Pacman AI - Implement Graph DFS

How to implement Graph DFS

Got it 👍 You want to implement **DFS (Depth-First Search) on a graph**.
This is very similar to tree DFS, but with an important twist: **we must track visited nodes** to avoid infinite loops in case of cycles.

DFS Approaches

There are two common ways to implement DFS:

1. **Recursive (simpler, uses call stack)**
2. **Iterative (using an explicit stack)**

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1. Recursive DFS

```python
def dfs_recursive(graph, start, visited=None):
    if visited is None:
        visited = set()
    visited.add(start)
    print(start)  # process the node (can be replaced with other logic)

    for neighbor in graph[start]:
        if neighbor not in visited:
            dfs_recursive(graph, neighbor, visited)
```

Usage:

```python
graph = {
    'A': ['B', 'C'],
    'B': ['D', 'E'],
    'C': ['F'],
    'D': [],
    'E': ['F'],
    'F': []
```

```
}

dfs_recursive(graph, 'A')
# Output order: A B D E F C
```

---

2. Iterative DFS (using a stack)

python

```python
def dfs_iterative(graph, start):
    visited = set()
    stack = [start]

    while stack:
        node = stack.pop()
        if node not in visited:
            print(node)  # process the node
            visited.add(node)

            # Push neighbors onto stack (reverse order if you want same order as recursion)
            for neighbor in reversed(graph[node]):
                if neighbor not in visited:
                    stack.append(neighbor)
```

Usage:

python

```python
dfs_iterative(graph, 'A')
# Output order: A C F B E D
```

✅ Key differences between tree and graph DFS:

- Graph DFS **must** track visited nodes to prevent cycles.
- Trees don't require this since they don't contain cycles.

Do you want me to also show how to adapt this into the **Pacman AI Project DFS (Q2 style)**, where the function returns a **list of actions** instead of just visiting nodes?

Start: (5, 5)
Is the start a goal? False
Start's successors: [((5, 4), 'South', 1), ((4, 5), 'West', 1)]

My start state is (5,5) and I need to reach the goal state, how would I do that?

Perfect 👍 you're already thinking in **Pacman Project 1 (UC Berkeley AI)** terms:

- **State** = `(x, y)` location (like `(5,5)`)
- **Goal test** = `problem.isGoalState(state)`
- **Successors** = `[(nextState, action, cost), …]`

Your job is to **find a path (list of actions like ['West', 'South', ...])** from the start to the goal. That's exactly what **DFS, BFS, UCS, and A*** are doing in this project.

How it works

At a high level:

1. Start at `(5,5)`.
2. Expand successors → e.g. `(5,4)` via `'South'`, `(4,5)` via `'West'`.
3. Choose one (depending on the search algorithm).
4. Keep track of the **path of actions** taken.
5. Stop when `isGoalState(state)` is `True`.

Example: DFS in Pacman Style

python

```
def depthFirstSearch(problem):
    from util import Stack

    start = problem.getStartState()
    fringe = Stack()
    visited = set()

    # Each item in stack = (state, path to reach state)
```

```python
    fringe.push((start, []))

    while not fringe.isEmpty():
        state, path = fringe.pop()

        if problem.isGoalState(state):
            return path   # list of actions that reaches the goal

        if state not in visited:
            visited.add(state)

            for (nextState, action, cost) in problem.getSuccessors(state):
                if nextState not in visited:
                    fringe.push((nextState, path + [action]))

    return []  # no solution found
```

Walking through your case

- Start = `(5,5)`
- Path = `[]`

Successors:

- `(5,4)` via `'South'`
- `(4,5)` via `'West'`

DFS will pick one (stack LIFO):

1. Pop `(5,4)` with path `['South']`.
   - If goal, return `['South']`.
   - Else expand.
2. If not, continue exploring deeper until goal is found.

When the goal is reached, the algorithm returns the **list of actions** like:

```python
['South', 'South', 'West', 'West', 'North']
```

Pacman will follow those moves to reach the goal.

👉 Do you want me to actually **simulate step-by-step how the DFS would expand from (5,5)** until it finds a goal, so you can see the path being built?

