# 6.01

Lecture 12: Graph Search

# 6.01: Introduction to EECS I

The **intellectual themes** in 6.01 are recurring themes in engineering:

- design of complex systems
- modeling and controlling physical systems
- augmenting physical systems with computation
- building systems that are robust to uncertainty

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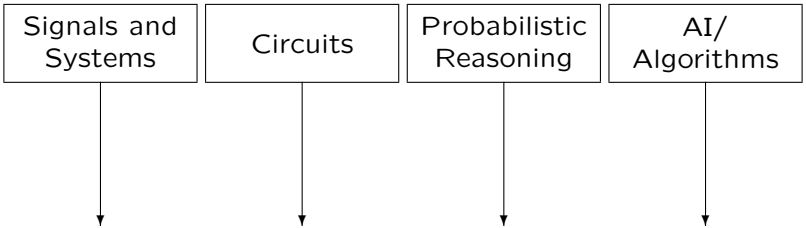

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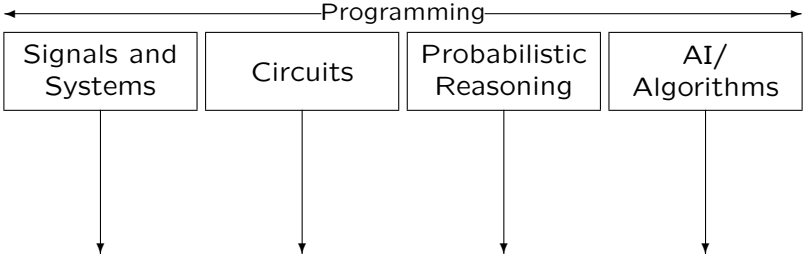
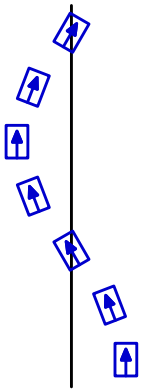


# Module 1: Signals and Systems

Modeling and analyzing behavior of physical systems

**Topics:** Feedback Control Systems

**Lab Exercises:** Wall-finder, Wall-follower, Jousting

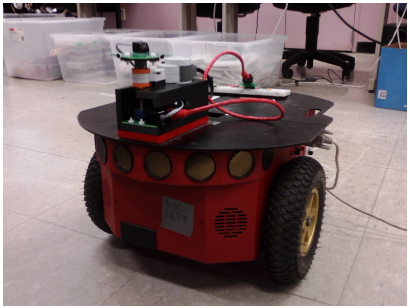


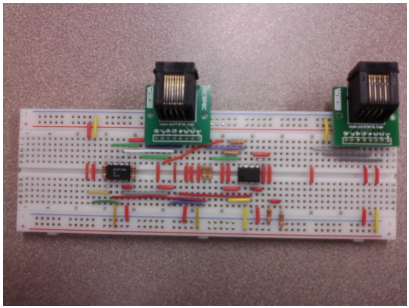
# Module 2: Circuits

Designing, constructing, and analyzing physical systems

**Topics:** Resistive Networks, Op-Amps, Linearity and Equivalence

**Lab Exercises:** Design a new sensory modality for the robot



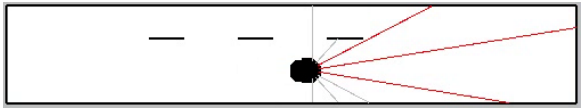


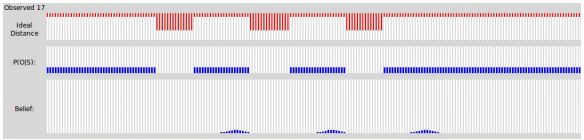
# Module 3: Bayesian Reasoning

Modeling uncertainty and designing robust systems

**Topics:** Subjective Probability, Bayesian Inference

**Lab Exercises:** Localization and Parking



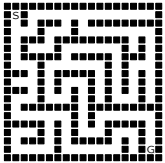


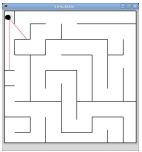
# Module 4: Planning

Augmenting physical systems with computation.

**Topics:** Graph Search

**Lab Exercises:** Solving mazes, Path planning on maps



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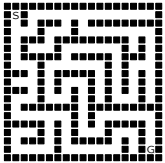
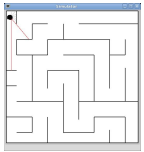


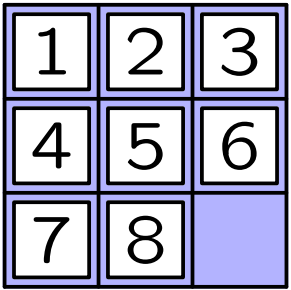
# Graph Search (Path Planning)

What is a graph?

- Some set $V$ of vertices
- Some collection $E$ of edges connecting vertices

# Example: 8-Puzzle

Start

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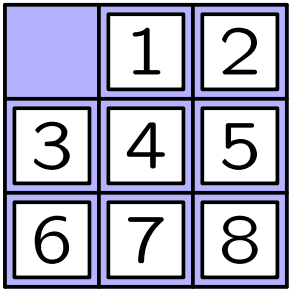

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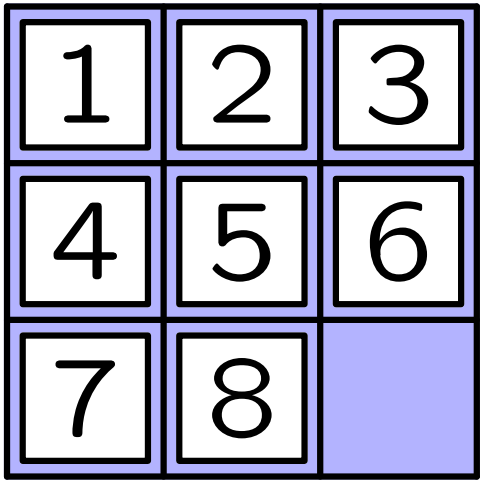

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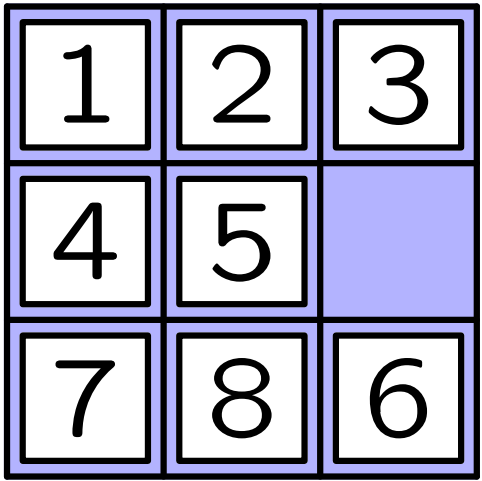

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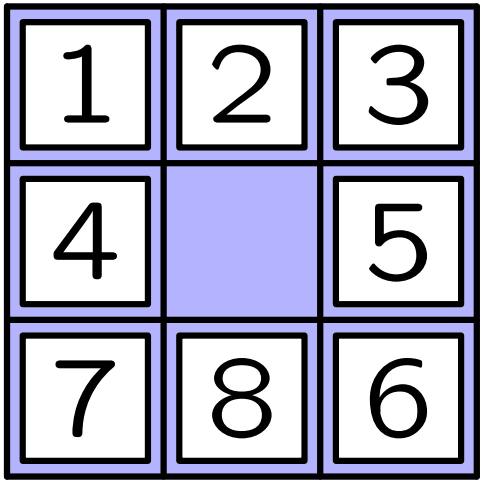

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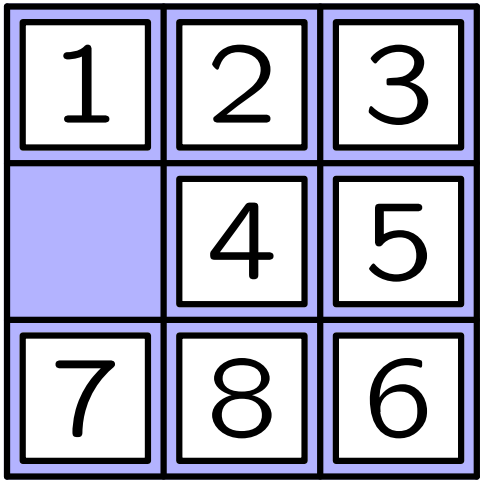

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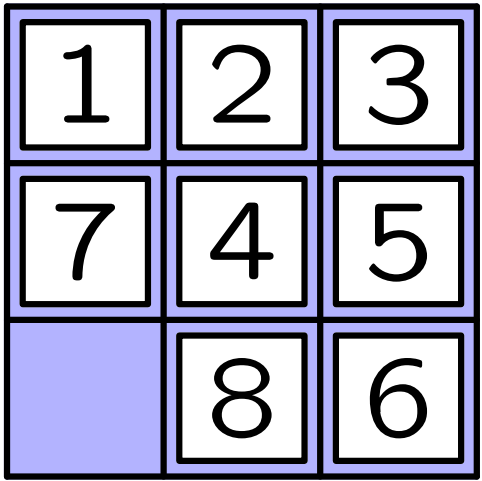

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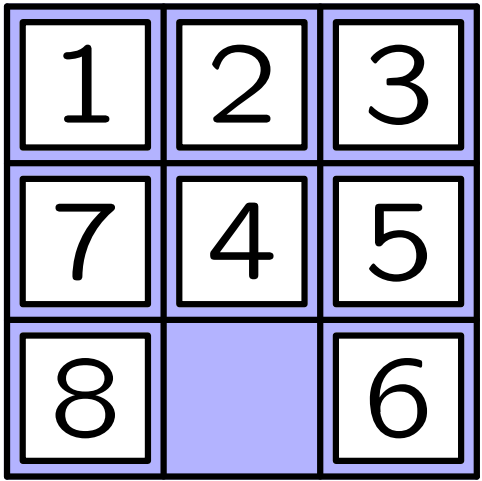

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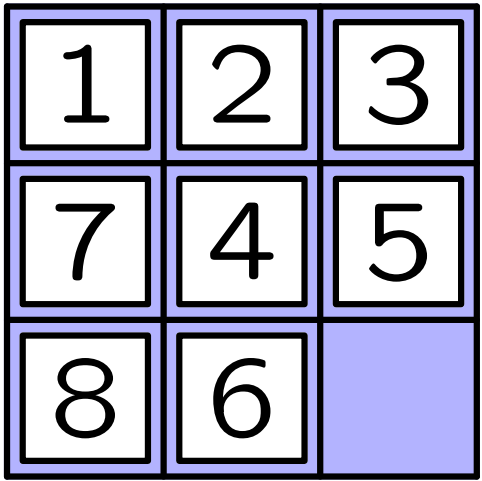

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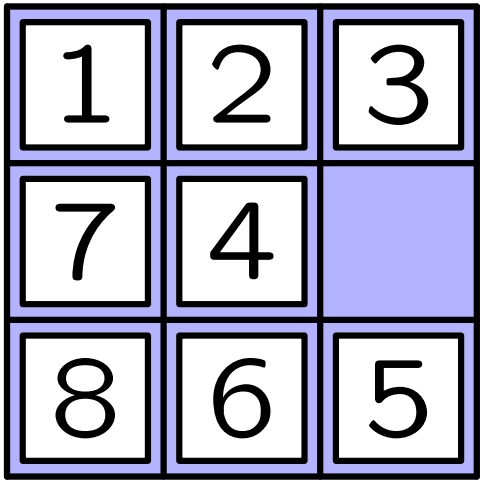

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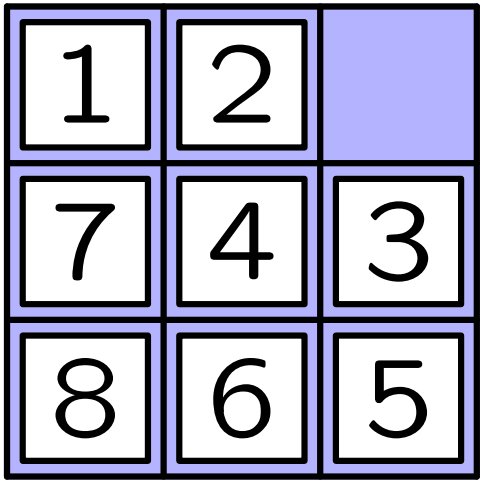

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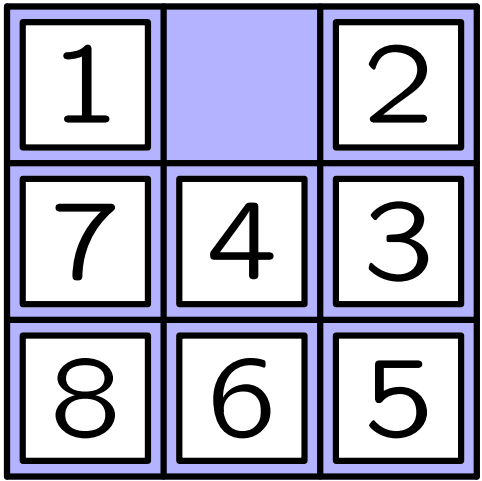

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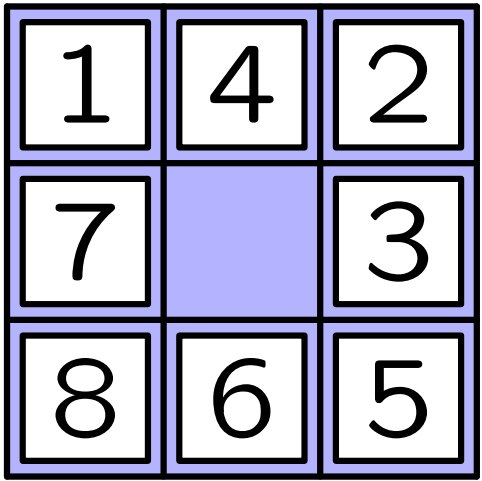

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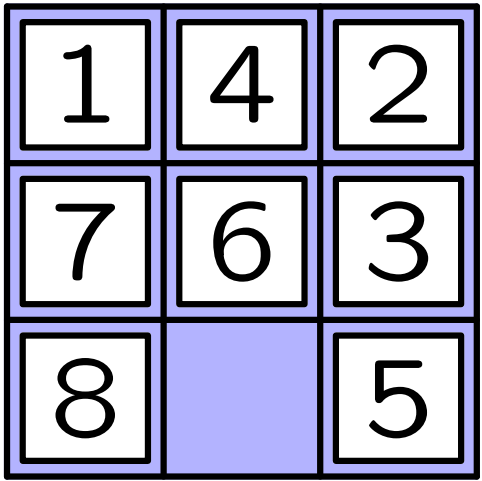

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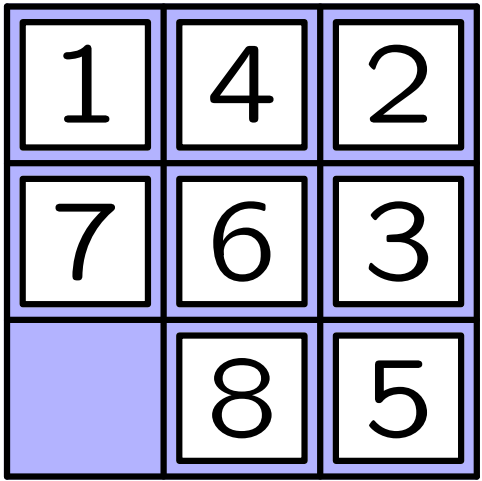

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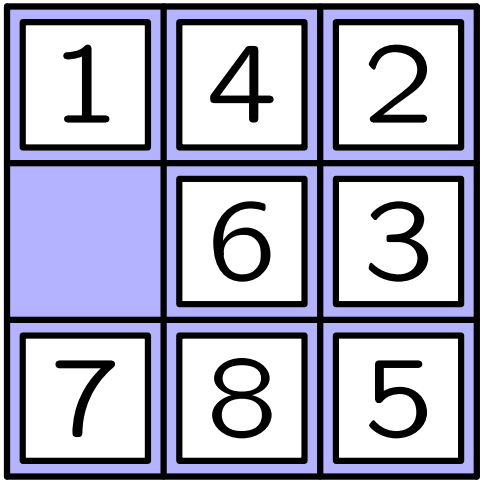

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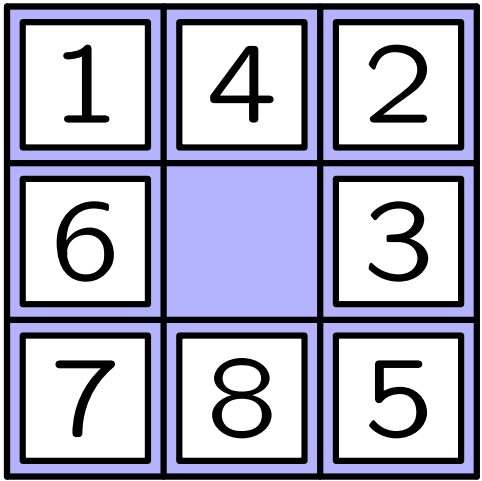

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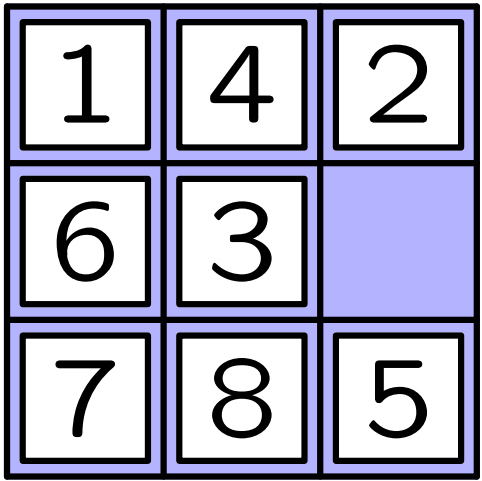

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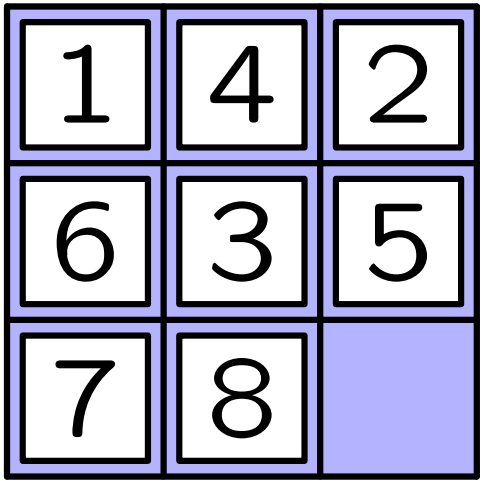

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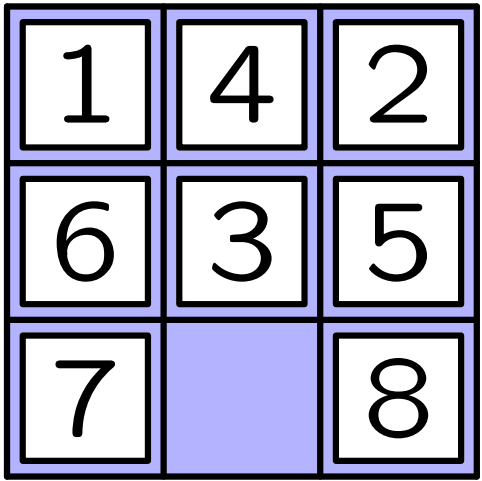

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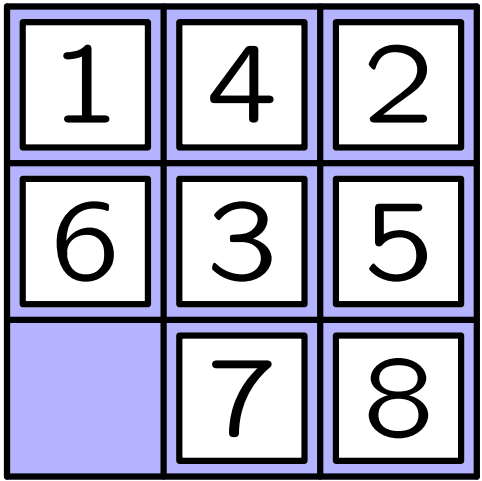

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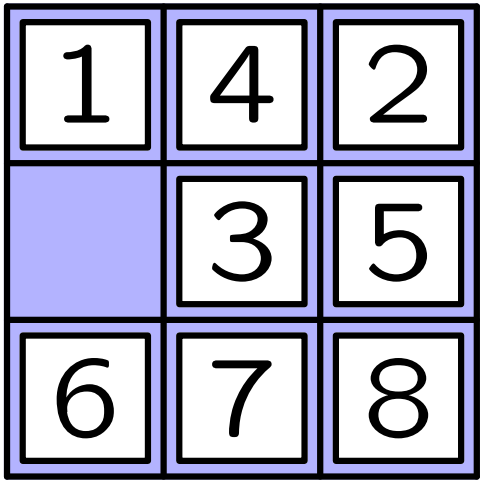

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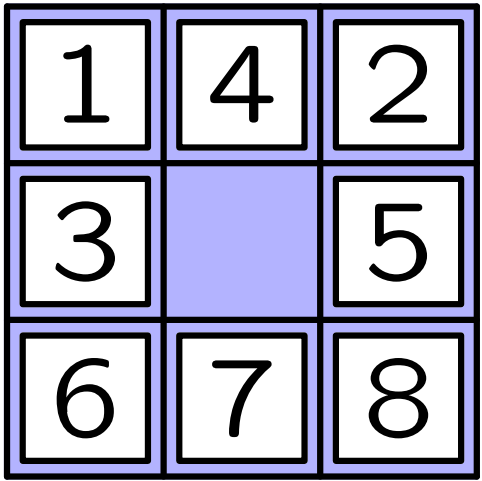

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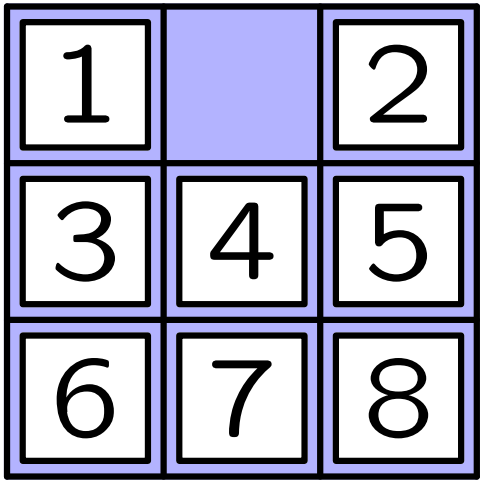

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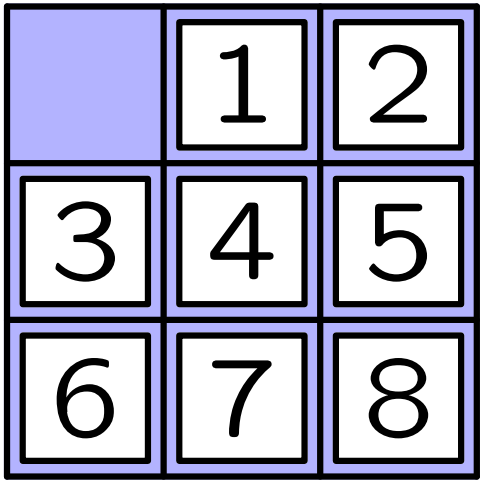

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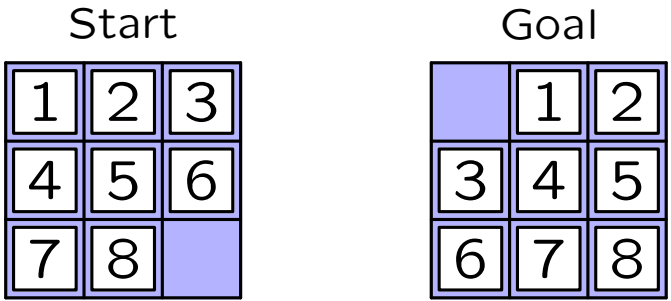


How many different board configurations (states) exist?

1. $8^2 = 64$
2. $9^2 = 81$
3. $8! = 40,320$
4. $9! = 362,880$
5. None of the above

# Check Yourself

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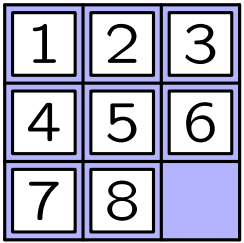
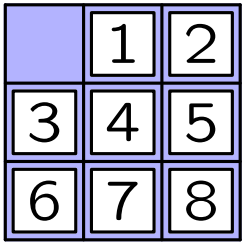



Goal

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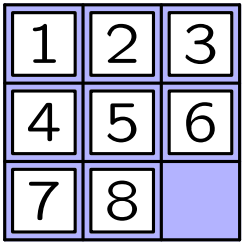


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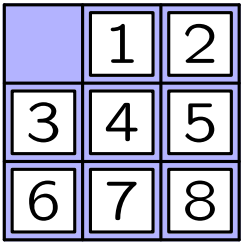


We could have to look through as many as $9! = 362,880$ states (or even more if we're not careful!)

- And we would have to figure out for each state, which of the other states can be reached through a single move.

Is the solution with 22 moves optimal? Do shorter solutions exist?

Do we have to look at all 362,880 configurations to be sure?

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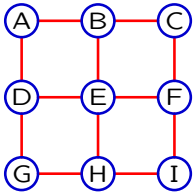
- Observe the algorithms at work in multiple contexts
  - Robot path-planning
  - Route Planning in USA
  - Language
  - Biology

# Example: Grid Search

Find path between 2 points on a rectangular grid.



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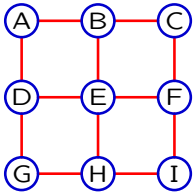
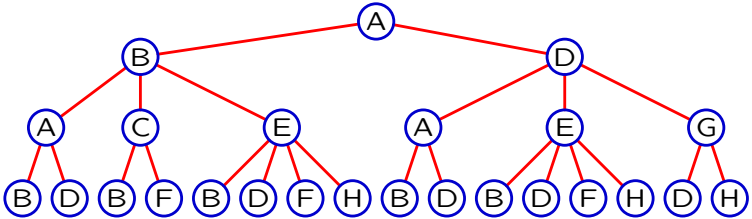


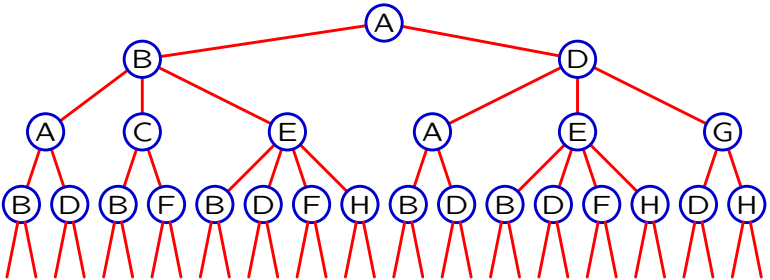

Represent **all possible paths** from $A$ with a **tree**:



# Problem?

Notice that there are infinitely many paths.

The tree is infinitely large!



