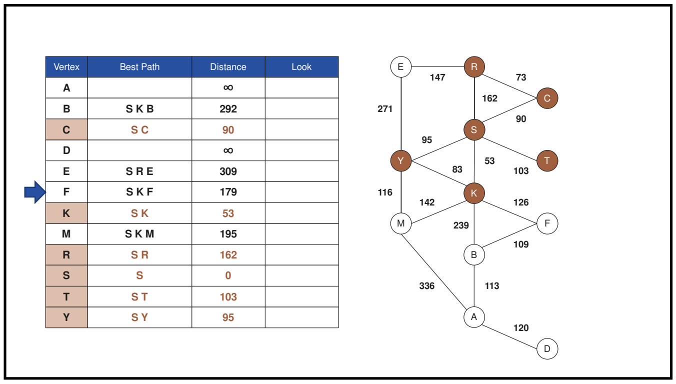
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S Y E	366	162 + 147
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

93



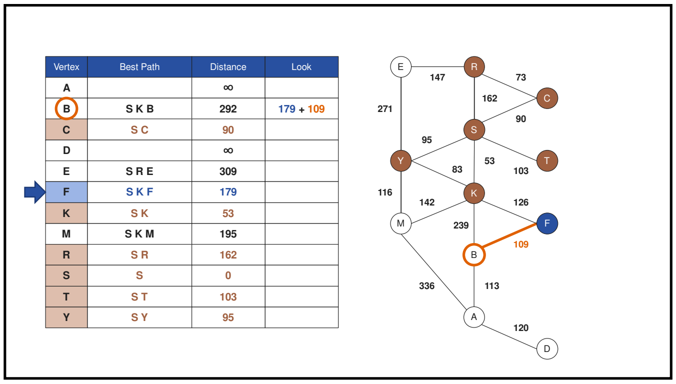
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S R E	309	162 + 147
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

94



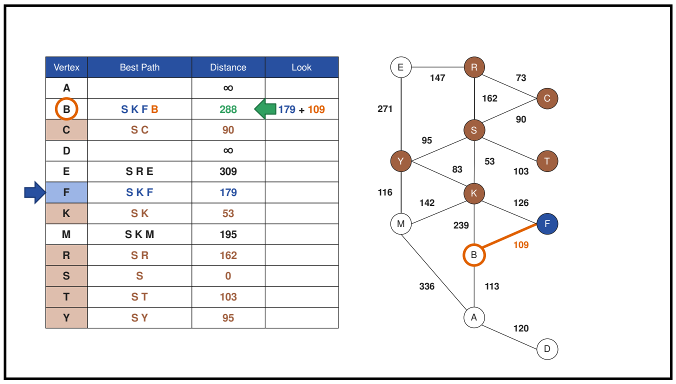
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

95



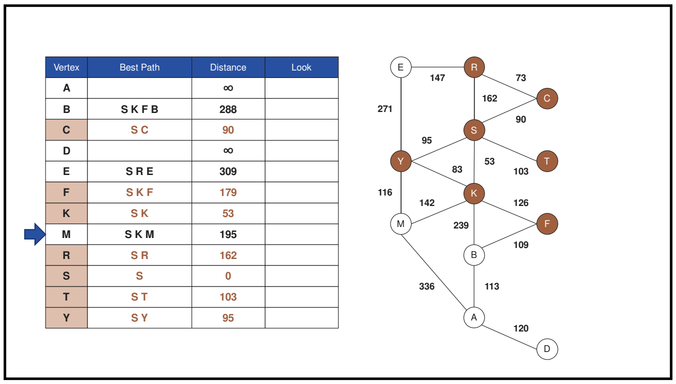
Vertex	Best Path	Distance	Look
A		∞	
B	S K B	292	179 + 109
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