Don't give me the code solution, just tell me how I would go about doing what I ask you

Totally—here's the **exact playbook** to reach the goal from `(5,5)` in the Pacman search setup, **without code**:

What you keep track of

- **Fringe** (the frontier of states to explore):
  - DFS → a **stack** (last in, first out)
  - BFS → a **queue** (first in, first out)
  - UCS/A* → a **priority queue** (lowest priority value first)
- **Visited set** to avoid re-expanding the same location and getting stuck in cycles.
- **Path so far** for each state (the sequence of actions to reach it), or equivalently a **parent map** so you can reconstruct the path when you hit the goal.

The basic loop (all algorithms)

1. **Initialize**
   - Put the start `(5,5)` on the fringe with an **empty path**.
2. **Repeat until done**
   - Take one state off the fringe.
   - **Goal test**: if it's a goal, **stop** and return its path.
   - If not visited:
     - Mark it visited.
     - **Expand** it: ask `successors = problem.getSuccessors(state)`.
       (You already saw: `[((5,4), 'South', 1), ((4,5), 'West', 1)]`.)
     - For each successor:
       - Compute the **new path** by appending that successor's **action** (e.g., `'South'` or `'West'`) to the current path.
       - Put the successor on the **fringe** with that new path (and with a priority if using UCS/A*).

That's it. The only difference between DFS/BFS/UCS/A* is **how you manage the fringe** (and for UCS/A*, how you compute priority).

How this plays out from your start `(5,5)`

- **Start**: `(5,5)`, path `[]`.
- **Is goal?** You said **False**, so expand it.
- **Successors**:
  - to `(5,4)` via **South**, cost `1`
  - to `(4,5)` via **West**, cost `1`
- **Push** both successors with their paths:
  - `(5,4)` with path `['South']`
  - `(4,5)` with path `['West']`

Now the order you'll explore those depends on the algorithm:

If you're doing DFS

- You'll **pop the most recently added.** If you added South then West, you'll explore **West first** (or vice versa—tie-breaking depends on how you push).
- Each time you pop a state:
  - If it's goal → **return its path** immediately.
  - Otherwise expand it, push its unvisited successors with the **extended path**, and continue.

If you're doing BFS

- You'll **dequeue in the order you enqueued**: first `(5,4)` then `(4,5)` (given the same insertion order).
- BFS guarantees the **shortest number of steps** path (when all step costs are 1), so as soon as you pop a goal you're done.

If you're doing UCS (Uniform Cost Search)

- Each fringe item carries its **g(n) total cost so far**.
- The priority is **g(n)**; you always expand the **cheapest-so-far** state next.
- If costs are all 1, UCS behaves like BFS in terms of path length optimality.

If you're doing A***

- Same as UCS but the priority is **g(n) + h(n)**, where **h(n)** is a heuristic estimate of remaining cost (e.g., **Manhattan distance** to the goal if walls don't break admissibility).
- Expand the state with the smallest **f(n) = g + h** next.

Path bookkeeping (crucial)

You must carry, for each fringe entry, either:

- The **path (list of actions)** taken to reach that state, or
- A **parent pointer map** `{child_state: (parent_state, action)}` and rebuild the path once you hit the goal.

Either way, when the goal is popped, you have the **exact sequence of moves** (e.g., `['South', 'South', 'West', ...]`) to get there from `(5,5)`.

Visited logic (to avoid loops)

- **Mark visited when you pop** (common pattern for DFS/BFS).
- For UCS/A*, you usually maintain a **best-known cost** for each state and only revisit a state if you've found a **strictly cheaper** route to it.

Tie-breaking & neighbor order

- The **order of successors** affects DFS's path and sometimes BFS's tie breaks.
- If you want predictable behavior, pick a consistent neighbor order (e.g., North, South, East, West) or reverse it depending on the project's autograder expectations.

Putting it all together for your run

From `(5,5)`:

1. Put `(5,4)` with path `['South']` and `(4,5)` with path `['West']` on the fringe.
2. Repeatedly:
   - Take one off the fringe (stack/queue/priority rule).
   - If it's goal → **stop and return the path** you've been carrying.
   - Else expand and push successors that aren't visited (or are cheaper, for UCS/A*), each with their **path extended by the action** used to get there.

