Problem Set 4: 数独

due by 7:00pm on Fri 10/8

Per the directions at this document's end, submitting this problem set involves submitting source code on `cloud.cs50.net` as well as filling out a Web-based form (the latter of which will be available after lecture on Wed 10/6), which may take a few minutes, so best not to wait until the very last minute, lest you spend a late day unnecessarily.

Be sure that your code is thoroughly commented
to such an extent that lines' functionality is apparent from comments alone.

Goals.

- Learn to use ncurses, a library for GUIs.
- Design and implement larger pieces of software.
- Master Sudoku.

Recommended Reading.

- Sections 1 – 13 of `http://tldp.org/HOWTO/NCURSES-Programming-HOWTO/`.

diff hacker4.pdf hacker4.pdf.

- Hacker Edition requires a [H]int feature.
- Hacker Edition doesn't require an add-on feature.

Academic Honesty.

All work that you do toward fulfillment of this course's expectations must be your own unless collaboration is explicitly allowed in writing by the course's instructor. Collaboration in the completion of problem sets is not permitted unless otherwise stated by some problem set's specification.

Viewing or copying another individual's work (even if left by a printer, stored in an executable directory, or accidentally shared in the course's virtual terminal room) or lifting material from a book, website, or other source—even in part—and presenting it as your own constitutes academic dishonesty, as does showing or giving your work, even in part, to another student. Similarly is dual submission academic dishonesty: you may not submit the same or similar work to this course that you have submitted or will submit to another. Nor may you provide or make available solutions to problem sets to individuals who take or may take this course in the future. Moreover, submission of any work that you intend to use outside of the course (*e.g.*, for a job) must be approved by the staff.

You are welcome to discuss the course's material with others in order to better understand it. You may even discuss problem sets with classmates, but you may not share code. In other words, you may communicate with classmates in English, but you may not communicate in, say, C. If in doubt as to the appropriateness of some discussion, contact the course's instructor.

You may turn to the Web for instruction beyond the course's lectures and sections, for references, and for solutions to technical difficulties, but not for outright solutions to problems on problem sets or your own final project. However, failure to cite (as with comments) the origin of any code or technique that you do discover outside of the course's lectures and sections (even while respecting these constraints) and then integrate into your own work may be considered academic dishonesty.

All forms of academic dishonesty are dealt with harshly. If the course refers some matter to the Administrative Board and the outcome for some student is *Warn*, *Admonish*, or *Disciplinary Probation*, the course reserves the right to impose local sanctions on top of that outcome for that student that may include, but not be limited to, a failing grade for work submitted or for the course itself.

Grades.

Your work on this problem set will be evaluated along three primary axes.

Correctness. To what extent is your code consistent with our specifications and free of bugs?
Design. To what extent is your code written well (*i.e.*, clearly, efficiently, elegantly, and/or logically)?
Style. To what extent is your code readable (*i.e.*, commented and indented with variables aptly named)?

Before you get started.

☐ If you think you might concentrate or minor in Computer Science or if you'd like to hear about CS goings-on plus jobs, subscribe to SEAS's mailing list for CS undergrads via the URL below:[1]

```
https://lists.seas.harvard.edu/mailman/listinfo/cs-undergrads
```

So that your subscription is approved by SEAS, best to subscribe with your `@college.harvard.edu` address.

You might also want to subscribe to some other CS-related lists at:

```
http://wiki.cs50.net/Mailing_Lists
```

☐ Between now (which had better not be Thursday night!) and this problem set's deadline, keep an eye out for some machine, program, or website whose user interface, you feel, is poorly designed. Don't focus too much on aesthetics, since reasonable people can certainly disagree on the subject of beauty. Focus more on the workflow that the interface demands of its users. Does it make sense? Does it optimize for the common case? Is it self-explanatory? Does it require that you go through eight steps just to get on a train?

When it comes time to submit this problem set, we'll ask for your thoughts via this problem set's Web-based form. It's fine if you have nothing nice to say about the machine, program, or website with which you find fault. But be sure you can articulate why its design is subpar and how you would fix it.