96



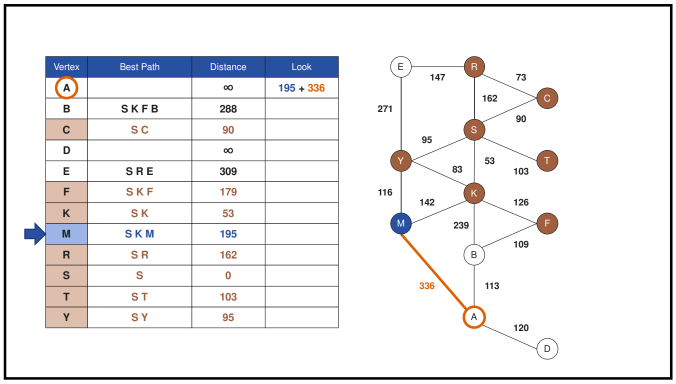
Vertex	Best Path	Distance	Look
A		∞	
B	S K F B	288	179 + 109
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

97



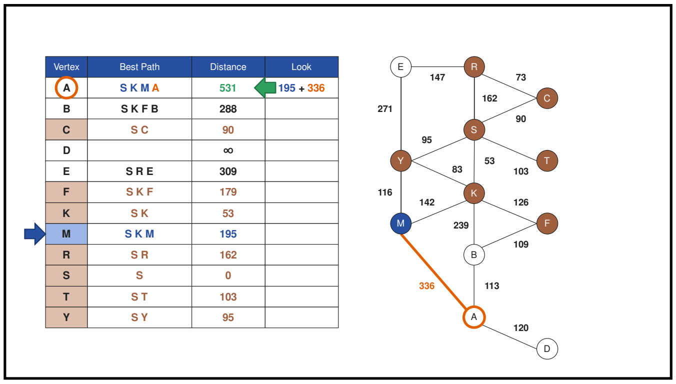
Vertex	Best Path	Distance	Look
A		∞	
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

98



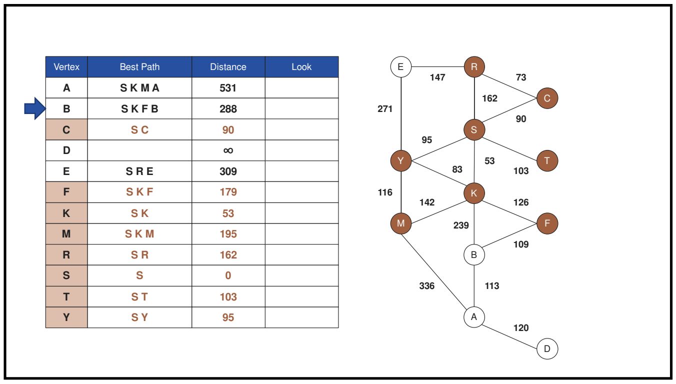
Vertex	Best Path	Distance	Look
A		∞	195 + 336
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

99



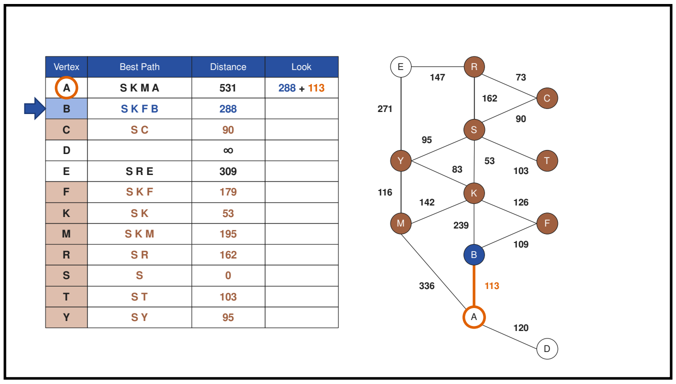
Vertex	Best Path	Distance	Look
A	S K M A	531	195 + 336
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

100



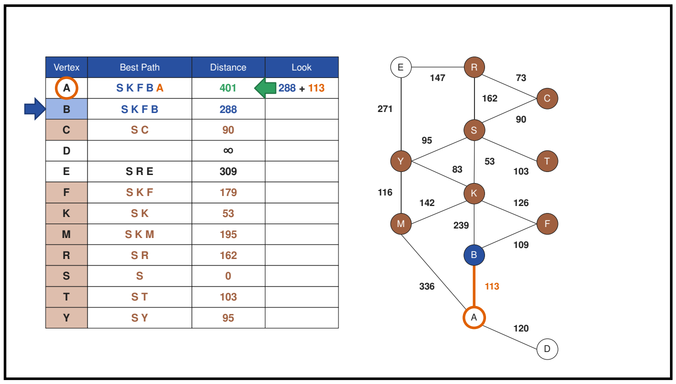
Vertex	Best Path	Distance	Look
A	S K M A	531	
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

