GAMES & LOGIC

# sudoku solver step by step

Published: September 3, 2026 | Index ID: #-

- Understand the foundational rules: Every row, column, and 3x3 block must contain numbers 1-9 without repetition.
- Master the 'Step by Step' workflow: Start with scanning, move to Snyder notation, then apply advanced elimination.
- Learn to identify complex patterns like X-Wings, Swordfish, and XY-Wings to break through difficult 'expert' puzzles.
- Avoid the guessing trap: Sudoku is a game of pure logic; every move can be deduced without trial and error.

## Introduction: The Logic of the 9x9 Grid

Sudoku is more than just a pastime; it is an exercise in pure deductive reasoning. While many beginners view the 9x9 grid as a daunting wall of numbers, a seasoned solver sees a structured landscape of possibilities and constraints. The term 'Sudoku' is derived from the Japanese phrase 'S ¶¦• wa dokushin ni kagiru,' meaning 'the digits must remain single.' This core principle—that every number from 1 to 9 must appear exactly once in each row, column, and 3x3 subgrid (often called a 'nonet' or 'box')—is the foundation upon which all solving strategies are built. In this comprehensive guide, we will walk you through a professional-grade Sudoku solver step-by-step methodology, moving from the simplest scanning techniques to the most advanced logic chains used by world-class competitors.

## Phase 1: The Foundations of Sudoku Solving

### The Anatomy of the Grid

To communicate effectively about Sudoku, we must define the coordinate system. A standard puzzle consists of 81 cells arranged in a 9x9 format. These are grouped into nine rows (labeled R1 through R9), nine columns (C1 through C9), and nine boxes (B1 through B9). A 'unit' or 'house' refers to any single row, column, or box. Because each unit must contain the numbers 1-9, the total sum of any unit is always 45. Understanding these 'houses' is critical because logic applied to one house often ripples through intersecting houses.

### Basic Rule Enforcement

The first step in any Sudoku solver's journey is the literal enforcement of the rules. If a '5' is placed in R1C1, it immediately eliminates '5' as a possibility for every other cell in Row 1, Column 1, and Box 1. This process of elimination is the engine that drives the game. Beginners often fail because they look for where a number *can* go, rather than identifying where a number *cannot* go.

## Phase 2: Beginner Step-by-Step Techniques

### 1. Cross-Hatching (Scanning)

The most basic step-by-step method is cross-hatching. Pick a number, say '1', and look at all the boxes where '1' is already placed. By extending imaginary lines from those '1s' through their respective rows and columns, you can often narrow down the location of '1' in an empty box. For example, if Box 1 is missing a '4', and there is a '4' in Row 2 and a '4' in Column 3, you can eliminate all cells in Box 1 that reside in Row 2 or Column 3. Often, this leaves only one available cell for the '4'.

### 2. The Naked Single

A 'Naked Single' occurs when a specific cell has only one possible candidate remaining after all other numbers have been ruled out by its row, column, and box. This is different from cross-hatching, where you look for a number's position; here, you are looking at a cell's specific potential. If a cell sees the numbers 1, 2, 3, 4, 5, 7, 8, and 9 in its intersecting houses, that cell *must* be 6. This is the simplest form of 'forcing' a digit.

### 3. The Hidden Single

A 'Hidden Single' is a digit that is the only one of its kind possible within a specific unit, even if the cell itself could theoretically hold other candidates. For example, in a row, the number '7' might only be able to fit into one specific cell because all other empty cells in that row are blocked by '7s' in their respective columns. To the untrained eye, that cell looks like it could hold a 3, 5, or 7, but the row-wide constraint makes the 7 a 'Hidden Single.'

## Phase 3: Intermediate Strategies and Pencil Marking

As you move into medium-difficulty puzzles, you will reach a point where scanning is no longer sufficient. This is where 'Pencil Marking' becomes essential. Professional solvers often use **Snyder Notation**, where you only write candidates in the corners of a cell if that candidate can only fit in exactly two spots within a 3x3 box. This keeps the grid clean and highlights 'pointing pairs' immediately.

### Locked Candidates (Pointing Pairs and Triples)

Sometimes, all possible locations for a candidate within a box are restricted to a single row or column. When this happens, that candidate *must* occupy one of those cells. Therefore, you can eliminate that candidate from the rest of that row or column outside of that box. Conversely, if a candidate in a row is restricted to a single box, you can eliminate that candidate from the rest of that box. This is a subtle but powerful step-by-step refinement that clears out 'noise' from your candidate list.

### Naked Pairs and Triples

A 'Naked Pair' occurs when two cells in the same unit contain the exact same two candidates and no others. For example, if two cells in Row 5 both contain only {2, 7}, then one must be 2 and the other must be 7. It doesn't matter which is which; we know that 2 and 7 cannot exist anywhere else in Row 5. This allows you to delete 2 and 7 from all other candidate lists in that row. 'Naked Triples' work the same way with three cells and three candidates (e.g., {1,2}, {2,3}, {1,3} across three cells in a box).

| Technique Name | Difficulty Level | Primary Benefit | Logic Type |
|---|---|---|---|
| Naked Single | Beginner | Fills a specific cell immediately | Direct Elimination |
| Hidden Single | Beginner | Fills a number in a unit | Constraint Logic |
| Pointing Pairs | Intermediate | Eliminates candidates in rows/cols | Locked Candidates |
| Naked Pair | Intermediate | Clears candidates from a house | Subset Logic |
| X-Wing | Advanced | Removes candidates across 4 cells | Fish Pattern |

## Phase 4: Advanced Step-by-Step Patterns

### The X-Wing Strategy

The X-Wing is the gateway to advanced Sudoku. It occurs when a candidate appears exactly twice in two different rows, and those appearances are in the same two columns. This forms a rectangle. Because the candidate *must* occupy two opposite corners of this rectangle, you can safely remove that candidate from those two columns in all other rows. The X-Wing is essentially a logic bridge that connects distant parts of the grid through shared constraints.

