CSE 331
Software Design & Implementation

Winter 2023

Section 7 – Dijkstra's algorithm; Model-View-Controller, HW7

Administrivia

- HW6 due today
  - Use a **`DEBUG`** flag to dial down an expensive **`checkRep`**
    - And be sure you can load and process the Marvel graph fairly quickly once the expensive **`checkRep`** tests are disabled
  - Revise your ADT with any feedback from HW5-2
- HW7 due one week from today (Thursday)
  - Assignment posted on web now
  - Starter code pushed late yesterday
- Any questions?

Agenda

- Overview of HW7 – “Pathfinder”
- Dijkstra’s algorithm
- Model-View-Controller (MVC) design
- The campus dataset

HW7 – Pathfinder

A program to find the shortest walking routes through campus *ca*. 2006

- Network of walkways in campus constitutes a graph!

Homework progresses through 4 steps:

1. Modify your graph ADT to use generic types for node/edge labels

2. Implement Dijkstra's algorithm
   - Starter code gives a path ADT to store search result: **`pathfinder.datastructures.Path`**

3. Run tests for your implementation of Dijkstra's algorithm

4. Complete starter code for the Pathfinder application

HW7 – Adding Generic Types

- You need to add generic type params to your Graph ADT
  - One type for node labels, one type for edge labels

- You will need to update past assignments to use **`Graph<String, String>`** (a graph with nodes and edges labeled by strings)
  a. Update HW5 to use the generic graph ADT
  b. Make sure all the HW5 tests pass!
  c. Update HW6 to use the generic graph ADT
  d. Make sure all the HW6 tests pass!

- No raw types! Never declare just as **`Graph`** (missing "**`<...>`**")
  - There should be no "raw use of parameterized type" errors

Dijkstra's algorithm

- Named for its inventor, Edsger Dijkstra (1930–2002)
  - Truly one of the "founders" of computer science
  - Just one of his many contributions
- Key idea: Proceed roughly like BFS, factoring in edge weights:
  - Track the path to each node with least-yet-seen cost
  - Shrink a set of pending nodes as they are visited
- A *priority queue* makes handling weights efficient and convenient
  - Helps track which node to process next
- **Note**: Dijkstra's algorithm requires all edge weights be nonnegative
  - (Other graph search algorithms can handle negative weights – see Bellman-Ford algorithm)

Priority queue

- A queue-like ADT that reorders elements by associated *priority*
  - Whichever element has the least value dequeues next (not FIFO)
  - Priority of an element traditionally given as a separate integer

- Java provides a standard implementation, **`PriorityQueue<E>`**
  - Implements the **`Queue<E>`** interface but has distinct semantics
  - Enqueue (add) with the **`add`** method
  - Dequeue (remove highest priority) with the **`poll`** method

- **`PriorityQueue<E>`** uses comparison order for priority order
  - Default: class **`E`** implements **`Comparable<E>`**
  - May configure otherwise with a **`Comparator<E>`**

Priority queue – example

q = new PriorityQueue<Double>();			
q.add(5.1);	5.1		
q.add(4.2);	4.2	5.1	
q.add(0.3);	0.3	4.2	5.1
q.poll(); // 0.3	4.2	5.1	
q.add(0.8);	0.8	4.2	5.1
q.poll(); // 0.8	4.2	5.1	
q.add(20.4);	4.2	5.1	20.4
q.poll(); // 4.2	5.1	20.4	

Finding the “shortest” path

- HW6 measured the “shortest” path by the number of its edges
  - So really, the path with the fewest edges (*i.e.*, fewest hops)
  - Implemented by breadth-first search (BFS)
  - Edge labels totally irrelevant (aside from our tie-breaking rules)

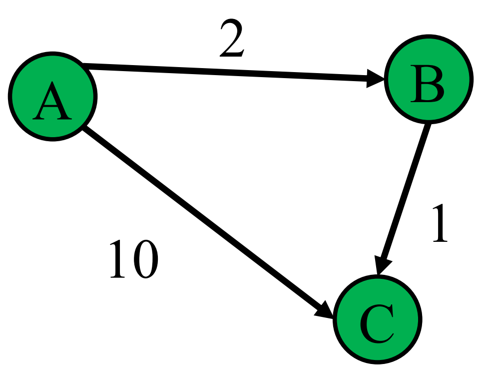
- In HW7, edge labels are numbers, called *weights*
  - Labeled graphs like that are called *weighted graphs*
  - An edge’s weight is considered its *cost* (think time, distance, price, …)

- HW7 measured the “shortest” path by the total weight of its edges
  - So really, the path with the least cost
  - Find using *Dijkstra’s algorithm*
  - Edge weights crucially relevant

Dijkstra's algorithm

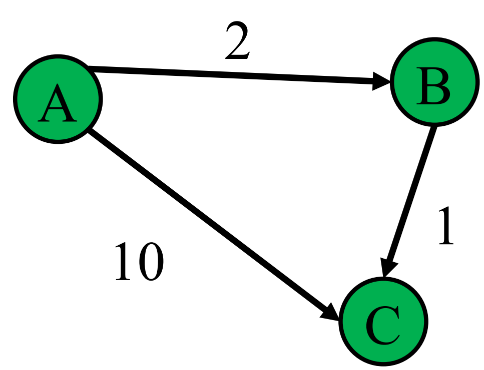
- **Main idea:** Start at the source node and find the shortest path to all reachable nodes.
  - This will include the shortest path to your destination!

- What is the shortest path from A to C for the given graph using Dijkstra's algorithm? Using BFS?

