Public-Service Announcement

“Autofocus is Berkeley’s first mobile photography club. Join us as we build a community of phone photographers at Cal. All you need to be part is an interest in photography and a mobile phone!

Infosessions on 2/2 and 2/7. Details at tiny.cc/autofocus”
Lecture #7: Tree Recursion
Tree Recursion

• The make_gasket function is an example of a tree recursion, where each call makes multiple recursive calls on itself.

• A linear recursion makes at most one recursive call per call.

• A tail recursion has at most one recursive call per call, and it is the last thing evaluated.

• A linear recursion such as for sum_squares produces the pattern of calls on the left, while make_gasket produces the pattern on the right—an instance of what we call a tree in computer science.
What About This?

What kind of recursion is this?

```python
def find_it(f, y, low, high):
    """Given that F is a nondecreasing function on integers, find a value of x between LOW and HIGH inclusive such that F(x) == Y. Return None if there isn’t one.""

    if low > high:
        return None
    mid = (low + high) // 2
    val = f(mid)
    return val == y \
    or (val < y and find_it(f, y, low, mid-1)) \
    or (val > y and find_it(f, y, mid+1, high))
```

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What About This?

What kind of recursion is this? **Tail Recursion**

def find_it(f, y, low, high):
    """Given that F is a nondecreasing function on integers, find a value of x between LOW and HIGH inclusive such that F(x) == Y. Return None if there isn’t one."""

    if low > high:
        return None
    mid = (low + high) // 2
    val = f(mid)
    return val == y \
    or (val < y and find_it(f, y, low, mid-1)) \
    or (val > y and find_it(f, y, mid+1, high))
What kind of recursion is this? Tree Recursion

```python
def find_it(f, y, low, high):
    """Given that F is a nondecreasing function on integers, find a value of x between LOW and HIGH inclusive such that F(x) == Y. Return None if there isn’t one."""

    if low > high:
        return None

    mid = (low + high) // 2
    val = f(mid)
    return val == y or (val < y and find_it(f, y, low, mid-1)) or (find_it(f, y, mid+1, high))
```
Finding a Path

- Consider the problem of finding your way through a maze of blocks:

From a given starting square, one can move down one level and up to one column left or right on each step, as long as the square moved to is unoccupied.

- Problem is to find a path to the bottom layer.

- Diagram shows one path that runs into a dead end and one that escapes.
Path-Finding Program

- Translating the problem into a function specification:

```python
def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some square (x1, 0) such that all squares on the path (including first and last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. Each step of a path goes down one row and 1 or 0 columns left or right."""
```

This grid would be represented by a predicate `M` where, e.g, `M(0,0), M(1,0), M(1,2), not M(1, 1), not M(2,2)`.

Here, `is_path(M, 5, 6)` is true; `is_path(M, 1, 6)` and `is_path(M, 6, 6)` are false.
def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some
    square (x1, 0) such that all squares on the path (including first and
    last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y)
    is true iff the grid square at (x, y) is occupied or off the edge.
    Each step of a path goes down one row and 1 or 0 columns left or right."""

    if __________:
        return __________

    elif __________:
        return __________

    else:
        return ________________________________
is_path Solution (II)

```python
def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some square (x1, 0) such that all squares on the path (including first and last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. Each step of a path goes down one row and 1 or 0 columns left or right."""

    if __________:
        return False

    elif __________:
        return True

    else:
        return ______________________________
```

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def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some square (x1, 0) such that all squares on the path (including first and last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. Each step of a path goes down one row and 1 or 0 columns left or right."""

    if blocked(x0, y0):
        return False

    elif _________:
        return True

    else:
        return ________________________________
is_path Solution (IV)

def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some
    square (x1, 0) such that all squares on the path (including first and
    last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y)
    is true iff the grid square at (x, y) is occupied or off the edge.
    Each step of a path goes down one row and 1 or 0 columns left or right."""

    if blocked(x0, y0):
        return False

    elif y0 == 0:
        return True

    else:
        return ________________________________
def is_path(blocked, x0, y0):
    """True iff there is a path of squares from (X0, Y0) to some
    square (x1, 0) such that all squares on the path (including first and
    last) are unoccupied. BLOCKED is a predicate such that BLOCKED(x, y)
    is true iff the grid square at (x, y) is occupied or off the edge.
    Each step of a path goes down one row and 1 or 0 columns left or right."""
    if blocked(x0, y0):
        return False
    elif y0 == 0:
        return True
    else:
        return is_path(blocked, x0-1, y0-1) or is_path(blocked, x0, y0-1) \
        or is_path(blocked, x0+1, y0-1)
def num_paths(blocked, x0, y0):
    """Return the number of unoccupied paths that run from (x0, y0)
    to some square (x1, 0). BLOCKED is a predicate such that BLOCKED(x, y)
is true iff the grid square at (x, y) is occupied or off the edge. """

