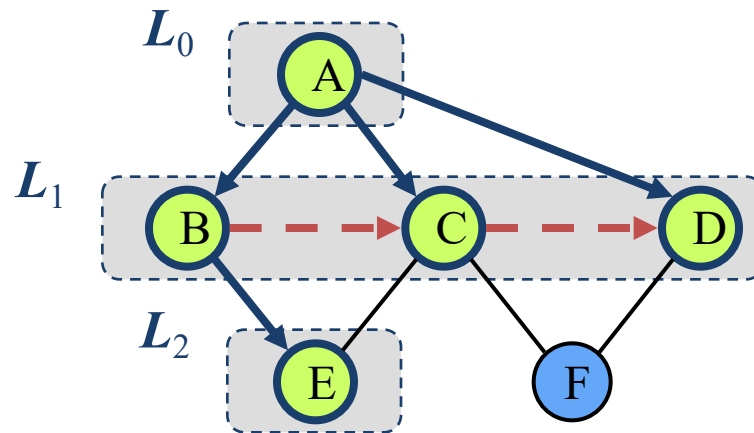


Breadth-First Search



Outline and Reading

Breadth-first search (6.3.3)

- Algorithm
- Example
- Properties
- Analysis
- Applications

DFS vs. BFS (6.3.3)

- Comparison of applications
- Comparison of edge labels

Breadth-First Search

- Breadth-first search (BFS) is a general technique for traversing a graph. A BFS traversal of a graph G
 - visits all the vertices and edges of G
 - determines whether G is connected
 - computes the connected components of G
 - computes a spanning forest of G
- BFS on a graph with n vertices and m edges takes $O(n + m)$ time
- BFS can be further extended to solve other graph problems
 - find and report a path with the minimum number of edges between two given vertices
 - find a simple cycle, if there is one

BFS Algorithm

The algorithm uses a mechanism for setting and getting “labels” of vertices and edges.

Algorithm *BFS(G)*

Input graph G

Output labeling of the edges
and partition of the
vertices of G

for all $u \in G.vertices()$

setLabel(u, UNEXPLORED)

for all $e \in G.edges()$

setLabel(e, UNEXPLORED)

for all $v \in G.vertices()$

if *getLabel(v) = UNEXPLORED*

BFS(G, v)

Algorithm *BFS(G, s)*

$L_0 \leftarrow$ new empty sequence

$L_0.insertLast(s)$

setLabel(s, VISITED)

$i \leftarrow 0$

if $\neg L_i.isEmpty()$

$L_{i+1} \leftarrow$ new empty sequence

for all $v \in L_i.elements()$

for all $e \in G.incidentEdges(v)$

if *getLabel(e) = UNEXPLORED*

$w \leftarrow opposite(v, e)$

if *getLabel(w) = UNEXPLORED*

setLabel(e, DISCOVERY)

setLabel(w, VISITED)

