# Rook Jumping Maze Generation for AI Education

Todd W. Neller
Gettysburg College

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|---|---|---|---|---|
| 3 | 2 | 1 | 4 | 1 |
| 3 | 2 | 1 | 3 | 3 |
| 3 | 3 | 2 | 1 | 4 |
| 3 | 1 | 2 | 3 | 3 |
| 1 | 4 | 4 | 3 | G |

# Rook Jumping Maze

- **Specification**: grid size, start state (square), goal state, jump numbers for each non-goal state.
- *Jump number:* Move *exactly* that many squares up, down, left, right. (*Not* diagonally.)
- **Objectives**:
  - Find a path from start to goal.
  - Find the shortest of these paths.

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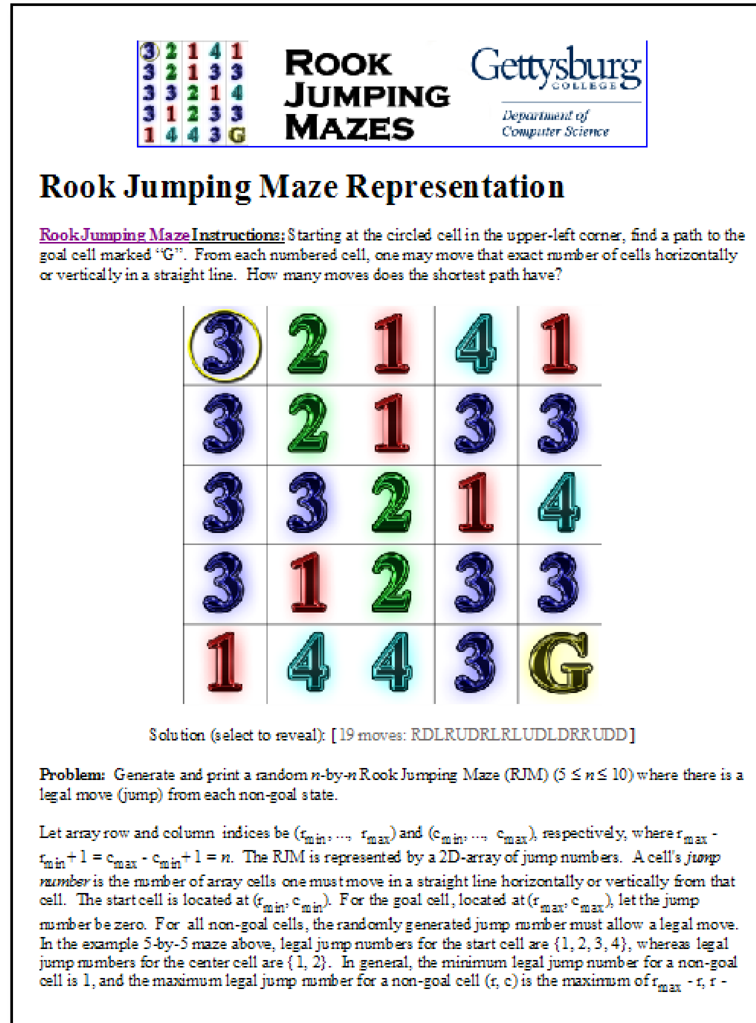
# The Assignments

- http://modelai.gettysburg.edu/2010/rjmaze
- Preliminaries:
  - Maze Representation
- Uninformed Search:
  - Maze Evaluation
  - Maze Evaluation II
- Stochastic Local Search:
  - Hill Descent
  - Hill Descent with Random Restarts
  - Hill Descent with Random Uphill Steps
  - Simulated Annealing
- Machine Learning
  - Restart Bandit
  - Restart SARSA

# Preliminaries

- [Maze Representation]
- **Problem**: Generate and print a random *n*-by-*n* Rook Jumping Maze (5 ≤ *n* ≤ 10) where there is a legal move (jump) from each non-goal state.