Getting Started.

☐ SSH to `cloud.cs50.net` and execute the command below.

```
cp -r ~cs50/pub/src/psets/hacker4/ ~
```

Recall that this command will copy this problem set's distribution code into your own home directory. Navigate your way to your copy by executing the command below.

```
cd ~/hacker4/
```

If you list the contents of your current working directory (remember how?), you should see the below. If you don't, don't hesitate to ask the staff for assistance.

```
debug.bin  l33t.bin  Makefile  n00b.bin  sudoku.c  sudoku.h
```

Well those look like fun!

[1] This URL is only accessible on campus.

The numbers must be single.

☐ Much like the Game of Fifteen, Sudoku is a game of logic involving numbers. But it's much more interesting. Consider the puzzle below.

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

The object of Sudoku is to fill this 9×9 grid in such a way that each column, each row, and each of the nine 3×3 boxes therein contain each of the numbers 1 through 9 exactly once. A whole bunch of strategies exist, but the general idea is to figure out iteratively what numbers could go where.

For instance, let's home in on one of the 3×3 boxes that already has a lot of numbers and work the ol' process of elimination. Consider the box in the middle, highlighted below.

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

Let's see, that box already has a 1, a 2, but no 3. Where could we put 3? Well, 3 can't go in that box's bottom row, since the box to the right already has a 3 in that row. And 3 can't go on either side of the 7, since the box to the left already has a 3 in that row. Aha! It must be that 3 belongs in that box's top row, in which case there's only one place to put it! And so we fill in that spot with a 3, per the below.

1			**3**	**4**				**5**
					6			**8**
				5			**6**	**3**
		1	**6**	**3**	**5**	**8**		**9**
		3		**7**		**5**		
9		**6**	**2**		**1**	**3**		
6	**8**			**2**				
3			**5**					
2				**1**	**9**			**7**

Let's try another trick now. Rather than figure out where a number can go, let's figure out where a number cannot! Let's home in on 9. Highlighted in gray now are all of the spots that 9 cannot go, either because there's already another number there or because there's already a 9 in the highlighted row, column, or box, per the below.

1			**3**	**4**				**5**
					6			**8**
				5			**6**	**3**
		1	**6**	**3**	**5**	**8**		**9**
		3		**7**		**5**		
9		**6**	**2**		**1**	**3**		
6	**8**			**2**				
3			**5**					
2				**1**	**9**			**7**

Well, look at that! Looks like we've found a home for 9 within that box in the middle because there's only one place it can possibly go, per the below.

1			**3**	**4**				**5**
					6			**8**
				5			**6**	**3**
		1	**6**	**3**	**5**	**8**		**9**
		3	**9**	**7**		**5**		
9		**6**	**2**		**1**	**3**		
6	**8**			**2**				
3			**5**					
2				**1**	**9**			**7**

Lather, rinse, and repeat these sorts of tricks enough times, and (assuming no PEBPAC) we'll end up with the solution below.[2]

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

If still not quite clear on how the game is played, feel free to turn to Wikipedia.

```
http://en.wikipedia.org/wiki/Sudoku
```

And if interested for your own edification in the mathematics and algorithmics behind the game, you might also find these articles of interest:

```
http://en.wikipedia.org/wiki/Mathematics_of_Sudoku
http://en.wikipedia.org/wiki/Algorithmics_of_sudoku
```

☐ Just for fun, we've included a whole bunch of puzzles (and solutions) at this document's end. And if you start finding yourself particularly addicted, odds are an implementation of Sudoku exists for your mobile phone!

☐ Alright, now the real fun begins. You're about to implement (most of) Sudoku in C.

