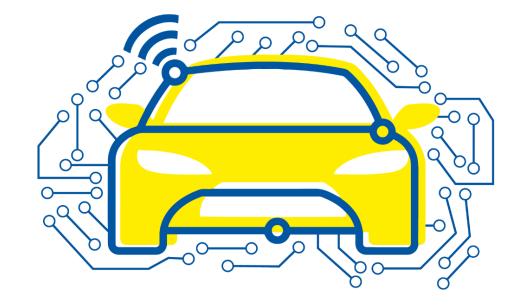


Automated and Connected Driving Challenges

Section 4 – Vehicle Guidance

Vehicle Guidance on Navigation Level Introduction



Bastian Lampe

Institute for Automotive Engineering





Bellman's Principle of Optimality

Principle of Optimality:

"An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision."

- Dynamic programming breaks the planning problem into simpler steps at different states in time
- The optimal solution is then composed from piece wise optimal solutions
- Discretization of configuration-space necessary

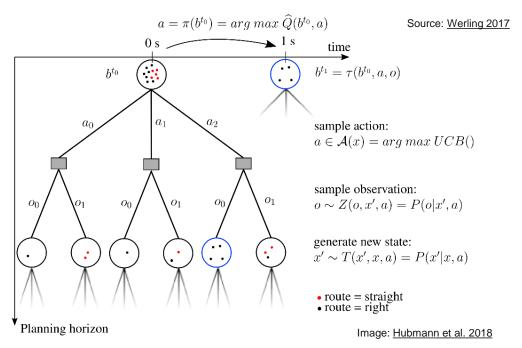


Dynamic Programming

- Almost any cost-function can be applied
- Global optimum can be calculated efficiently
- → Combinatorial problems:
 - Parking applications
 - Route-Planning
 - Collision avoidance of multiple obstacles
 - Decision making

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- "Curse of dimensionality"
 - Exponential increase in complexity with increasing number of states
- A priori constraints for possible maneuvers



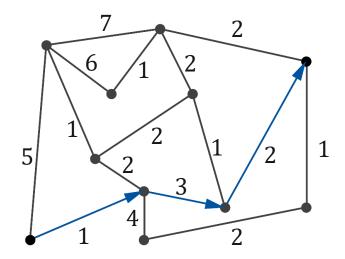
POMDP with Tree-Search



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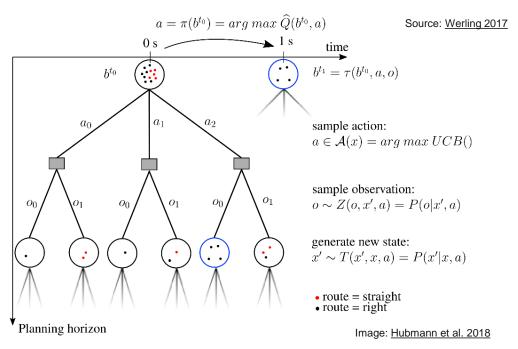
Dynamic Programming

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Dijkstra Graph-Search Source: Dijkstra 1959

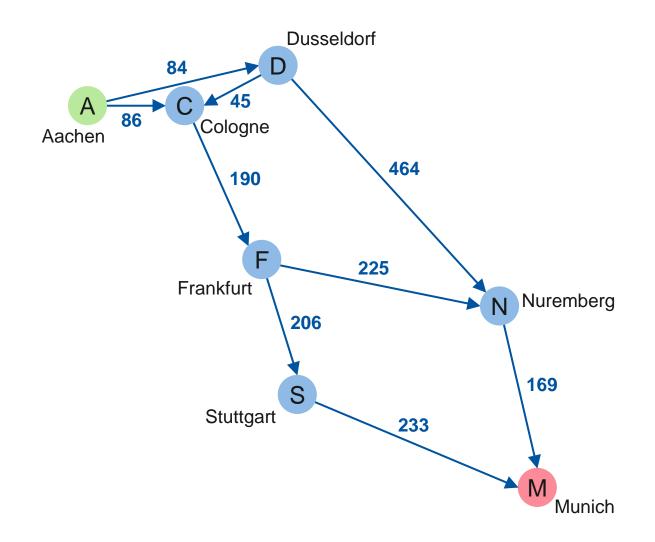
- "Curse of dimensionality"
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POMDP with Tree-Search