101



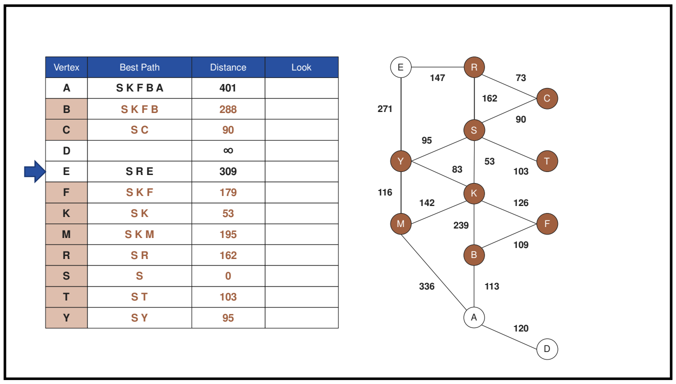
Vertex	Best Path	Distance	Look
A	S K M A	531	288 + 113
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

102



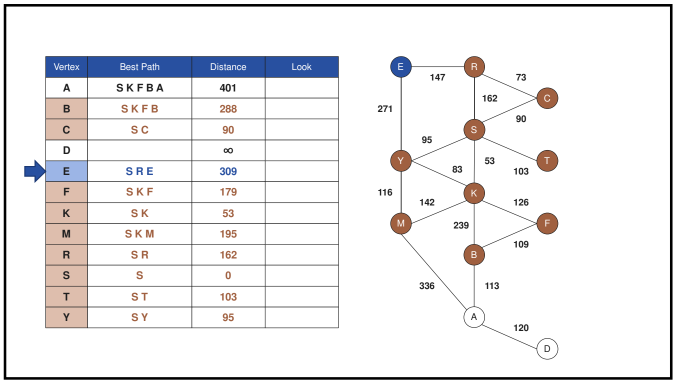
Vertex	Best Path	Distance	Look
A	S K F B A	401	288 + 113
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

103



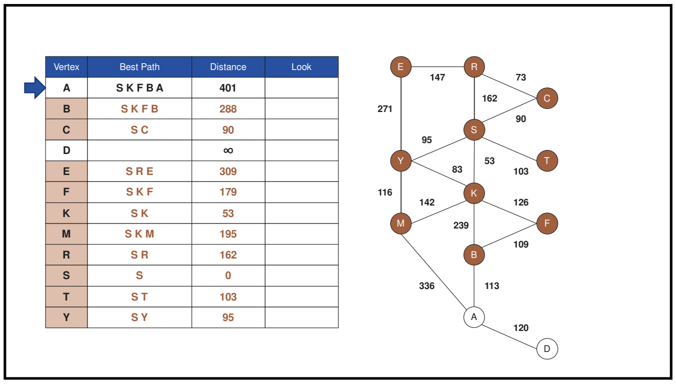
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

104



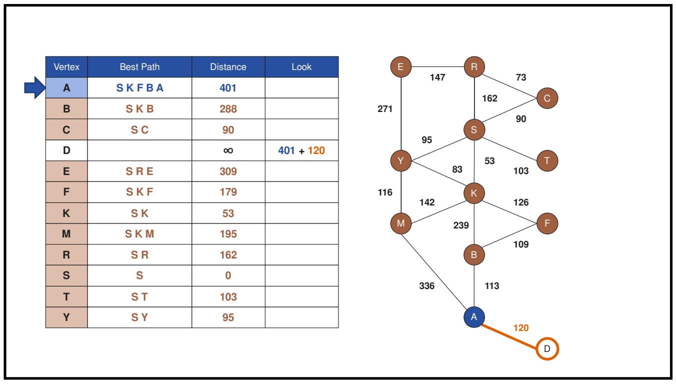
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