Much like we provided you with some code for the Game of Fifteen, similarly have we provided you with a skeleton for Sudoku. Whereas Problem Set 3 relied on ANSI escape sequences to implement the Game of Fifteen's "graphics," though, this problem set introduces a library called "ncurses" (formerly called "curses") that will provide your implementation of Sudoku with a nicer GUI (graphical user interface). To be sure, your program won't look like Mac OS or Windows, but it should look sexier than that Game of Fifteen! Not only does ncurses make it pretty easy to integrate colors into a program (and even dialogs and menus), it also allows you to treat your terminal window as a grid of `char`s, any one of which can be updated without affecting the others. That sort of feature is perfect for a game like Sudoku, as you'll be able to add numbers to the game's board one at a time without having to re-generate the whole screen after each move (as you did with `printf` for the Game of Fifteen).

[2] The second 'P' stands for "puzzle," and you're in the chair:
`http://www.urbandictionary.com/define.php?term=pebkac`

Now, a typical terminal window is 80 characters wide by 24 characters tall (*i.e.*, 80×24), and ncurses addresses those characters by way of (y, x) coordinates, whereby (0, 0) refers to your window's top-left corner, (0, 79) refers to your window's top-right corner, (23, 0) refers to your window's bottom-left corner, and (23, 79) refers to your window's bottom-right corner.[3] Even if your window boasts dimensions smaller or larger than these, the idea is the same. When it comes time to fill in a blank with respect to Sudoku, you'll simply update the `char` at some (y, x) coordinate.

Now, how about that skeleton. Essentially, we've implemented an aesthetic framework for the game so that you can focus on the more interesting parts: namely, the game's features. In fact, we've written the code (and comments) in such a way that you should be able to learn quite a bit about ncurses and more simply by reading our code. And you'll find that we've structured Sudoku's framework much like we did the Game of Fifteen's. It's in `main` that we have a big loop, waiting and waiting for some user's input. And it's in separate functions that we (and, soon, you) set the game up and respond to that input.

Because this game is meant to be more sophisticated (and fun) than the last, you'll also find that we've given you more code this time. Don't freak out, but it's just over 600 lines. But know now that none of it is all that complicated. In fact, if you look at each of the functions in isolation, you'll likely find each pretty straightforward. What's neat is that when you combine so many building blocks, you get some pretty compelling results. In fact, let's take a look.

If you're not still there, navigate your way to `~/hacker4/` and execute the (increasingly familiar) command below.

```
make
```

You should find a brand-new executable called `sudoku` in your current working directory. Go ahead and run it by typing the command below.

```
./sudoku
```

You won't yet see our skeleton but instead the game's usage:

```
Usage: sudoku n00b|l33t [#]
```

Not only does our skeleton support two levels of game play (n00b[4] and l33t[5]), it also comes with 1024 different boards for each level. Ultimately, if you'd like to play a pseudorandomly chosen n00b board, you'll want to execute just:[6]