If you tell me which algorithm you're required to use (DFS vs BFS vs UCS vs A*), I can walk the **exact sequence of expansions** from `(5,5)` using that rule and show where the goal would be found in the search order.

Not relating to this pacman project, can you just show me a graph implementation of BFS?

Got it 👍 — let's leave Pacman aside and just do a **plain graph BFS**.

Idea of BFS on a graph

- Use a **queue** (FIFO).
- Keep a **visited set** so you don't revisit nodes.
- For each node you pop, enqueue all its unvisited neighbors.
- This guarantees you visit nodes in **layers** (shortest distance from start).

Example Graph

We'll represent the graph as an adjacency list (dictionary):

```python
graph = {
    'A': ['B', 'C'],
    'B': ['A', 'D', 'E'],
    'C': ['A', 'F'],
    'D': ['B'],
    'E': ['B', 'F'],
    'F': ['C', 'E']
}
```

BFS Implementation

```python
from collections import deque

def bfs(graph, start):
    visited = set()
    queue = deque([start])
```

```python
    while queue:
        node = queue.popleft()   # FIFO
        if node not in visited:
            print(node)        # process node
            visited.add(node)

            for neighbor in graph[node]:
                if neighbor not in visited:
                    queue.append(neighbor)
```

Running it

```python
bfs(graph, 'A')
# Output order: A B C D E F
```

🔑 What this does:

- Visits `A`, then all its neighbors (`B`, `C`),
- Then neighbors of those (`D`, `E`, `F`),
- Always expanding outward level by level.

Do you want me to also show you how to make BFS **return the shortest path** between two nodes instead of just visiting them in order?

Ok I got the BFS working, now how do I work with cost?

Great 👌 you've got BFS working!

Now, about **cost**:

- BFS assumes **every edge has the same cost** (like `1`).
- If edges can have **different weights**, BFS no longer guarantees the shortest path.

- To handle **costs**, you need **Uniform Cost Search (UCS)**, which is basically **Dijkstra's algorithm**.

How to work with cost

Instead of a **queue (FIFO)**, you use a **priority queue (min-heap)** where:

- Each item = `(total_cost_so_far, node, path)`
- You always expand the node with the **lowest total cost so far**.

Example Graph with Costs

```python
graph = {
    'A': [('B', 2), ('C', 5)],
    'B': [('A', 2), ('D', 1), ('E', 3)],
    'C': [('A', 5), ('F', 2)],
    'D': [('B', 1)],
    'E': [('B', 3), ('F', 1)],
    'F': [('C', 2), ('E', 1)]
}
```

Uniform Cost Search (Dijkstra style)

```python
import heapq

def ucs(graph, start, goal):
    visited = set()
    pq = [(0, start, [])]  # (cost_so_far, node, path)

    while pq:
        cost, node, path = heapq.heappop(pq)

        if node in visited:
            continue
        visited.add(node)
```

```python
            path = path + [node]

            if node == goal:
                return cost, path

            for neighbor, edge_cost in graph[node]:
                if neighbor not in visited:
                    heapq.heappush(pq, (cost + edge_cost, neighbor, path))

    return float("inf"), []  # if no path found
```

Running it

python

```python
cost, path = ucs(graph, 'A', 'F')
print("Cost:", cost)
print("Path:", path)

# Output:
# Cost: 6
# Path: ['A', 'B', 'E', 'F']
```

✅ Key difference from BFS

- BFS: “expand in order of number of steps.”
- UCS/Dijkstra: “expand in order of **lowest accumulated cost**.”

Would you like me to also show how you can extend this further into **A*** search (adding a heuristic to cost for even faster search)?

```
def uniformCostSearch(problem: SearchProblem):
    """Search the node of least total cost first."""
    "*** YOUR CODE HERE ***"
    print("Start:", problem.getStartState())
```

print("Is the start a goal?",
problem.isGoalState(problem.getStartState()))
print("Start's successors:",
problem.getSuccessors(problem.getStartState()))
start = problem.getStartState()
fringe = util.PriorityQueue()
visited = set()

fringe.push((0, start, []), 0)

while not fringe.isEmpty():
cost, state, path = fringe.pop()

if state not in visited:
visited.add(state)

path += [state]

if problem.isGoalState(state):
return cost, path

for (nextState, action, stepCost) in
problem.getSuccessors(state):
if nextState not in visited:
fringe.push((cost + stepCost, nextState, path +
[action]),)

What do I put for the priority?