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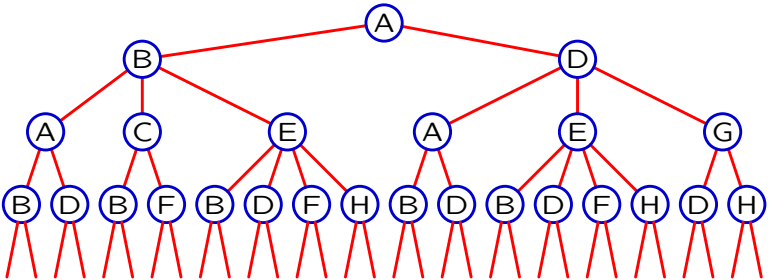
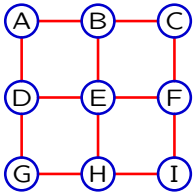



Strategy:
construct the tree **incrementally** while looking for a path

# Python Representation of Grid

Represent the grid as instance of class `Grid`

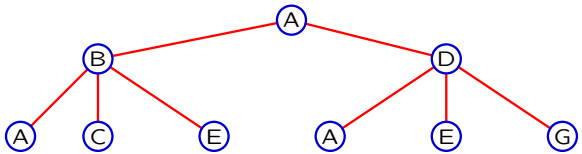



```
class Grid:
    def __init__(self, width, height, start, goal):
        self.width = width
        self.height = height
        self.start = start
        self.goal = goal

grid = Grid(3, 3, (0,0), (2,2))
```

# Search Trees in Python

Represent each **node** in the tree as an instance of `SearchNode`



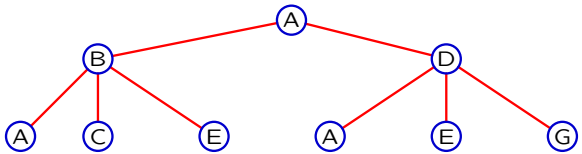

Note: no explicit representation for *entire* tree

Issues:

- need to "grow" the tree as we search it
- need to reconstruct paths in tree

# Search Trees in Python

Represent each **node** in the tree as an instance of `SearchNode`

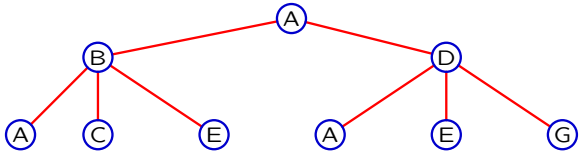



```
class SearchNode:
    def __init__(self, state, parent):
        self.state = state
        self.parent = parent

    def path(self):
        p = []
        node = self
        while node:
            p.append(node.state)
            node = node.parent
        return p[::-1]
```

# Pathfinding Algorithm

Construct the tree and find a path to the goal.



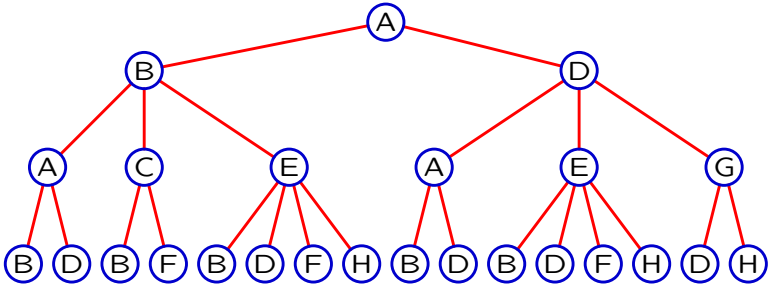

Algorithm:

- Initialize **agenda** (list of nodes to consider)
- Repeat the following:
  - Remove one node from the agenda ("expand")
  - Add that node's successors to the agenda ("visit")

  until **goal is found** or **agenda is empty**
- Return resulting path

# Order Matters!

Strategy: Replace last node in agenda by its successors



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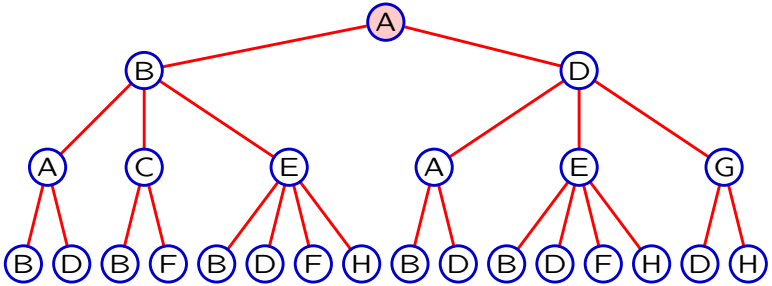


Agenda: A

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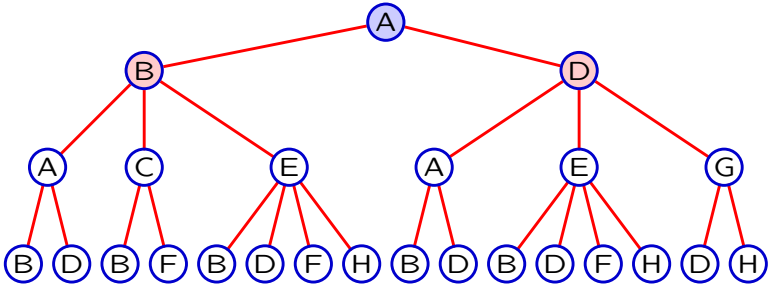


Agenda: ~~A~~ AB AD

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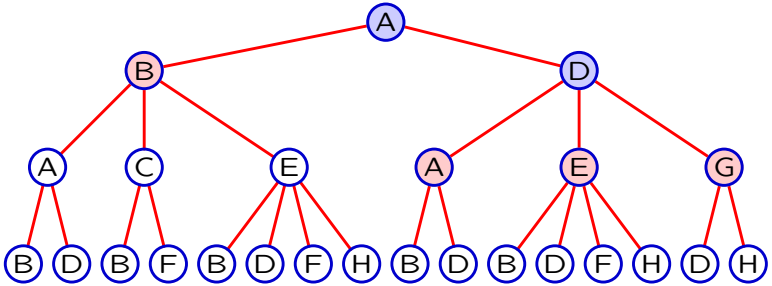


Agenda: ~~A~~ AB ~~AD~~ ADA ADE ADG

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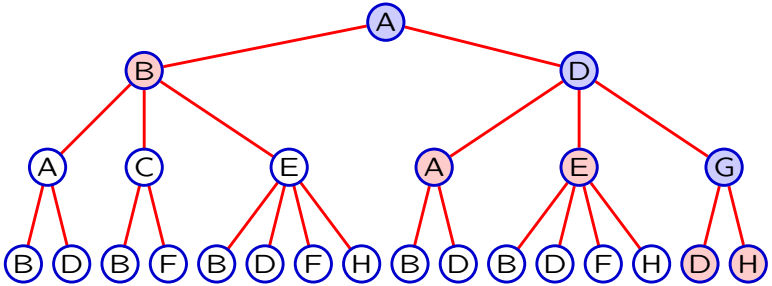


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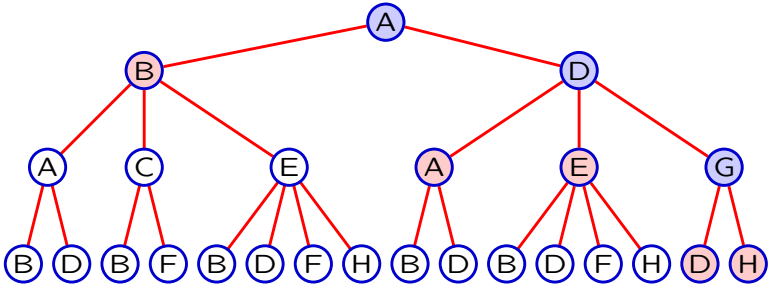


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*Depth-first* Search

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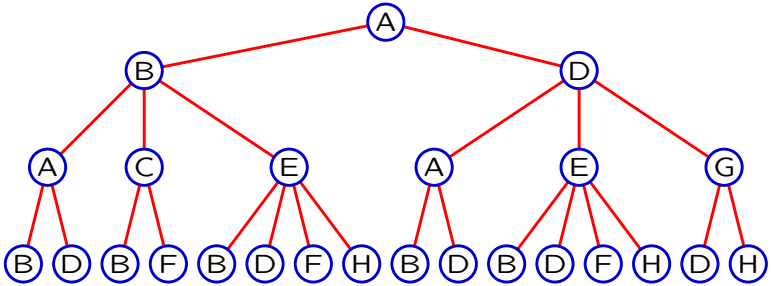

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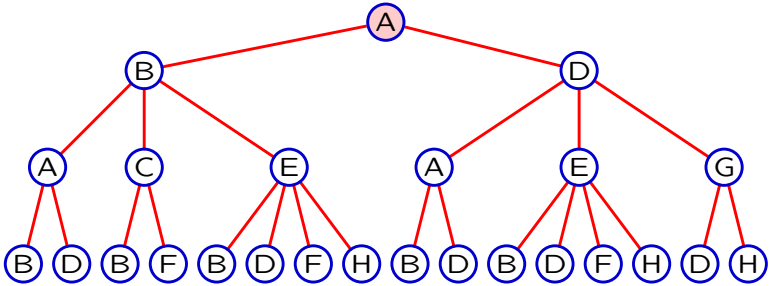


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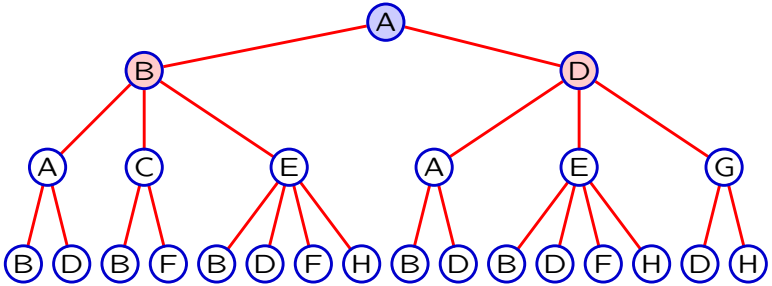


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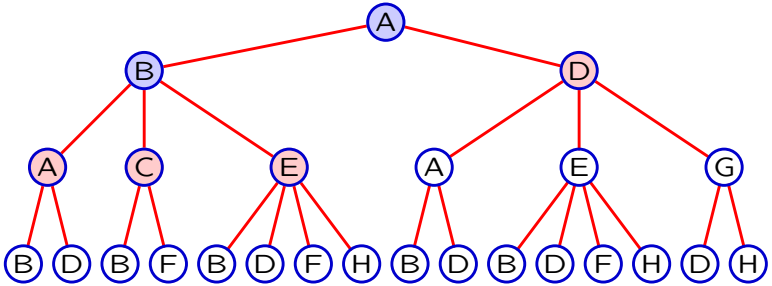


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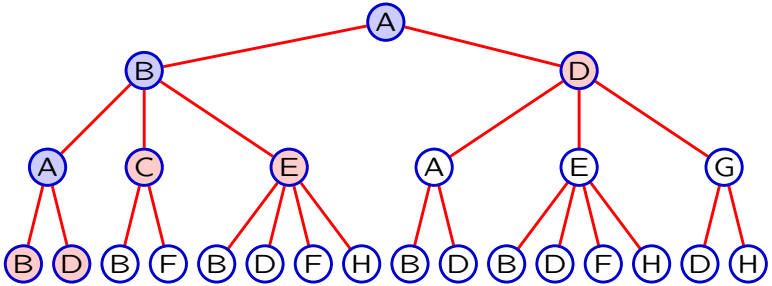


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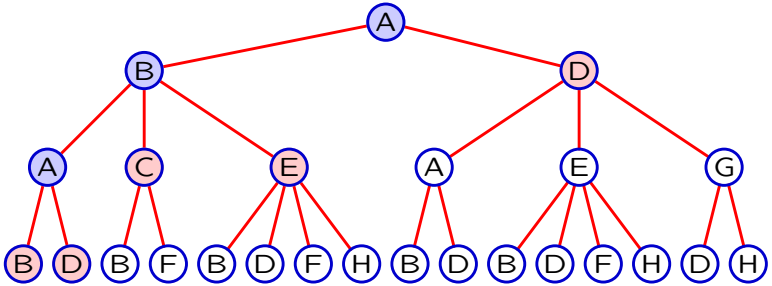


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Still *Depth-first* Search

# Order Matters!

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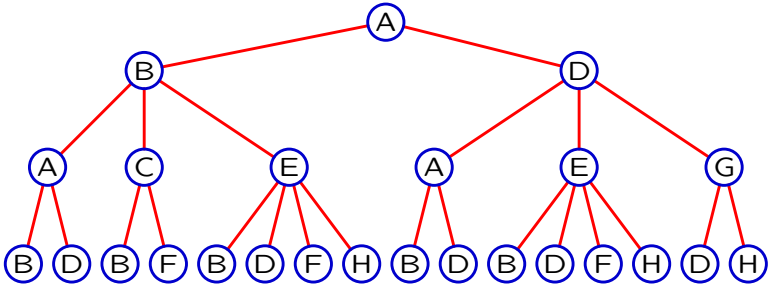

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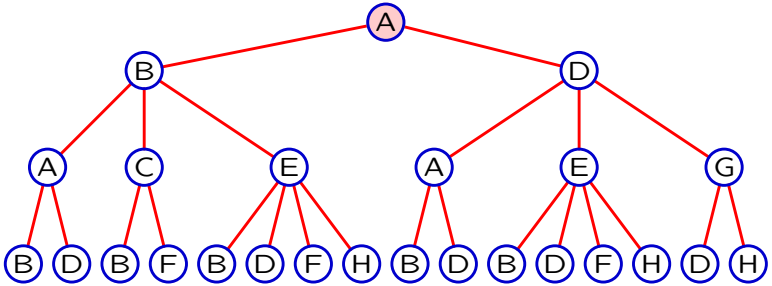


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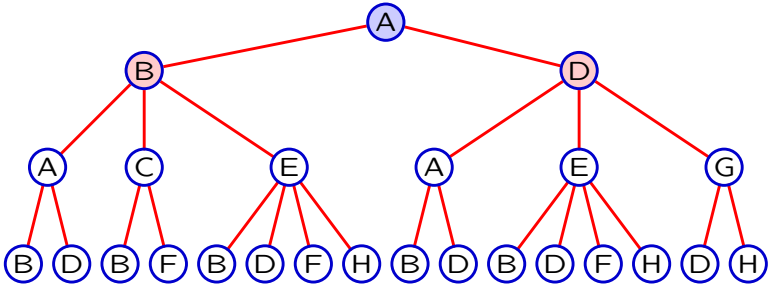


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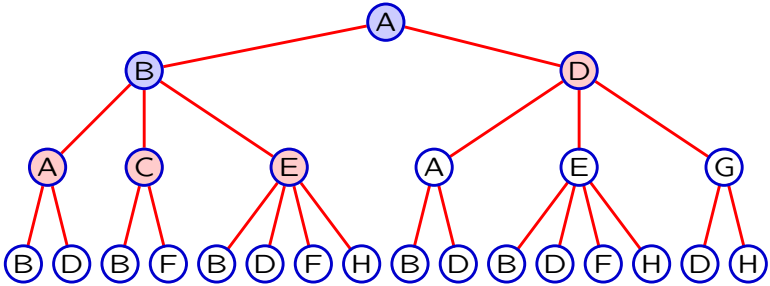


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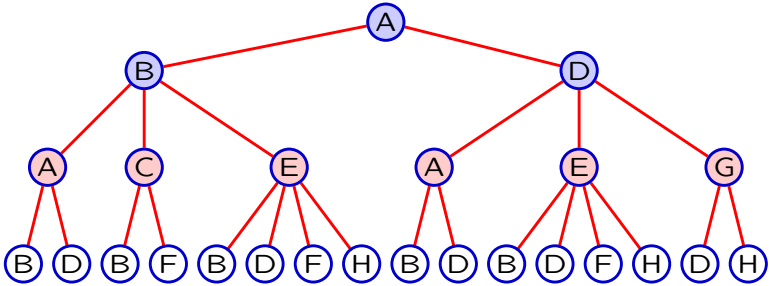


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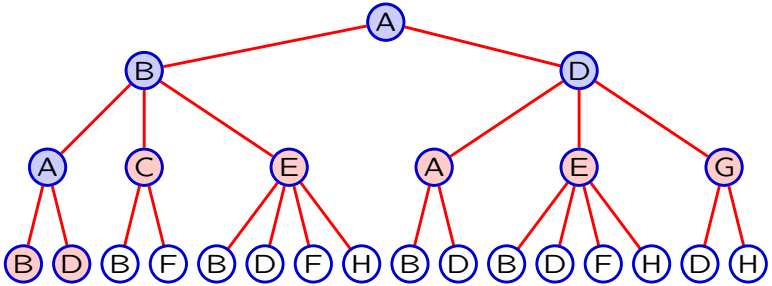


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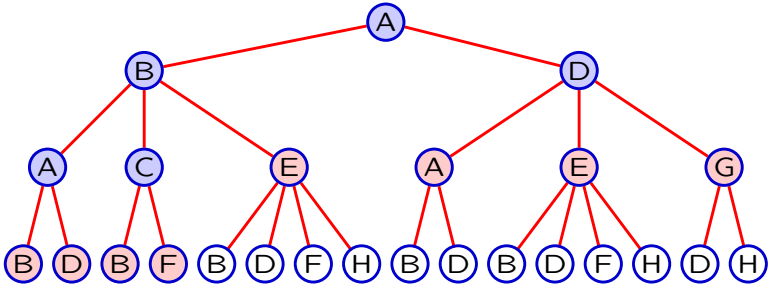


Agenda: ~~A~~ ~~AB~~ ~~AD~~ ~~ABA~~ ~~ABC~~ ABE ADA ADE ADG ABAB ABAD ABCB ABCF

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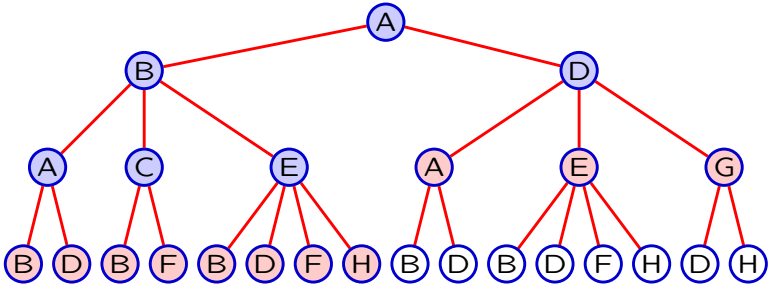


Agenda: ~~A AB AD ABA ABC ABE~~ ADA ADE ADG ABAB ABAD ABCB ABCF ABEB ABED ABEF ABEH

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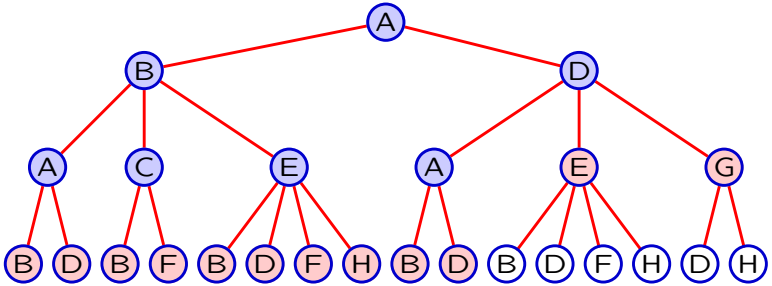


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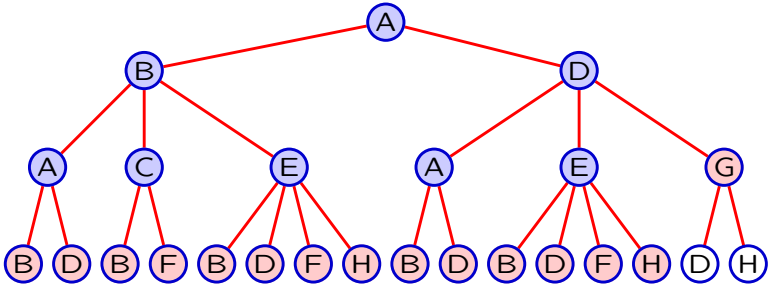


Agenda: ~~A AB AD ABA ABC ABE ADA ADE~~ ADG ABAB ABAD ABCB ABCF ABEB ABED ABEF ABEH ADAB ADAD ADEB ADED ADEF ADEH

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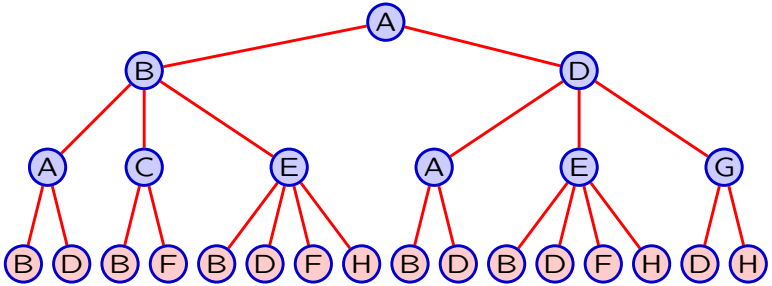


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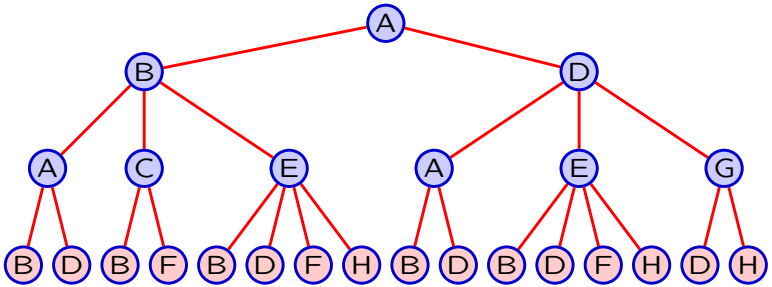



Agenda: ~~A~~ ~~AB~~ ~~AD~~ ~~ABA~~ ~~ABC~~ ~~ABE~~ ~~ADA~~ ~~ADE~~ ~~ADG~~ ABAB ABAD ABCB ABCF ABEB ABED ABEF ABEH ADAB ADAD ADEB ADED ADEF ADEH ADGD ADGH

*Breadth-first* Search

# Order Matters!

Depth-First Search (DFS):

- Push and Pop from same side of agenda
- Works down one branch of the tree before moving on to another branch

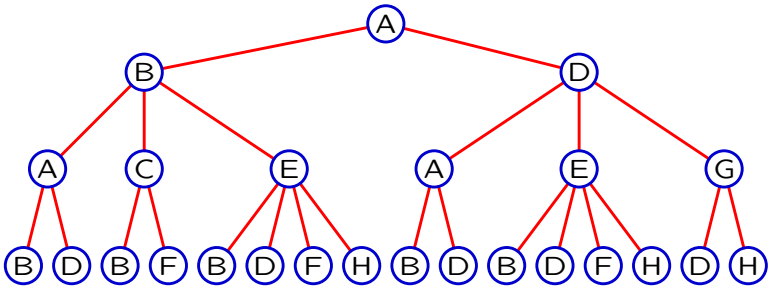
Breadth-First Search (BFS):

- Push and Pop from different sides of agenda
- Considers all paths of length $n$ before considering paths of length $n+1$

# Too Much Searching

Find path between 2 points on a rectangular grid.

Represent **all possible paths** with a **tree**:




But don't need to consider all nodes!

# Pruning

"Prune" the tree to reduce the amount of work.

**Pruning Strategy 1**:
Don't consider any path the visits the same state twice.

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Algorithm:

- Initialize **agenda** (list of nodes to consider)
- Repeat the following:
  - Remove one node from the agenda
  - Add each child (of that node) to the agenda **if its state is not in the parent's path**.

  until **goal is found** or **agenda is empty**
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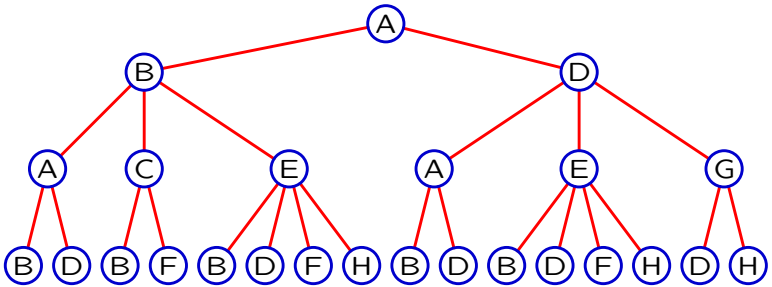

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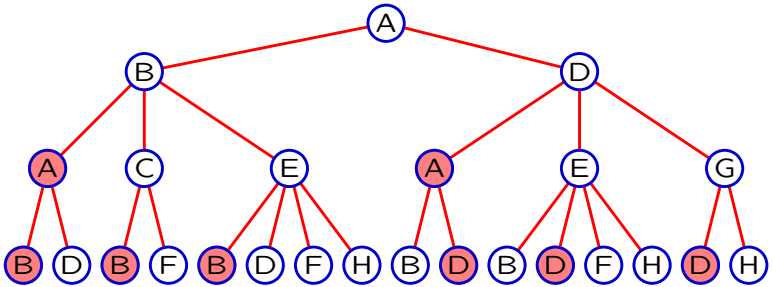

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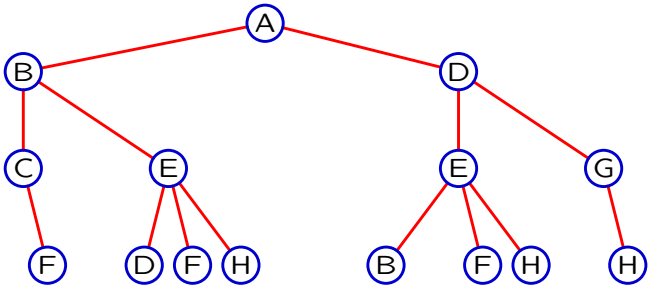
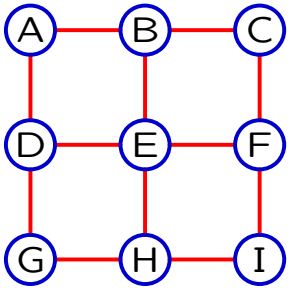


# Pruning

Under strategy 1, BFS in the 3x3 grid still visits 16 nodes...

# Pruning

Under strategy 1, BFS in the 3x3 grid still visits 16 nodes...
but there are only 9 states!




We should be able to reduce the search even further.

# Dynamic Programming

Basic idea behind dynamic programming:

- Break big problem into easy ones, solve and combine.
- Remember the solutions to the easy problems for later use.

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Basic idea behind dynamic programming:

- Break big problem into easy ones, solve and combine.
- Remember the solutions to the easy problems for later use.

Appropriate if problem has:

- *optimal substructure:* best solution is combination of optimal solutions to sub-problems
- *overlapping sub-problems:* same sub-problem occurs many times while solving overall problem

# Dynamic Programming

As applies to search:
(Depends slightly on which algorithm we're using)

# Dynamic Programming

As applies to search:
(Depends slightly on which algorithm we're using)

**BFS:** The shortest path $S \to X \to G$ is made up of the shortest path $S \to X$ and the shortest path $X \to G$.

# Dynamic Programming

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(Depends slightly on which algorithm we're using)

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Said another way: Many paths that include $S \to X$, but don't need to recompute while exploring rest of path (*memoization*); and once have a satisfactory path $S \to X$, don't need to keep looking for others (*dynamic programming*).

# Dynamic Programming

As applied to graph search: Don't consider any path that visits a state that you have already visited via some other path.

Need to remember which states we have visited to avoid visiting them again.

# Dynamic Programming

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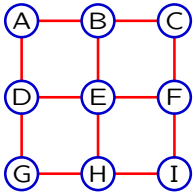
Algorithm:

- Initialize **visited set**
- Initialize **agenda** (list of nodes to consider)
- Repeat the following:
  - Remove one node from the agenda
  - Add each child (of that node) to the agenda **if its state is not already in the visited set**, and **add each of these new states to the visited set**

  until **goal is found** or **agenda is empty**
- Return resulting path

# Check Yourself!




Consider a breadth-first search with dynamic programming, from $A$ to $I$. How many states are visited?