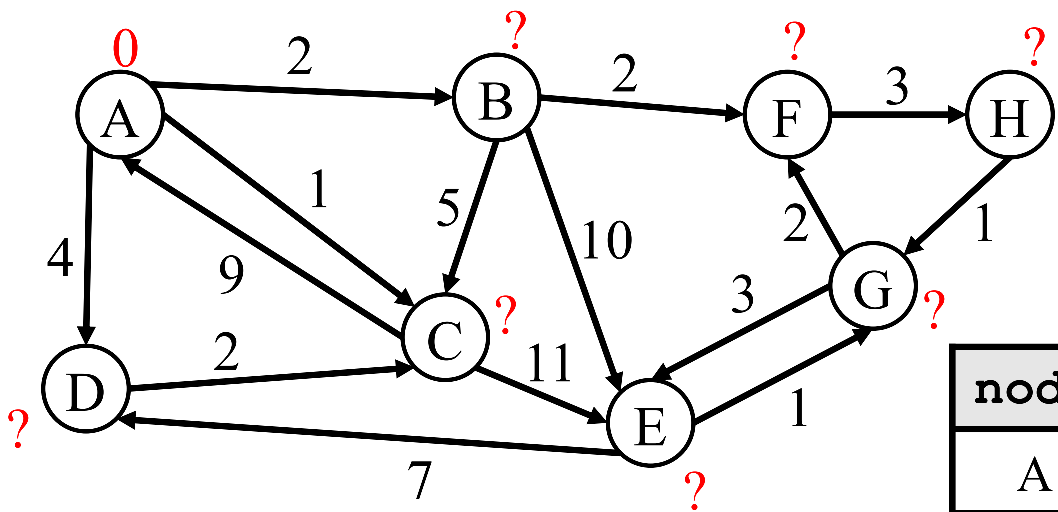


Dijkstra’s algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv ???> What would be a good invariant for this loop?
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```