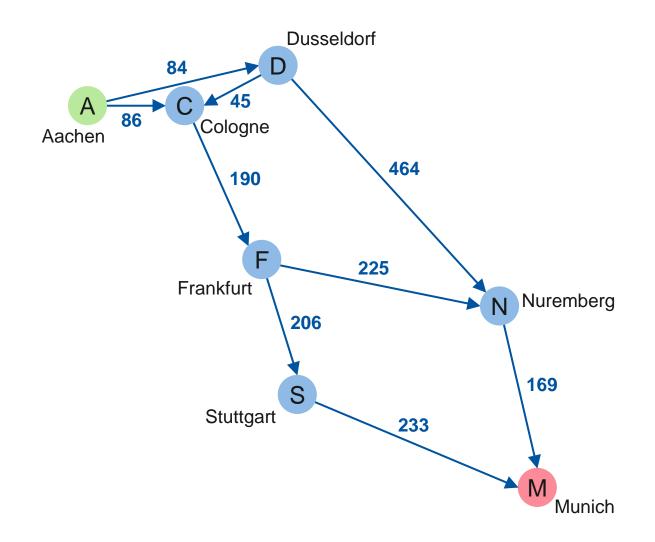






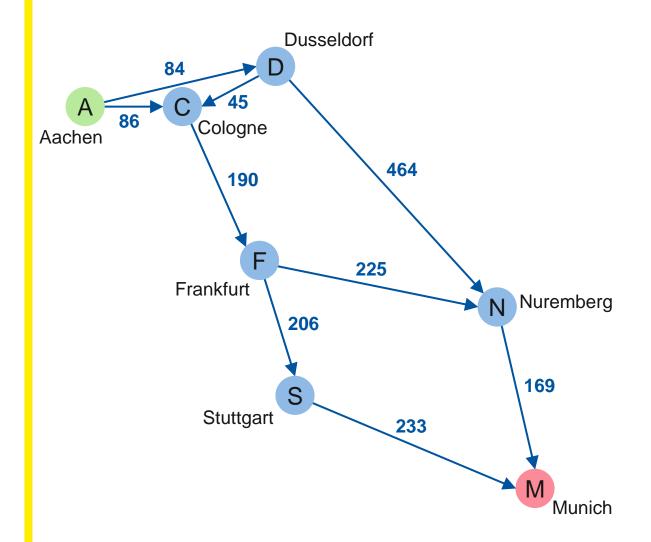








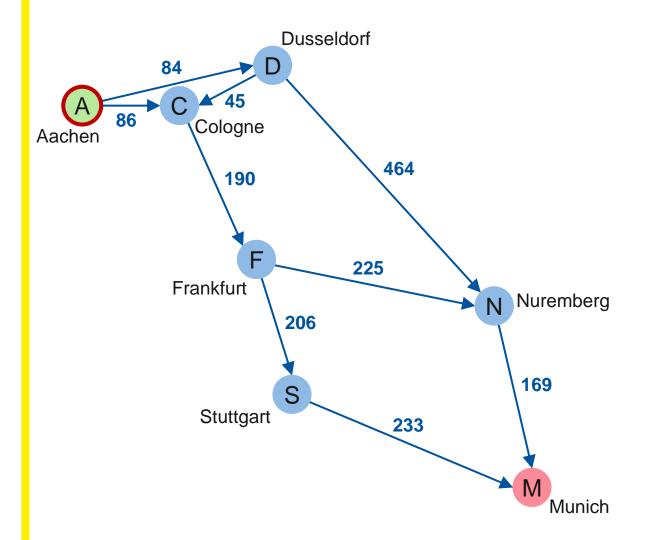
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| | | Α | С | D | F | S | N | M |
|----------|------|---|---|---|---|---|---|---|
| 0 | Cost | | | | | | | |
| | Pre | | | | | | | |
| 1 | Cost | | | | | | | |
| ı | Pre | | | | | | | |
| 2 | Cost | | | | | | | |
| | Pre | | | | | | | |
| 3 | Cost | | | | | | | |
| <u>S</u> | Pre | | | | | | | |
| 4 | Cost | | | | | | | |
| 4 | Pre | | | | | | | |
| 5 | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| 6 | Pre | | | | | | | |