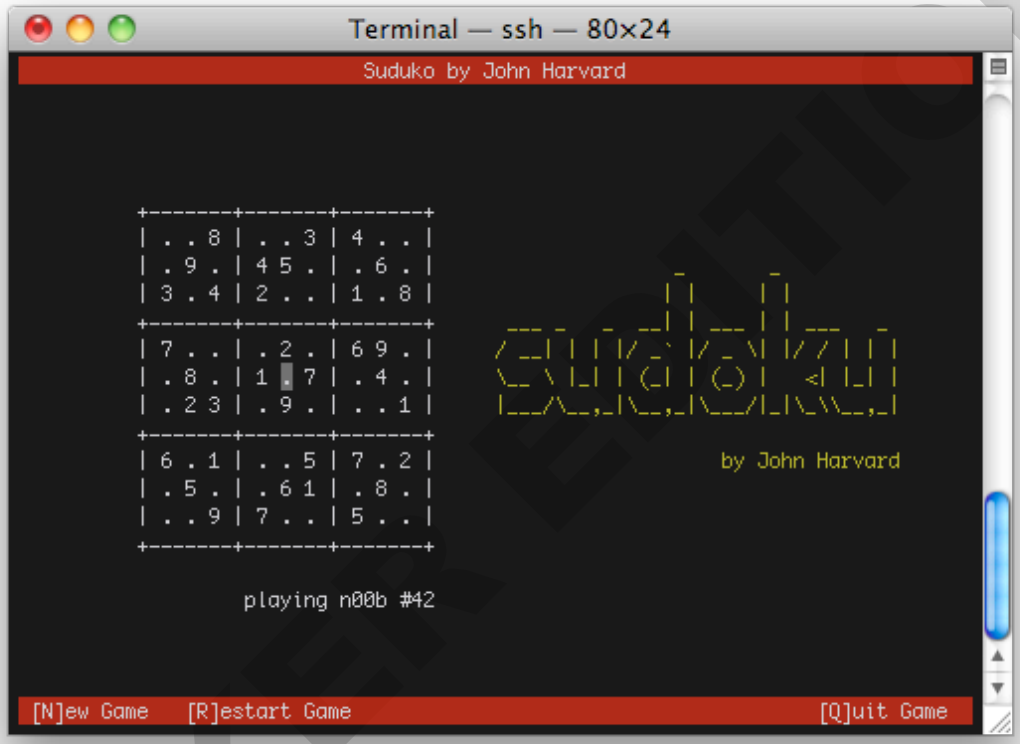
```
./sudoku n00b
```

[3] Annoyingly, yes, it's (y, x) and not (x, y).
[4] `http://en.wikipedia.org/wiki/Newbie`
[5] `http://en.wikipedia.org/wiki/Leet`
[6] Those are two zeroes in `n00b`.

Per the menu along the game's bottom, just hit Q to quit. Now, if you want to play a specific board (*e.g.*, n00b #42), perhaps one that defeated you earlier, you can load it up manually. In fact, go ahead and execute

```
./sudoku n00b 42
```

to fire up our skeleton with n00b #42. You should see a GUI like that below.[7]



Notice how, for clarity's sake, we use periods for blanks; underneath the hood, we represent each of those same blanks with 0 (an actual `int`). So this is all pretty neat, but this skeleton lacks that personal touch (not to mention support for moving the cursor). What do work out of the box are **[N]ew Game**, **[R]estart Game**, and **[Q]uit Game**. Go ahead and hit **Q** to quit.

Then open up `sudoku.h` (as with `nano`). You'll find in that file a whole bunch of constants that get compiled into the program. Go ahead and change, at least, `AUTHOR` to your own name. Feel free to change `TITLE` as well. To see the results, save your changes and quit. Then re-run `make` followed by `sudoku` itself. You've just made the program your own!

[7] If using PuTTY on Windows or Terminal on Mac OS, you should see a colorful GUI. If you're instead using SecureCRT on Windows and only see monochrome (*e.g.*, black and white), go to **Options** → **Session Options...** → **Terminal** → **Emulation**, and change **Terminal** to **Linux** and check the box next to **ANSI Color**. After clicking **OK**, go to **Options** → **Save Settings Now**. You may then need to log out and back in to see our GUI in color. If you can't get color to work, head to `help.cs50.net` for advice!

Now go back into `sudoku.h` and play with all those mentions of color. It turns out that ncurses deals with colors in pairs, whereby characters have both a foreground color and a background color. By default, characters' foregrounds are white and backgrounds are black. But clearly we've overridden those defaults for our skeleton's borders and logo. For now, you'll want to leave that `enum` alone, but feel free to change the values of any constants whose names begin with `FG_` or `BG_`. Here are the colors that ncurses comes with:

```
COLOR_BLACK
COLOR_RED
COLOR_GREEN
COLOR_YELLOW
COLOR_BLUE
COLOR_MAGENTA
COLOR_CYAN
COLOR_WHITE
```

You will, of course, need to recompile your game to see any colorful changes. Not all that hard to make one hideous game, eh?

Okay, now take a quick glance at `Makefile`. It should look pretty similar to the Game of Fifteen's, but take note that we've included a `-lncurses` flag. And be sure not to change the two tabs in that file to spaces!