Dijkstra's algorithm – paths from A

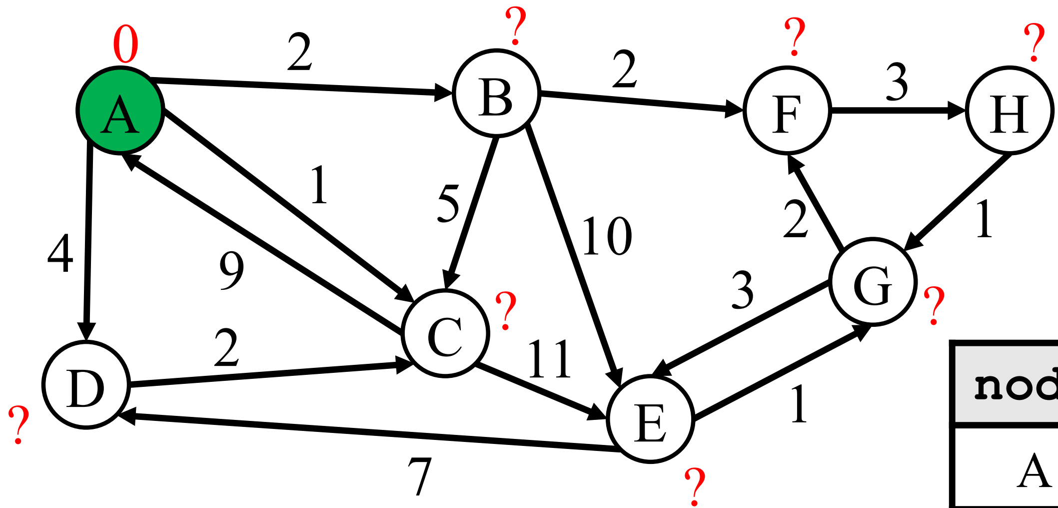


priority queue

path	cost
[A]	0

node	finished	cost	prev
A		0	-
B			
C			
D			
E			
F			
G			
H			

Dijkstra's algorithm – paths from A

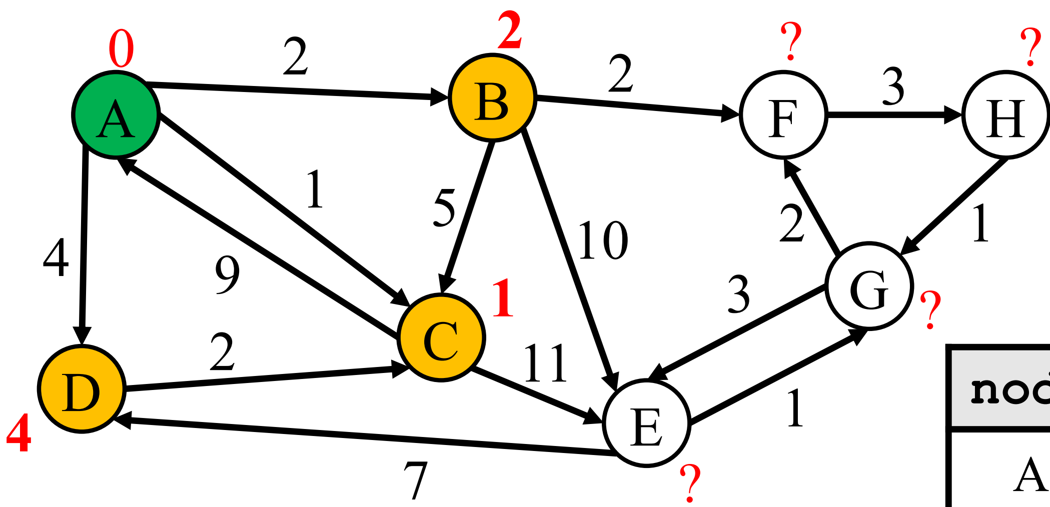


priority queue

path	cost

node	finished	cost	prev
A	Y	0	-
B			
C			
D			
E			
F			
G			
H			

Dijkstra's algorithm – paths from A

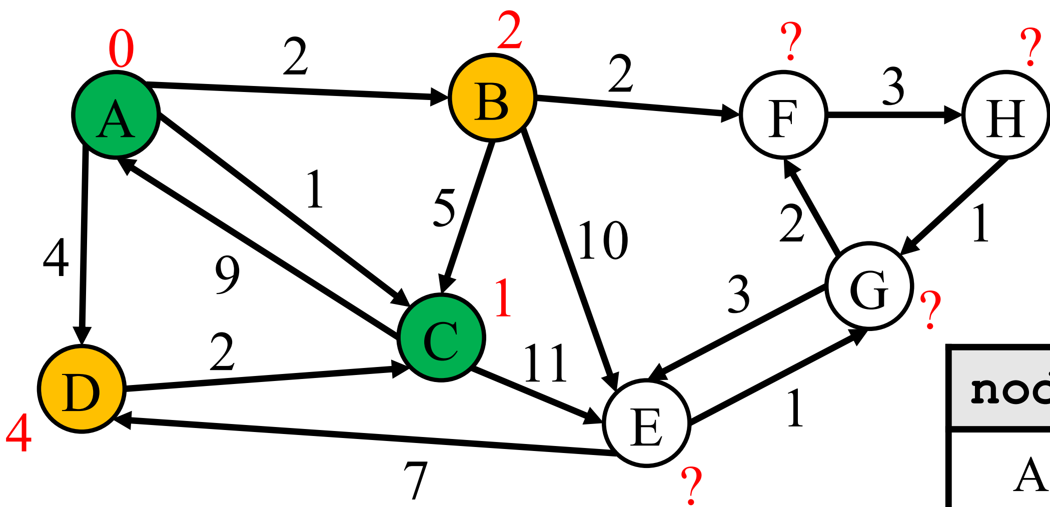


priority queue

path	cost
[A, C]	1
[A, B]	2
[A, D]	4

node	finished	cost	prev
A	Y	0	-
B		≤ **2**	**A**
C		≤ **1**	**A**
D		≤ **4**	**A**
E			
F			
G			
H			

Dijkstra's algorithm – paths from A

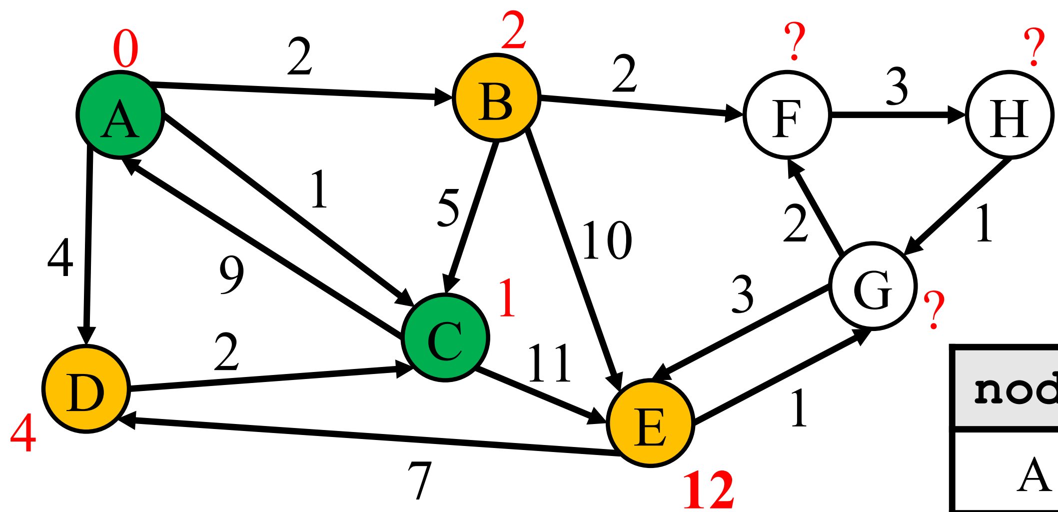


priority queue

path	cost
[A, B]	2
[A, D]	4

node	finished	cost	prev
A	Y	0	-
B		≤ 2	A
C	Y	**1**	A
D		≤ 4	A
E			
F			
G			
H			

Dijkstra's algorithm – paths from A

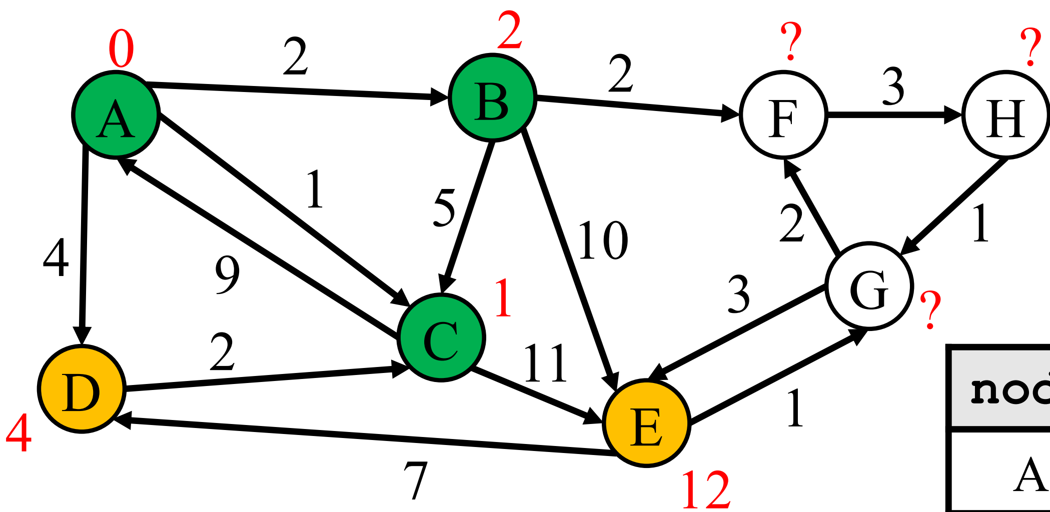


priority queue

path	cost
[A, B]	2
[A, D]	4
[A, C, E]	12

node	finished	cost	prev
A	Y	0	-
B		≤ 2	A
C	Y	1	A
D		≤ 4	A
E		**≤ 12**	**C**
F			
G			
H			

