Search

Let's explore a particular (example) implementation of breadth-first search. The approach here uses an agenda of future nodes or paths to try. We keep track of nodes already seen, so we don't re-visit unsuccessful nodes.

A little later, we will reimplement our search using different queue abstractions, and then experiment with those to see the difference between **breadth-first** and **depth-first** search.

In [ ]:
```
from table import notebook_table #visualization
```

In [ ]:
```
def search(start, is_goal, successors):
    """ Search for and return a node satisfying a goal

    start: the starting node
    is_goal(node): returns True if node satisfies the goal
    successors(node): a sequence of successor nodes to node

    Uses a list to keep track of an agenda of nodes to try
    """
    agenda = [start]

    seen = {start}
    print_in_table = notebook_table('seen', 'agenda', 'node =')
    while agenda:
        print_in_table(seen)
        print_in_table(agenda)
        node = agenda.pop(0)
        print_in_table(node)
        if is_goal(node):
            return node
        for s in successors(node):
            if s not in seen:
                agenda.append(s)
                seen.add(s)
```

In [ ]:
```
# Search for a node that has a particular value
#
def example_1():
    def is_goal(node):
        return node == 5
    def successors(node):
        if node < 100:
            return [node+1, node+3] #try different things here...
        return []

    start = 0
    res = search(start, is_goal, successors)
    notebook_table.display()
    print("search: start =", start, "; result =", res)
```

In [ ]:
```
example_1()
```

In [ ]:
```
# Search for non-zero number divisible by x and y
#
def example_2():
    x = 3; y = 4
    def is_goal(node):
        return node != 0 and node % x == 0 and node % y == 0
    def successors(node):
        if node < 100:
            return [node+1] #try different things here
        return []
    start = 0
    res = search(start, is_goal, successors)
    notebook_table.display()
    print("search: start =", start, "; result =", res)
```

In [ ]:
```
example_2()
```

Reimplement search using a queue abstraction

In [ ]:
```
def search(start, is_goal, successors):
    """ Search for a node that satisfies a goal.

    Uses a queue, implemented as a group of functions:
    make_queue, queue_empty, queue_next, queue_add
    """
    agenda = make_queue(start) ##
    seen = {start}
    print_in_table = notebook_table('seen', 'queue_elts(agenda)', 'node =')
    while not queue_empty(agenda): ##
        print_in_table(seen)
        print_in_table(queue_elts(agenda)) ##
        node = queue_next(agenda) ##
        print_in_table(node)
        if is_goal(node):
            return node
        for s in successors(node):
            if s not in seen:
                queue_add(agenda, s) ##
                seen.add(s)
```

In [ ]:

```
# FIFO (first in, first out) queue as a list
#
# Add elements to end of list; pop off front of list
#
def make_queue(e):
    return [e]

def queue_empty(q):
    return len(q) == 0

def queue_next(q):
    return q.pop(0)

def queue_add(q, elt):
    q.append(elt)

def queue_elts(q):
    return q
```

In [ ]:

```
example_1()
```

Change implementation of queue

In [ ]:
```python
# FIFO queue as a dictionary
#
# We'll fill items in the dict with an integer
# index as key and the element as value, with
# the smallest index being the oldest. Will `del`
# dict entry once returned.
#
def make_queue(e):
    return {'oldest': 0,
            'newest': 0,
            0: e}

def queue_empty(q):
    return q['newest']-q['oldest'] < 0

def queue_add(q, elt):
    q[q['newest']+1] = elt
    q['newest'] += 1

def queue_elts(q):
    return [q[pos] for pos in range(q['oldest'], q['newest']+1)]

def fifo_queue_next(q):
    """ FIFO -- First In, First Out: pull from oldest end of queue """
    c = q['oldest']
    val = q[c]
    del q[c]
    q['oldest'] += 1
    return val

def lifo_queue_next(q):
    """ LIFO -- Last In, First Out: pull from newest end of queue """
    c = q['newest']
    val = q[c]
    del q[c]
    q['newest'] -= 1
    return val

queue_next = fifo_queue_next
#queue_next = lifo_queue_next
```

In [ ]:
```python
example_1()
```

A message-passing queue implementation (using closures!)

In [ ]:
```python
# Example of this 'message-passing' interface:
def test_dict_queue():
    q = make_queue(1, lifo=True)
    for e in [2, 3, 4, 2]:
        q('add', e)
    while not q('empty'):
        print("q elts:", q('elts'), "; next:", q('next'))
```

In [ ]:
```python
# Message passing queue implementation
def make_queue(e, lifo=False):
    q = {'oldest': 0, 'newest': 0, 0: e}

    def _empty():
        return q['newest']-q['oldest'] < 0

    def _add(elt):
        q['newest'] += 1
        q[q['newest']] = elt

    def _elts():
        return [q[p] for p in range(q['oldest'], q['newest']+1)]

    def _fifo_next():
        """ FIFO -- pull from the oldest end of queue """
        c = q['oldest']
        val = q[c]
        del q[c]
        q['oldest'] += 1
        return val

    def _lifo_next():
        """ LIFO -- pull from the newest end of queue """
        c = q['newest']
        val = q[c]
        del q[c]
        q['newest'] -= 1
        return val

    _dispatch = {'empty': _empty,
                 'next': _lifo_next if lifo else _fifo_next,
                 'add': _add,
                 'elts': _elts,
    }

    def _message(msg, *args):
        return _dispatch[msg](*args)

    return _message
```