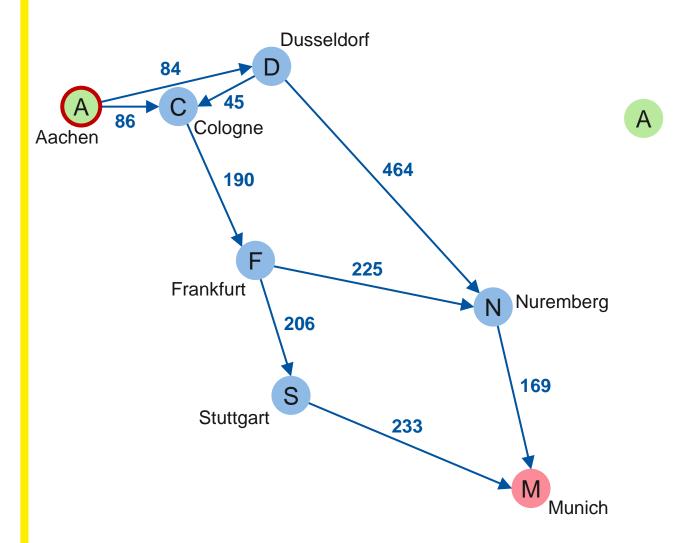
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| | | Α | С | D | F | S | N | M |
|----------|------|---|---|---|---|---|---|----------|
| | Cost | 0 | 8 | 8 | ∞ | ∞ | ∞ | ∞ |
| 0 | Pre | ı | | | | | | |
| 1 | Cost | | | | | | | |
| ı | Pre | | | | | | | |
| 2 | Cost | | | | | | | |
| | Pre | | | | | | | |
| 3 | Cost | | | | | | | |
| <u>S</u> | Pre | | | | | | | |
| 4 | Cost | | | | | | | |
| 4 | Pre | | | | | | | |
| 5 | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| 6 | Pre | | | | | | | |



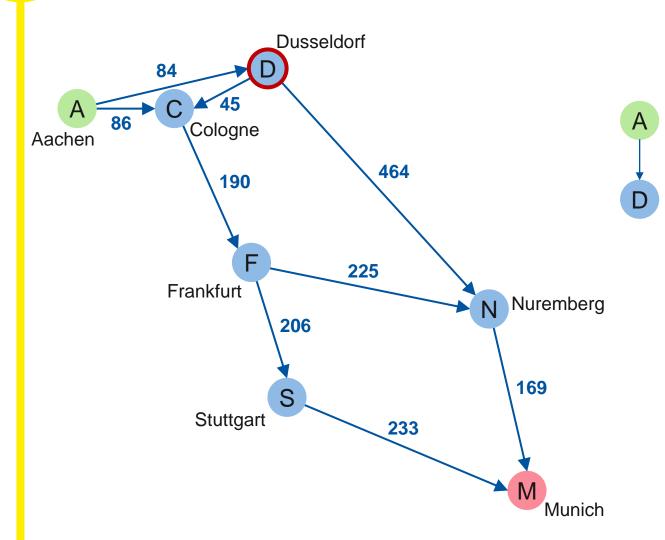




| | | Α | С | D | F | S | Ν | М |
|---|------|---|----|----|---|---|---|---|
| | Cost | 0 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 8 | 8 | 8 | 8 |
| Ľ | Pre | ı | A | A | | | | |
| 2 | Cost | | | | | | | |
| 2 | Pre | | | | | | | |
| 3 | Cost | | | | | | | |
| | Pre | | | | | | | |
| 4 | Cost | | | | | | | |
| 4 | Pre | | | | | | | |
| _ | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| | Pre | | | | | | | |