Dijkstra's algorithm – paths from A

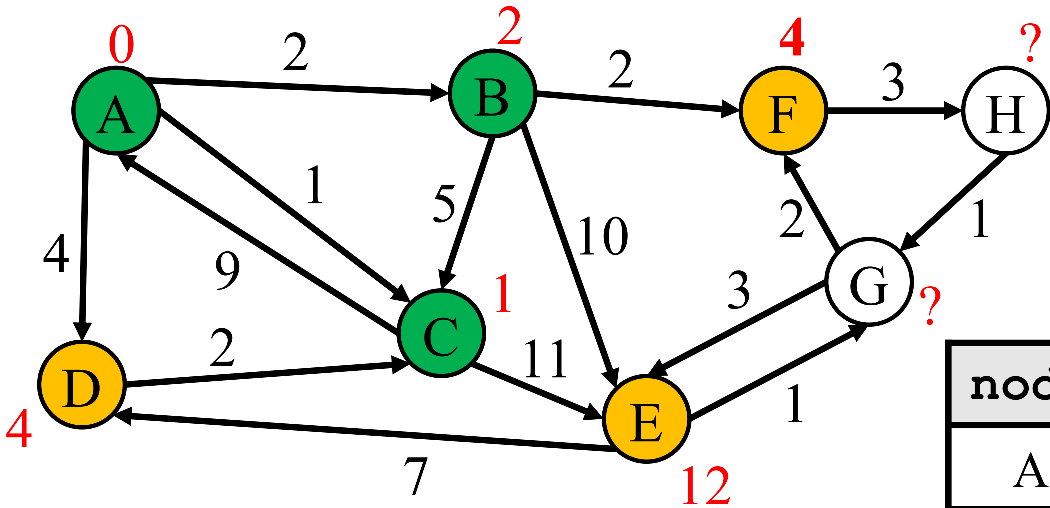


priority queue

path	cost
[A, D]	4
[A, C, E]	12

node	finished	cost	prev
A	Y	0	-
B	**Y**	**2**	A
C	Y	1	A
D		≤ 4	A
E		≤ 12	C
F			
G			
H			

Dijkstra's algorithm – paths from A

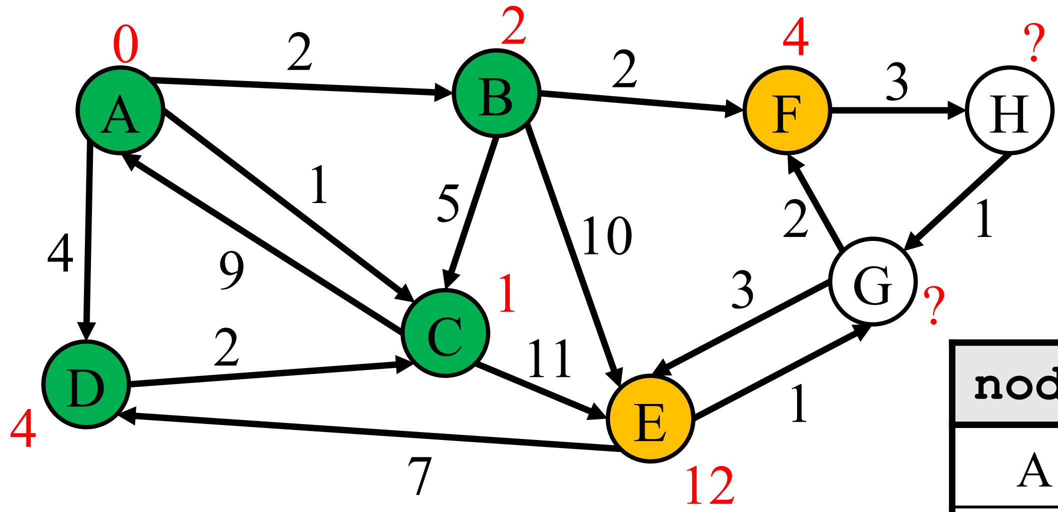


priority queue

path	cost
[A, D]	4
[A, B, F]	4
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D		≤ 4	A
E		≤ 12	C
F		**≤ 4**	**B**
G			
H			