105



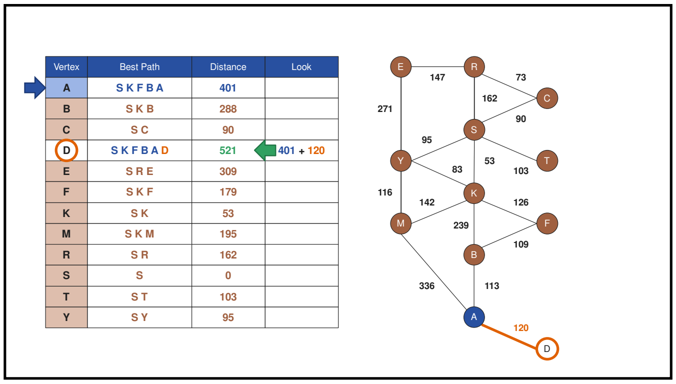
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K F B	288	
C	S C	90	
D		∞	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

106



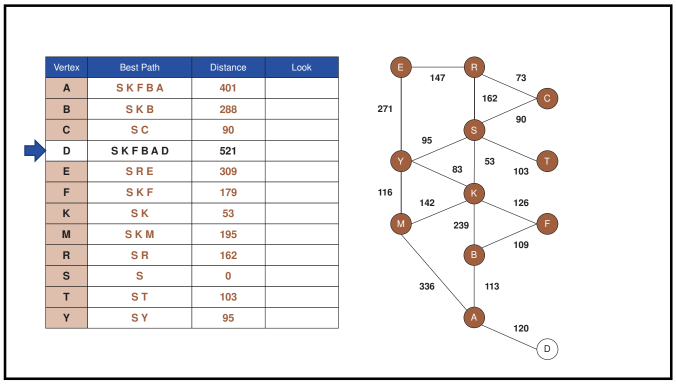
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K B	288	
C	S C	90	
D		∞	401 + 120
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

107



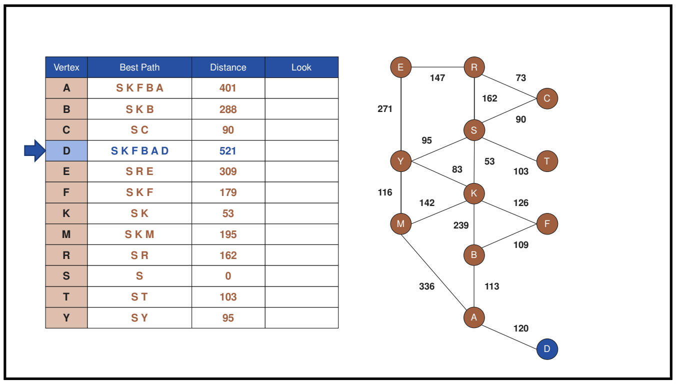
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K B	288	
C	S C	90	
D	S K F B A D	521	401 + 120
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

108



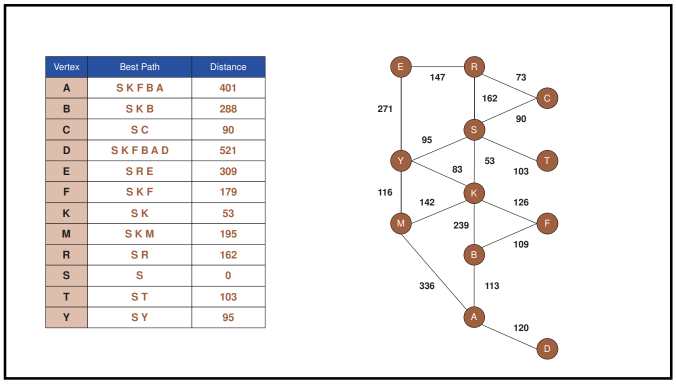
Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K B	288	
C	S C	90	
D	S K F B A D	521	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

109



Vertex	Best Path	Distance	Look
A	S K F B A	401	
B	S K B	288	
C	S C	90	
D	S K F B A D	521	
E	S R E	309	
F	S K F	179	
K	S K	53	
M	S K M	195	
R	S R	162	
S	S	0	
T	S T	103	
Y	S Y	95	

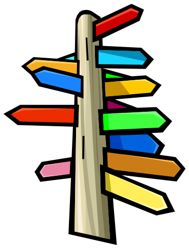
110



Vertex	Best Path	Distance
A	S K F B A	401
B	S K B	288
C	S C	90
D	S K F B A D	521
E	S R E	309
F	S K F	179
K	S K	53
M	S K M	195
R	S R	162
S	S	0
T	S T	103
Y	S Y	95