1. 2
2. 4
3. 6
4. 8
5. 10

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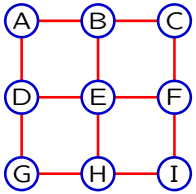


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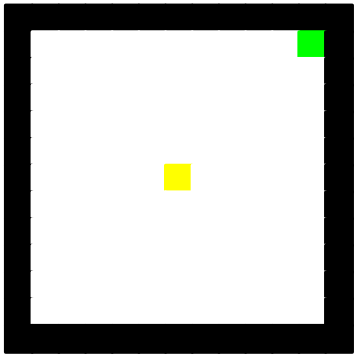
# Before we continue...

Properties of DFS/BFS

# Grid: BFS 1



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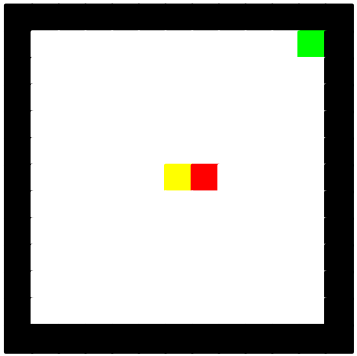

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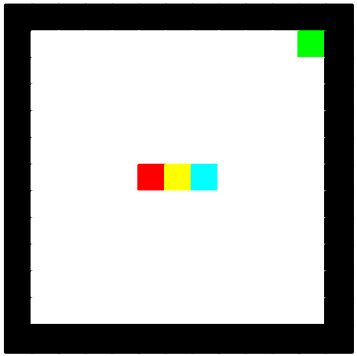

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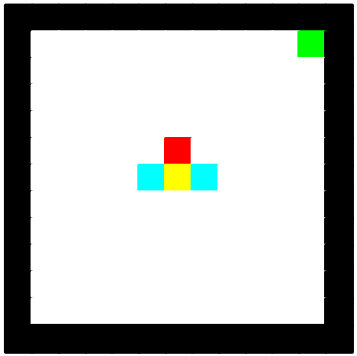

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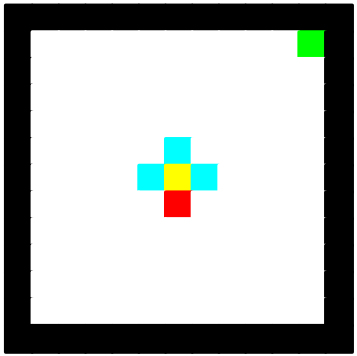

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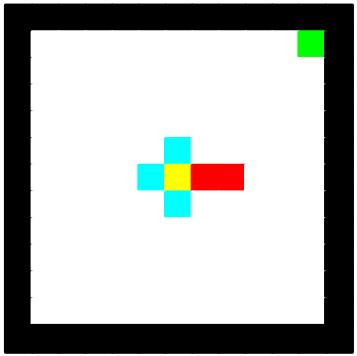

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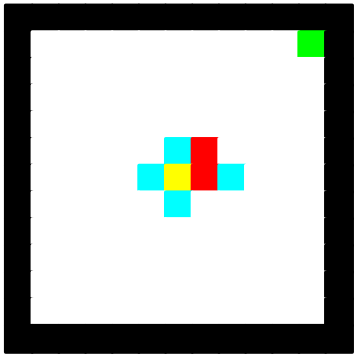

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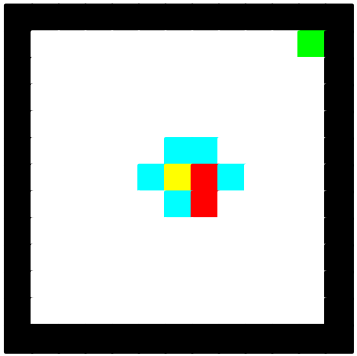

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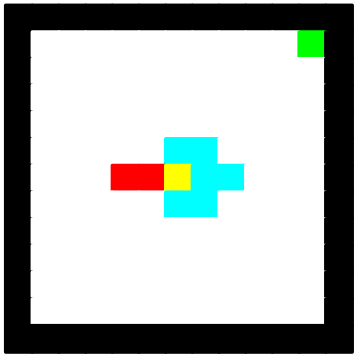

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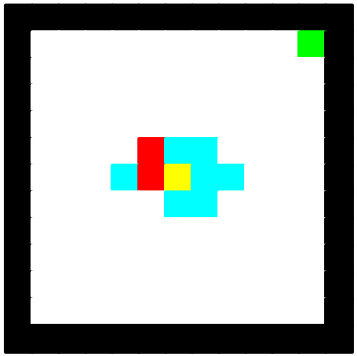

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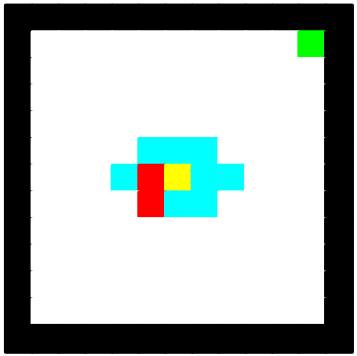

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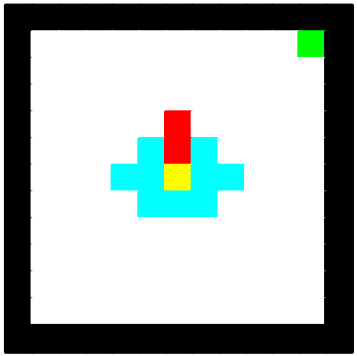

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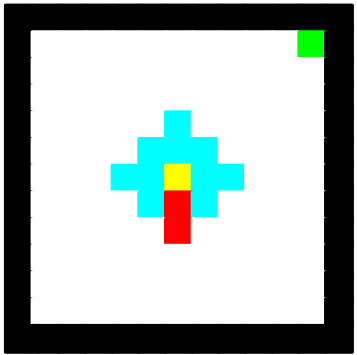

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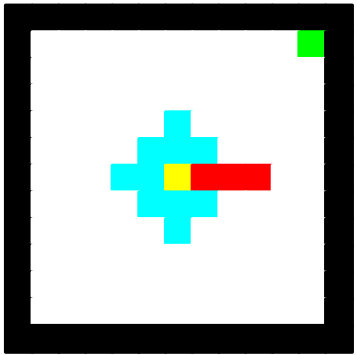

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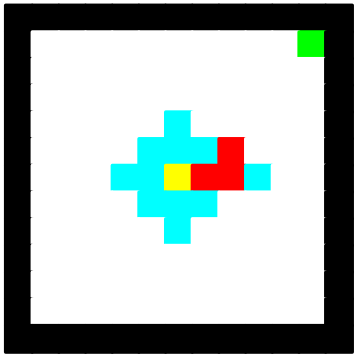

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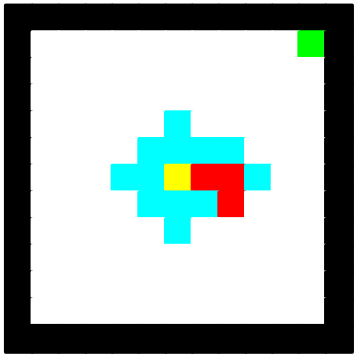

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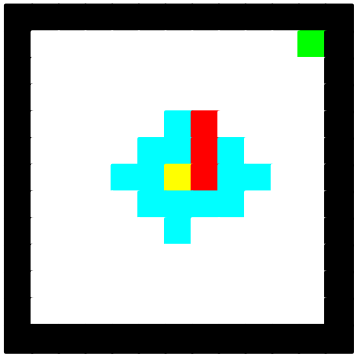

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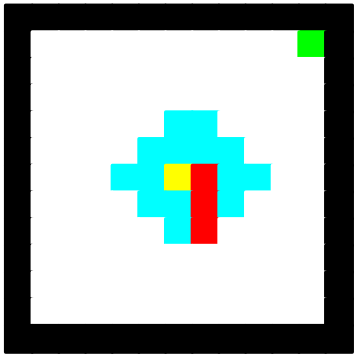

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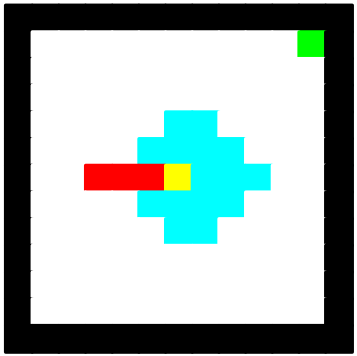

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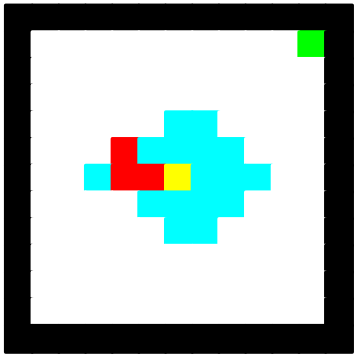

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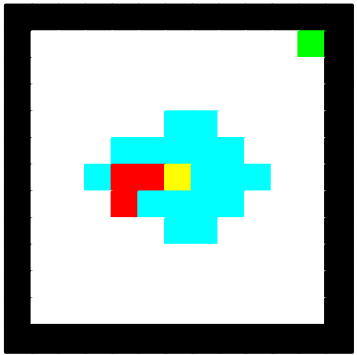

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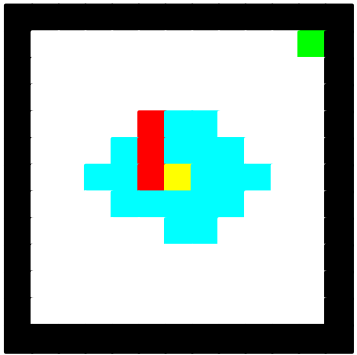

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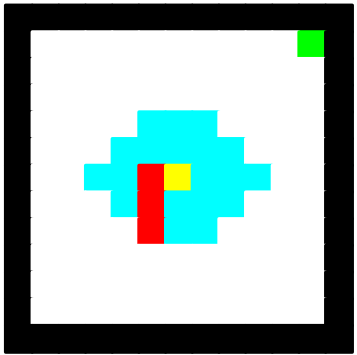

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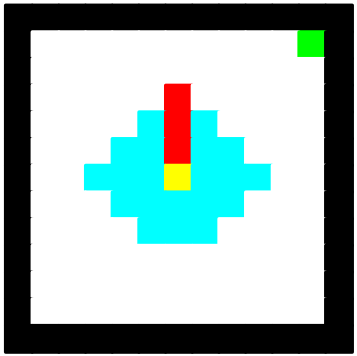

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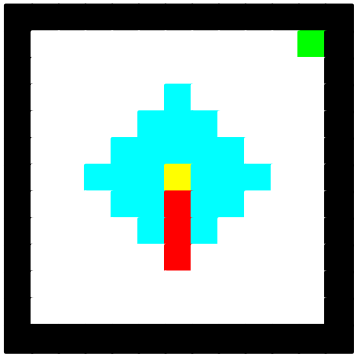

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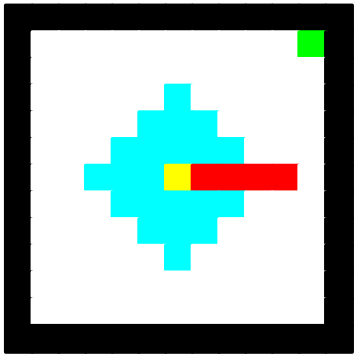

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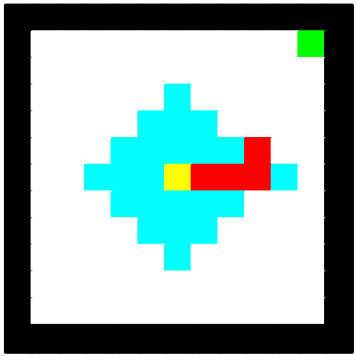

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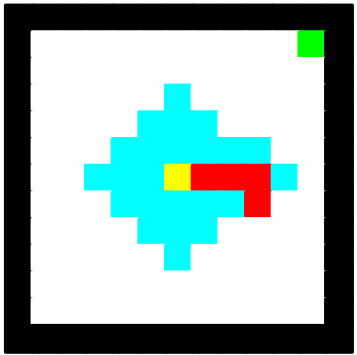

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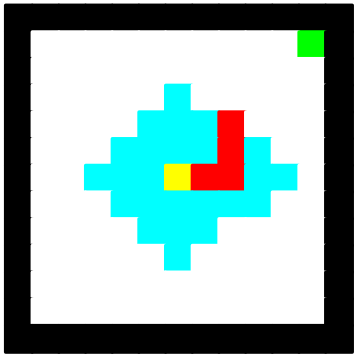

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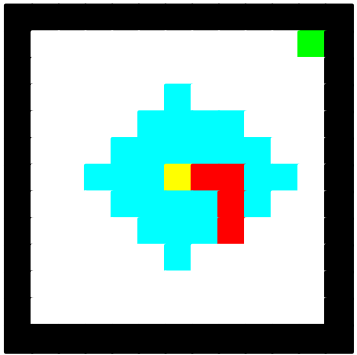

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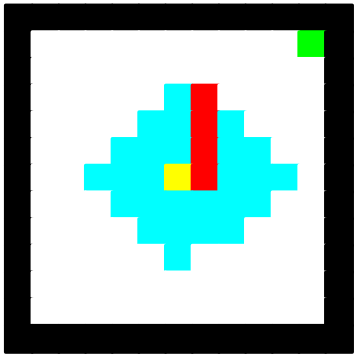

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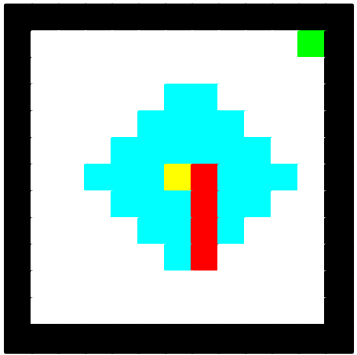

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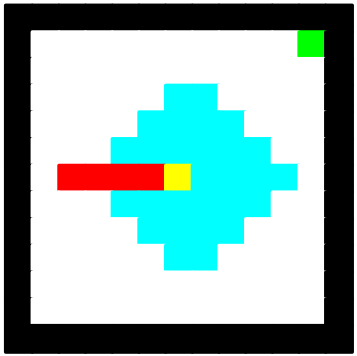

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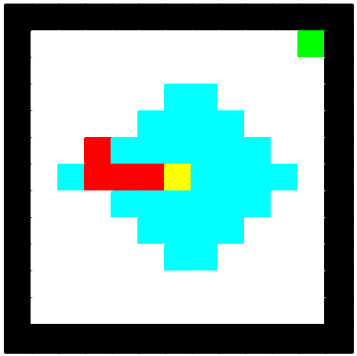

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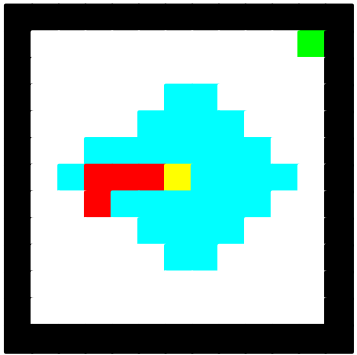

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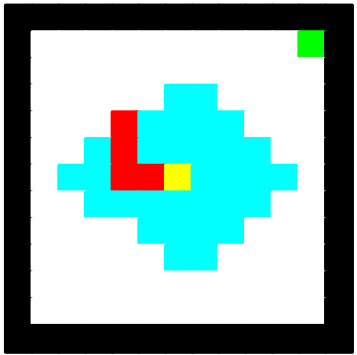

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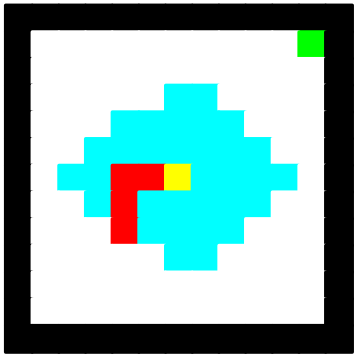

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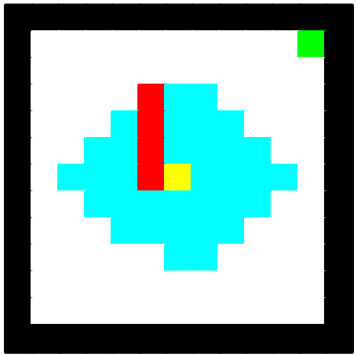

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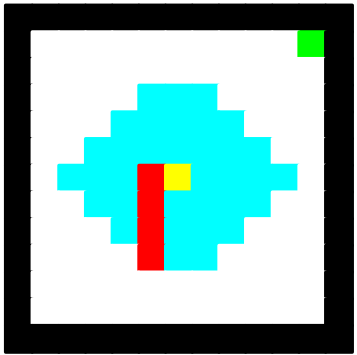

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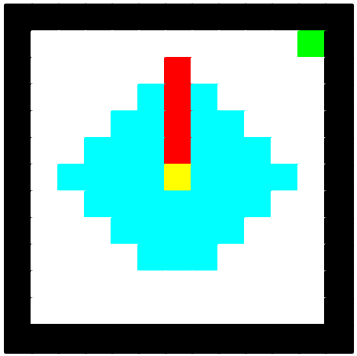

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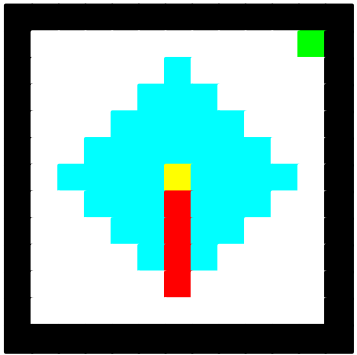

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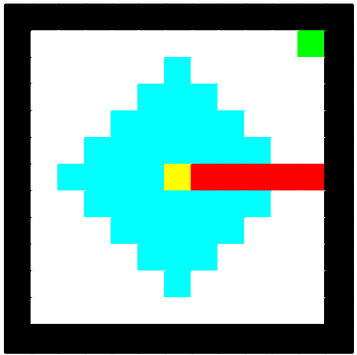

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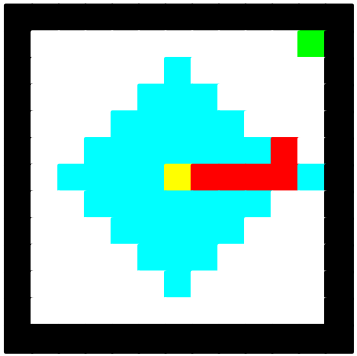

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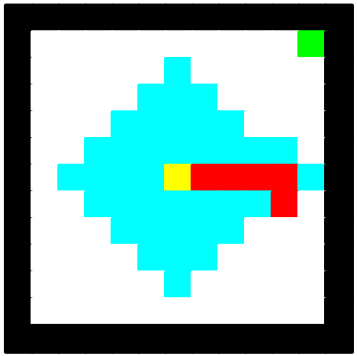

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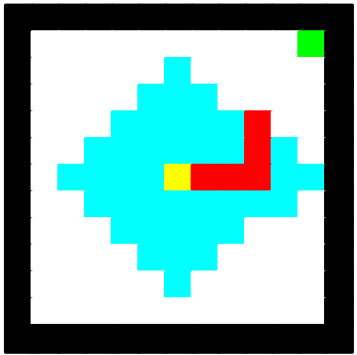

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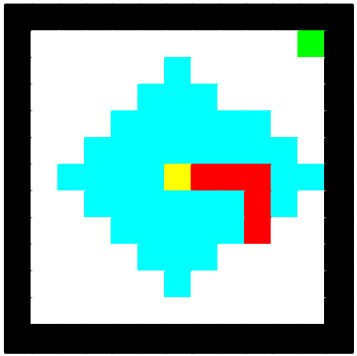

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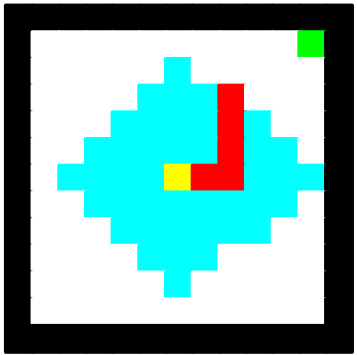

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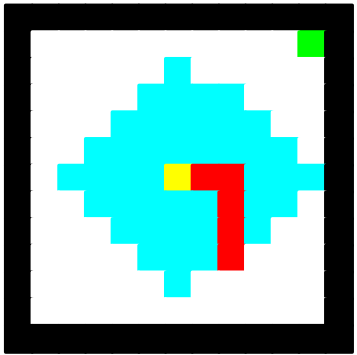

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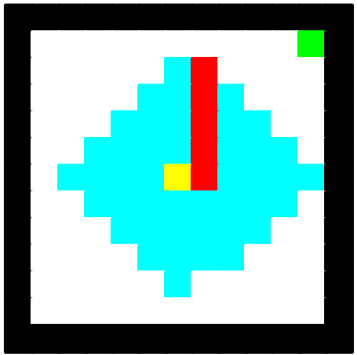

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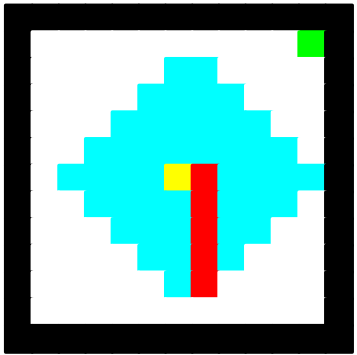

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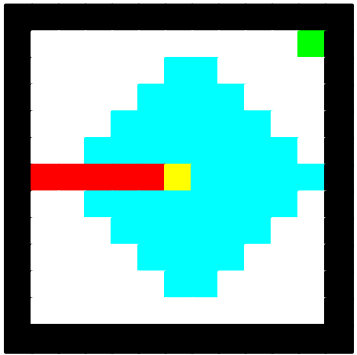

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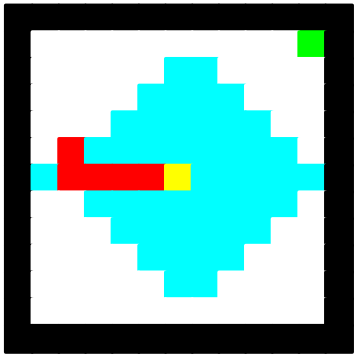

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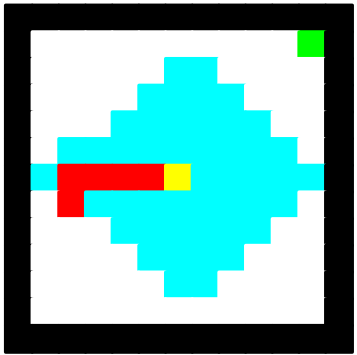

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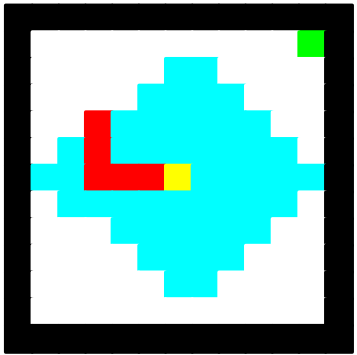

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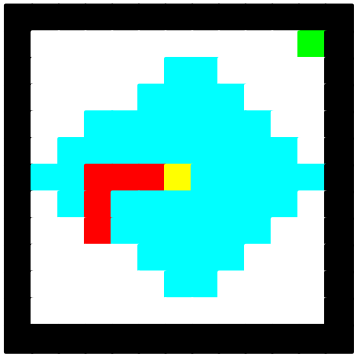

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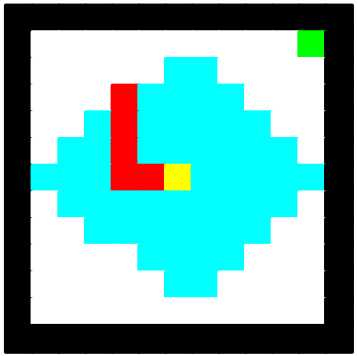

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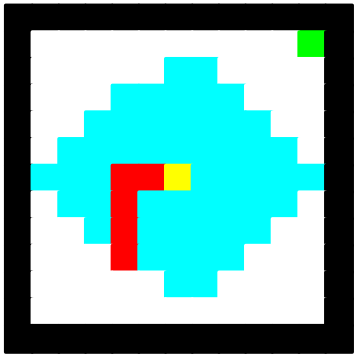

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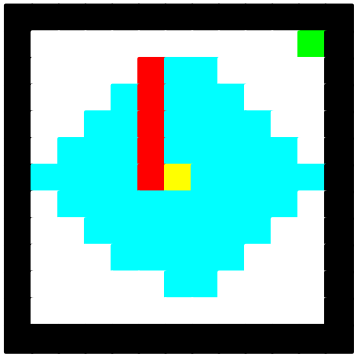

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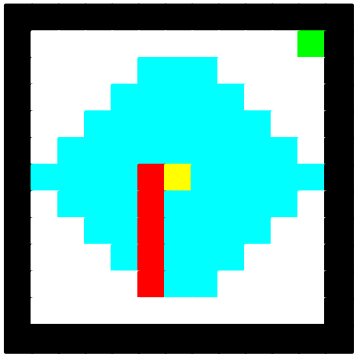

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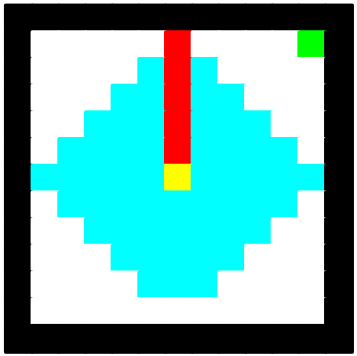

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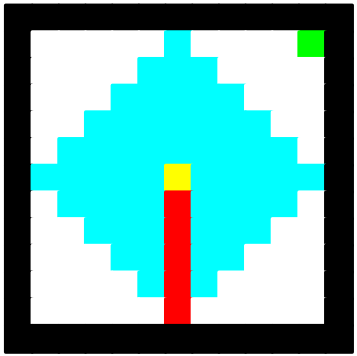

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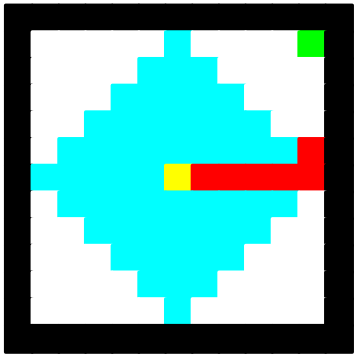

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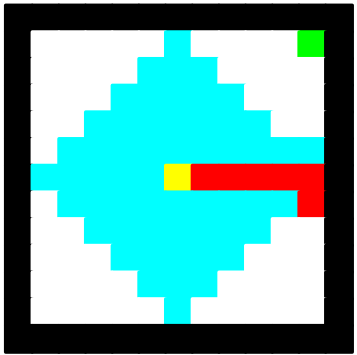

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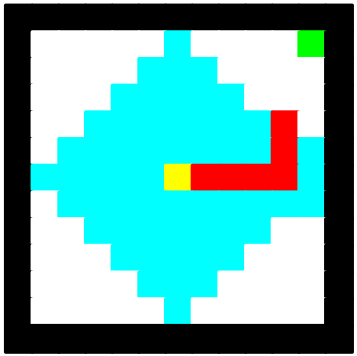