Good question 👍 you're right at the crucial step.

In **Uniform Cost Search**, the **priority** you push into the fringe is simply the **total path cost so far** (the `g(n)` value).

Let's look at your push line:

```python
fringe.push((cost + stepCost, nextState, path + [action]), )
```

Right now you're missing the **priority** argument. The structure should be:

```python
fringe.push((nextState, newCost, newPath), newCost)
```

- The **item** you store in the queue is whatever you need later (state, cost, path).
- The **priority** is the accumulated cost (`cost + stepCost`).

Corrected snippet

```python
for (nextState, action, stepCost) in problem.getSuccessors(state):
    if nextState not in visited:
        newCost = cost + stepCost
        newPath = path + [action]
        fringe.push((nextState, newCost, newPath), newCost)
```

Important notes

1. **Don't mix up path vs state**:
   - The `path` should be a list of **actions** (e.g., `['South', 'West']`), not states.
   - You don't usually keep the raw state sequence in `path`.

   So instead of `path += [state]`, just keep extending with `action`.
2. **Return value** (depending on project instructions):
   - In Pacman P1, UCS should return only the **list of actions**, not `(cost, path)`.
   - So you'd return `path` once the goal is found.

👉 Do you want me to show you how the **loop looks step by step with UCS** using a small graph, so you see exactly how the `newCost` becomes the priority?

So I should remove path += state?

Exactly ✅ — you don't want to append the **state** into the path.

In these search problems:

- `path` = **list of actions** (like `['South', 'West', 'North']`),
- not a list of visited states.

That's why you already do `newPath = path + [action]` when expanding successors.

So yes — remove this line:

```python
path += [state]
```

Instead, just carry the `path` forward with actions only.

Why?

- The autograder (and Pacman engine) expects your search function to return a **list of actions** to get from start to goal.
- If you mix states into the path, you'll end up with something like:

  ```bash
  (5,5), 'South', (5,4), 'West' ...
  ```

  which is not what the framework wants.

So your UCS main loop should look more like:

```python
while not fringe.isEmpty():
    cost, state, path = fringe.pop()

    if state not in visited:
        visited.add(state)

        if problem.isGoalState(state):
            return path  # just the actions!

        for (nextState, action, stepCost) in problem.getSuccessors(state):
            if nextState not in visited:
                newCost = cost + stepCost
```

```
        newPath = path + [action]
        fringe.push((newCost, nextState, newPath), newCost)
```

👉 Do you want me to also explain **why UCS still works even if you don't mark visited until you pop from the queue** (instead of when you push)? That's a subtle but important point.

fringe.push((0, start, []), 0) is this line correct?

Almost 🙂 — the idea is right, but the ordering of fields inside your tuple is inconsistent with the way you later unpack it.

Right now your loop does:

```python
cost, state, path = fringe.pop()
```

That means whatever you push must be `(cost, state, path)`.

But in your line you have:

```python
fringe.push((0, start, []), 0)
```

which is `(cost, state, path)` ✅ — so it **does match** your unpacking.

So yes, it works — but it's not the usual way it's written in this project.

Standard convention

Most students (and the project's hints) use:

```python
```

```
fringe.push((start, [], 0), 0)
```

and then unpack as:

```python
state, path, cost = fringe.pop()
```

That way the first element is always the **state**, not the cost.

TL;DR

- Your current line is "correct" as long as you consistently treat the tuple as `(cost, state, path)`.
- If you prefer the cleaner convention:

  ```python
  fringe.push((start, [], 0), 0)
  ```

  and unpack it as `(state, path, cost)`.

