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BCA Honours | Semester III | Calicut University

# Data Structures using C

Course Code: BCA3CJ201 • Module 4 Notes

# MODULE IV: GRAPHS, SHORTEST PATHS & HASHING

## 1. Graph Algorithms and Dijkstra's Shortest Path

Dijkstra's algorithm finds the shortest path from a single source vertex to all other vertices in a weighted graph with non-negative edge weights using a greedy priority queue approach.

## 2. Illustrative Computational Working: Step-by-Step Numerical Example

### Worked Example: Dijkstra's Shortest Path Algorithm Step-by-Step Execution

**Problem Statement:**

Consider a network of 5 nodes $A, B, C, D, E$ with directed weighted edges:

$$(A,B):4, (A,C):2, (B,C):1, (B,D):5,$$
$$(C,D):8, (C,E):10, (D,E):2$$

Compute the shortest path distances from source node $A$ to all other nodes using Dijkstra's algorithm. Show the full distance table at each iteration.

### Solution & Step-by-Step Working:

Initialize distance array: $dist[A] = 0$, all other distances = $\infty$. Visited set $S = emptyset$.

| Iteration | Current Node Selected | Visited Set $S$ | $dist[A]$ | $dist[B]$ | $dist[C]$ | $dist[D]$ | $dist[E]$ |
|---|---|---|---|---|---|---|---|
| Initial | - | $emptyset$ | 0 | $\infty$ | $\infty$ | $\infty$ | $\infty$ |
| Pass 1 | $A$ (min dist 0) | $A$ | 0 | 4 (via $A$) | 2 (via $A$) | $\infty$ | $\infty$ |
| Pass 2 | $C$ (min dist 2) | $A, C$ | 0 | 4 | 2 | 10 (via $C$) | 12 (via $C$) |
| Pass 3 | $B$ (min dist 4) | $A, C, B$ | 0 | 4 | 2 | 9 (via $B$) | 12 |
| Pass 4 | $D$ (min dist 9) | $A, C, B, D$ | 0 | 4 | 2 | 9 | 11 (via $D$) |
| Pass 5 | $E$ (min dist 11) | $A, C, B, D, E$ | 0 | 4 | 2 | 9 | 11 |

**Final Shortest Path Results:**

- Shortest distance to $A$: 0 (Path: $A$)
- Shortest distance to $B$: 4 (Path: $A \to B$)
- Shortest distance to $C$: 2 (Path: $A \to C$)
- Shortest distance to $D$: 9 (Path: $A \to B \to D$)
- Shortest distance to $E$: 11 (Path: $A \to B \to D \to E$)

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## Advanced Architectural Extensions & Industrial Systems Synthesis

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### 1. Contemporary Engineering Dilemmas and Architectural Solutions

Engineering teams designing systems centered around Data Structures using C must systematically navigate fundamental computational trade-offs:

- **Time Complexity Optimization versus Space Consumption:** In high-throughput algorithmic pipelines related to Graph Optimization and Shortest Paths, pre-computing intermediate lookup tables (memoization, spatial indices, hash tables) achieves near-instantaneous $O(1)$ query latency, but inflates physical memory footprints. Conversely, in-place algorithms minimize RAM utilization at the expense of higher cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped I/O and cache-aware data layouts.
- **Concurrency Scalability versus Thread Contention:** While multi-core architectures allow massive horizontal execution, concurrent modifications to shared state structures create severe lock contention, thread synchronization bottlenecks, and cache line invalidation storms. High-performance frameworks deploy lock-free algorithms, optimistic concurrency control, and atomic compare-and-swap (CAS) primitives.
- **Algorithmic Determinism versus Real-World Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial explosions as problem dimensions scale. Contemporary industrial systems bridge this gap by deploying bounded approximation algorithms and meta-heuristics that produce near-optimal solutions within guaranteed execution time windows.

### 2. Empirical Comparative Framework

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| **System Telemetry &** | Static text logging with periodic post-incident | Distributed tracing (OpenTelemetry), structured | Mean Time to Detection (MTTD) and Recovery |

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| **Auditing** | analysis. | JSON metrics, and automated root-cause diagnostics. | (MTTR) reduced from hours to seconds. |

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| | regulations (DPDP Act, GDPR), audit trail gaps. | administrative data modifications. | periodic external compliance audits. |

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