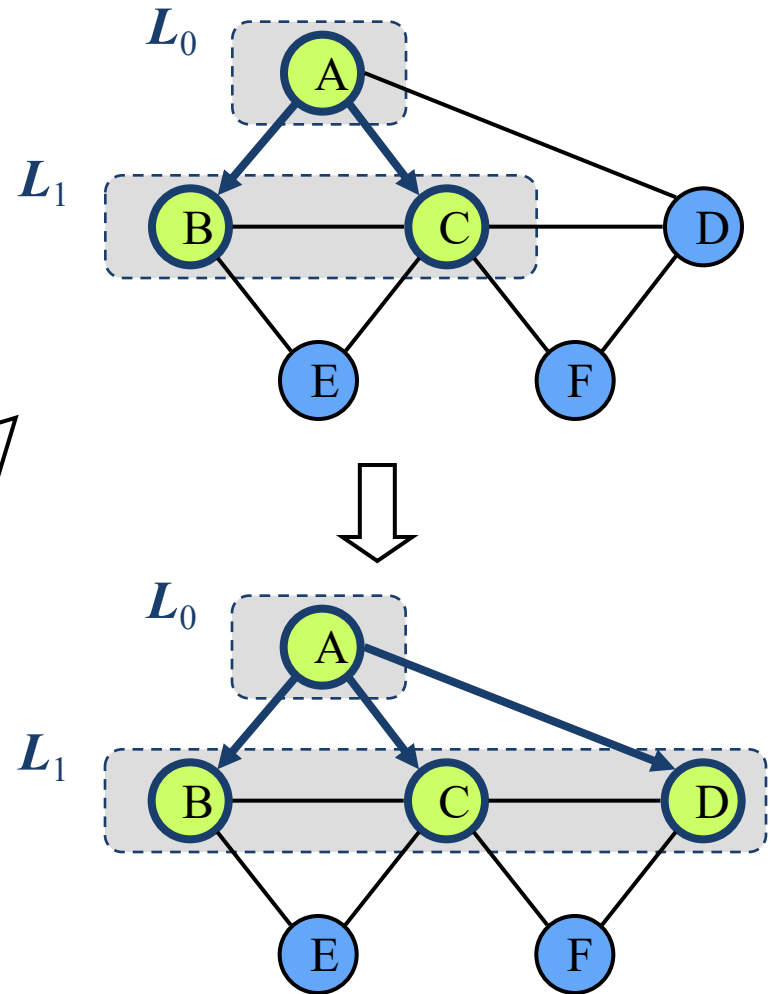
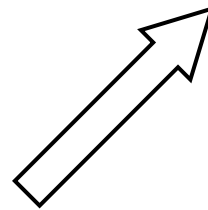
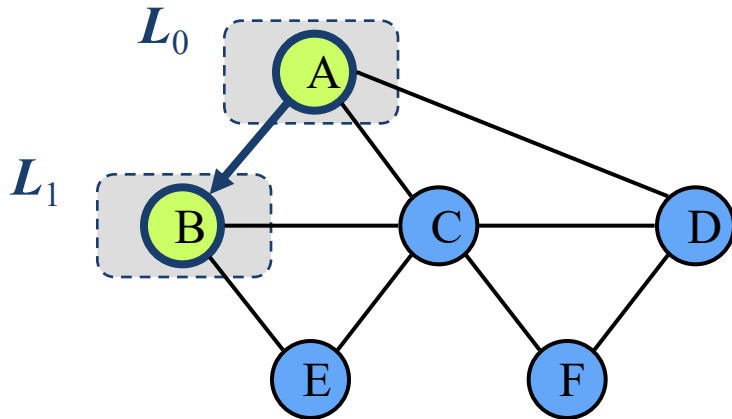
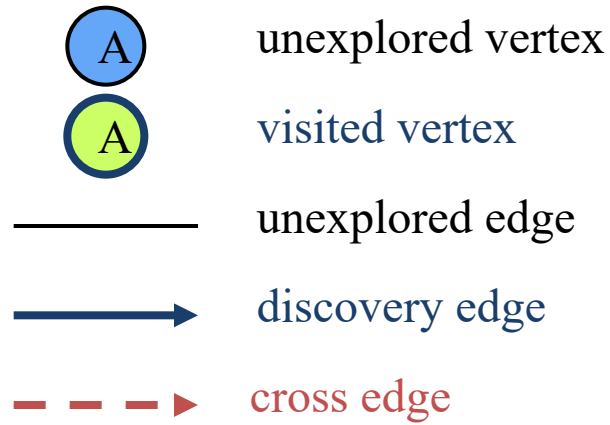
$L_{i+1}.insertLast(w)$