In [ ]:
```python
def test_dict_queue(lifo=False):
    print("\ntest_dict_queue of type", "LIFO" if lifo else "FILO")
    q = make_queue(1, lifo=lifo)
    for e in [2, 3, 4, 2]:
        q('add', e)
    while not q('empty'):
        print("q elts:", q('elts'), "; next:", q('next'))

test_dict_queue()
test_dict_queue(lifo=True)
```

New search implementation using message-passing queue

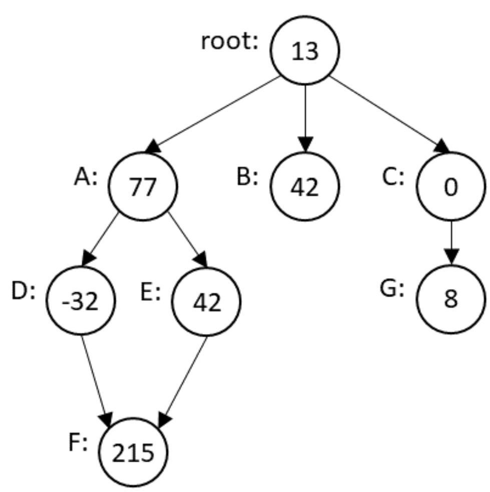
In [ ]:
```
def search(start, is_goal, successors, dfs=False):
    """ Search for a node that satisfies a goal.

    Internal use of a message-passing queue:
    q = make_queue(start, lifo=False) #fifo by default
    q('empty'), q('next'), q('add', elt), q('elts')
    """
    agenda = make_queue(start, lifo=dfs)
    seen = {start}
    print_in_table = notebook_table('seen', 'agenda("elts")', 'node =')
    while not agenda('empty'):
        print_in_table(seen)
        print_in_table(agenda('elts'))
        node = agenda('next')
        print_in_table(node)
        if is_goal(node):
            return node
        for s in successors(node):
            if s not in seen:
                agenda('add', s)
                seen.add(s)
```

In [ ]:
```
example_1()
```

In [ ]:
```
example_2()
```

Example directed graph



In [ ]:
```
graph1 = {'root': [13, ['A', 'B', 'C']],
          'A': [77, ['D', 'E']],
          'B': [42, []],
          'C': [0, ['G']],
          'D': [-32, ['F']],
          'E': [42, ['F']],
          'F': [215, []],
          'G': [8, []],
}
```

In [ ]:
```python
def example_3(dfs):
    start = 'root'
    goal_value = 42

    def is_goal(node):
        return graph1[node][0] == goal_value

    def successors(node):
        return graph1[node][1]

    res = search(start, is_goal, successors, dfs=dfs)
    notebook_table.display()
```

In [ ]:
```python
example_3(dfs=False)
```

In [ ]:
```python
example_3(dfs=True)
```

Consider a search_path capability to find a path to a node that satisfies a goal

In [ ]:
```python
def search_path(start, is_goal, successors, dfs=False):
    """ Search for a path that satisfies a goal.

    start:              the starting node
    is_goal(node):      returns True if node satisfies the goal
    successors(node): a sequence of successor nodes to node
    """
    # MODIFY search (DUPLICATED BELOW) TO IMPLEMENT search_path
    agenda = make_queue(start, lifo=dfs)
    seen = {start}
    print_in_table = notebook_table('seen', 'agenda("elts")', 'node =')
    while not agenda('empty'):
        print_in_table(seen)
        print_in_table(agenda('elts'))
        node = agenda('next')
        print_in_table(node)
        if is_goal(node):
            return node
        for s in successors(node):
            if s not in seen:
                agenda('add', s)
                seen.add(s)
```

In [ ]:
```
def example_4(dfs=False):
    start = 'root'

    def is_goal(node):
        #return graph1[node][0] == 42 # node with value
        return graph1[node][0] > 0 and graph1[node][0] % 2 == 0 # node with positive even v

    def successors(node):
        return graph1[node][1]

    res = search_path(start, is_goal, successors, dfs=dfs)
    notebook_table.display()
    print('result: ', res)
```

In [ ]:
```
example_4(dfs=False)
```

In [ ]:
```
example_4(dfs=True)
```

An alternative search_paths

The `search_paths` function above is somewhat inefficient, in that it does a lot of copying of tuples to create new paths. An alternative is to create "nested" paths during the search, e.g., `(s, path)` rather than `path + (s,)`, and then convert the nested result back to the "flat" path format once we've found a successful path. That alternative is left as an exercise for the reader.

What if we want *all* paths?

Our code above only finds one path to a node that satisfies the goal. How would we gather all paths? Assume that there are no cycles in the graph.

In [ ]:
```
# Search for all paths whose end satisfies a goal.
#
def search_all_paths(start, is_goal, successors, dfs=False):
    pass
```

In [ ]:
```
def example_5(dfs=False):
    start = 'root'

    def is_goal(node):
        #return graph1[node][0] == 42 # node with value
        return graph1[node][0] > 0 and graph1[node][0] % 2 == 0 # node with positive even v

    def successors(node):
        return graph1[node][1]

    res = search_all_paths(start, is_goal, successors, dfs=dfs)
    notebook_table.display()
    print('result: ', res)
```

In [ ]:
```
example_5(dfs=False)
```

In [ ]:
```
example_5(dfs=True)
```