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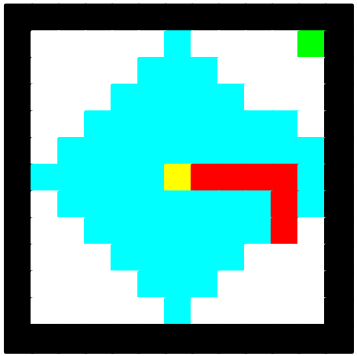

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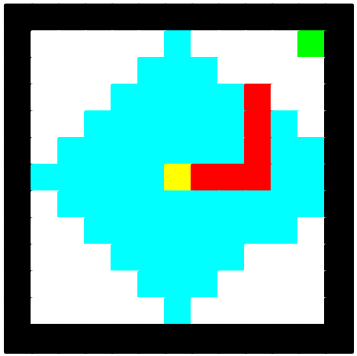

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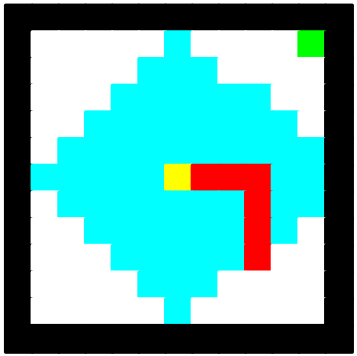

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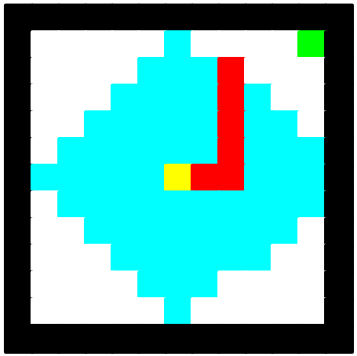

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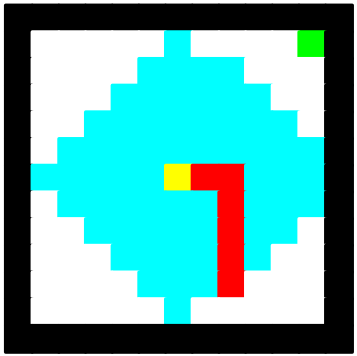

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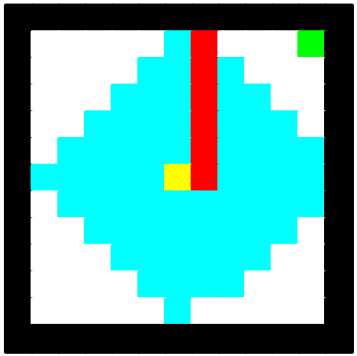

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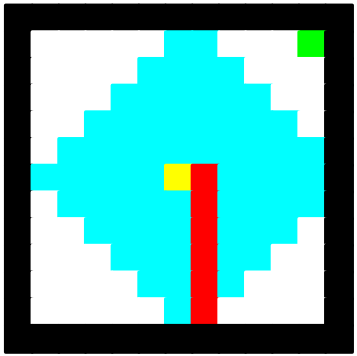

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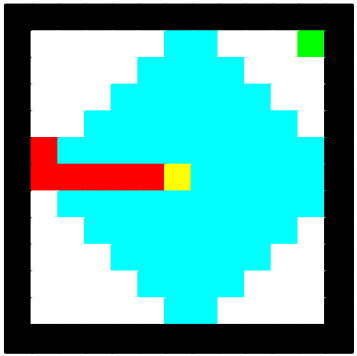

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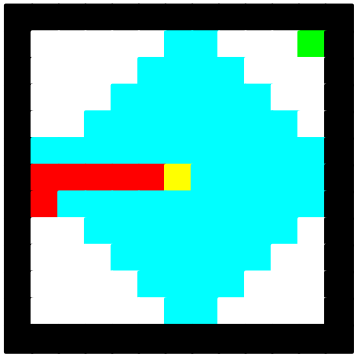

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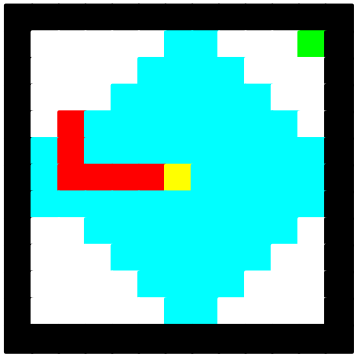

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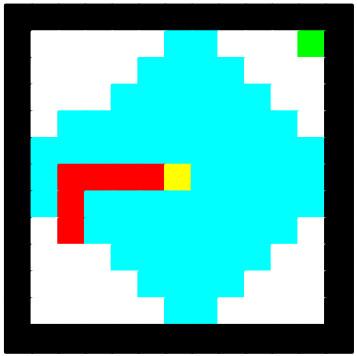

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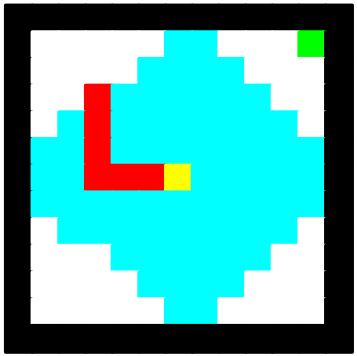

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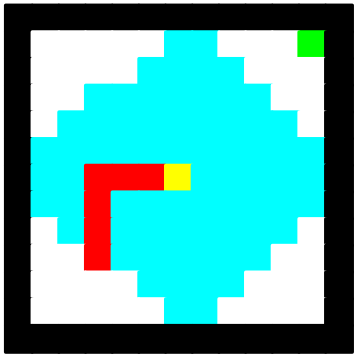

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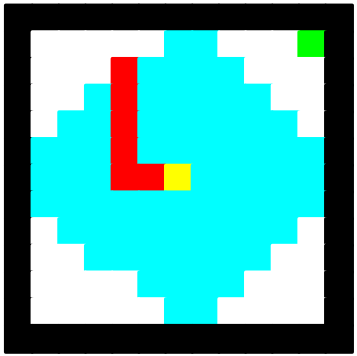

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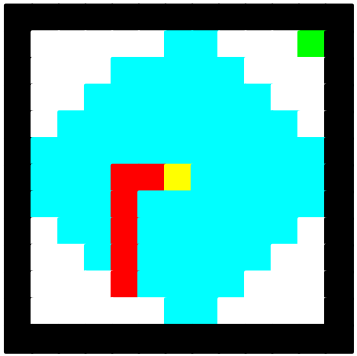

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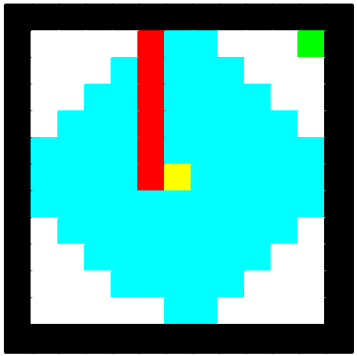

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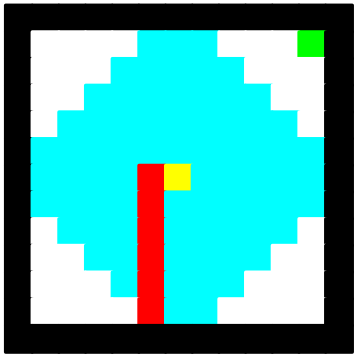

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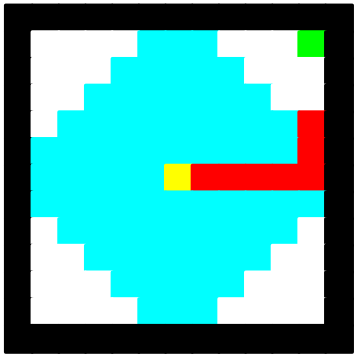

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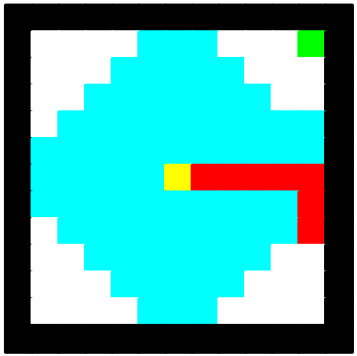

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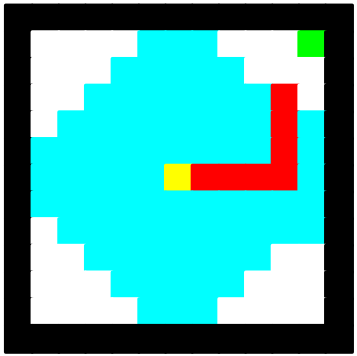

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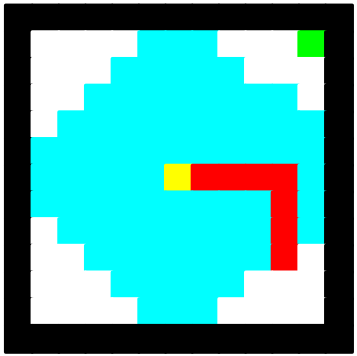

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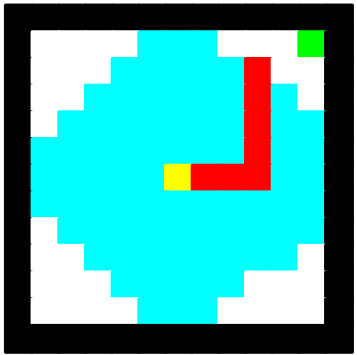

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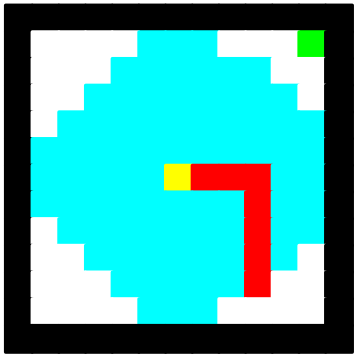

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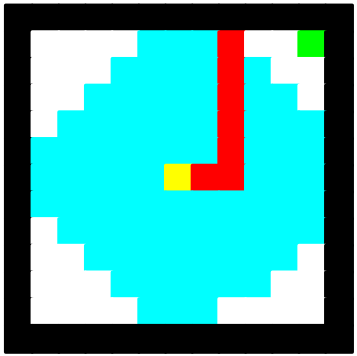

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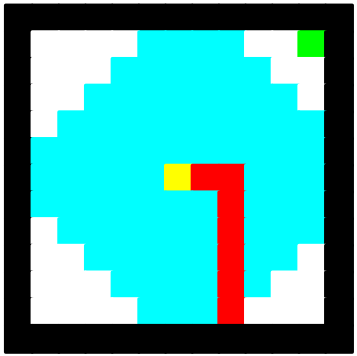

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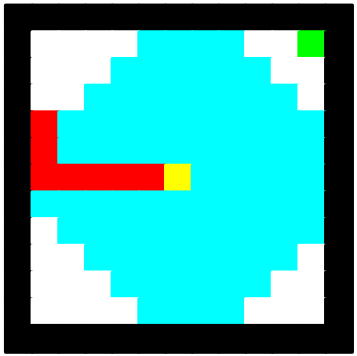

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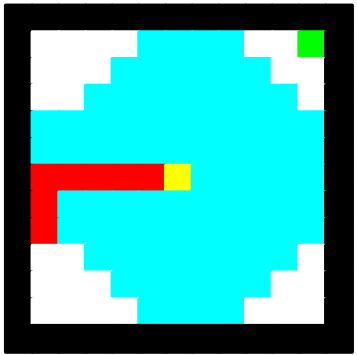

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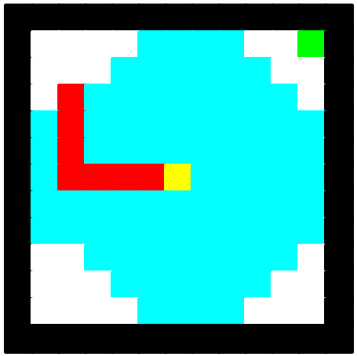

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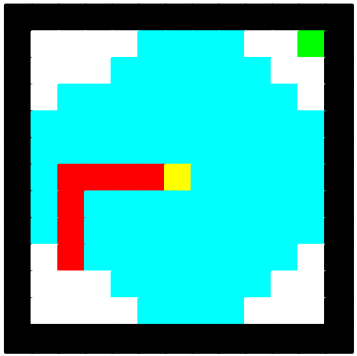

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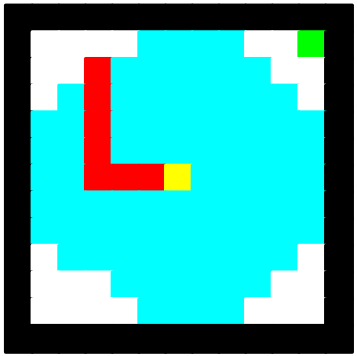

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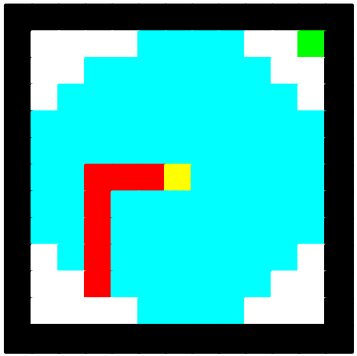

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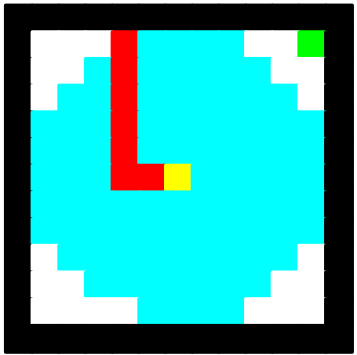

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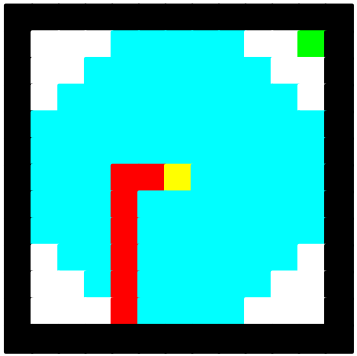

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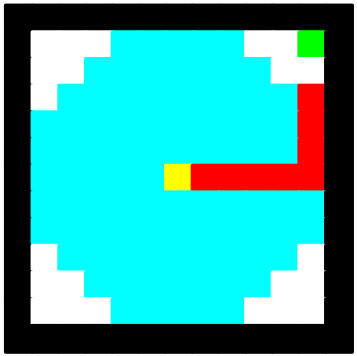

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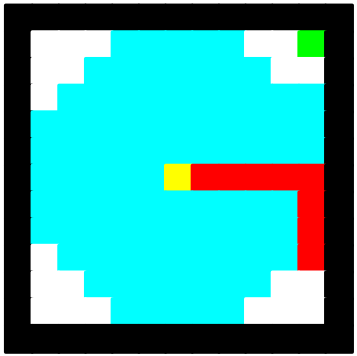

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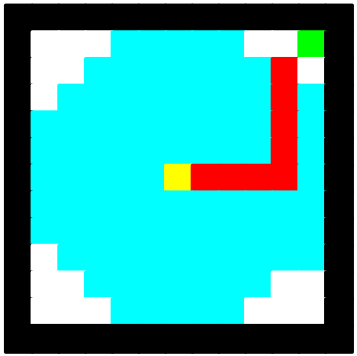

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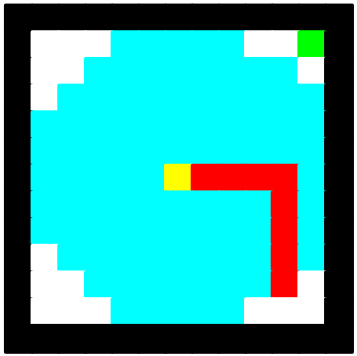

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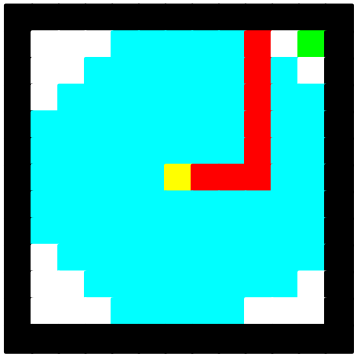

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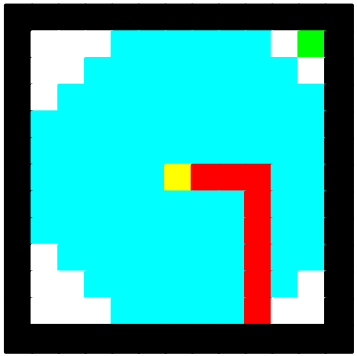

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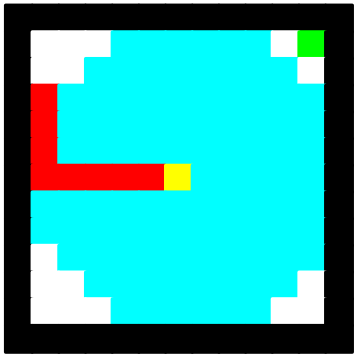

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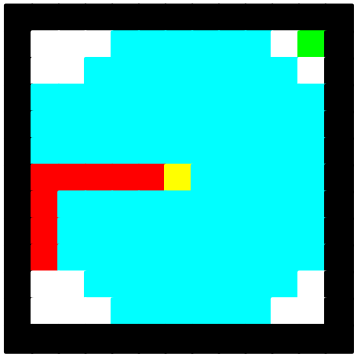

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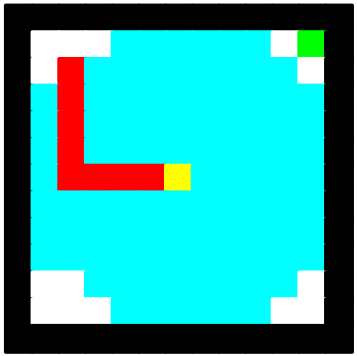

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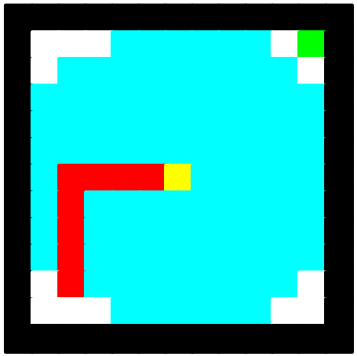

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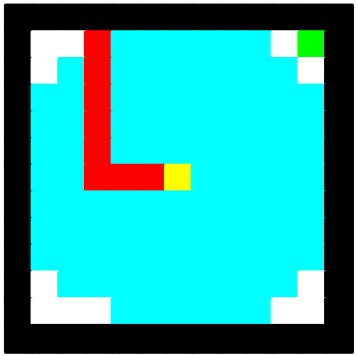

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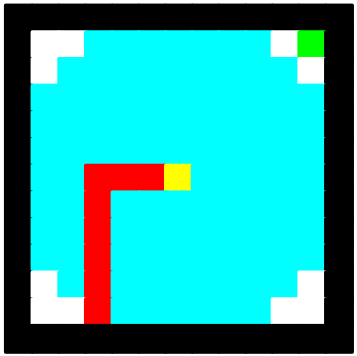

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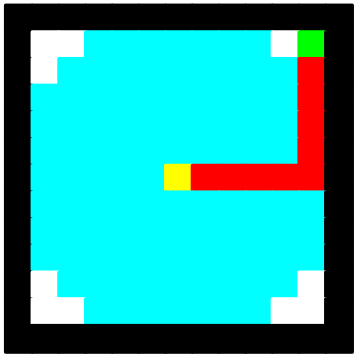

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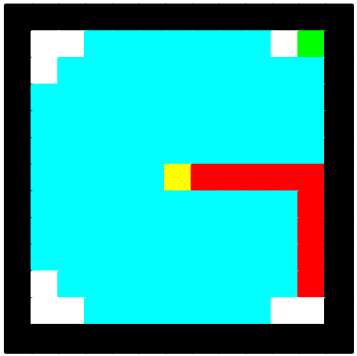

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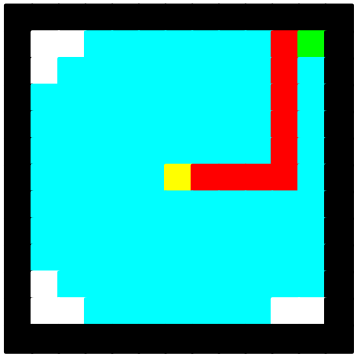

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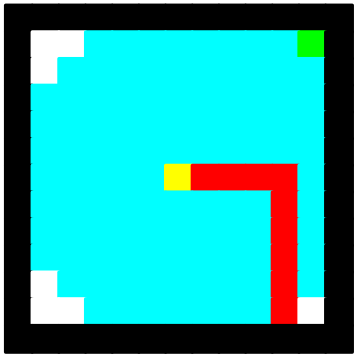

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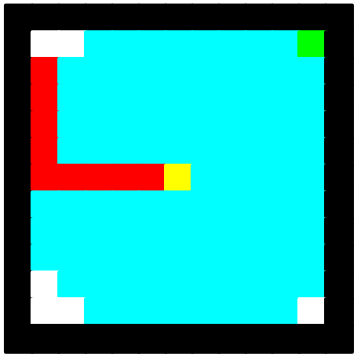

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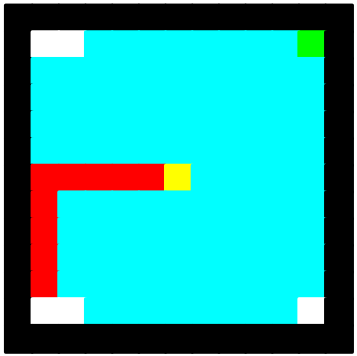

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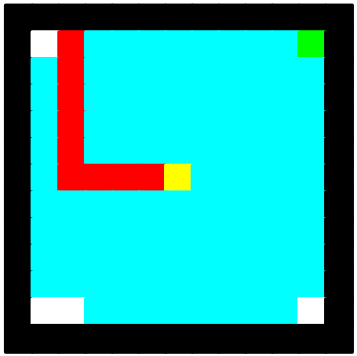

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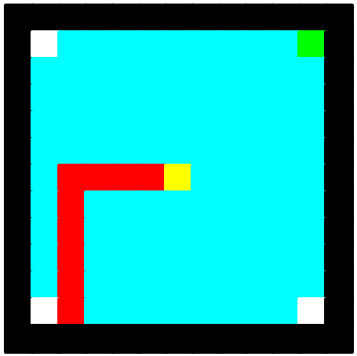

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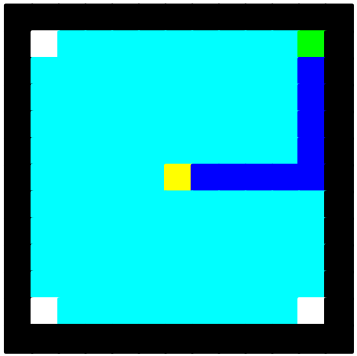

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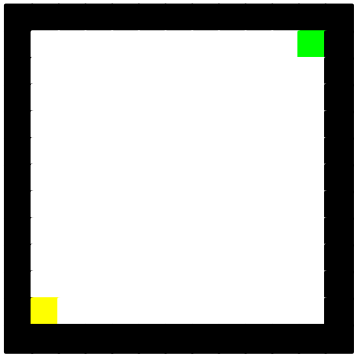

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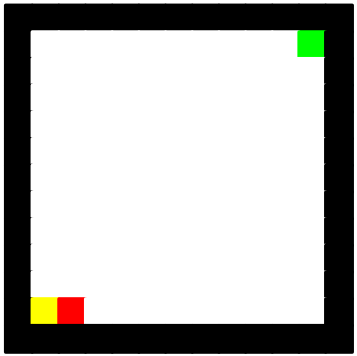

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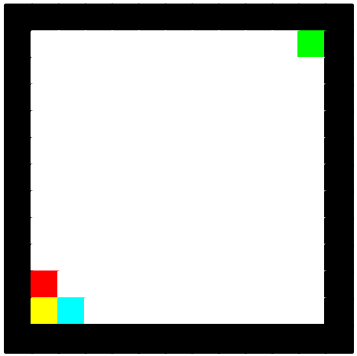

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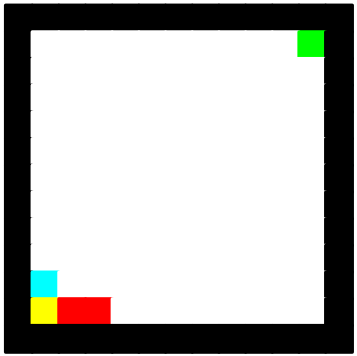

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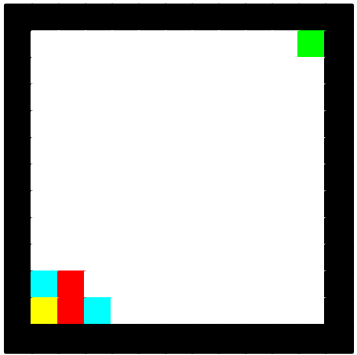

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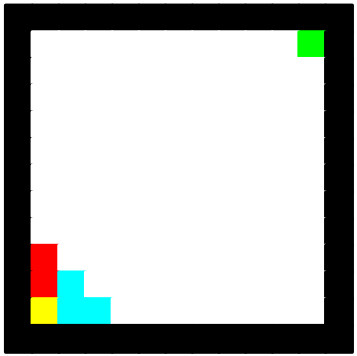

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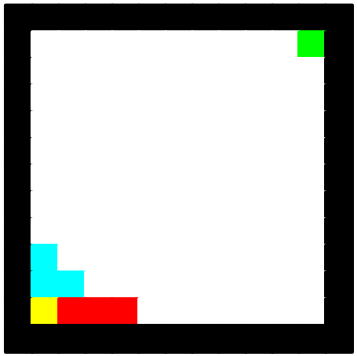

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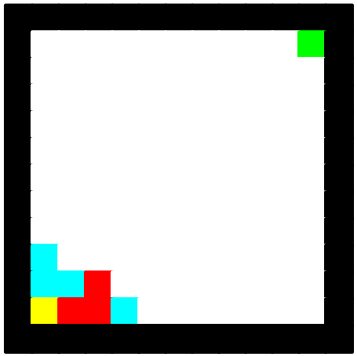

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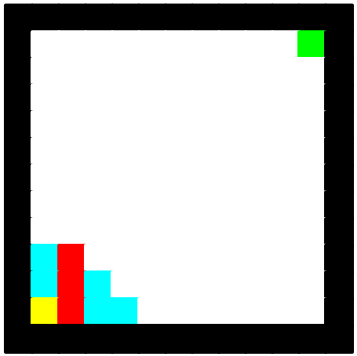

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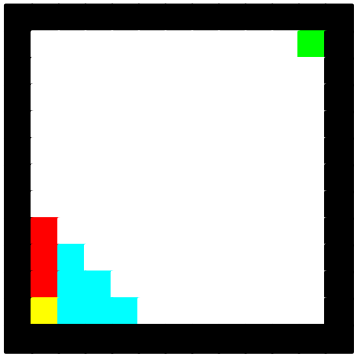

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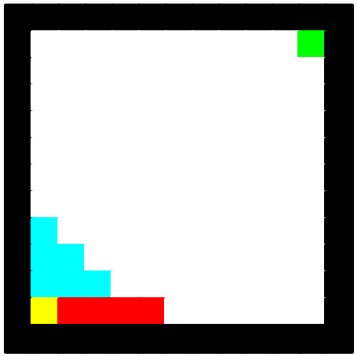

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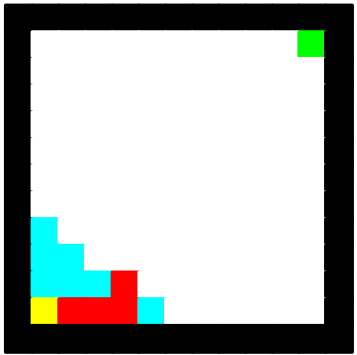