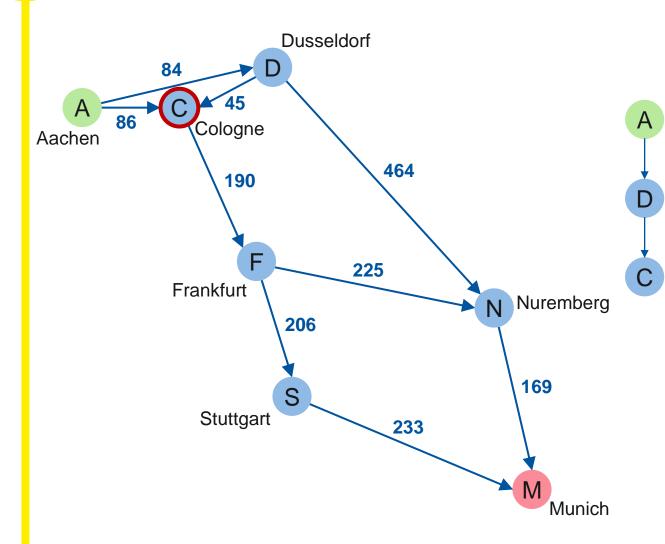




| | | Α | С | D | F | S | N | М |
|---|------|---|----|----|----|---|-----|----------|
| | Cost | 0 | 80 | ∞ | 80 | ∞ | ∞ | ∞ |
| 0 | Pre | 1 | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 8 | 8 | 8 | 8 |
| ľ | Pre | ı | 4 | A | | | | |
| 2 | Cost | 0 | 86 | 84 | 8 | 8 | 548 | 8 |
| 2 | Pre | ı | A | A | | | Α | |
| 3 | Cost | | | | | | | |
| S | Pre | | | | | | | |
| 4 | Cost | | | | | | | |
| 4 | Pre | | | | | | | |
| _ | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| 6 | Pre | | | | | | | |



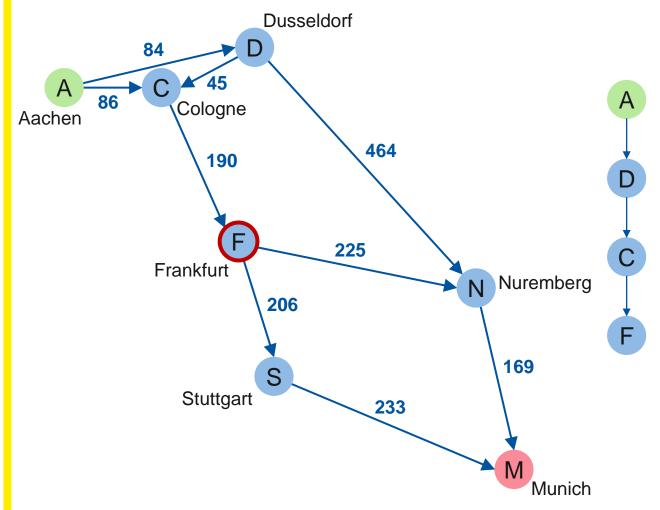




| | | Α | С | D | F | S | N | М |
|---|------|---|----|----|-----|----------|-----|----------|
| | Cost | 0 | ∞ | ∞ | 80 | ∞ | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 8 | 8 | ∞ | ∞ |
| ľ | Pre | 1 | A | A | | | | |
| 2 | Cost | 0 | 86 | 84 | 8 | % | 548 | ∞ |
| 2 | Pre | 1 | A | A | | | D | |
| 2 | Cost | 0 | 86 | 84 | 276 | ∞ | 548 | ∞ |
| 3 | Pre | - | A | A | С | | D | |
| 1 | Cost | | | | | | | |
| 4 | Pre | | | | | | | |
| _ | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| 6 | Pre | | | | | | | |