else

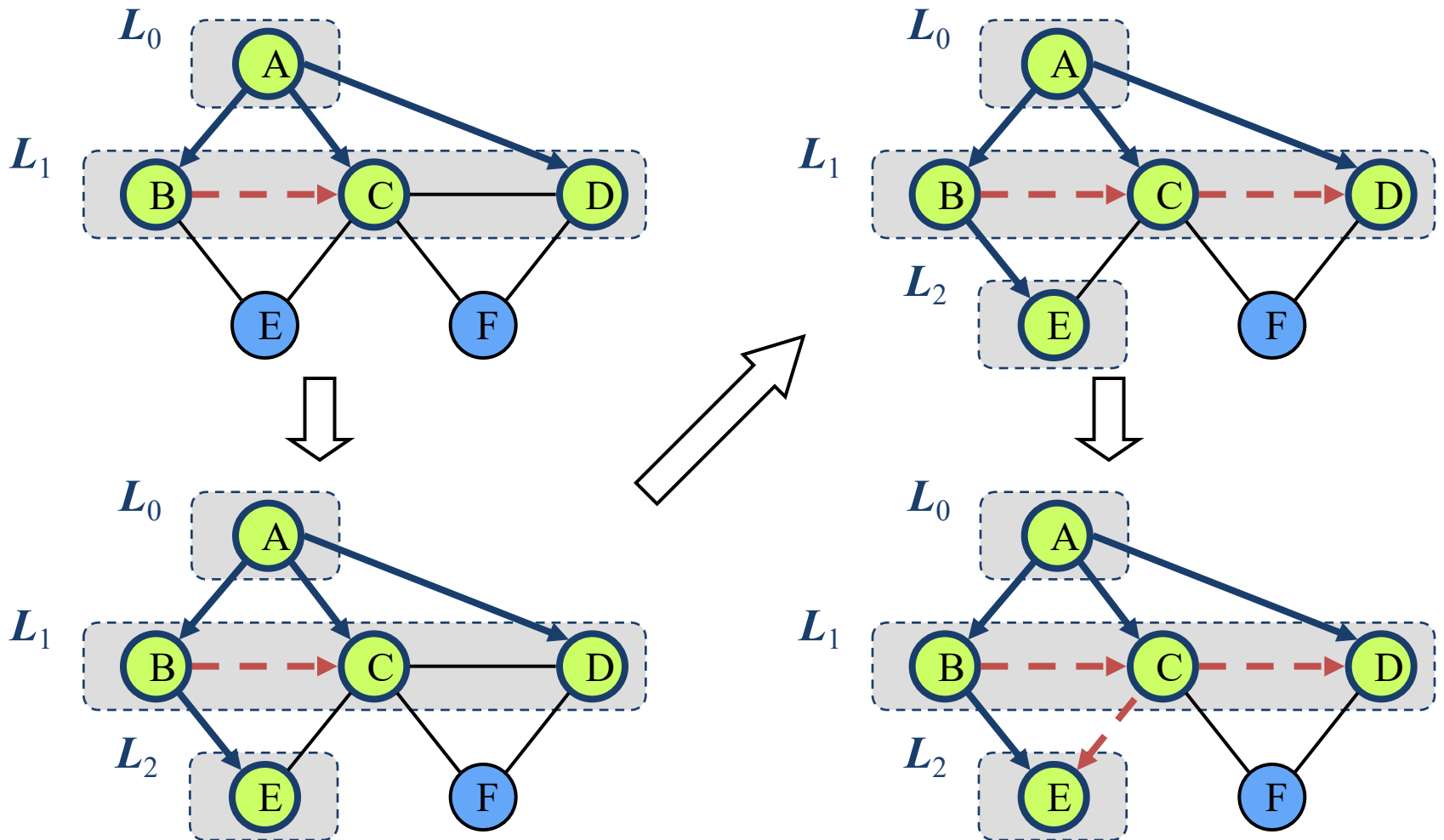
setLabel(e, CROSS)