👉 Do you want me to rewrite your full UCS loop in the "cleaner" style so you can just drop it in without mixing cost/state ordering?

```
def uniformCostSearch(problem: SearchProblem):
    """Search the node of least total cost first."""
    "*** YOUR CODE HERE ***"
    start = problem.getStartState()
    fringe = util.PriorityQueue()
    visited = set()

    fringe.push((start, [], 0), 0)

    while not fringe.isEmpty():
        state, path, cost = fringe.pop()

        if problem.isGoalState(state):
```

```
            return path

        if state not in visited:
            visited.add(state)

        for (nextState, action, stepCost) in
problem.getSuccessors(state):
            if nextState not in visited:
                newCost = cost + stepCost
                nextPath = path + [action]
                fringe.push((nextState, nextPath, newCost),
newCost)
    return []

asherb@AsherRazer:~/Programs/CS6364/Project01_Se
arch$ python autograder.py -q q3
Starting on 9-16 at 21:37:52

Question q3
===========
*** PASS: test_cases/q3/graph_backtrack.test
***     solution:               ['1:A->C', '0:C->G']
***     expanded_states:        ['A', 'B', 'C', 'D']
*** PASS: test_cases/q3/graph_bfs_vs_dfs.test
***     solution:               ['1:A->G']
***     expanded_states:        ['A', 'B']
*** PASS: test_cases/q3/graph_infinite.test
***     solution:               ['0:A->B', '1:B->C', '1:C->G']
***     expanded_states:        ['A', 'B', 'C']
*** FAIL: test_cases/q3/graph_manypaths.test
***     graph:
***             B1          E1
***            ^  \        ^  \
***           /    V      /    V
***         *A --> C --> D --> F --> [G]
***           \    ^      \    ^
***            V  /        V  /
***             B2          E2
***
***         A is the start state, G is the goal.  Arrows mark
***         possible state transitions.  This graph has
multiple
```

```
***         paths to the goal, where nodes with the same
state
***         are added to the fringe multiple times before
they
***         are expanded.
***     student solution:               ['1:A->C', '0:C->D', '1:D-
>F', '0:F->G']
***     student expanded_states:        ['A', 'B1', 'C', 'B2',
'C', 'D', 'D', 'E1', 'E1', 'F', 'F', 'E2', 'E2', 'F', 'F']
***
***     correct solution:               ['1:A->C', '0:C->D', '1:D-
>F', '0:F->G']
***     correct expanded_states:        ['A', 'B1', 'C', 'B2',
'D', 'E1', 'F', 'E2']
***     correct rev_solution:           ['1:A->C', '0:C->D', '1:D-
>F', '0:F->G']
***     correct rev_expanded_states:    ['A', 'B1', 'C', 'B2',
'D', 'E1', 'F', 'E2']
*** PASS: test_cases/q3/ucs_0_graph.test
***     solution:               ['Right', 'Down', 'Down']
***     expanded_states:        ['A', 'B', 'D', 'C', 'G']
*** PASS: test_cases/q3/ucs_1_problemC.test
***     pacman layout:          mediumMaze
***     solution length: 68
***     nodes expanded:         275
*** PASS: test_cases/q3/ucs_2_problemE.test
***     pacman layout:          mediumMaze
***     solution length: 74
***     nodes expanded:         266
*** PASS: test_cases/q3/ucs_3_problemW.test
***     pacman layout:          mediumMaze
***     solution length: 152
***     nodes expanded:         175
*** PASS: test_cases/q3/ucs_4_testSearch.test
***     pacman layout:          testSearch
***     solution length: 7
***     nodes expanded:         14
*** PASS: test_cases/q3/ucs_5_goalAtDequeue.test
***     solution:               ['1:A->B', '0:B->C', '0:C->G']
***     expanded_states:        ['A', 'B', 'C']
*** Tests failed.
```

Question q3: 0/3

Finished at 21:37:52

Provisional grades
==================
Question q3: 0/3

Total: 0/3

Why did it fail?

You're expanding the same state multiple times.

In your loop you do `getSuccessors(state)` **unconditionally**, even when that `state` has already been visited. The autograder's "expanded_states" counts a state as expanded when you call `getSuccessors` on it, so popping duplicates and expanding them again produces the repeated sequence seen in `graph_manypaths.test`.

Fix

Only expand a state the **first time** you pop it:

1. On pop, **skip** if already visited.
2. Otherwise mark visited, then (optionally) goal-test, then expand.

Conceptually:

```perl
while fringe not empty:
    cost, state, path = pop_min()

    if state in visited:
        continue
    visited.add(state)

    if isGoal(state):
        return path
```

```
    for (nextState, action, stepCost) in getSuccessors(state):
        push(nextState, path+[action], cost+stepCost) with priority = cost+stepCost
```

This change will make your expanded list match the expected one for `graph_manypaths.test`.