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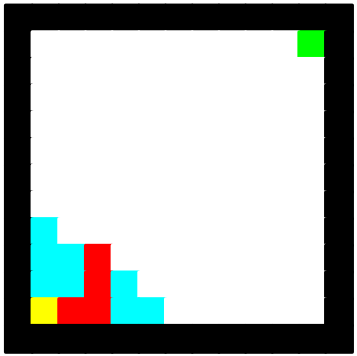

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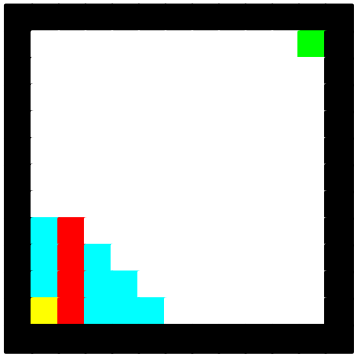

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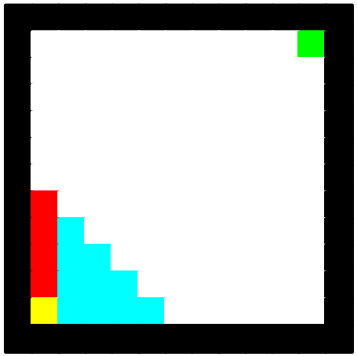

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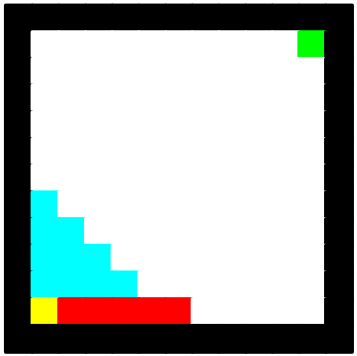

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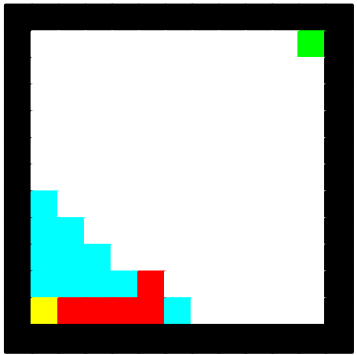

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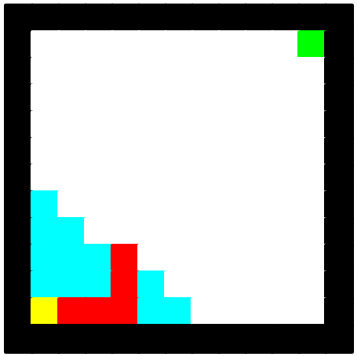

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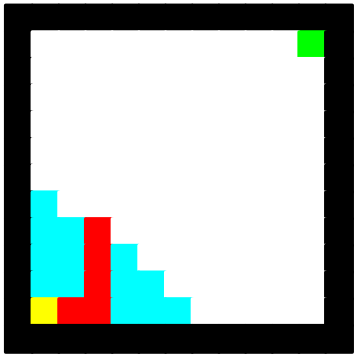

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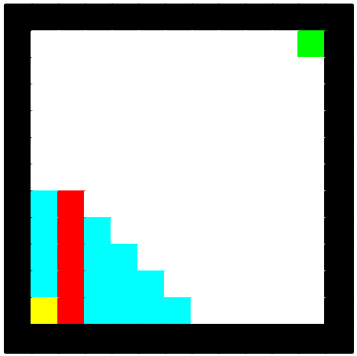

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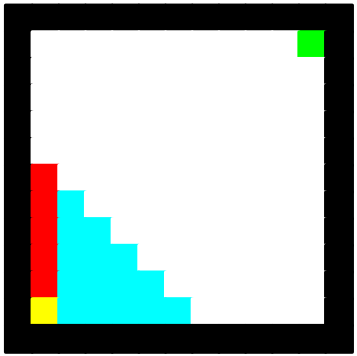

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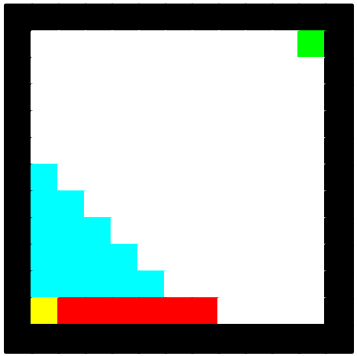

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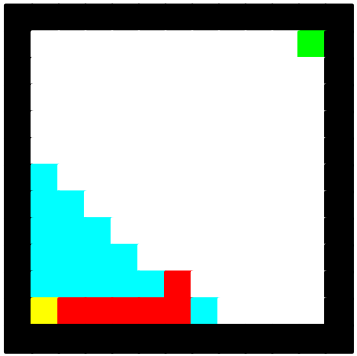

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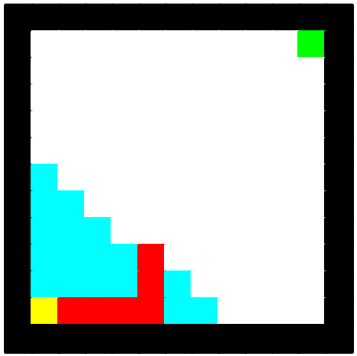

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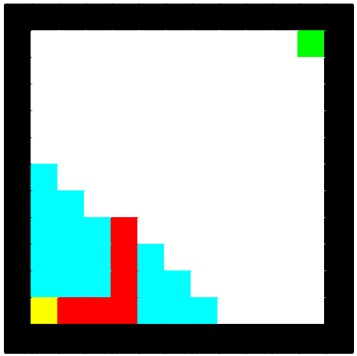

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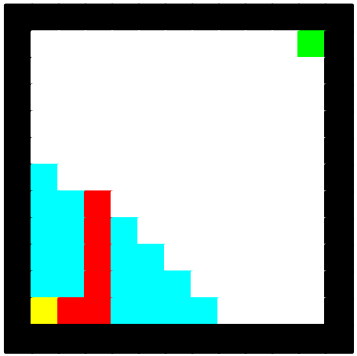

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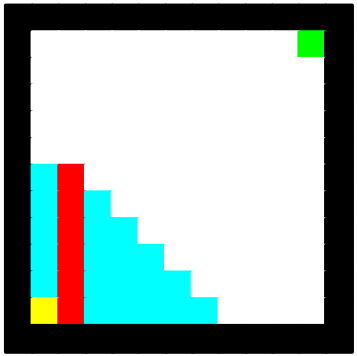

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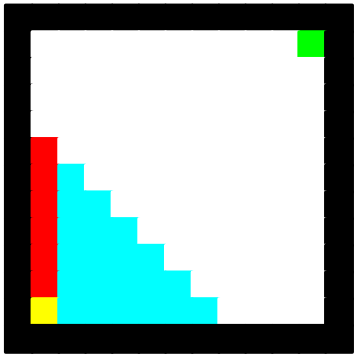

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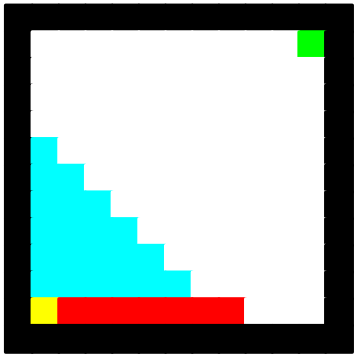

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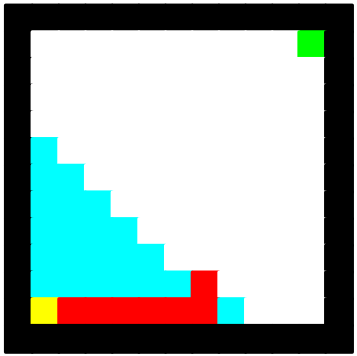

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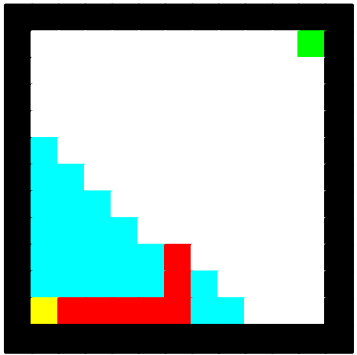

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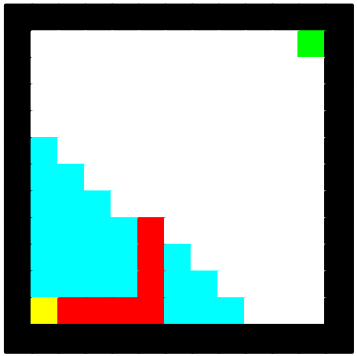

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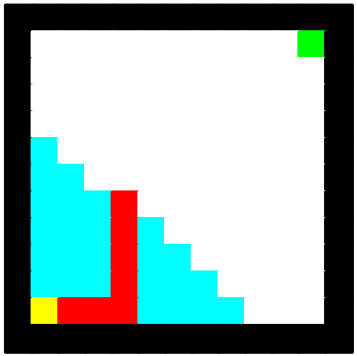

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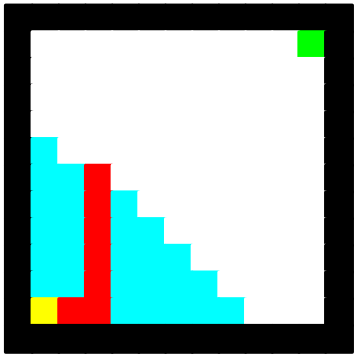

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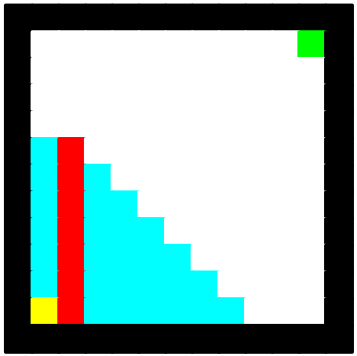

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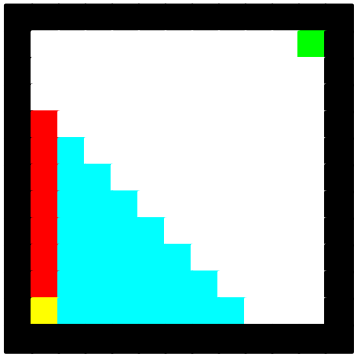

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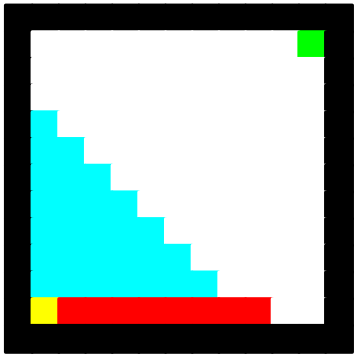

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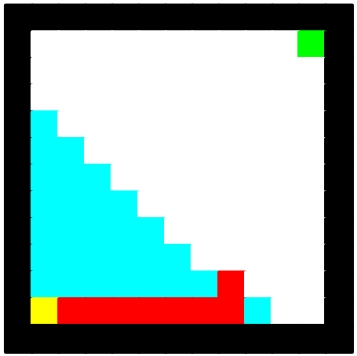

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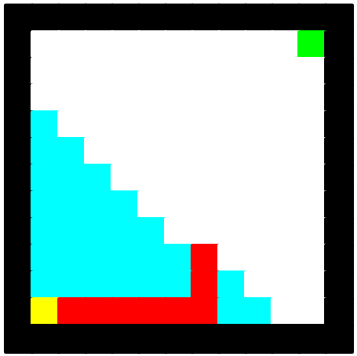

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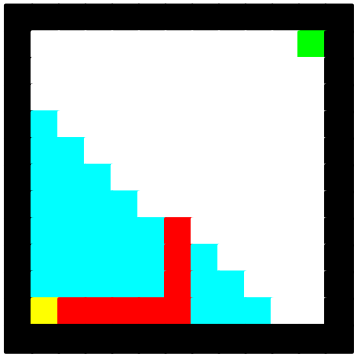

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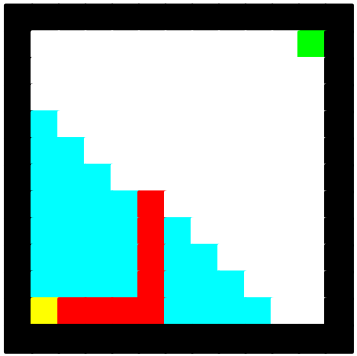

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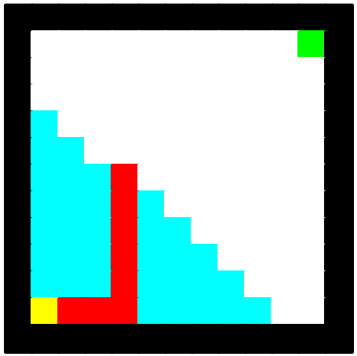

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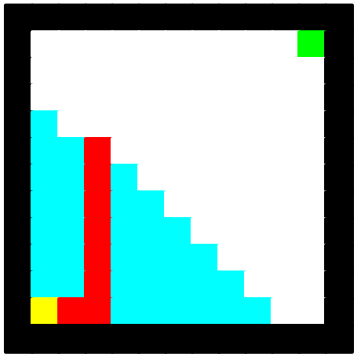

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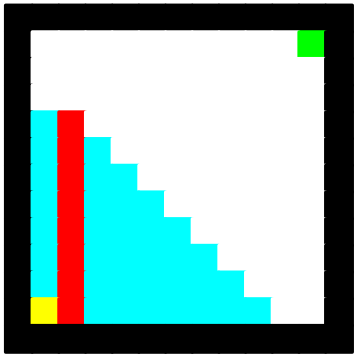

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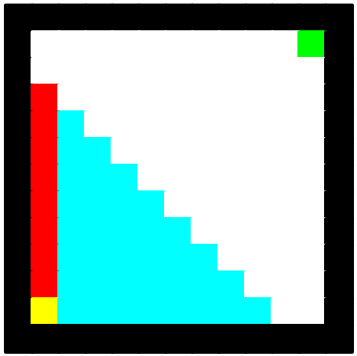

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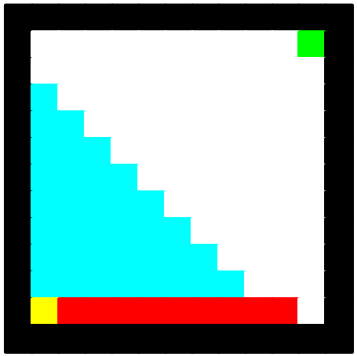

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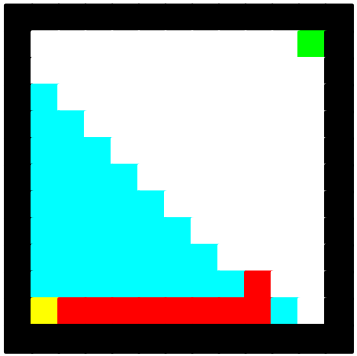

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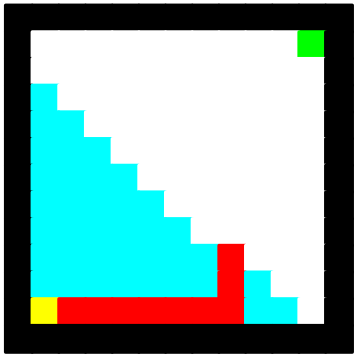

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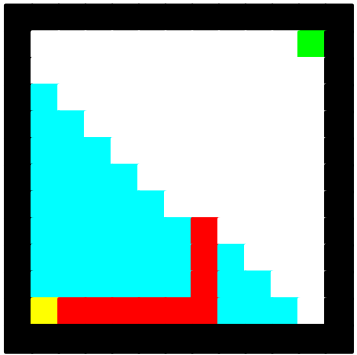

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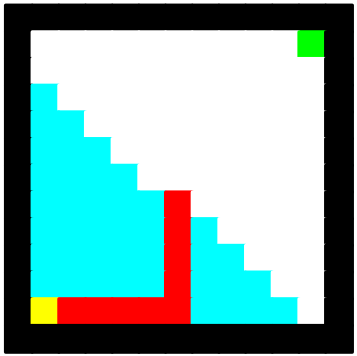

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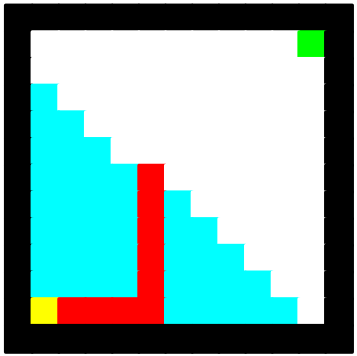

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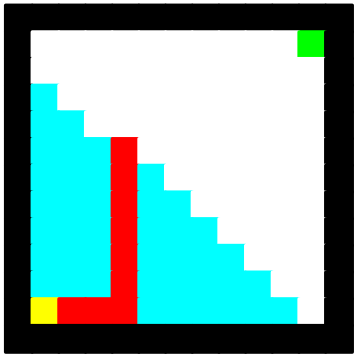

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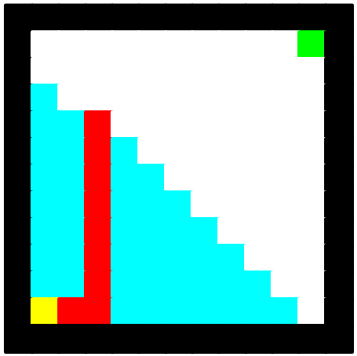

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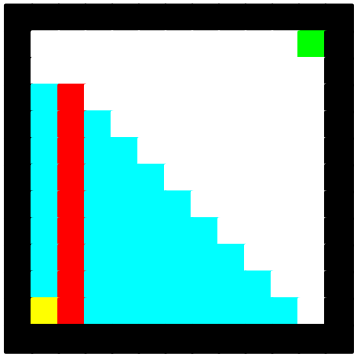

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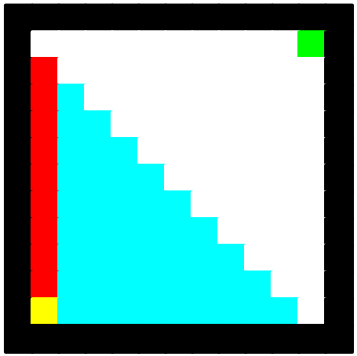

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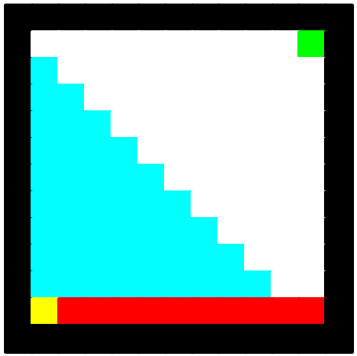

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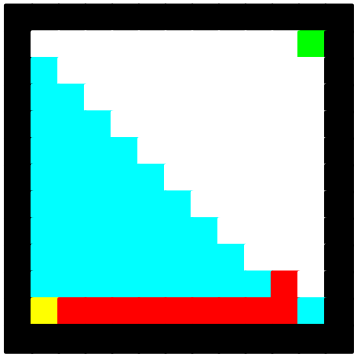

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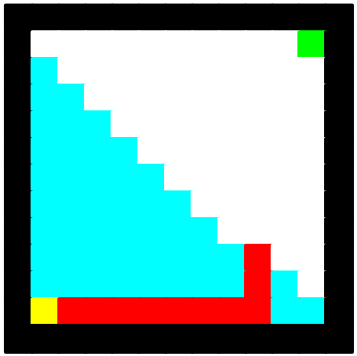

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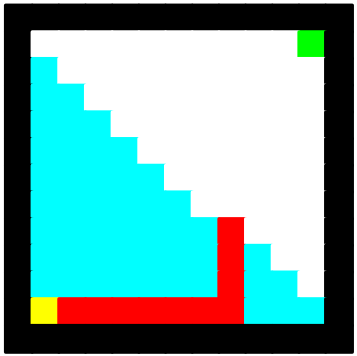

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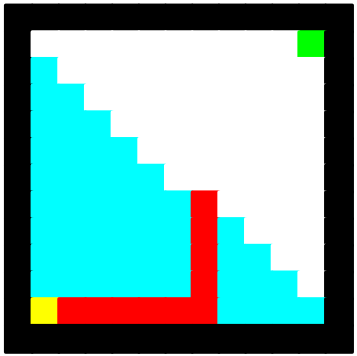

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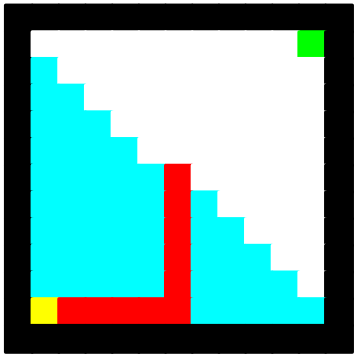

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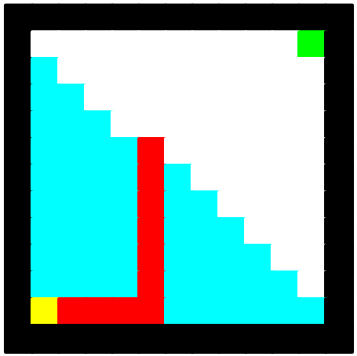

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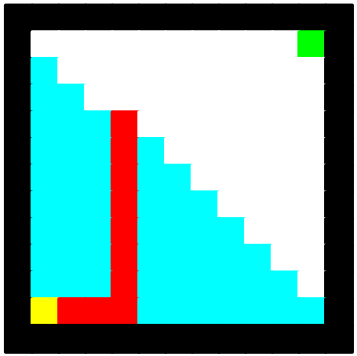

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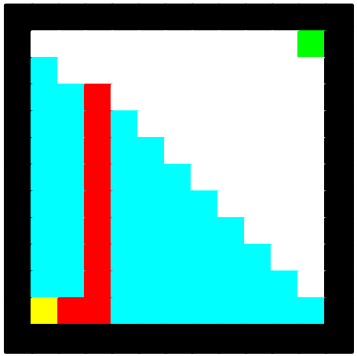

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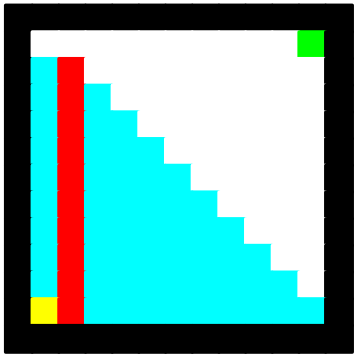

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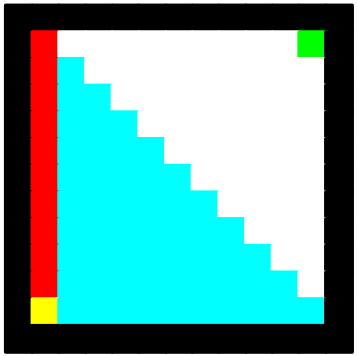

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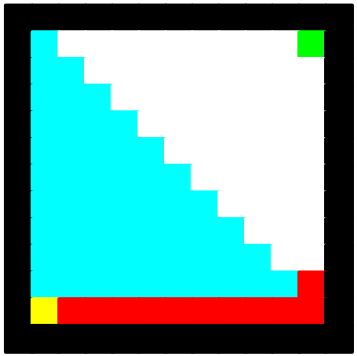

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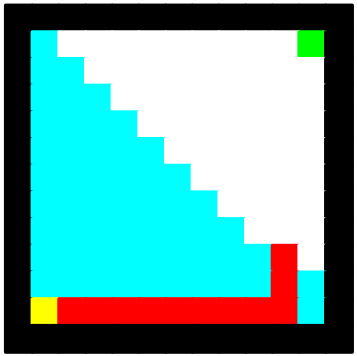

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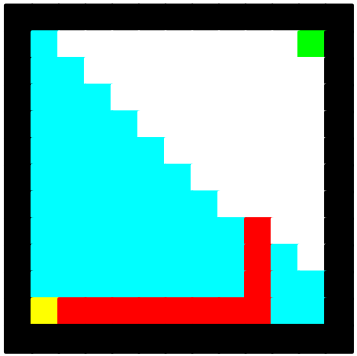

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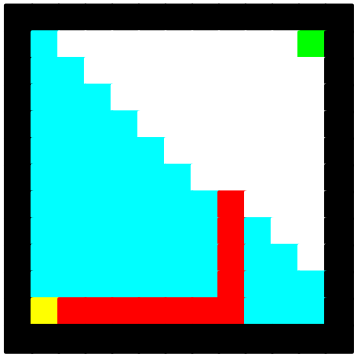

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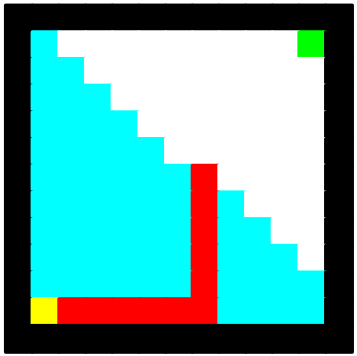

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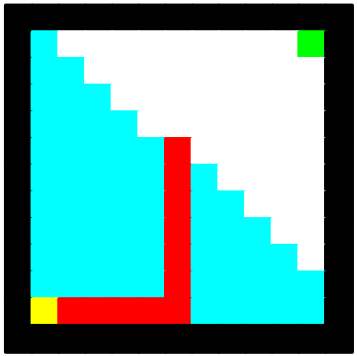

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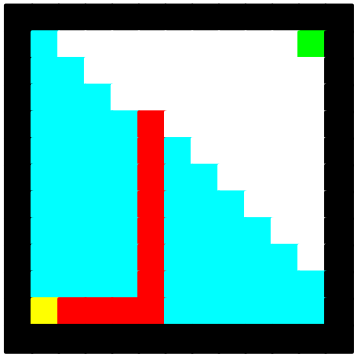

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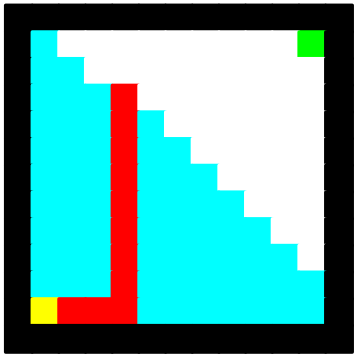

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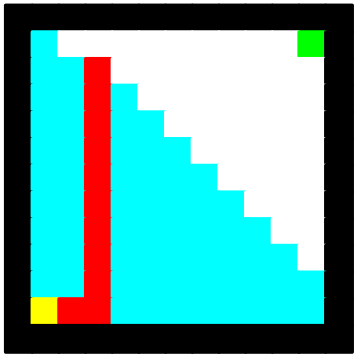

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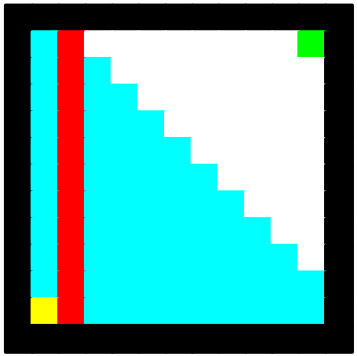

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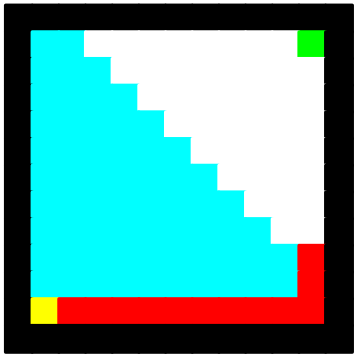