$i \leftarrow i + 1$

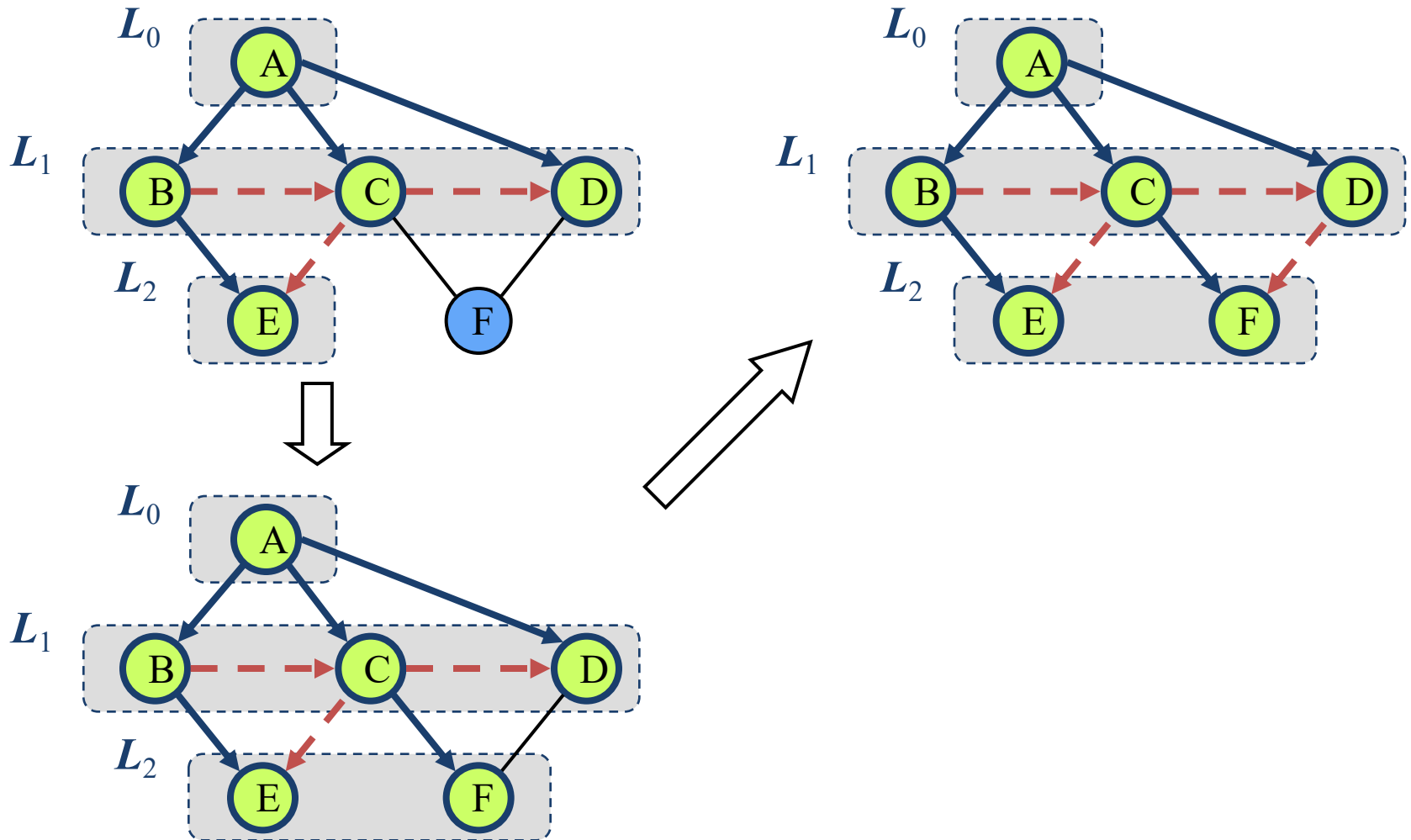
Example



Example (cont.)



Example (cont.)



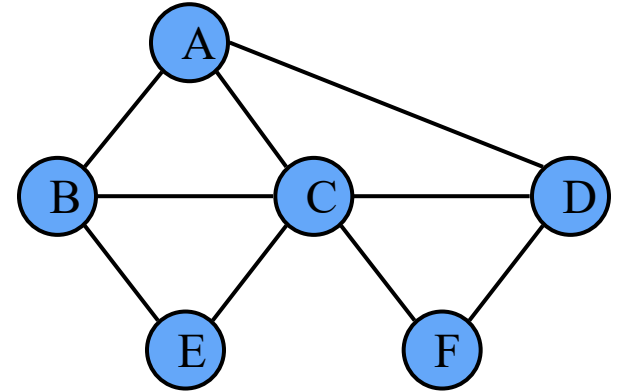
Properties

Notation

G_s : connected component of s

Property 1

$BFS(G, s)$ visits all the vertices and edges of G_s



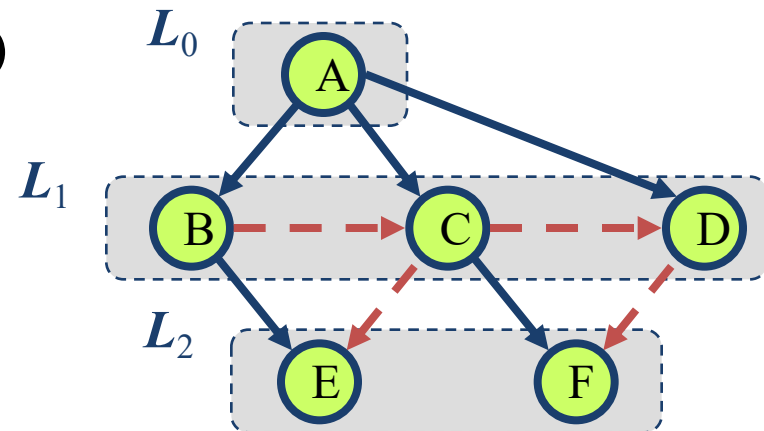
Property 2

The discovery edges labeled by $BFS(G, s)$ form a spanning tree T_s of G_s

Property 3

For each vertex v in L_i

- The path of T_s from s to v has i edges
- Every path from s to v in G_s has at least i edges



Analysis

- Setting/getting a vertex/edge label takes $O(1)$ time
- Each vertex is labeled twice
 - once as UNEXPLORED
 - once as VISITED
- Each edge is labeled twice
 - once as UNEXPLORED
 - once as DISCOVERY or CROSS
- Each vertex is inserted once into a sequence L_i
- Method incidentEdges is called once for each vertex
- BFS runs in $O(n + m)$ time provided the graph is represented by the adjacency list structure
 - Recall that $\sum_v \deg(v) = 2m$