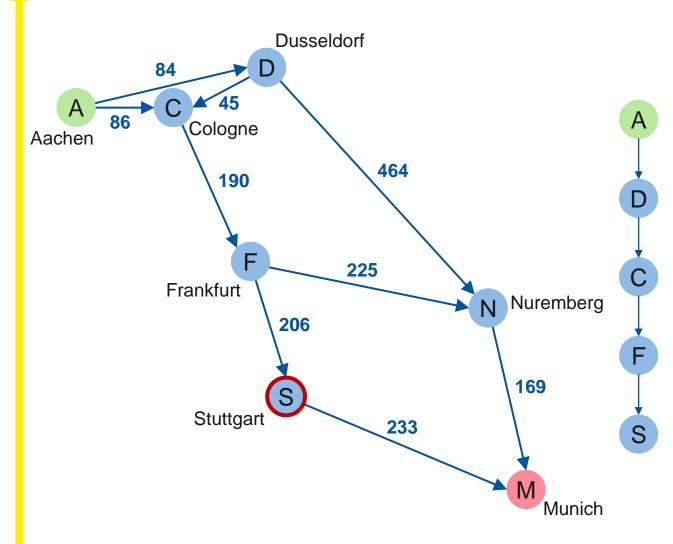




| | | Α | С | D | F | S | N | М |
|---|------|---|----|----|----------|-----|-----|----------|
| | Cost | 0 | ∞ | ∞ | % | ∞ | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 8 | 8 | 8 | ∞ |
| I | Pre | ı | A | A | | | | |
| 2 | Cost | 0 | 86 | 84 | 8 | 8 | 548 | ∞ |
| 2 | Pre | ı | A | A | | | Α | |
| 2 | Cost | 0 | 86 | 84 | 276 | 8 | 548 | ∞ |
| 3 | Pre | ı | A | A | C | | Α | |
| 4 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 8 |
| 4 | Pre | ı | A | A | C | F | F | |
| _ | Cost | | | | | | | |
| 5 | Pre | | | | | | | |
| 6 | Cost | | | | | | | |
| | Pre | | | | | | | |



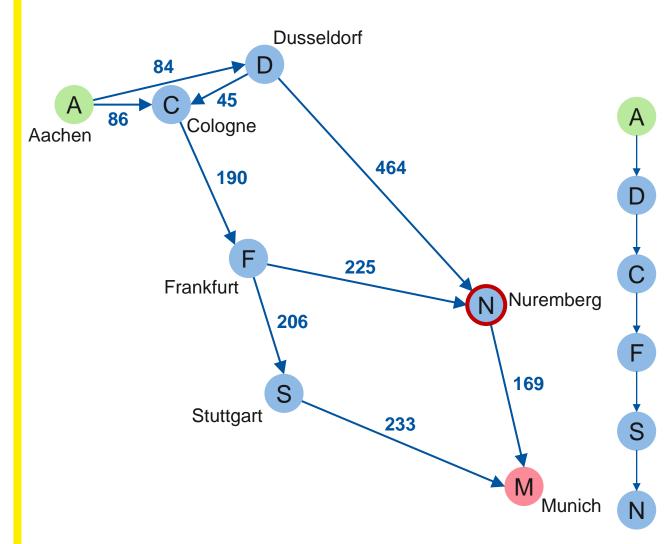




| | | Α | С | D | F | S | N | М |
|---|------|---|----|----|-----|-----|-----|-----|
| | Cost | 0 | ∞ | 80 | ∞ | 00 | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | ∞ | 8 | 8 | 8 |
| | Pre | ı | A | A | | | | |
| 2 | Cost | 0 | 86 | 84 | ∞ | 8 | 548 | 8 |
| | Pre | ı | A | 4 | | | Α | |
| 2 | Cost | 0 | 86 | 84 | 276 | 8 | 548 | ∞ |
| 3 | Pre | 1 | A | A | C | | Α | |
| 4 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 8 |
| 4 | Pre | 1 | A | A | C | F | F | |
| _ | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 715 |
| 5 | Pre | - | A | A | С | F | F | S |
| 6 | Cost | | | | | | | |
| 6 | Pre | | | | | | | |