(Optional but better) Track best costs

UCS/Dijkstra is usually done with a `best_cost[state]` map; you only push a neighbor if `newCost < best_cost.get(nextState, inf)`. That further reduces duplicate enqueues and guarantees optimal expansions.

Ok how to implement this map?

Great follow-up 👌 — the `best_cost` map is how you implement **true Dijkstra / UCS**.

Why a `best_cost` map?

- A state may be discovered multiple times with different costs.
- UCS should only expand it on the **cheapest path**.
- The map keeps track of the **lowest cost found so far** to reach each state.

How to integrate it

1. **Initialize**

```python
best_cost = {}
start = problem.getStartState()
best_cost[start] = 0
fringe.push((start, [], 0), 0)
```

2. **Loop**

```python
while not fringe.isEmpty():
    state, path, cost = fringe.pop()
```

```
    # If this path is worse than a known one, skip it
    if cost > best_cost.get(state, float("inf")):
        continue

    if problem.isGoalState(state):
        return path

    for (nextState, action, stepCost) in problem.getSuccessors(state):
        newCost = cost + stepCost
        if newCost < best_cost.get(nextState, float("inf")):
            best_cost[nextState] = newCost
            newPath = path + [action]
            fringe.push((nextState, newPath, newCost), newCost)
```

What changed compared to your version

- We no longer need a `visited` set.
- Instead, **skip** expansions if we've already found a cheaper way (`if cost > best_cost[state]: continue`).
- Only push a successor if its new cost is **better than the best known cost**.

This way:

- Each state is expanded at most once with its optimal cost.
- The autograder's `expanded_states` will now match (no duplicates like you saw in `graph_manypaths.test`).

👉 Want me to show you a **step-by-step trace** of this logic on the small `graph_manypaths.test` example (the A–C–D–F–G graph), so you see how the map prevents repeated expansions?

Why didn't you tell me that I needed a math before.
Can you explain what the code is doing

Ah, sorry about that — I should've introduced the **best-cost map** earlier. The `visited`-only version often *works*, but UCS/Dijkstra is really driven by "what's the cheapest cost we've seen for this state so far," which is what the map tracks.

Here's what the code (with `best_cost`) is doing, conceptually:

The moving parts

- **Priority queue (min-heap):** always pops the state with the **lowest total cost so far**.
- **best_cost map:** `best_cost[s] = cheapest g(s) found so far`.
  This prevents expanding/worsening duplicates.
- **Path:** list of actions to reconstruct how we got there.

The loop logic (in words)

1. **Initialize**
   - Start state goes in the priority queue with cost `0` and empty path.
   - Record `best_cost[start] = 0`.
2. **Pop cheapest**
   - Take the `(state, path, cost)` with **minimum cost** from the queue.
3. **Dominance check (critical)**
   - If this `cost` is **greater** than `best_cost[state]`, skip it.
     (We already found a strictly **cheaper** way to this state earlier; this entry is stale.)
4. **Goal check**
   - If `state` is goal, return `path`.
     (Because of the min-heap and the dominance check, the first time we pop the goal is optimal.)
5. **Expand successors**
   - For each `(nextState, action, stepCost)`:
     - Compute `newCost = cost + stepCost`.
     - If `newCost < best_cost.get(nextState, ∞)`:
       - Update `best_cost[nextState] = newCost`.
       - Push `(nextState, path + [action], newCost)` with **priority = newCost**.

Why this fixes your failing test

- In graphs with many overlapping paths, the same state can be discovered multiple times.
- Without `best_cost`, you might:
  - enqueue the same state many times,
  - pop it multiple times,
  - **expand** it multiple times (which is what the autograder flagged as "expanded_states" duplicates).
- With `best_cost`, only the **cheapest** path to any state survives; worse duplicates get **skipped** when popped.

Micro-trace (intuitive)

- Suppose you reach `C` with cost `7`, then later discover a path to `C` with cost `5`.
- When the `(C, cost=7)` entry is popped, the check sees `7 > best_cost[C] (=5)` → **skip** expand.
- Only the `(C, cost=5)` entry leads to expansion, keeping expansions clean and optimal.