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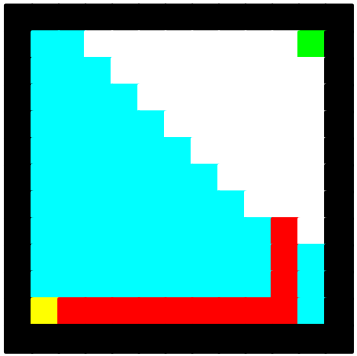

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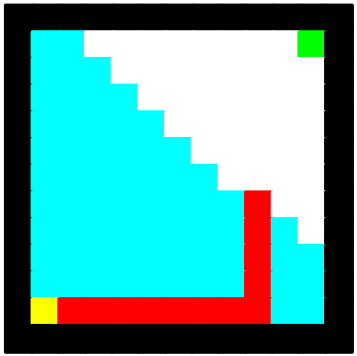

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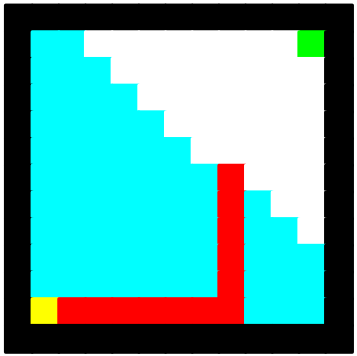

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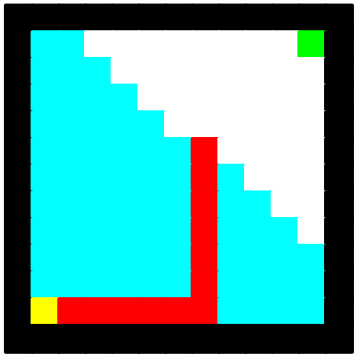

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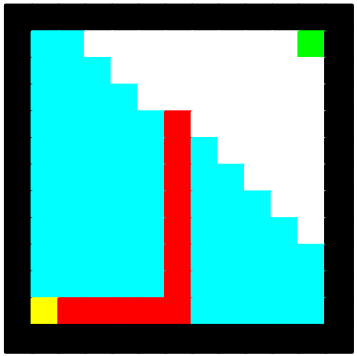

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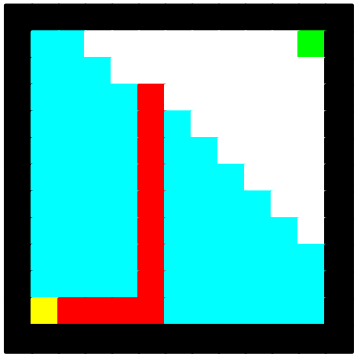

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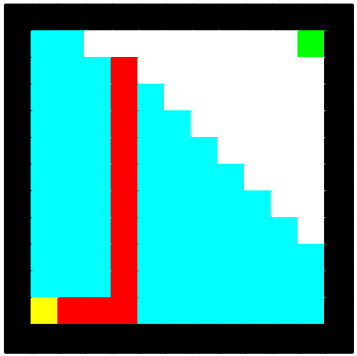

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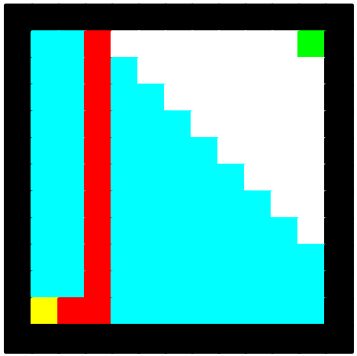

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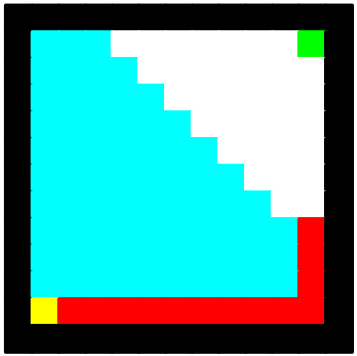

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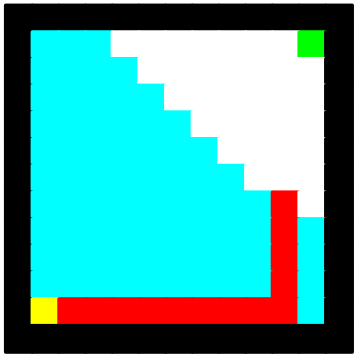

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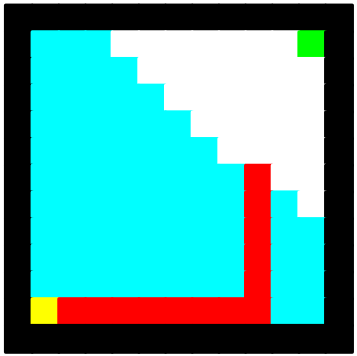

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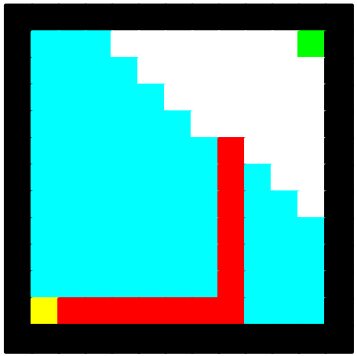

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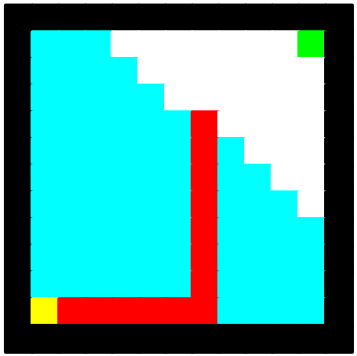

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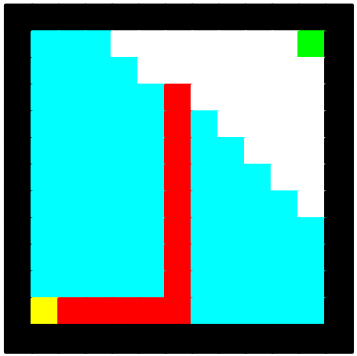

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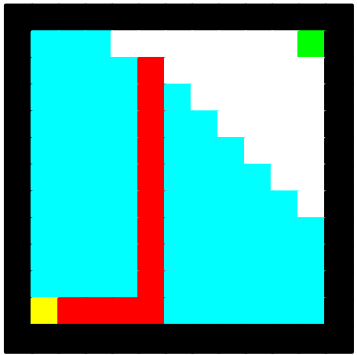

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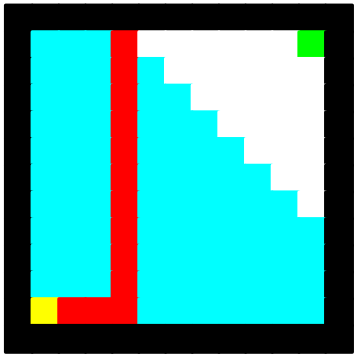

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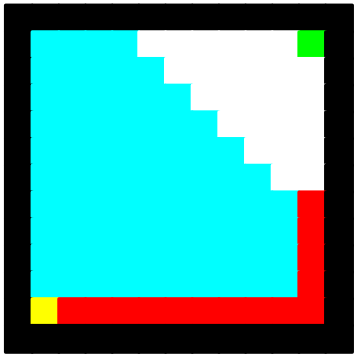

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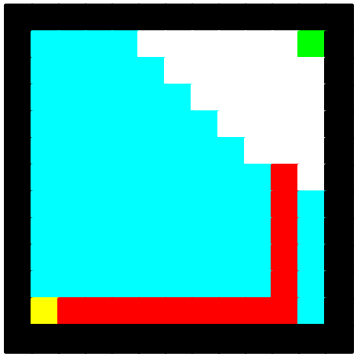

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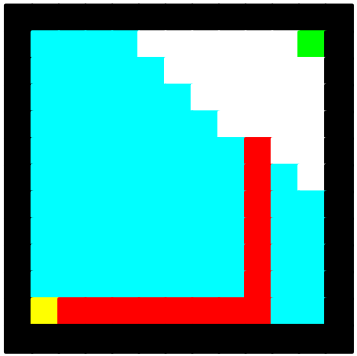

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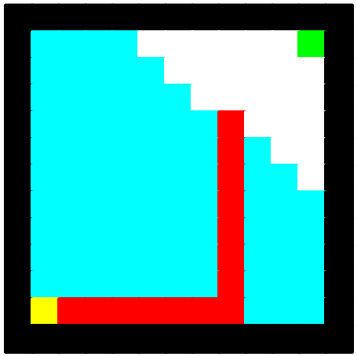

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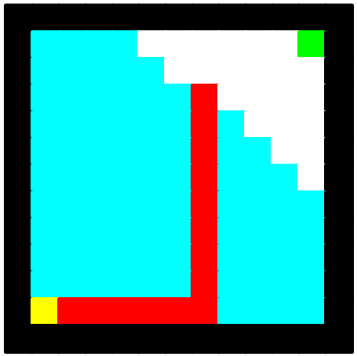

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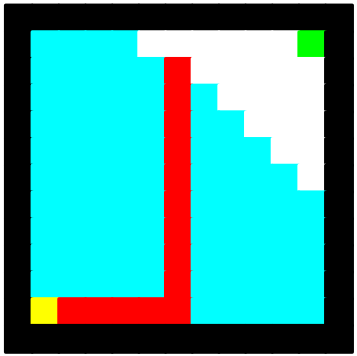

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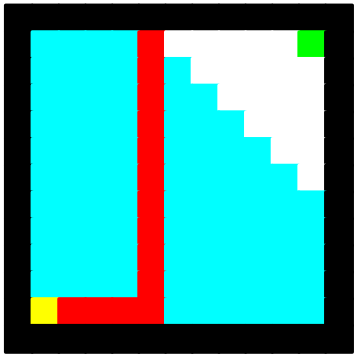

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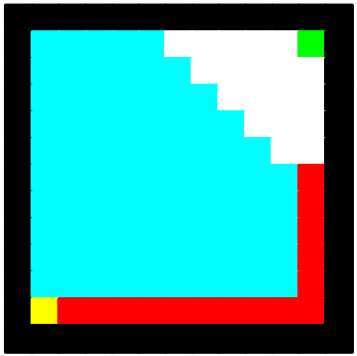

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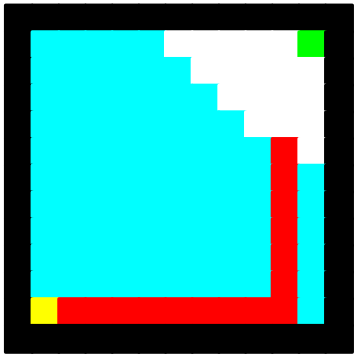

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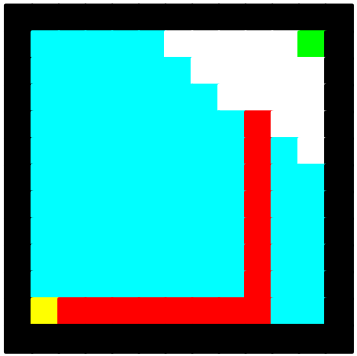

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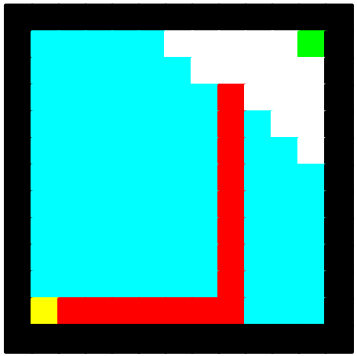

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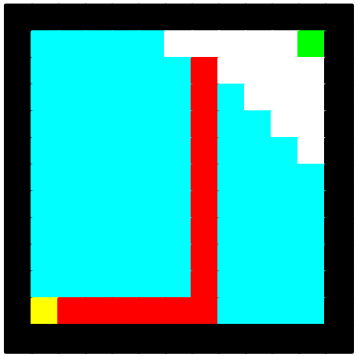

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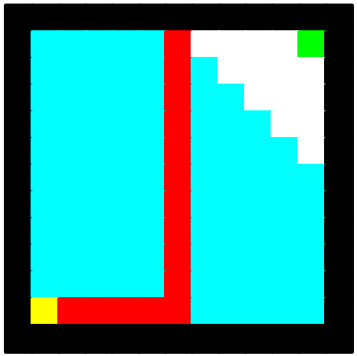

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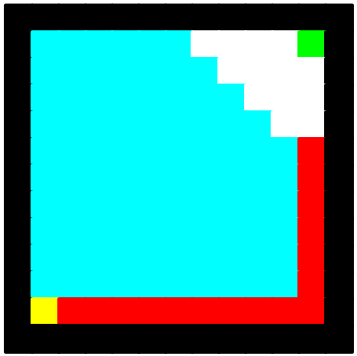

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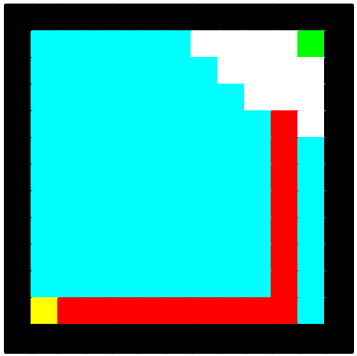

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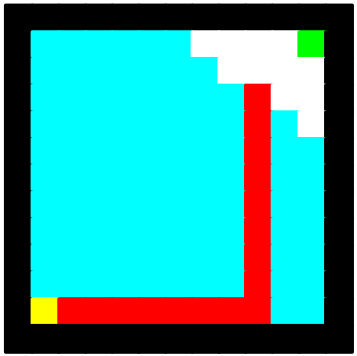

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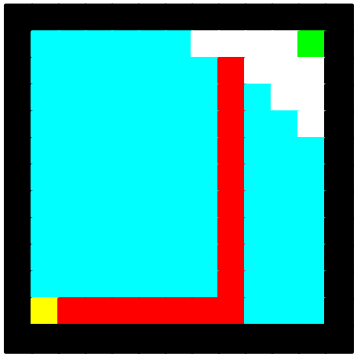

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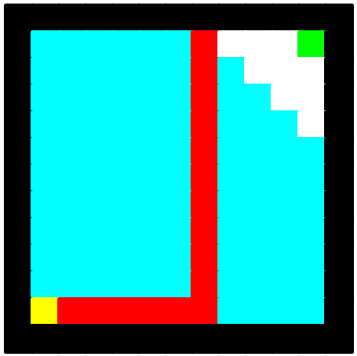

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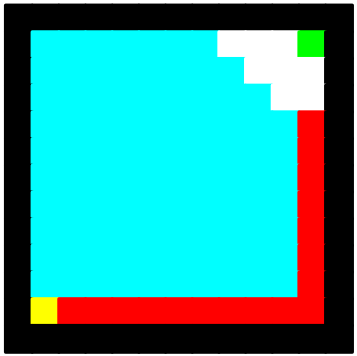

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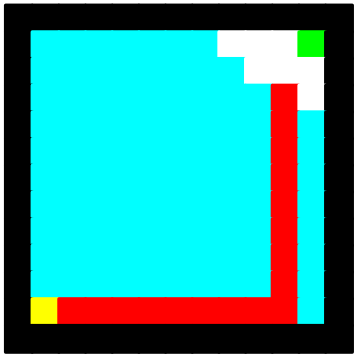

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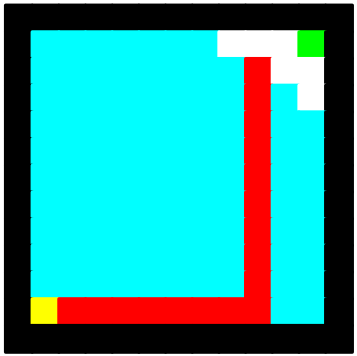

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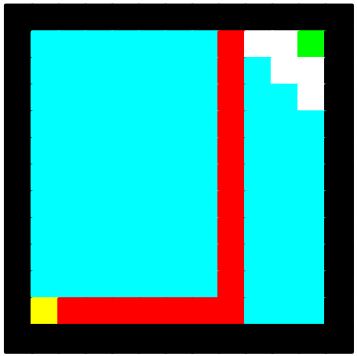

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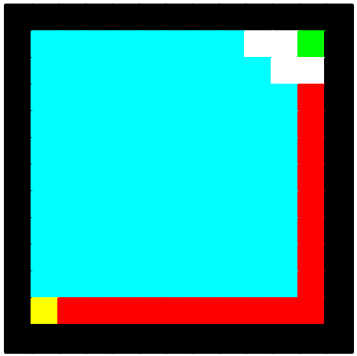

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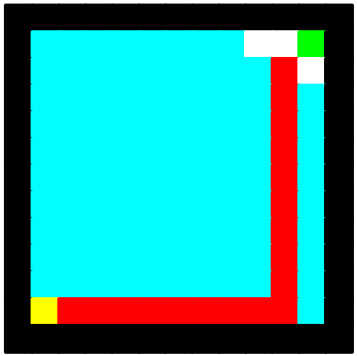

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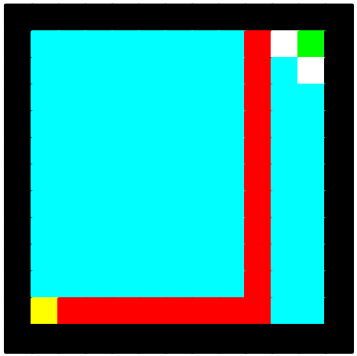

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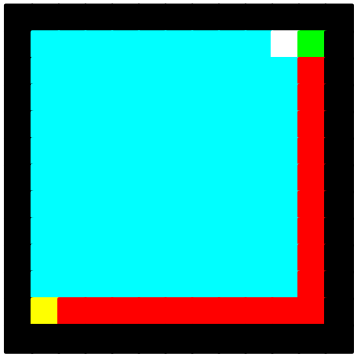

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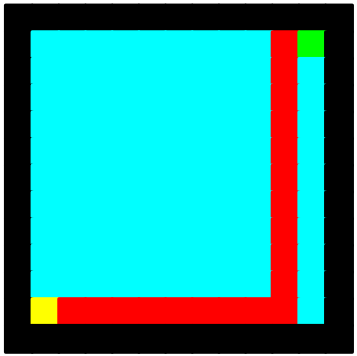

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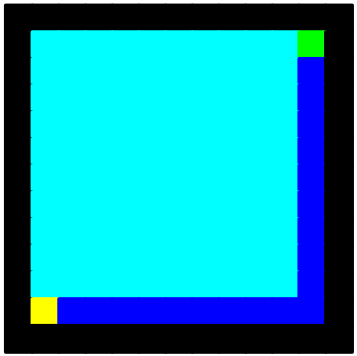

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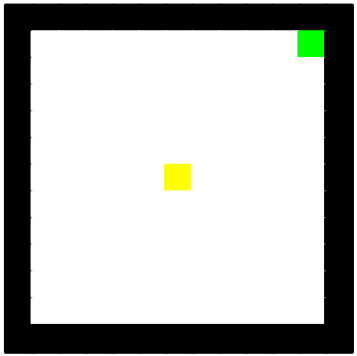

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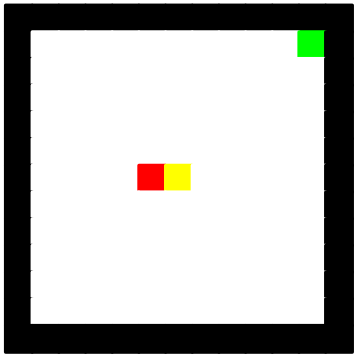

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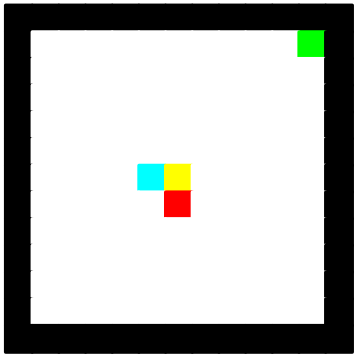

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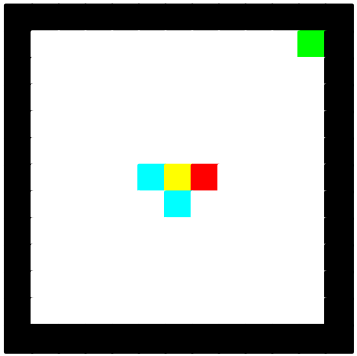

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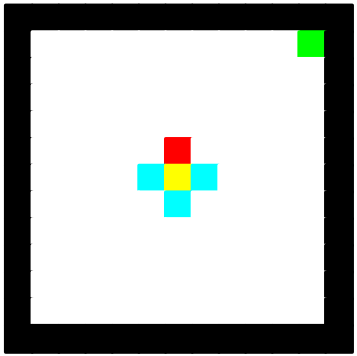

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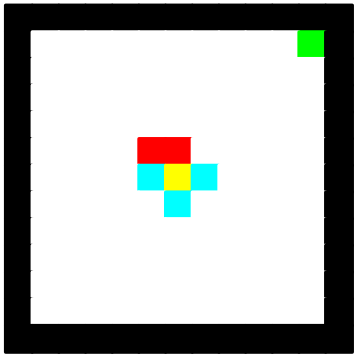

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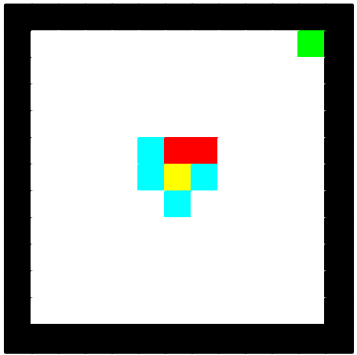

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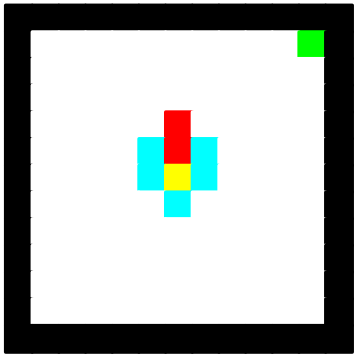

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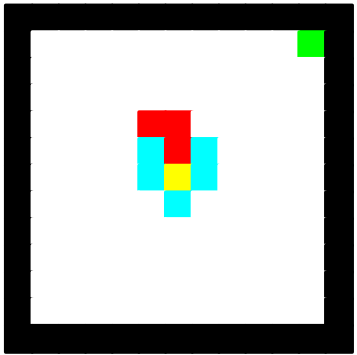

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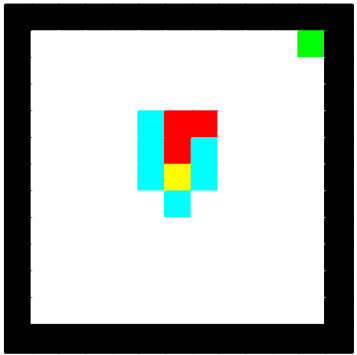

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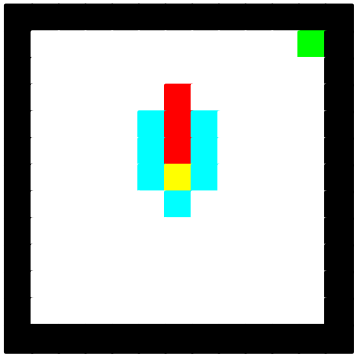

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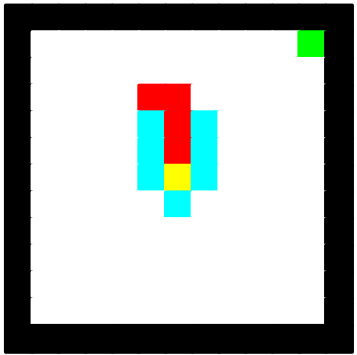

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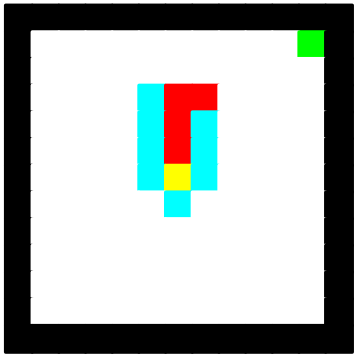

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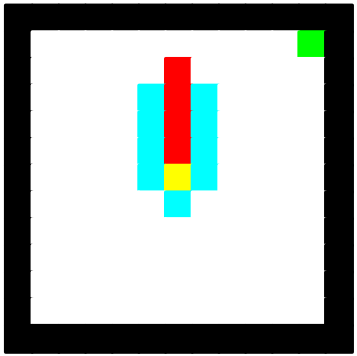

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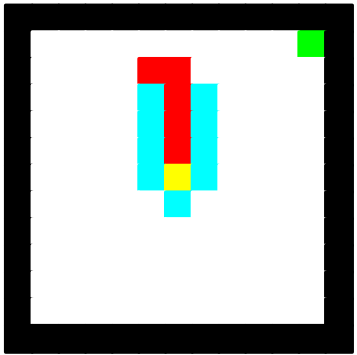

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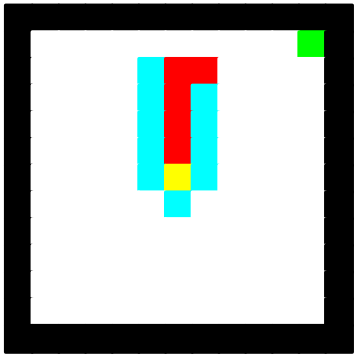

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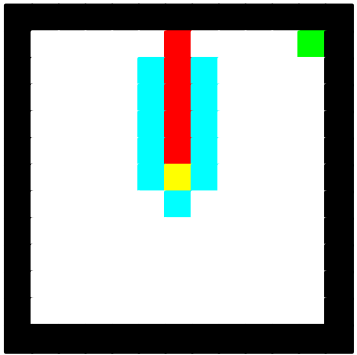

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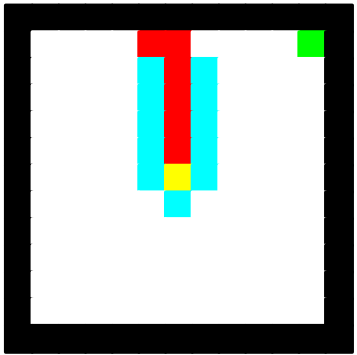

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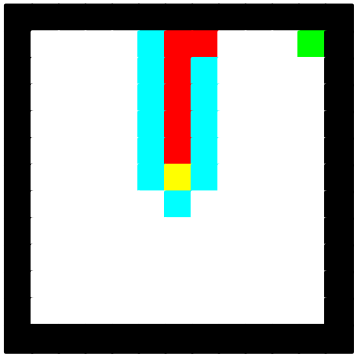

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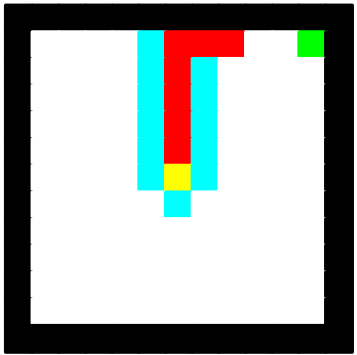

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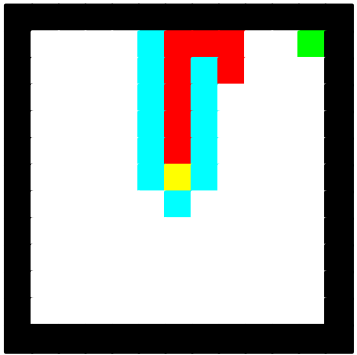

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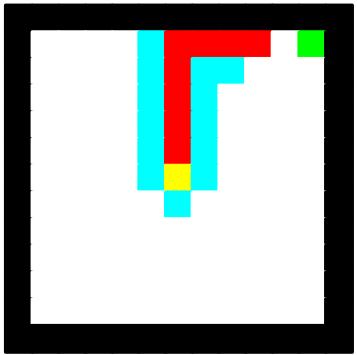