Dijkstra's algorithm – paths from A

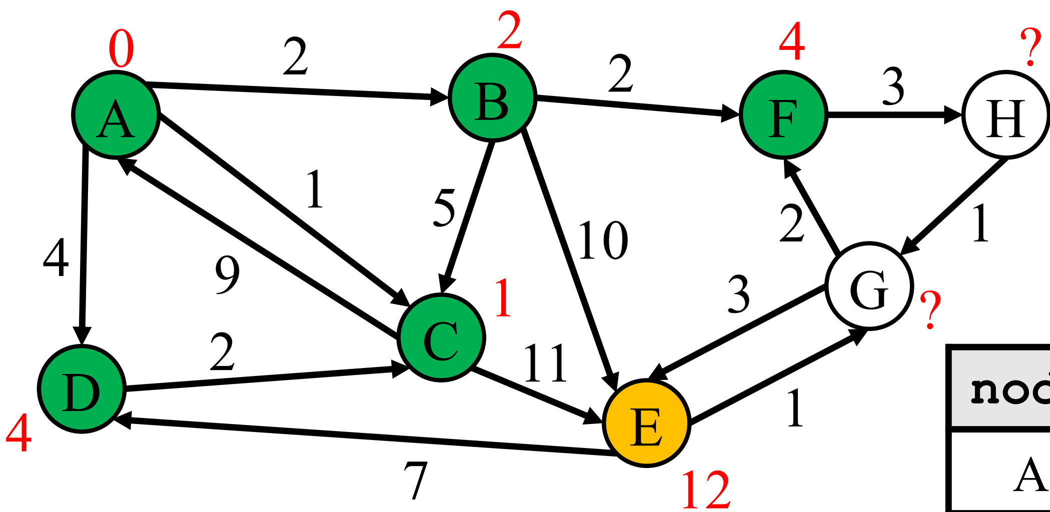


priority queue

path	cost
[A, B, F]	4
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	**4**	A
E		≤ 12	C
F		≤ 4	B
G			
H			

Dijkstra's algorithm – paths from A

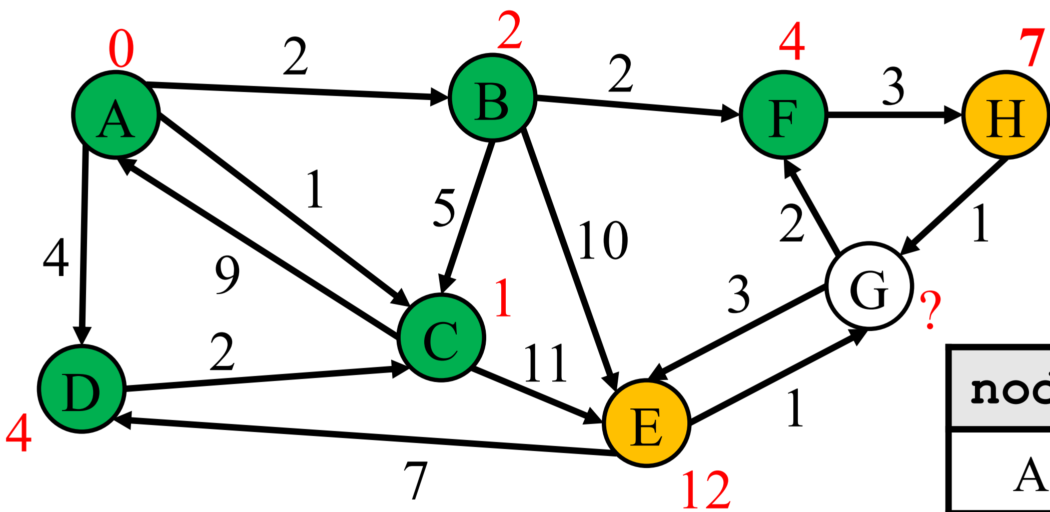


priority queue

path	cost
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		≤ 12	C
F	Y	**4**	B
G			
H			

Dijkstra's algorithm – paths from A

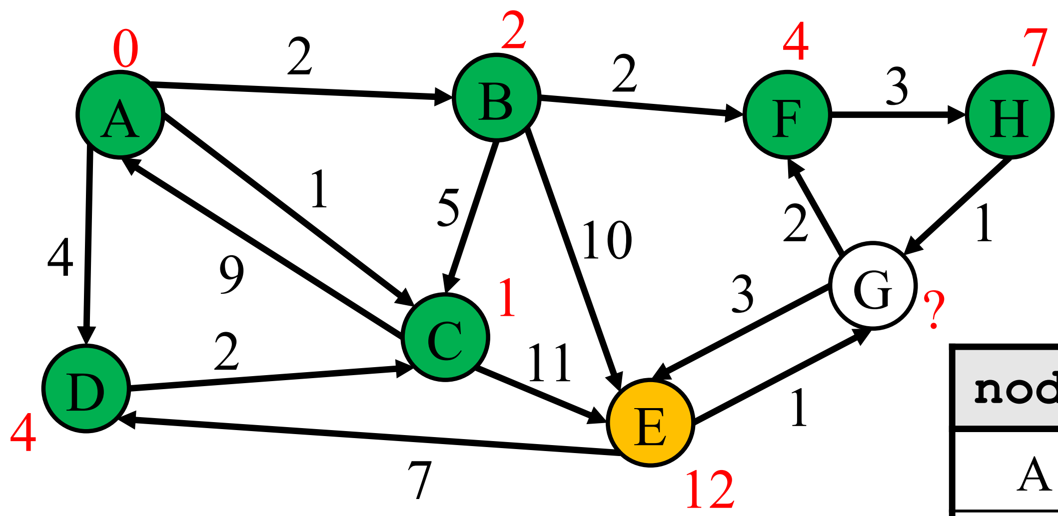


priority queue

path	cost
[A, B, F, H]	7
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		≤ 12	C
F	Y	4	B
G			
H		**≤ 7**	**F**