111

Best Path Complete



- It appears like the best route from Sacramento to San Diego is on the minimal spanning tree
- That makes sense… no "short cut" roads can be built

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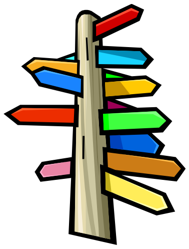
Best Path Complete



- However, our best path isn't always on the MST
- Path to Eureka skips Chico
- Path to Monterey goes around San Francisco

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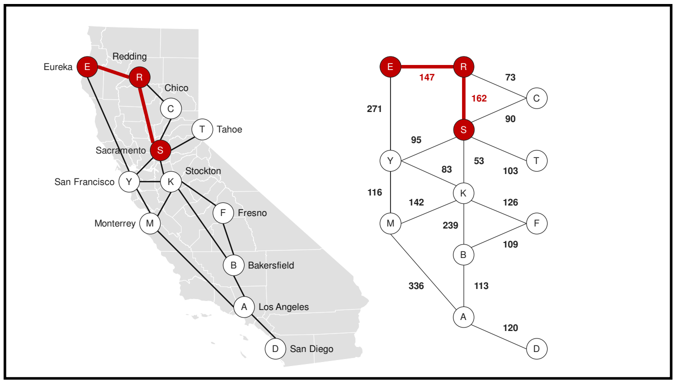
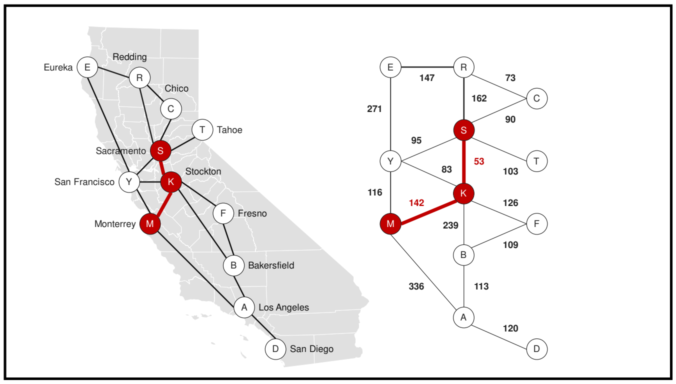
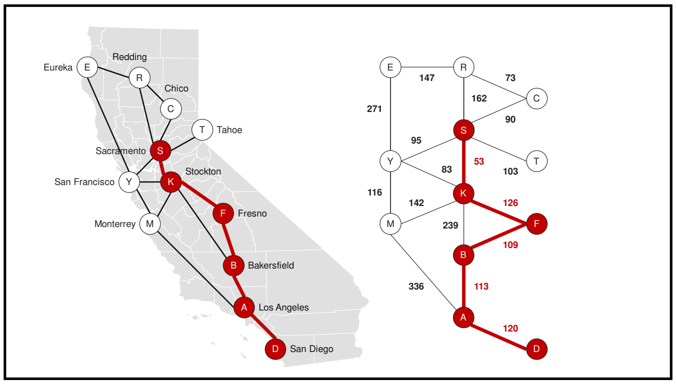


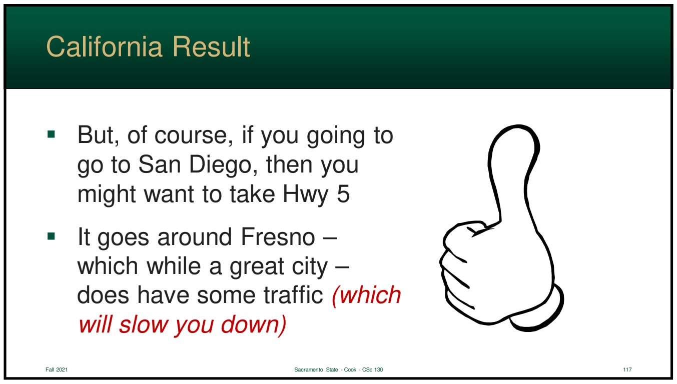
114



115



116



California Result

- But, of course, if you going to go to San Diego, then you might want to take Hwy 5
- It goes around Fresno – which while a great city – does have some traffic *(which will slow you down)*

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