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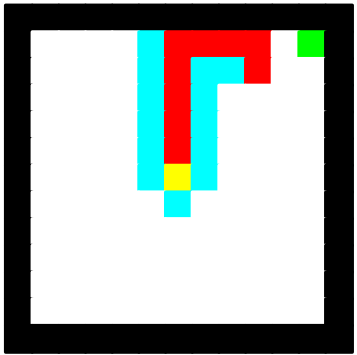

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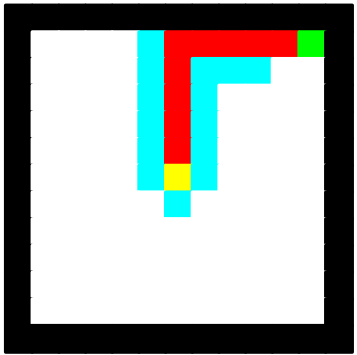

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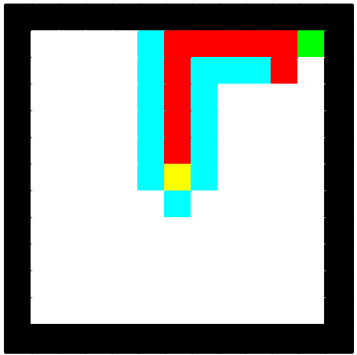

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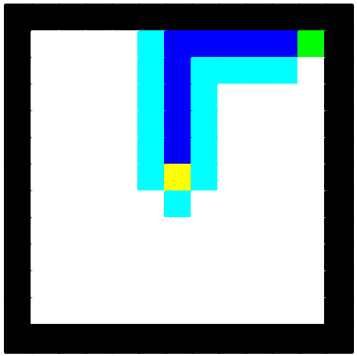

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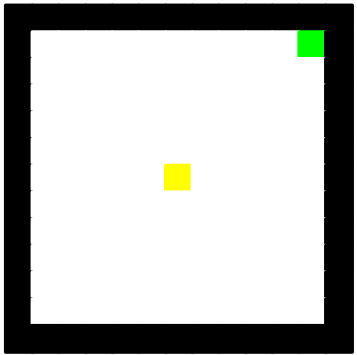

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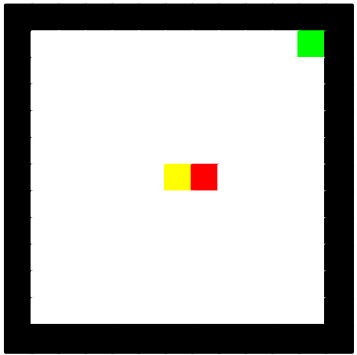

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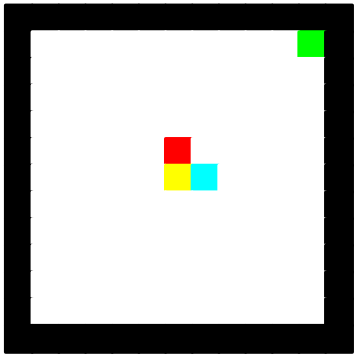

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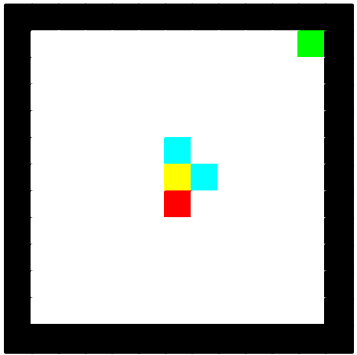

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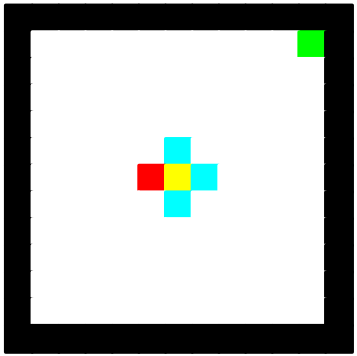

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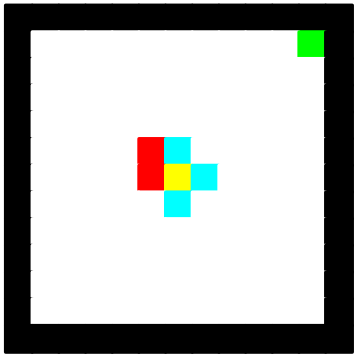

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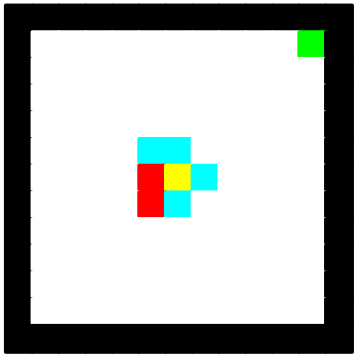

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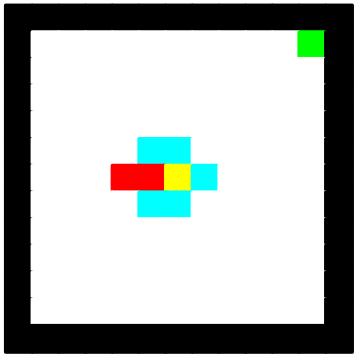

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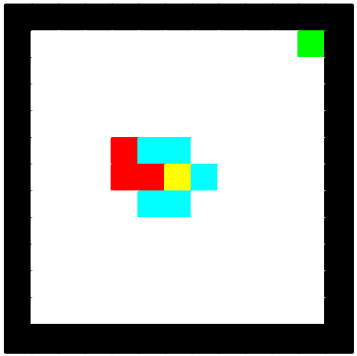

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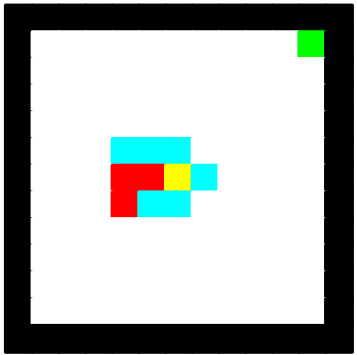

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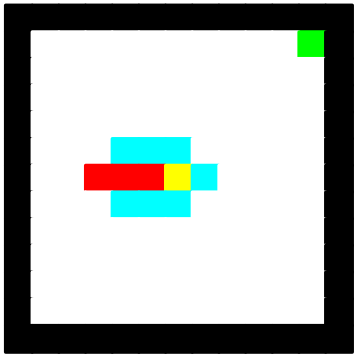

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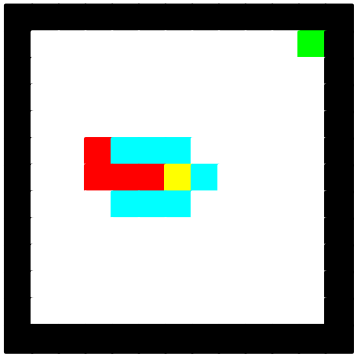

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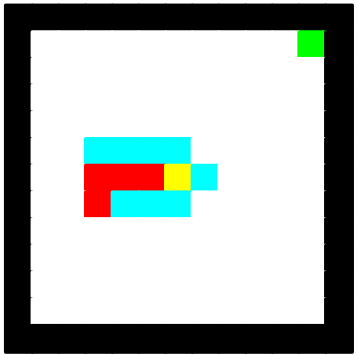

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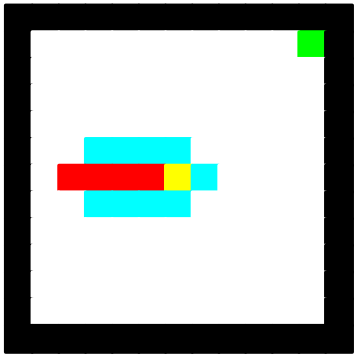

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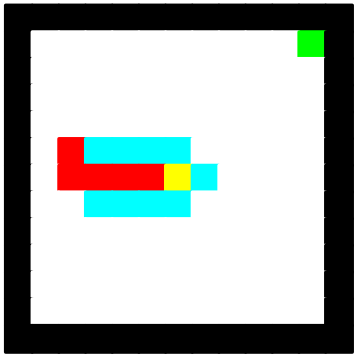

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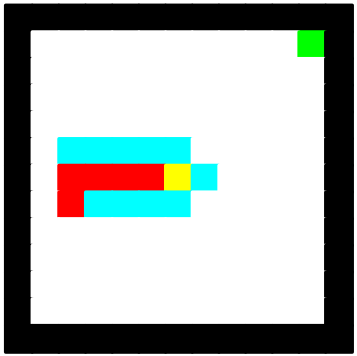

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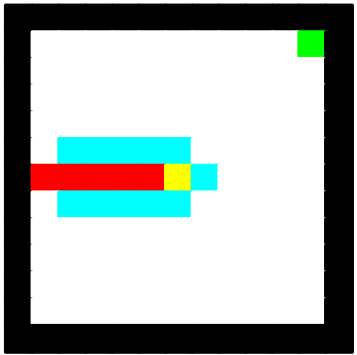

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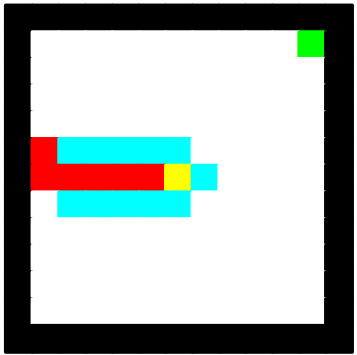

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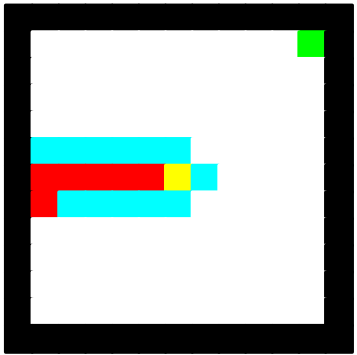

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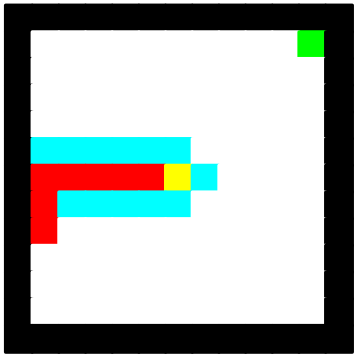

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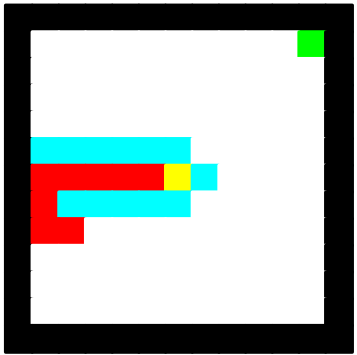

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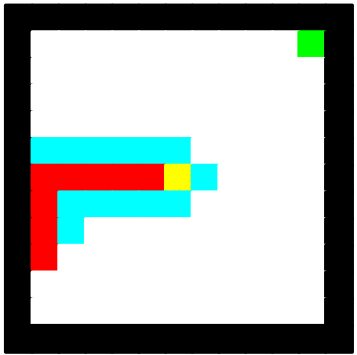

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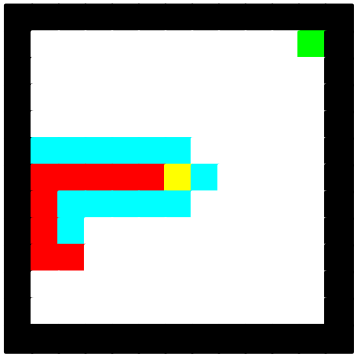

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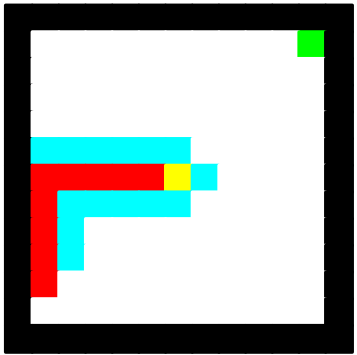

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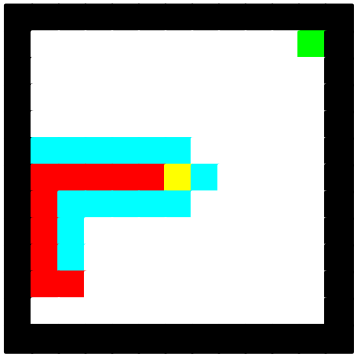

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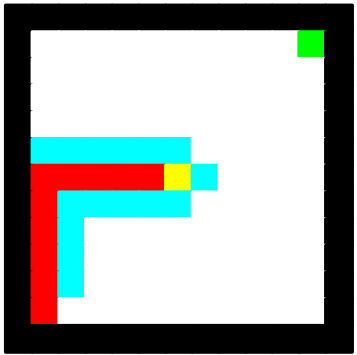

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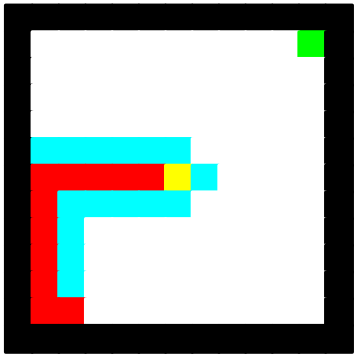

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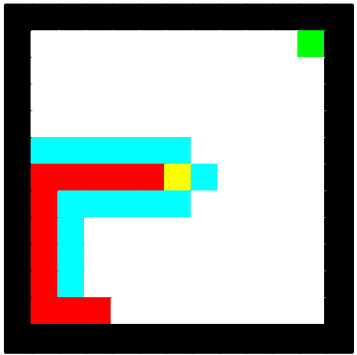

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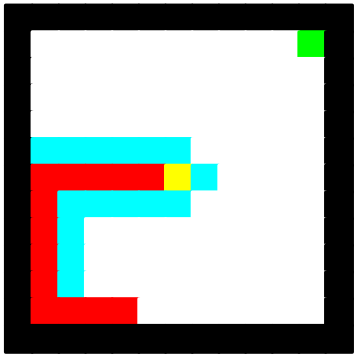

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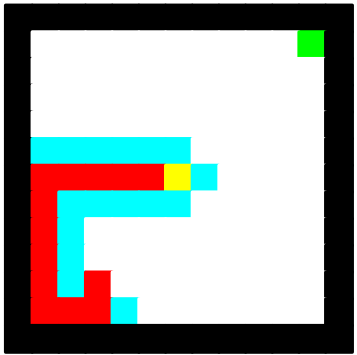

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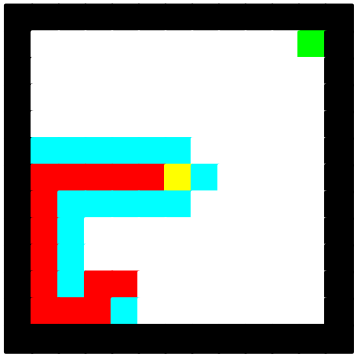

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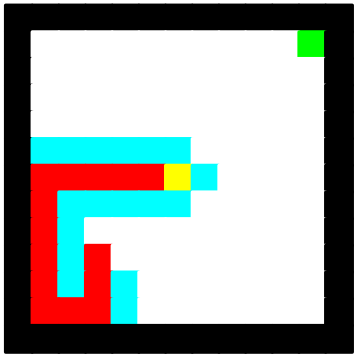

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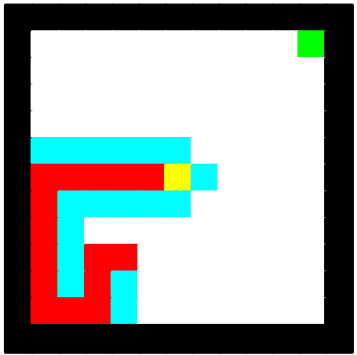

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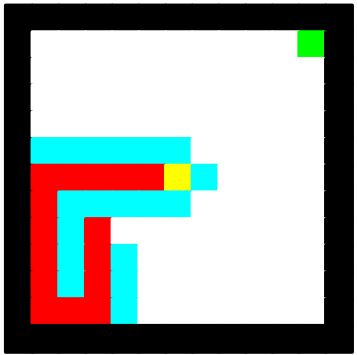

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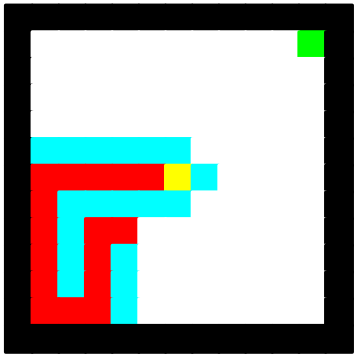

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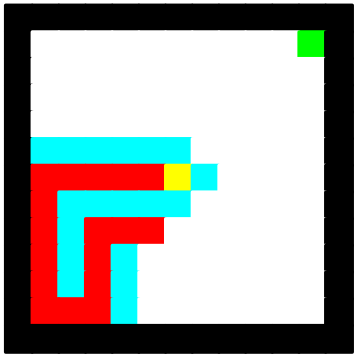

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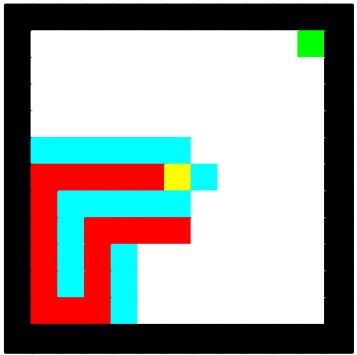

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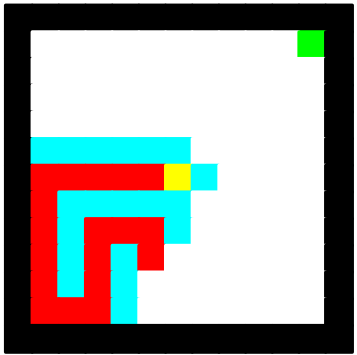

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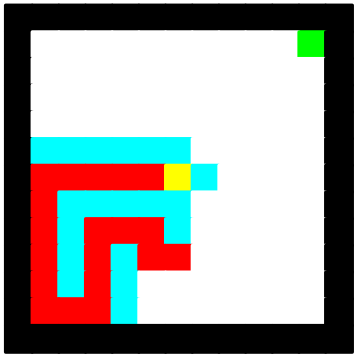

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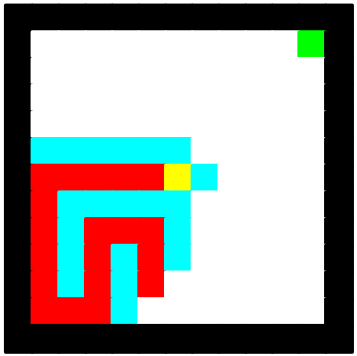

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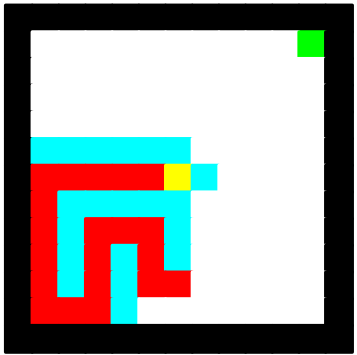

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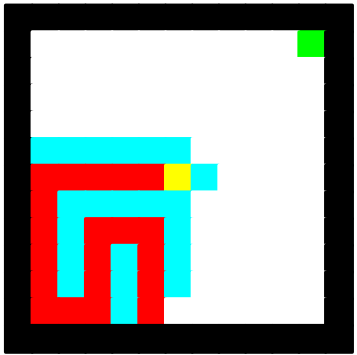

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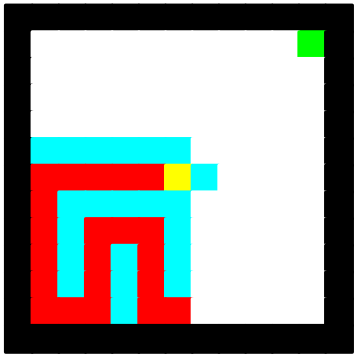

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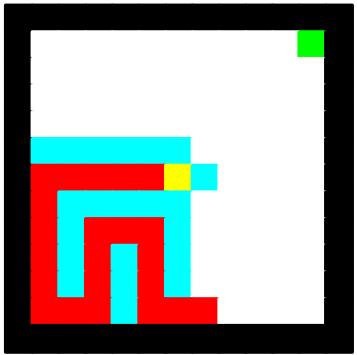

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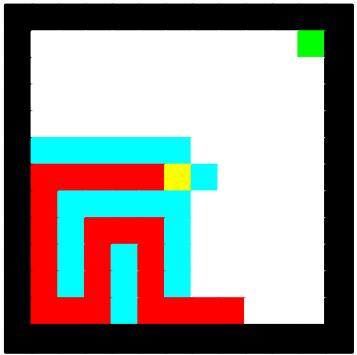

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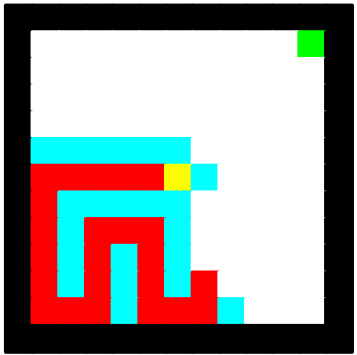

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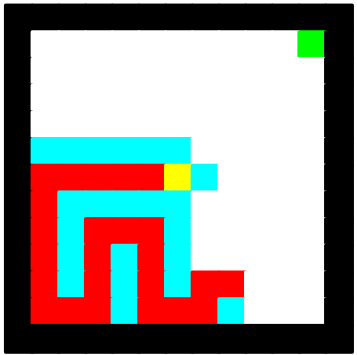

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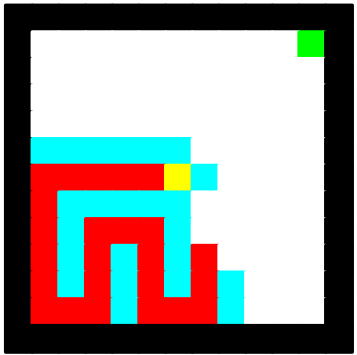

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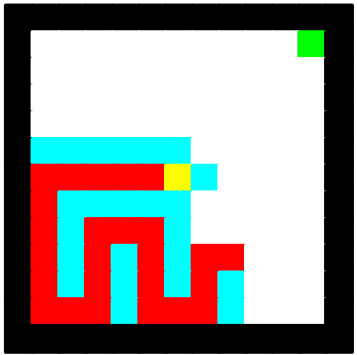

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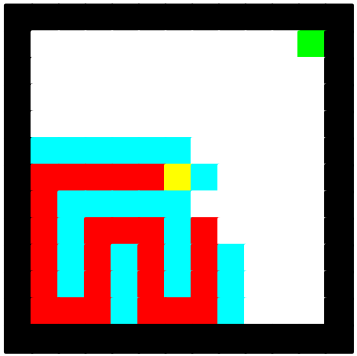

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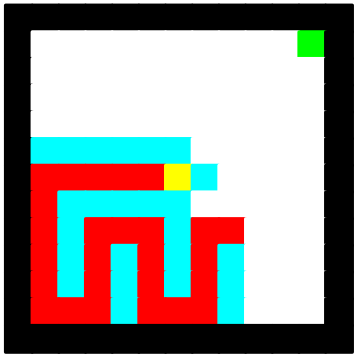

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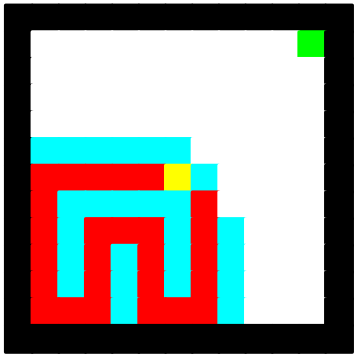

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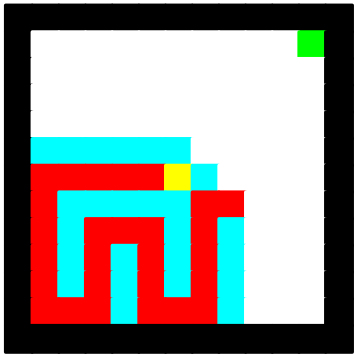

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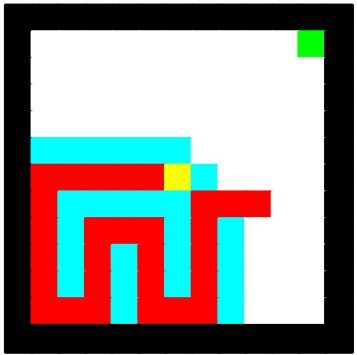

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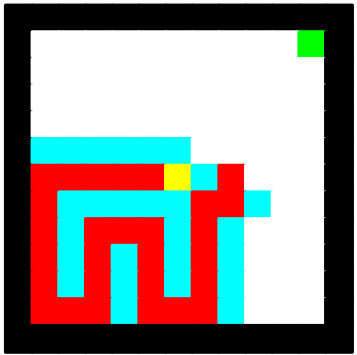

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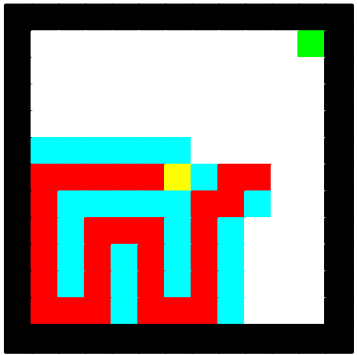

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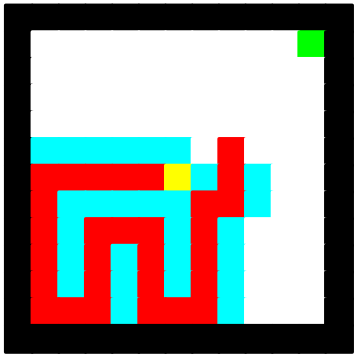

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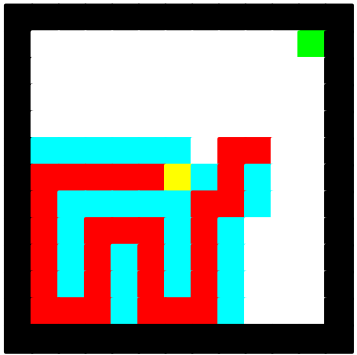

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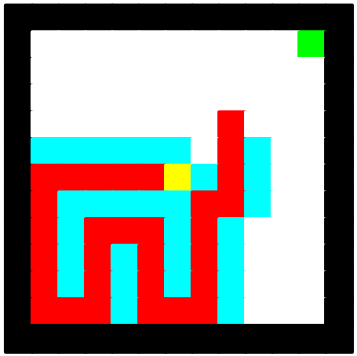

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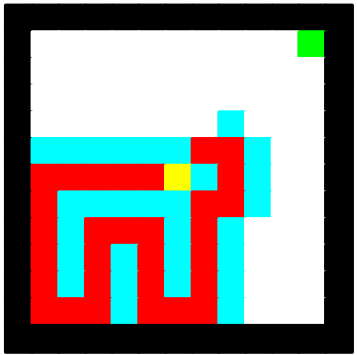

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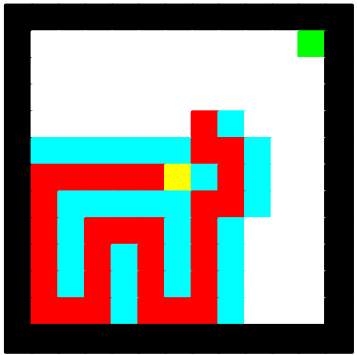

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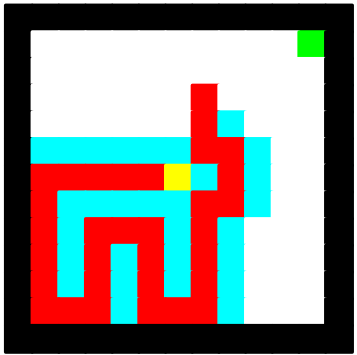