Dijkstra's algorithm – paths from A

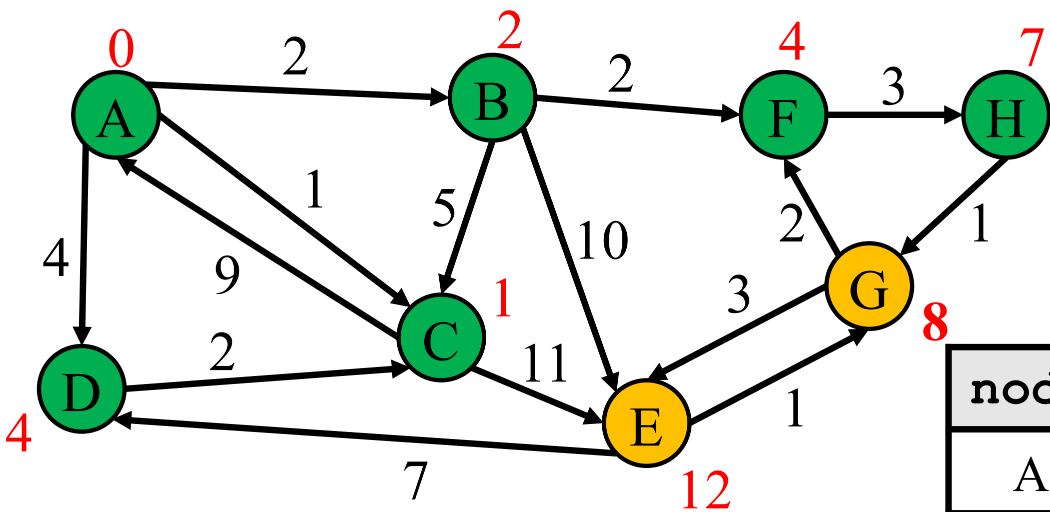


priority queue

path	cost
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		≤ 12	C
F	Y	4	B
G			
H	**Y**	**7**	F

Dijkstra's algorithm – paths from A

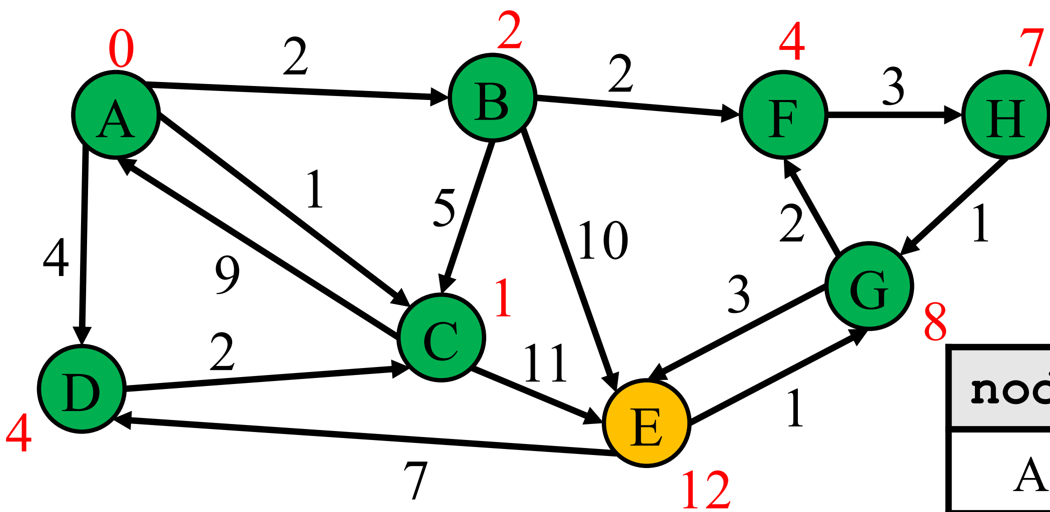


priority queue

path	cost
[A, B, F, H, G]	8
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		≤ 12	C
F	Y	4	B
G		**≤ 8**	**H**
H	Y	7	F

Dijkstra's algorithm – paths from A

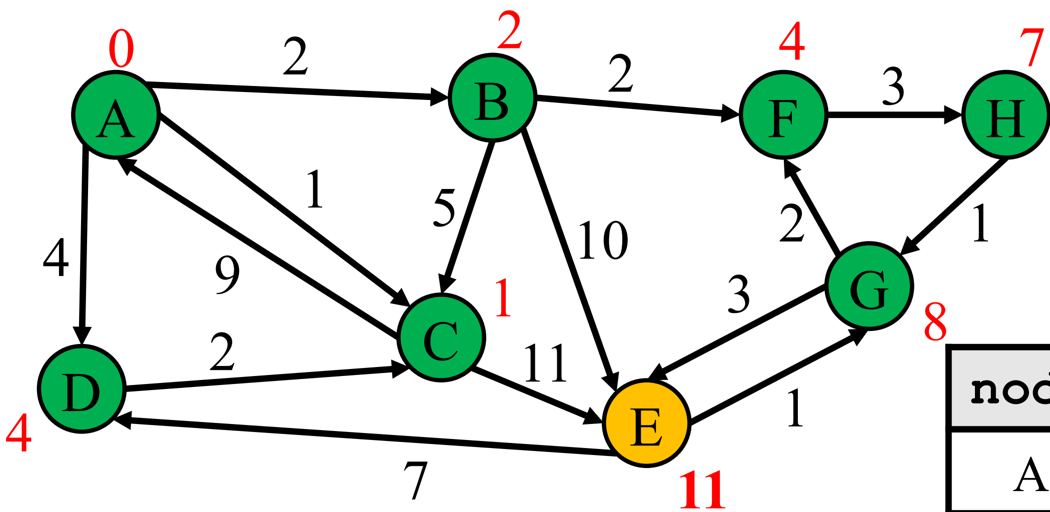


priority queue

path	cost
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		≤ 12	C
F	Y	4	B
G	**Y**	**8**	H
H	Y	7	F