Why "visited" alone isn't enough

- Marking "visited" when popped works for **unit-cost BFS** but not for **weighted edges**.
- You could see a state first via a **more expensive** path, mark it visited, and then **ignore** a later **cheaper** path — breaking optimality.
- `best_cost` fixes this by allowing revisits **only if cheaper**; and with the skip-on-pop check, stale entries don't expand.

If you want, I can walk through your specific `graph_manypaths.test` structure with the exact `best_cost` updates and queue contents at each step so you can see precisely where duplicates are pruned.

Onto Q4, please give me the standard implementation of A*. I want to try it myself and see if I can get it before asking you

Awesome—here's the **standard A*** pattern you can drop into the Pacman framework and fill in. It follows the canonical Dijkstra+heuristic structure, returns **actions only**, checks goal **on pop**, and uses a **best-g map** to avoid expanding dominated paths.

python

```python
def aStarSearch(problem, heuristic=lambda s, p=None: 0):
    """
    Standard A*:
      - Priority = f(n) = g(n) + h(n)
      - g(n): best cost-so-far to reach n
      - h(n): heuristic(n)
    Returns a list of actions from start to goal.
    """
    from util import PriorityQueue

    start = problem.getStartState()
    pq = PriorityQueue()

    # g-costs map: best cost-so-far seen for each state
    best_g = {start: 0}

    # Push start: item carries (state, path, g)
    f0 = heuristic(start, problem)
    pq.push((start, [], 0), f0)

    while not pq.isEmpty():
        state, path, g = pq.pop()

        # Skip stale entries (dominated by a cheaper g we've already recorded)
        if g > best_g.get(state, float("inf")):
            continue

        if problem.isGoalState(state):
            return path  # actions only

        for (ns, action, stepCost) in problem.getSuccessors(state):
            new_g = g + stepCost
            # Only consider if we've found a strictly better path to ns
            if new_g < best_g.get(ns, float("inf")):
                best_g[ns] = new_g
                new_path = path + [action]
                f = new_g + heuristic(ns, problem)
                pq.push((ns, new_path, new_g), f)

    return []  # no solution
```

Notes you'll care about

- **Goal test on pop** (not on push) ensures optimality with A*.
- The `best_g` map replaces a plain visited set: it lets you revisit a state *only* if you found a cheaper route.
- Works with any **admissible (and ideally consistent)** `heuristic(state, problem)`.
- If you need deterministic tie-breaks, you can add a monotonic counter to the priority (not required by the project).

If you run into a failing edge case, paste the failing test's expanded states and we'll trace it.

What is f- and what is heuristic, also I meant give me the skeleton code for A* so I can try implement myself first

Got it 👍 — let's break this down without giving you the full solution yet.

The A* ingredients

- **g(n):** the actual cost to reach a state from the start (path cost so far).
- **h(n):** the **heuristic function**, i.e. an estimate of the cost from the state to the goal (like Manhattan distance, Euclidean distance, etc.).
- **f(n) = g(n) + h(n):** the *priority* in the fringe; A* always expands the state with the lowest f.

So:

- **g** → what you've really spent so far.
- **h** → your guess at what remains.
- **f** → the sum, i.e. "best guess" at total path length.

Skeleton for A* (Pacman project style)

```python

```

```python
def aStarSearch(problem, heuristic=nullHeuristic):
    """Search the node that has the lowest combined cost and heuristic first."""
    start = problem.getStartState()
    fringe = util.PriorityQueue()
    # maybe some structure for best costs here

    # push the start state into fringe
    # priority should be g(start) + h(start)

    while not fringe.isEmpty():
        state, path, cost = fringe.pop()

        # goal test

        # check/update best cost for this state

        # expand successors
        for (nextState, action, stepCost) in problem.getSuccessors(state):
            # compute new cost g
            # compute priority f = g + h(nextState)
            # push into fringe
            pass

    return []
```

That's the "scaffold":

- You decide **when** to check/update best costs,
- how to **skip stale nodes**,
- and how to compute and push `(state, path, cost)` with `priority = cost + heuristic(state)`.

👉 Do you want me to also show you a **toy heuristic example** (like Manhattan distance in a grid) so you can picture what `heuristic(state, problem)` is actually doing?