### The XY-Wing (The Y-Wing)

An XY-Wing involves three cells: a 'pivot' and two 'pincers.' The pivot cell contains two candidates (X, Y). One pincer sees the pivot and contains (X, Z). The second pincer also sees the pivot and contains (Y, Z). No matter what the pivot cell ends up being (X or Y), one of the pincers will be forced to be Z. Therefore, any cell that can 'see' both pincer cells cannot contain Z. This technique is remarkably effective at cracking open 'stuck' expert puzzles.

### Swordfish and Jellyfish

These are extensions of the X-Wing logic. A Swordfish occurs when three rows have a candidate appearing in the same three columns. This creates a 3x3 pattern of potential eliminations. A Jellyfish extends this to four rows and four columns. While rare in manual play, identifying a Swordfish is often the key to solving 'Evil' difficulty grids without resorting to bifurcation (guessing).

## Phase 5: Expert Techniques and Chains

For the most difficult puzzles (often labeled 'Diabolical'), solvers must use logic chains. These techniques involve tracing the 'if-then' consequences of a candidate being true or false across multiple cells.

### Simple Coloring

Simple Coloring focuses on a single candidate. You find a 'strong link' (where a candidate only has two possible spots in a unit) and alternate 'colors' or labels (A and B). If any cell sees two different cells of the same color, or if two different colors collide in a way that creates a contradiction, you can eliminate candidates. This is a visual way to handle Alternating Inference Chains (AIC).

### Medusa and 3D Medusa

Medusa is an advanced version of coloring that looks at multiple candidates across multiple cells. It follows the logic that if candidate X in cell A is true, then candidate Y in cell B must be false, and so on. If the chain leads to a contradiction (like a cell having no possible candidates left), the starting premise is proven false.

Most Sudoku puzzles are designed to have exactly one solution. This leads to the 'Unique Rectangle' strategy. If you find a pattern that would result in two possible solutions (a deadly pattern), you can assume the puzzle creator avoided this, and use that assumption to eliminate candidates. While some purists dislike this 'meta-game' approach, it is a highly effective tool for speed-solving.

## A Universal Step-by-Step Blueprint for Solving

If you want a reliable algorithm to solve any puzzle, follow this sequence:

1. Scan for Singles: Use cross-hatching to fill in all obvious Hidden Singles.
2. Identify Naked Singles: Check cells that are heavily constrained by their intersecting houses.
3. Pencil Mark with Snyder: Mark boxes where a number only has two positions.
4. Analyze Locked Candidates: Check if Snyder marks in a box form a line that eliminates candidates in the rest of the row/column.
5. Search for Subsets: Look for Naked Pairs, Triples, and Quads. If found, clear out those candidates from the rest of the house.
6. Apply Basic Fish: Scan for X-Wings in the rows and columns.
7. Apply Wing Logic: Look for XY-Wings or XYZ-Wings to eliminate specific candidates.
8. Advanced Fish: Scan for Swordfish patterns if the grid is still stalled.
9. Chain Logic: If all else fails, use Simple Coloring or AIC to find contradictions.

## Computer Algorithms: How Automated Solvers Work

While humans use pattern recognition, computers use different 'step by step' logic. The most common is the **Backtracking Algorithm**. The computer picks an empty cell, tries a number (1-9), checks if it is valid, and moves to the next cell. If it hits a dead end, it 'backtracks' to the previous cell and tries the next number. A more efficient computer method is **Donald Knuth's Algorithm X**, using the **Dancing Links (DLX)** data structure. This treats Sudoku as an 'Exact Cover' problem, solving even the hardest puzzles in milliseconds by mathematically representing the grid's constraints.

## Frequently Asked Questions (FAQ)

## Common Pitfalls to Avoid

- Over-marking: Writing down every possible candidate in every cell too early can lead to 'visual noise' and simple mistakes.
- Ignoring the Boxes: Many players focus only on rows and columns, forgetting that the 3x3 box is often where the most restrictive logic happens.
- Assuming Uniqueness: While most puzzles have one solution, poorly generated ones (often from cheap apps) might have several. If your logic feels broken, the puzzle might be the problem.
- Misplacing a Pencil Mark: One wrong small number can ruin a 30-minute solve. Be meticulous when updating your candidates after placing a large number.

## Conclusion: The Path to Sudoku Mastery

Mastering Sudoku is a journey of shifting from 'seeing numbers' to 'seeing patterns.' By following the step-by-step methodology outlined here—starting with simple cross-hatching and graduating to complex fish and wing patterns—you can solve virtually any puzzle ever created. Remember that the beauty of Sudoku lies in its certainty. There is no luck involved, only the patient application of logic. Whether you are solving on paper or using a digital Sudoku solver to check your progress, the goal is the same: to sharpen the mind and enjoy the satisfaction of a perfectly completed grid.

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