Dijkstra's algorithm – paths from A

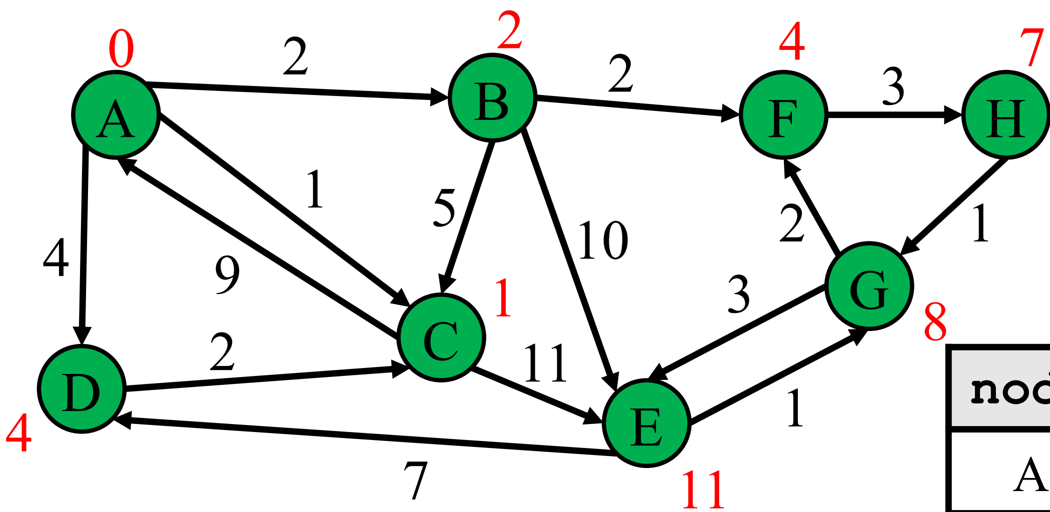


priority queue

path	cost
[A, B, F, H, G, E]	11
[A, C, E]	12
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E		**≤ 11**	**G**
F	Y	4	B
G	Y	8	H
H	Y	7	F

Dijkstra's algorithm – paths from A

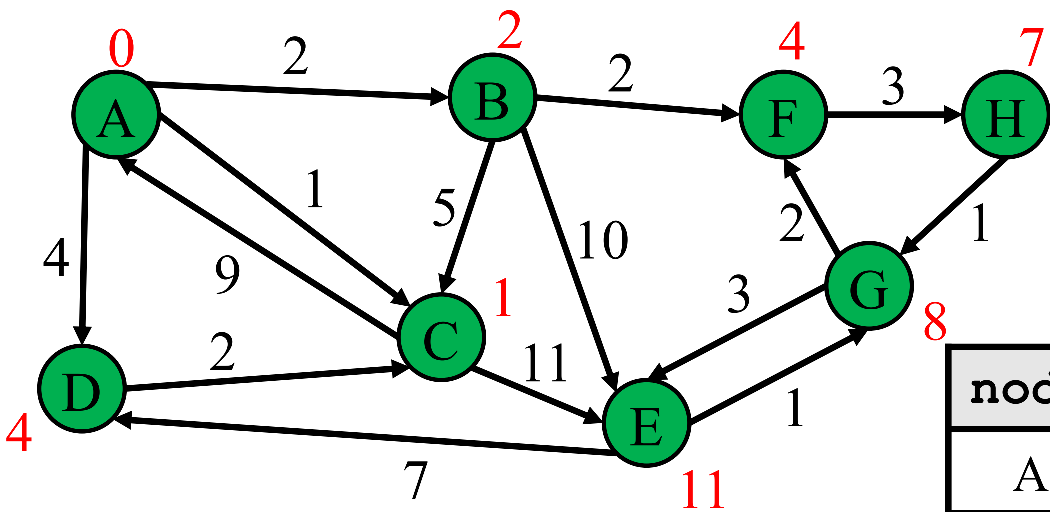


`priority queue`

`path`	`cost`
[A, C, E]	12
[A, B, E]	12

`node`	`finished`	`cost`	`prev`
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E	**Y**	**11**	G
F	Y	4	B
G	Y	8	H
H	Y	7	F

Dijkstra's algorithm – paths from A

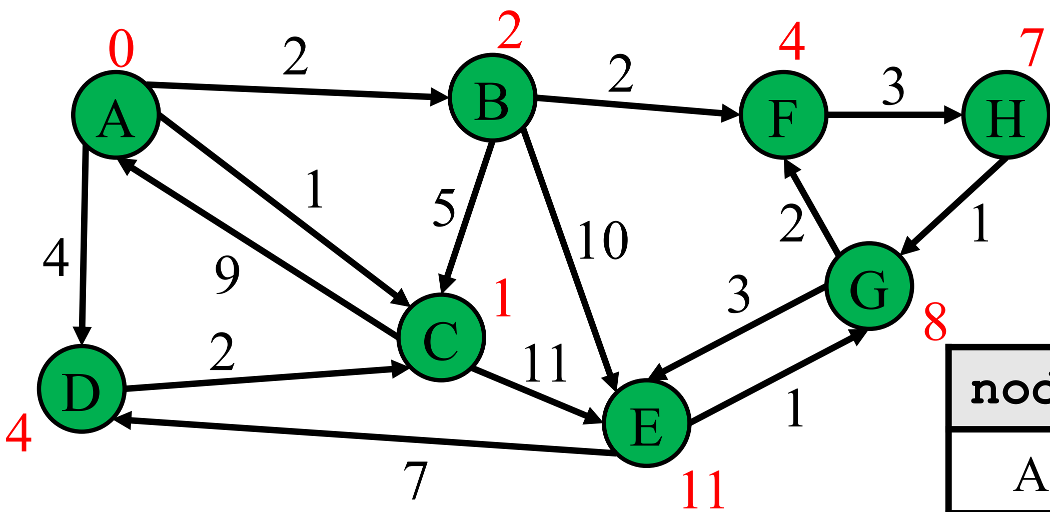


priority queue

path	cost
[A, B, E]	12

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E	**Y**	**11**	G
F	Y	4	B
G	Y	8	H
H	Y	7	F

Dijkstra's algorithm – paths from A



Now we know the cost and path to every single node by looking at the table!

node	finished	cost	prev
A	Y	0	-
B	Y	2	A
C	Y	1	A
D	Y	4	A
E	**Y**	**11**	G
F	Y	4	B
G	Y	8	H
H	Y	7	F

priority queue

path	cost

Dijkstra’s algorithm - Worksheet

Now it’s your turn!