ROOK JUMPING MAZES

Gettysburg College

Department of Computer Science

## Rook Jumping Maze Representation

**Rook Jumping Maze Instructions:** Starting at the circled cell in the upper-left corner, find a path to the goal cell marked "G". From each numbered cell, one may move that exact number of cells horizontally or vertically in a straight line. How many moves does the shortest path have?

| | | | | |
|---|---|---|---|---|
| 3 | 2 | 1 | 4 | 1 |
| 3 | 2 | 1 | 3 | 3 |
| 3 | 3 | 2 | 1 | 4 |
| 3 | 1 | 2 | 3 | 3 |
| 1 | 4 | 4 | 3 | G |

Solution (select to reveal): [19 moves: RDLRUDRLRLUDLDRRUDD]

**Problem:** Generate and print a random *n*-by-*n* Rook Jumping Maze (RJM) (5 ≤ *n* ≤ 10) where there is a legal move (jump) from each non-goal state.

Let array row and column indices be ($r_{min}, \ldots, r_{max}$) and ($c_{min}, \ldots, c_{max}$), respectively, where $r_{max} - r_{min} + 1 = c_{max} - c_{min} + 1 = n$. The RJM is represented by a 2D-array of jump numbers. A cell's *jump number* is the number of array cells one must move in a straight line horizontally or vertically from that cell. The start cell is located at ($r_{min}, c_{min}$). For the goal cell, located at ($r_{max}, c_{max}$), let the jump number be zero. For all non-goal cells, the randomly generated jump number must allow a legal move. In the example 5-by-5 maze above, legal jump numbers for the start cell are {1, 2, 3, 4}, whereas legal jump numbers for the center cell are {1, 2}. In general, the minimum legal jump number for a non-goal cell is 1, and the maximum legal jump number for a non-goal cell (r, c) is the maximum of $r_{max}$ - r, r -

# Uninformed Search

- Maze Evaluation
  - **Problem**: [Maze Representation step] Then, for each cell, compute and print the minimum number of moves needed to reach that cell from the start cell, or "--" if no path exists from the start cell, i.e. the cell is *unreachable*.
  - Breadth-first search
  - Print objective function: negative goal distance, or a large positive number if goal is unreachable.

# Stochastic Local Search

- Maze design as search
  - Search space of possible maze designs for one that minimizes objective function.
- Stochastic Local Search (SLS):
  - Hill Descent
  - Hill Descent with Random Restarts
  - Hill Descent with Random Uphill Steps
  - Simulated Annealing
- Additional resources for teaching SLS: http://cs.gettysburg.edu/~tneller/resources/sls/index.html

# As You Wish…

- "I really hate this damned machine; I wish that they would sell it. / It never does quite what I want but only what I tell it." – Anonymous
- Our maze designs are only as good as our obj. function.
  - While maximizing shortest path is a simple starting point for maze design, we can do better.
- Maze Evaluation II
  - **Problem:** Define a *better* maze objective function and argue why it leads to improved maze quality.
  - Features: Black/white holes, start/goal positions, shortest solution uniqueness, forward/backward branching, same-jump clusters, etc.
  - ICCG'10 paper: *Rook Jumping Maze Design Considerations*

# Machine Learning

- SLS is an anytime algorithm
  - More search iterations → same/better maze design
  - When generating many mazes, how does one balance utility of computational time versus utility of maze quality?
- Restart Bandit
  - *n*–armed bandit MDP with # iterations as arms
  - ϵ–greedy/softmax strategy for action selection
- Restart SARSA
  - Use SARSA to map # iterations since restart and best maze evaluation to actions {GO, RESTART}

# Variations

- Many variations are possible to avoid plagiarism:
  - Use different regular **tilings**, e.g. triangular or hexagonal.
  - **Topological constraints** may be added (e.g. impassable walls/tiles) or removed (e.g. toroidal wrap-around).
  - **Movement constraints** may be varied as well.
    - Add diagonal moves → Queen Jumping Maze
    - Abbott's "no-U-turn" rule increases state complexity

# Conclusion

- The best puzzle assignments have a high fun to source-lines-of-code (SLOC) ratio:
  - RJMs are fun, novel, interesting mazes with simple representation and rules.
  - RJMs are particularly well suited to application of graph algorithms (evaluation) and stochastic local search (design).
- Everything you'd ever want to know about RJMs:
  - http://tinyurl.com/rjmaze
- Questions?