For the previous predicate M, the result of num_paths(M, 5, 6) is 1.
For the predicate M2, denoting this grid (missing (7, 1)):

```
0 1 2 3 4 5 6 7 8 9
0
1
2
3
4
5
6
```

the result of num_paths(M2, 5, 6) is 5.
def num_paths(blocked, x0, y0):
    """Return the number of unoccupied paths that run from (X0, Y0)
    to some square (x1, 0). BLOCKED is a predicate such that BLOCKED(x, y)
    is true iff the grid square at (x, y) is occupied or off the edge. """

    if blocked(x0, y0):
        return ________________

    elif y0 == 0:
        return ________________

    else:
        return ________________
def num_paths(blocked, x0, y0):
    """Return the number of unoccupied paths that run from (X0, Y0) to some square (x1, 0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    if blocked(x0, y0):
        return 0

    elif y0 == 0:
        return 1

    else:
        return ______________________________________________________________________
def num_paths(blocked, x0, y0):
    """Return the number of unoccupied paths that run from (X0, Y0) to some square (x1, 0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    if blocked(x0, y0):
        return 0

    elif y0 == 0:
        return 1
    else:
        return num_paths(blocked, x0-1, y0-1) + num_paths(blocked, x0, y0-1) + num_paths(blocked, x0+1, y0-1)
def find_path(blocked, x0, y0):
    """Return a string containing the steps in an unoccupied path from (X0, Y0) to some unoccupied square (x1, 0), or None if not is_path(BLOCKED, X0, Y0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

Possible result of find_path(M, 5, 6):
""""(5, 6) (6, 5) (6, 4) (7, 3) (6, 2) (5, 1) (6, 0)"""
find_path Solution (I)

```python
def find_path(blocked, x0, y0):
    """Return a string containing the steps in an unoccupied path from (X0, Y0) to some unoccupied square (x1, 0), or None if not is_path(BLOCKED, X0, Y0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    if blocked(x0, y0):
        return ______________________

    elif y0 == 0:
        return ______________________

    else:
        return ______________________
```

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def find_path(blocked, x0, y0):
    """Return a string containing the steps in an unoccupied path from (X0, Y0) to some unoccupied square (x1, 0), or None if not is_path(BLOCKED, X0, Y0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    step = "({}, {})".format(x0, y0)
    # Alternative: step = str((x0, y0))
    if blocked(x0, y0):
        return None
    elif y0 == 0:
        return step
    else:
        return step
def find_path(blocked, x0, y0):
    """Return a string containing the steps in an unoccupied path from (X0, Y0) to some unoccupied square (x1, 0), or None if not is_path(BLOCKED, X0, Y0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    step = "({}, {})".format(x0, y0)
    if blocked(x0, y0):
        return None
    elif y0 == 0:
        return step
    else:
        p = find_path(blocks, x0-1, y0-1)
        if p is not None: return p + " " + step
        p = find_path(blocks, x0, y0-1)
        if p is not None: return p + " " + step
        p = find_path(blocks, x0+1, y0-1)
        if p is not None: return step + " " + p
    return None
def find_path(blocked, x0, y0):
    """Return a string containing the steps in an unoccupied path from (X0, Y0) to some unoccupied square (x1, 0), or None if not is_path(BLOCKED, X0, Y0). BLOCKED is a predicate such that BLOCKED(x, y) is true iff the grid square at (x, y) is occupied or off the edge. """

    step = "(({0}, {1}))".format(x0, y0)
    if blocked(x0, y0):
        return None
    elif y0 == 0:
        return step
    else:
        for x in (x0-1, x0, x0+1):
            p = find_path(blocks, x, y0-1)
            if p is not None: return p + " " + step
        return None
A Change in Problem

• Suppose we changed the definition of “path” for the maze problems to allow paths to go left or right without going down.

• And suppose we changed solutions in the obvious way, adding clauses for the \((x_0 - 1, y_0)\) and \((x_0 + 1, y_0)\) cases.

• Will this work? What would happen?
And a Little Analysis

• All our linear recursions took time proportional (in some sense) to the size of the problem.

• What about is_path?
And a Little Analysis

- All our linear recursions took time proportional (in some sense) to the size of the problem.

- What about `is_path`? Each call spawns up to three others, up to $y_0$ “generations.” That means the number of possible calls could be as many as $3^{y_0}$—exponential growth.