Dijkstra's algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv: All paths found so far are shortest paths>
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

Dijkstra's algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
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while active is non-empty:
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    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

What else?

Dijkstra's algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv: All paths found so far are shortest paths>
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

All nodes not reached yet are farther away than those reached so far

Dijkstra’s algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv: All paths found so far are shortest paths>
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

All nodes not reached yet are farther away than those reached so far

The queue contains all paths formed by adding 1 more edge to a node we already reached.

Dijkstra's algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv: All paths found so far are shortest paths & … >
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

Let's take a moment to think what else is true here?

Dijkstra's algorithm – pseudocode

```
active = priority queue of paths.
finished = empty set of nodes.
add a path from start to itself to active
<inv: All paths found so far are shortest paths & … >
while active is non-empty:
    minPath = active.removeMin()
    minDest = destination node in minPath
    if minDest is dest:
        return minPath
    if minDest is in finished:
        continue
    for each edge e = ⟨minDest, child⟩:
      if child is not in finished:
        newPath = minPath + e
        add newPath to active
    add minDest to finished
```

It follows from our updated invariant that this path is the shortest path (assuming node is not in finished)

Model-View-Controller

- Model-View-Controller (MVC) is a ubiquitous design pattern:
  - The **model** abstracts + represents the application's data.
  - The **view** provides a user interface to display the application data.
  - The **controller** handles user input to affect the application.

Model-View-Controller: Example

- Accessing my Google Drive files through my laptop and my phone

<table>
<tr><th>Laptop</th><th>Phone</th></tr>
<tr><td colspan="2">View: The screen displays options for me to select files</td></tr>
<tr><td>Control: Get input selection from mouse/keyboard</td><td>Control: Get input selection from touch sensor</td></tr>
<tr><td colspan="2">Control: Request the selected file from Google Drive</td></tr>
<tr><td colspan="2">Model: Google Drive sends back the request file to my device</td></tr>
<tr><td colspan="2">Control: Receive the file and pass it to View</td></tr>
<tr><td colspan="2">View: The screen displays the file</td></tr>
</table>

HW 7 – Model-View-Controller

- HW7 is an MVC application, with much given as starter code.
  - View: **`pathfinder.textInterface.TextInterfaceView`**
  - Controller: **`pathfinder.textInterface.TextInterfaceController`**

- You will need to fill out the code in **`pathfinder.CampusMap`**.
  - Since your code implements the model functionality

- This way, we can reuse the model (the **`CampusMap`** and pathfinding) while swapping out our view and controller for HW9

HW7: text-based View-Controller

- `TextInterfaceView`
  - Displays output to users from the result received from `TextInterfaceController`.
  - Receives input from users.
    - Does not process anything; directly pass the input to the `TextInterfaceController` to process.
- `TextInterfaceController`
  - Process the passed input from the `TextInterfaceView`
    - Include talking to the **Model** (the graph & supporting code)
  - Give the processed result back to the `TextInterfaceView` to display to users.

* HW9 will be using the same **Model** but different and more sophisticated View and Controller

Campus dataset

- Two CSV files in **`src/main/resources/data`**:
  - **`campus_buildings.csv`** – building entrances on campus
  - **`campus_paths.csv`** – straight-line walkways on campus
- Exact points on campus identified with (x, y) coordinates
  - Pixels on a map of campus (**`campus_map.jpg`**, next to CSV files)
  - Position $(0, 0)$, the origin, is the top left corner of the map
- Parser in starter code: **`pathfinder.parser.CampusPathsParser`**
  - **`CampusBuilding`** object for each entry of **`campus_buildings.csv`**
  - **`CampusPath`** object for each entry of **`campus_paths.csv`**

Campus dataset – coordinate plane

`campus_map.jpg`

Campus dataset – sample

- **`campus_buildings.CSV`** has entries like the following:

shortName	*longName*	*x*	*y*
`BGR,`	`By George,`	`1671.5499,`	`1258.4333`
`MOR,`	`Moore Hall,`	`2317.1749,`	`1859.502`

- **`campus_paths.CSV`** has entries like the following:

x1	*y1*	*x2*	*y2*	*distance*
`1810.0,`	`431.5,`	`1804.6429,`	`437.92857,`	`17.956615…`
`1810.0,`	`431.5,`	`1829.2857,`	`409.35714,`	`60.251364…`

- See **`campus_routes.jpg`** for nice visual rendering of **`campus_paths.csv`**

Campus dataset – zoomed in

(sorry for the low-resolution image)

- Paths connect points on the map
- Paths will have a series of segments
  - e.g. the path from CSE to CSE2 is not a straight line
- Your nodes should be points on the map
  - Not just buildings!

Campus dataset – demo

- Your TA will open the starter files of HW 7.

Script testing in HW7

- Extends the test-script mechanism from HW5
  - Using numeric weights instead of string labels on edges
  - New command **`FindPath`** to find shortest path with Dijkstra's algorithm
  - No command like **`LoadGraph`**

- Must write the test driver (**`PathfinderTestDriver`**) yourself
  - Feel free to copy pieces from **`GraphTestDriver`** in HW5

Command (in *foo*.test)	Output (in *foo*.expected)
`FindPath` *graph* $node_1$ $node_n$	**`path from`** $node_1$ **`to`** $node_n$**`:`** $node_1$ **`to`** $node_2$ **`with weight`** $w_{1,2}$ $node_2$ **`to`** $node_3$ **`with weight`** $w_{2,3}$ . . . $node_{n-1}$ **`to`** $node_n$ **`with weight`** $w_{n-1,n}$ **`total cost:`** w
. . .	. . .