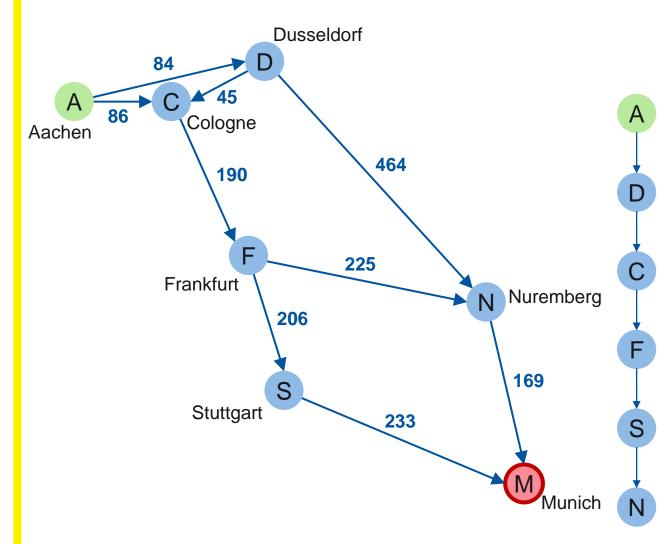




| | | Α | С | D | F | S | N | M |
|---|------|---|----|----|-----|-----|-----|----------|
| | Cost | 0 | ∞ | 80 | ∞ | 00 | ∞ | ∞ |
| 0 | Pre | 1 | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 80 | 8 | 8 | ∞ |
| I | Pre | ı | A | A | | | | |
| 2 | Cost | 0 | 86 | 84 | 8 | 8 | 548 | ∞ |
| 2 | Pre | - | A | A | | | Δ | |
| 2 | Cost | 0 | 86 | 84 | 276 | 00 | 548 | ∞ |
| 3 | Pre | - | A | A | С | | D | |
| 1 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | ∞ |
| 4 | Pre | 1 | A | A | С | F | F | |
| _ | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 715 |
| 5 | Pre | 1 | A | A | С | F | F | S |
| 6 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 670 |
| O | Pre | _ | A | A | С | F | F | 7 |



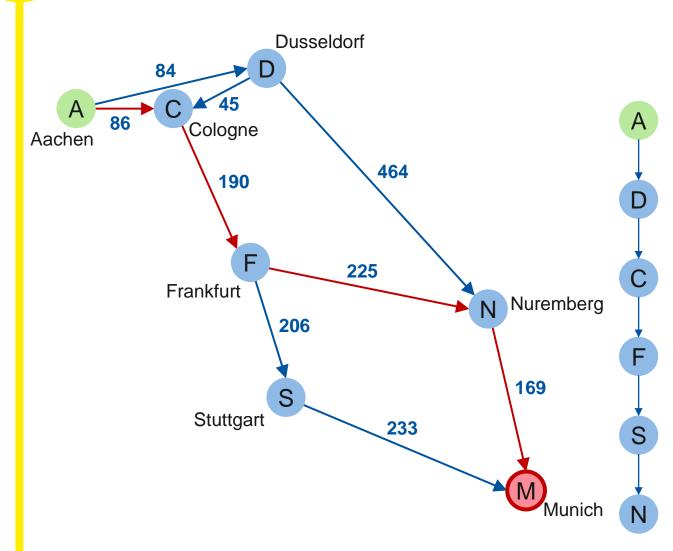




| | | Α | С | D | F | S | N | M |
|---|------|---|----|----|-----|-----|-----|----------|
| | Cost | 0 | ∞ | 8 | ∞ | 8 | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | 8 | 8 | 8 | ∞ |
| | Pre | ı | A | A | | | | |
| 5 | Cost | 0 | 86 | 84 | ∞ | 8 | 548 | ∞ |
| 2 | Pre | - | A | A | | | Δ | |
| 2 | Cost | 0 | 86 | 84 | 276 | 00 | 548 | ∞ |
| 3 | Pre | - | A | A | С | | D | |
| 4 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | ∞ |
| 4 | Pre | - | A | A | C | F | F | |
| _ | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 715 |
| 5 | Pre | ı | A | A | С | F | F | S |
| 6 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 670 |
| 6 | Pre | - | A | A | С | F | F | 7 |







| | | Α | С | D | F | S | N | М |
|---|------|---|----|----|-----|-----|-----|----------|
| | Cost | 0 | ∞ | 8 | ∞ | ∞ | ∞ | ∞ |
| 0 | Pre | - | | | | | | |
| 1 | Cost | 0 | 86 | 84 | ∞ | ∞ | ∞ | ∞ |
| | Pre | - | A | A | | | | |
| 2 | Cost | 0 | 86 | 84 | ∞ | ∞ | 548 | ∞ |
| 2 | Pre | - | A | A | | | D | |
| 2 | Cost | 0 | 86 | 84 | 276 | ∞ | 548 | ∞ |
| 3 | Pre | - | A | A | С | | D | |
| 1 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | ∞ |
| 4 | Pre | - | A | A | С | F | F | |
| _ | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 715 |
| 5 | Pre | - | A | A | С | F | F | S |
| 6 | Cost | 0 | 86 | 84 | 276 | 482 | 501 | 670 |
| 6 | Pre | _ | A | A | С | F | F | 7 |