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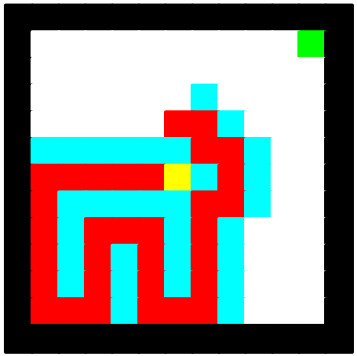

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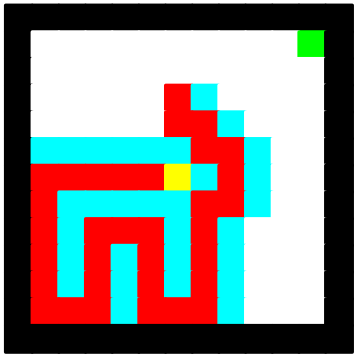

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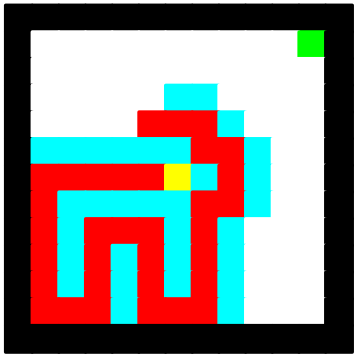

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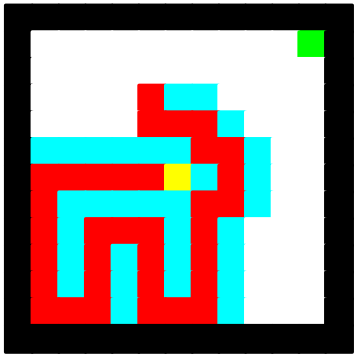

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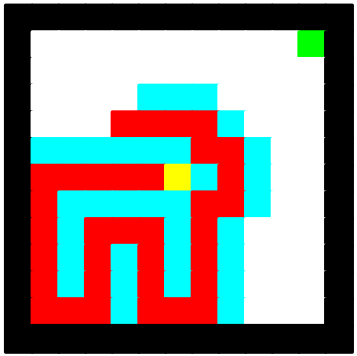

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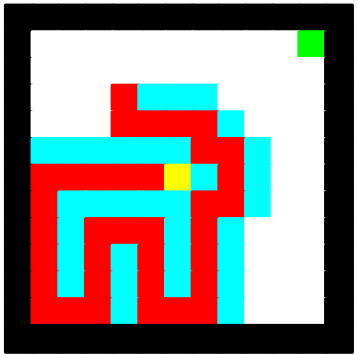

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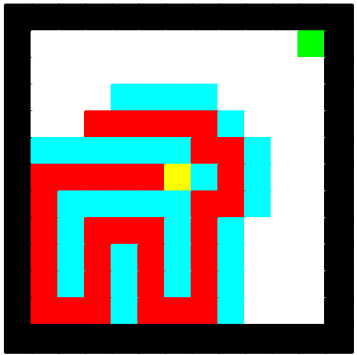

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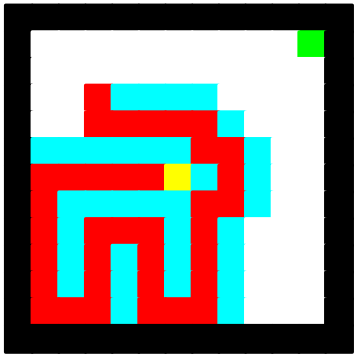

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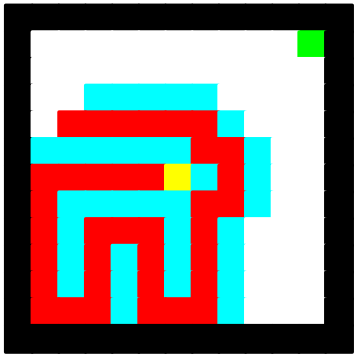

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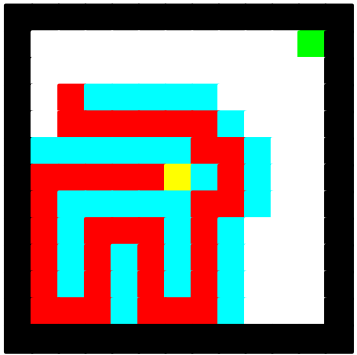

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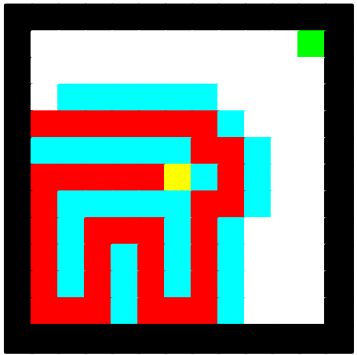

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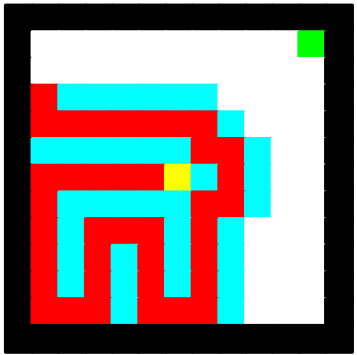

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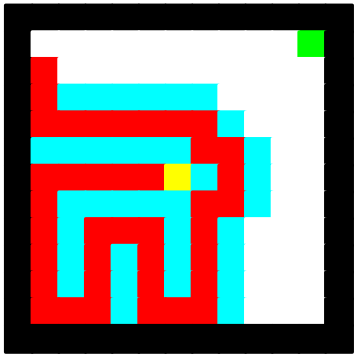

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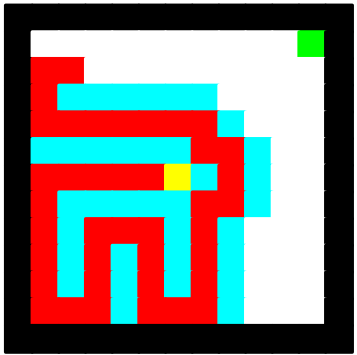

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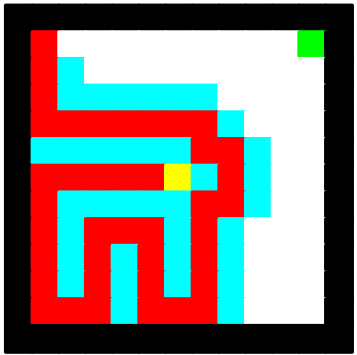

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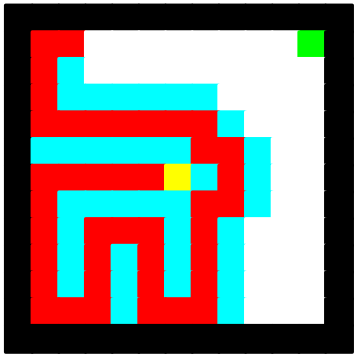

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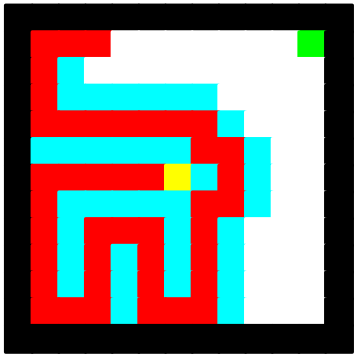

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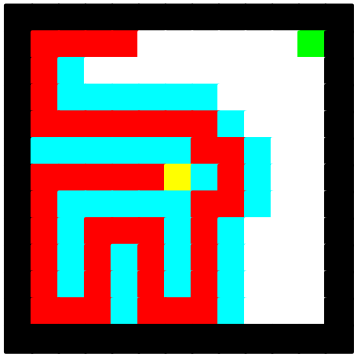

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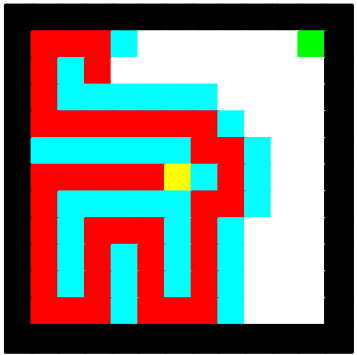

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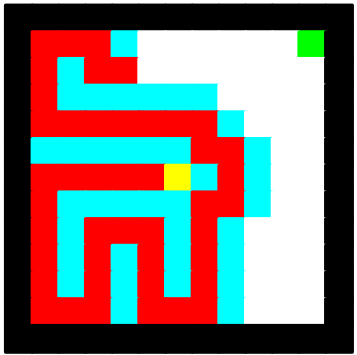

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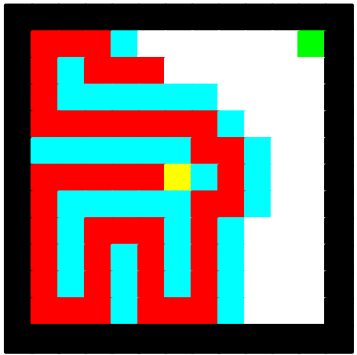

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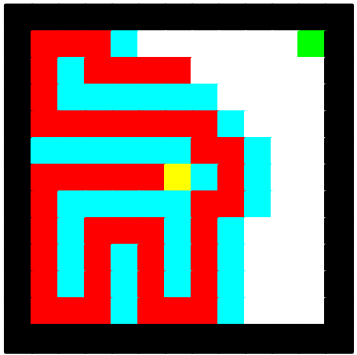

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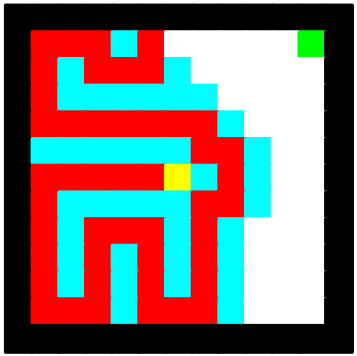

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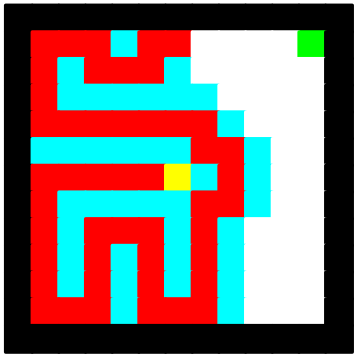

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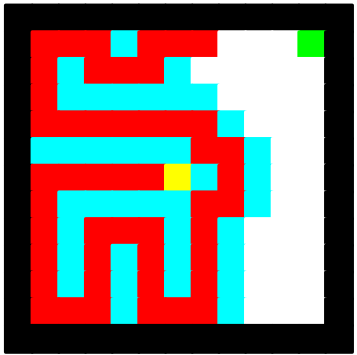

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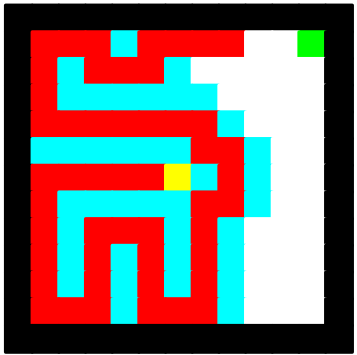

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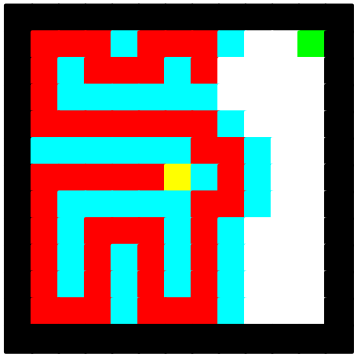

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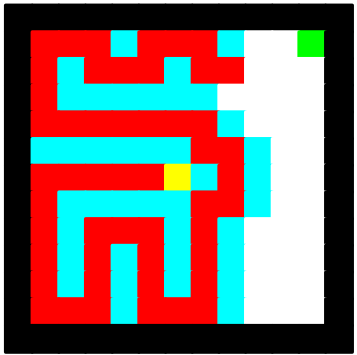

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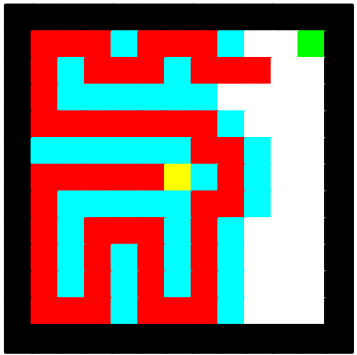

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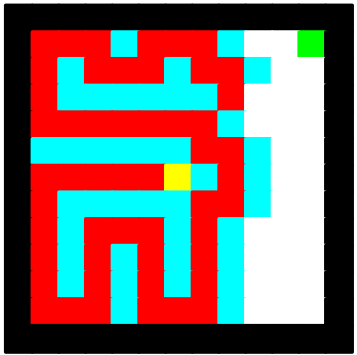

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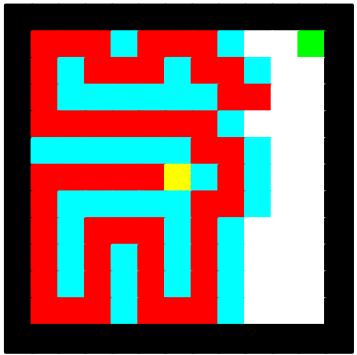

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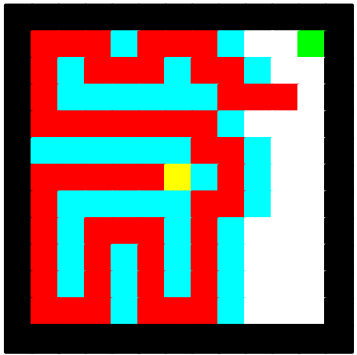

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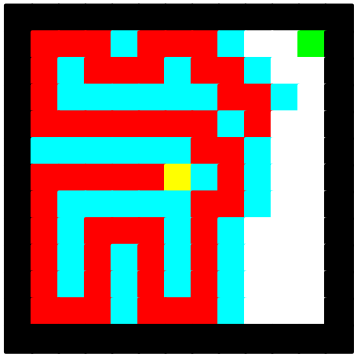

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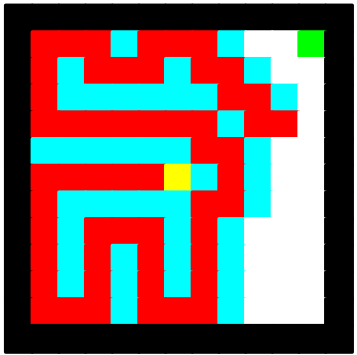

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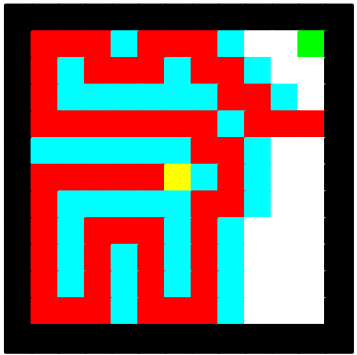

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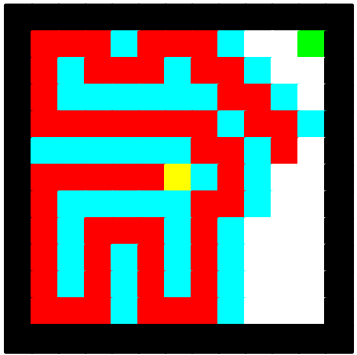

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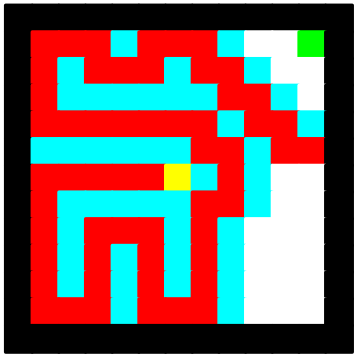

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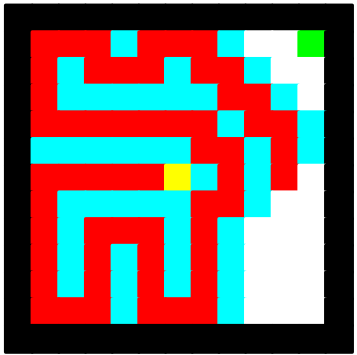

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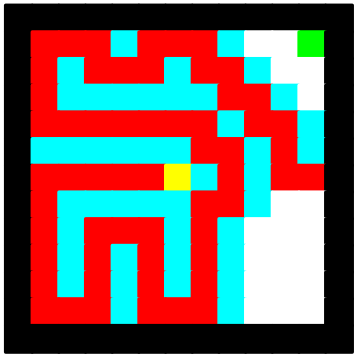

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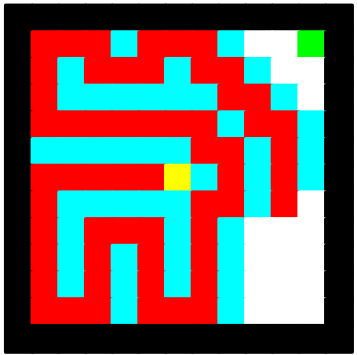

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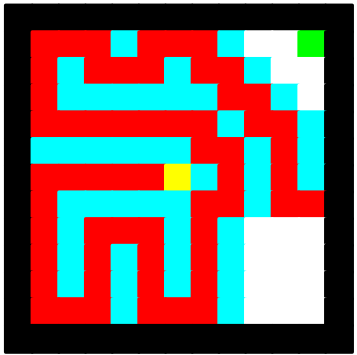

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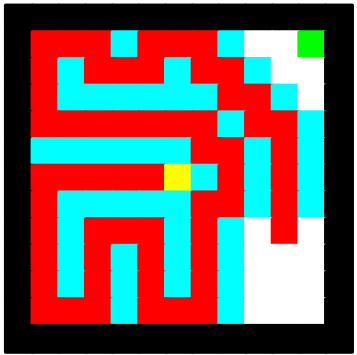

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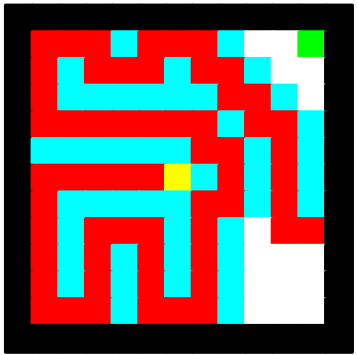

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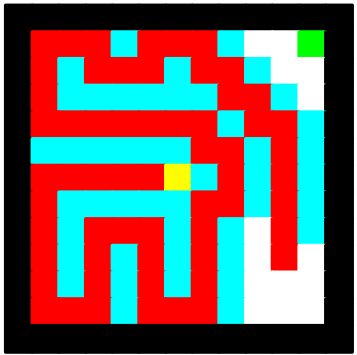

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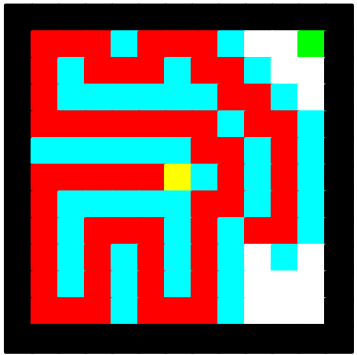

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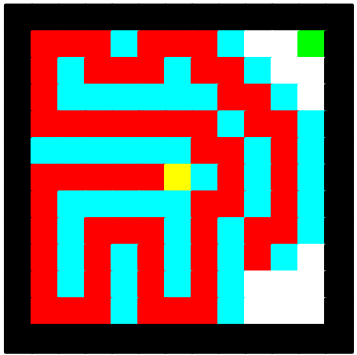

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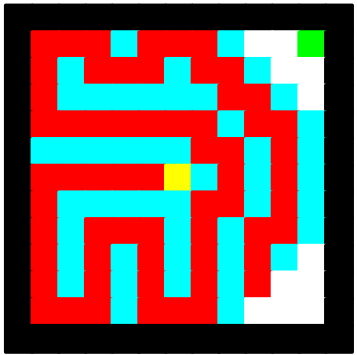

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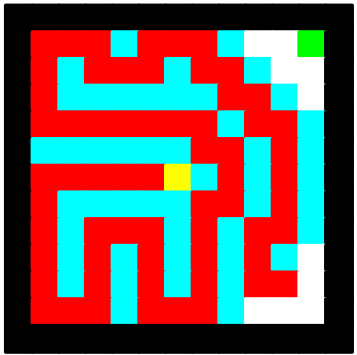

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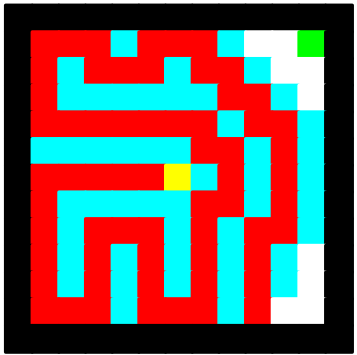

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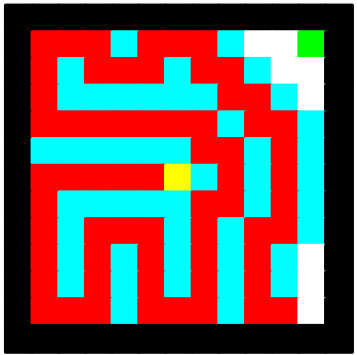

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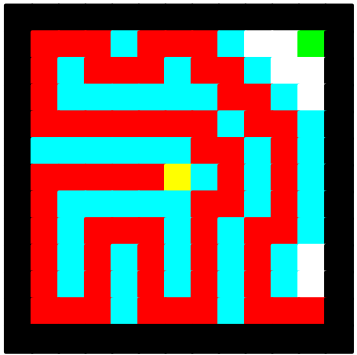
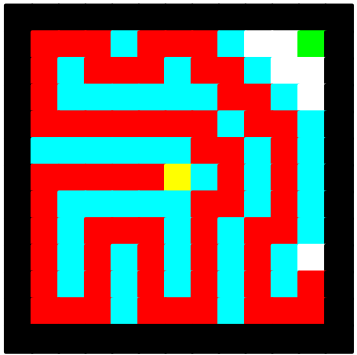
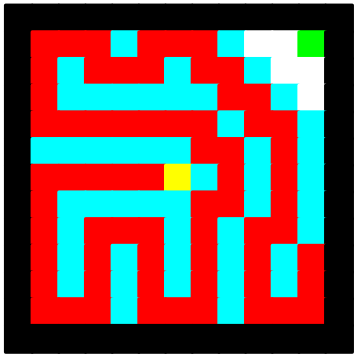


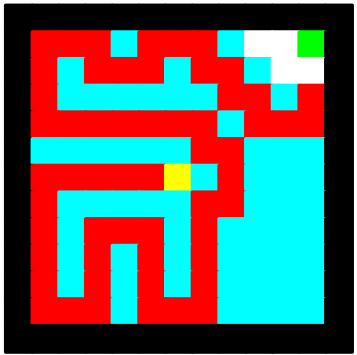
# Grid: DFS 2



# Grid: DFS 2



# Grid: DFS 2



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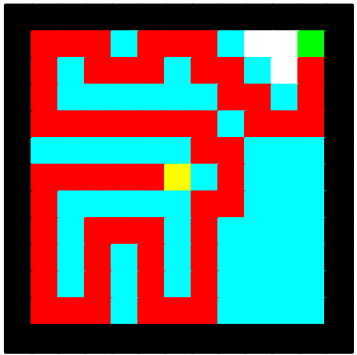
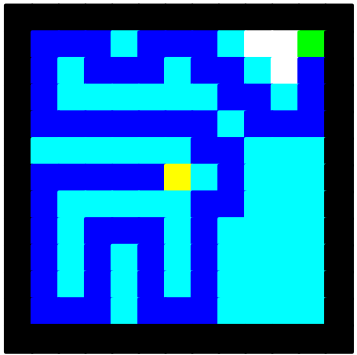


# Grid: DFS 2



# Words: DFS

quiz

# Words: DFS

quit

# Words: DFS

suit

# Words: DFS

suet

# Words: DFS

sues

# Words: DFS

sups

# Words: DFS

sops

# Words: DFS

soys

# Words: DFS

says

# Words: DFS

saws

# Words: DFS

sawn

# Words: DFS

sown

# Words: DFS

soon

# Words: DFS

soot

# Words: DFS

sort

# Words: DFS

sore

# Words: DFS

some

# Words: DFS

same

# Words: DFS

save

# Words: DFS

wave

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wavy

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waxy

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snit

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spit

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suet

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skid

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skim

# Words: BFS

skin

# Words: BFS

skip

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skis

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alit

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flit

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slat

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span

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diet

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dues

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stem

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seed

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shed

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feat

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plan

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play

# Words: BFS

scab

# Words: BFS

scan

# Words: BFS

scar

# Words: BFS

beat

# Words: BFS

best

# Words: BFS vs DFS

**BFS**

quiz → quit → suit → slit → slat → seat → beat → best

**DFS**

quiz → quit → suit → suet → sues → sups → sops → soys → says → saws → sawn → sown → soon → soot → sort → sore → some → same → save → wave → wavy → wary → wart → want → wand → wind → wins → wits → with → wish → wisp → wasp → rasp → rash → rush → rust → runt → runs → ruts → rots → rote → rove → rive → rise → risk → rink → ring → rang → sang → sank → sack → suck → such → much → mach → mace → maze → raze → rare → tare → tars → tats → vats → vans → vane → vase → vast → vest → best

# Search in `lib601`

`lib601` procedure called `search`, takes arguments:

- *successors*: function that takes a state and returns a list of successor states
- *start_state*: the state from which to start the search
- *goal_test*: a function that takes a state and returns `True` if that state satisfies the goal condition, and `False` otherwise
- *dfs*: boolean; if `True`, run a depth-first search; if `False`, run a breadth-first search

`search` returns a list of states from the root of the tree to the goal, or `None` if no path exists.

# 16 Lines!

```
def search(successors, start_state, goal_test, dfs = False):
    if goal_test(start_state):
        return [start_state]
    else:
        agenda = [SearchNode(start_state, None)]
        visited = {start_state}
        while len(agenda) > 0:
            parent = agenda.pop(-1 if dfs else 0)
            for child_state in successors(parent.state):
                child = SearchNode(child_state, parent)
                if goalTest(child_state):
                    return child.path()
                if child_state not in visited:
                    agenda.append(child)
                    visited.add(child_state)
        return None
```

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# Casting Problems as Search Problems

Biggest issue is choice of **state**.

# Casting Problems as Search Problems

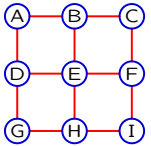
Biggest issue is choice of **state**.

From the state, we must be able to:

- Determine successors
- Test for goal condition

We'll get a lot of practice with this during the labs and homeworks this week.

# Example: Grid Search




```
class Grid:
    def __init__(self, width, height, start, goal):
        self.width = width
        self.height = height
        self.start = start
        self.goal = goal

grid = Grid(3, 3, (0,0), (2,2))

def grid_successors(state):
    r,c = state
    out = []
    for (dr,dc) in [(0,1),(1,0),(0,-1),(-1,0)]:
        if 0<=(r+dr)<grid.height and 0<=(c+dc)<grid.width:
            out.append((r+dr,c+dc))
    return out

result = search(grid_successors, grid.start, lambda x: x==grid.goal, False)
```

# Recap

Developed two search algorithms:

- Breadth-first search
- Depth-first search

Discussed the benefits and drawbacks of each

Developed two pruning rules:

- Don't consider paths that revisit states
- Only consider the first path to a given state

# Labs This Week

**Software Lab**: Solving Mazes
**Design Lab**: Robots in Mazes