Applications

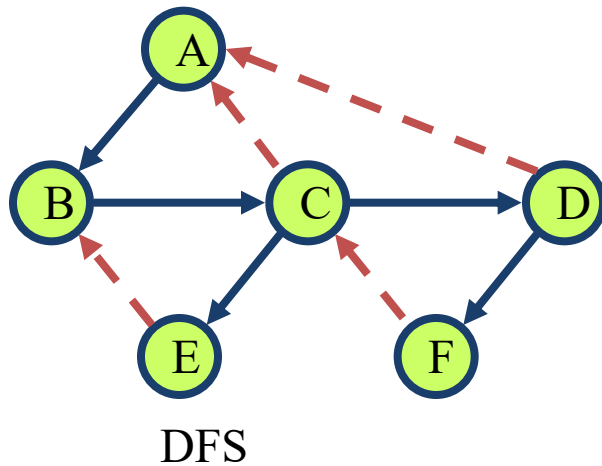
Using the template method pattern, we can specialize the BFS traversal of a graph G to solve the following problems in $O(n + m)$ time:

- Compute the connected components of G
- Compute a spanning forest of G
- Find a simple cycle in G , or report that G is a forest
- Given two vertices of G , find a path in G between them with the minimum number of edges, or report that no such path exists

DFS vs. BFS

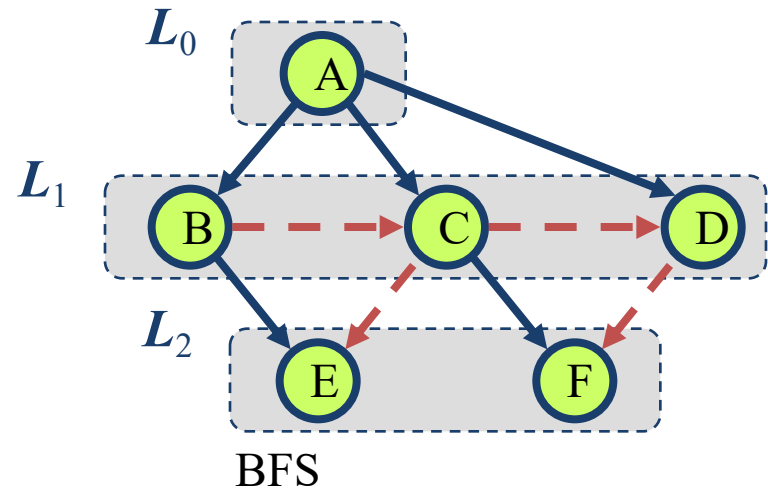
Back edge (v, w)

- w is an ancestor of v in the tree of discovery edges



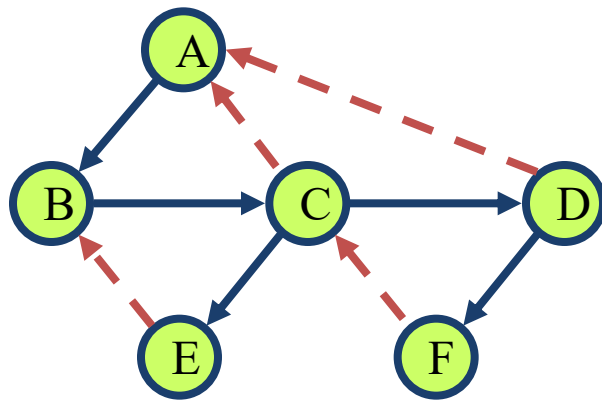
Cross edge (v, w)

- w is in the same level as v or in the next level in the tree of discovery edges

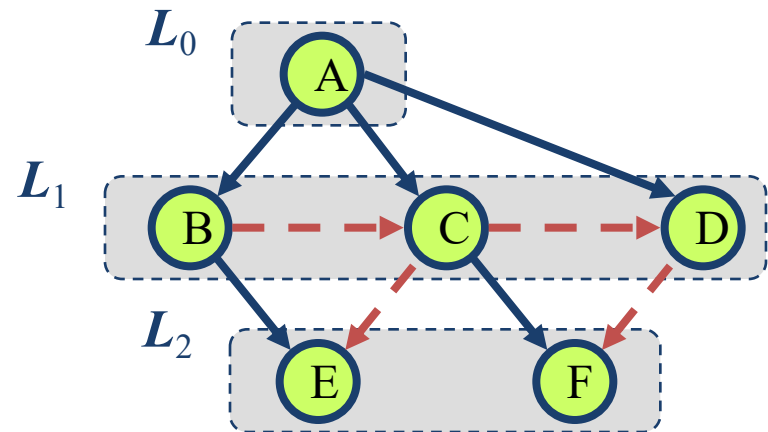


DFS vs. BFS

Applications	DFS	BFS
Spanning forest, connected components, paths, cycles	√	√
Shortest paths		√
Biconnected components	√	



DFS



BFS