Now take a look at, say, `n00b.bin`, but not with `nano` this time! Instead, execute the command below.[8]

```
xxd -b n00b.bin
```

Wow, a whole lot of numbers probably flew past. You've just looked at the contents of a binary file. Inside that file are a whole bunch of 32-bit `ints`, 1024 × 81 = 82,944 of them, in fact, as that file contains 1024 n00b boards, each of which includes 81 numbers and/or blanks (for a 9×9 grid).[9] Similarly does `l33t.bin` contain 1024 l33t boards.

Now that you've run `sudoku` at least once, you might also have noticed a file called `log.txt` that wasn't there when you first copied our code over. You're welcome to look, but you needn't pay much attention; it's generated by our framework in order to facilitate automated tests of your code.

Alright, we're really moving along. Only one file to go!

[8] Note that "n00b" is spelled with two zeroes!

[9] We could have used `unsigned chars` instead of `ints`, since Sudoku only needs numbers from 1 to 9, but we decided that `ints` would be simpler, despite the additional cost in space.

☐ Damn, there's a lot of code in this one.

Go ahead and open up `sudoku.c` (as with `nano`).

The best way to tackle this problem set is to start by understanding this file. We'll get you started.

First take note of one of the file's first lines:

```
#define CTRL(x) ((x) & ~0140)
```

Just as you can define what we know as constants with `#define`, you can also define "macros," short snippets of code that behave a little bit like functions but without the overhead (*e.g.*, stack frames) of an actual function call. This particular macro will enable you to detect control characters from users, if you so desire. Out of the box, our skeleton already understands ctrl-L, a keystroke meant to induce a redrawing of the game's screen.

Now take a look at the `struct` called `g` just below that macro. Per Week 5's first lecture, think of a `struct` as a wrapper that groups related variables together. Inside this particular `struct` is a whole bunch of fields, each of which can be accessed via the dot (`.`) operator (*e.g.*, `g.level`). Because `g` is a global variable, so are those fields effectively global as well. Truth be told, we could have defined those fields as global variables themselves without using a `struct`, much like we did for the Game of Fifteen. But because there are so many, all related to this game, we decided to keep them together in one big struct called `g`. That way, it'll be all the more obvious when these variables are used that they're not, in fact, locals.

Next notice our skeleton's prototypes. Much like we divided the Game of Fifteen into functions whose names described their particular role, similarly have we taken that approach here. But more on those later.

Now dive into `main`. Best, though, if we not hold your hand too much through this one. We daresay that learning to program is as much about writing your own programs as it is about reading others', particularly when your assignment (or job) is to build on the latter. Odds are you'll thank us some day for actually having comments in ours!

To be sure, there's a lot going on in this file, but you don't need to read each and every line (yet) to get a sense of the program's overall flow.

Do read each and every line in `main`, though. After all, that's the function that drives this whole program. And because our other functions' names rather say what those functions do, you can probably read `main` from top to bottom and have a pretty good idea of how the program currently works.

In fact, notice that we've embedded a secret `debug` level that has 9 boards. You should find that those boards, because they're solvable so quickly, facilitate debugging.

Next dive into some of the functions that `main` calls. A good one to start with is `startup`, as it gets ncurses going. Notice how it calls a bunch of other functions that appear to configure

ncurses. Although we've commented each call, you might want to pull up the man page for some or all of those functions, if only to get all the more comfortable with ncurses.

Next take a look at `load_board`, the function that loads a n00b or l33t (or debug) board from disk, depending on the value, if any, in `main`'s `argv[2]`. You needn't understand how `fopen`, `fseek`, `fread`, or `fclose` work for this problem set, but it is kind of neat how they get all those bits into memory. What this function ultimately does is load 81 `ints` into the global array called `g.board`. Not all that hard!

Let's see, next take a look at `draw_borders`. It's this function that creates the game's, well, borders. Of particular note in this function is how to use ncurses. Notice, for instance, that the function first determines your terminal window's dimensions using a macro called `getmaxyx` (that comes with ncurses).[10] It eventually uses those maxima to fill your window's topmost and bottommost rows with some color (and instructions). Notice how the function enables color, specifically turning on the `COLOR_PAIR` attribute that we called `PAIR_BORDER` (back in `suduko.h`). It then proceeds to draw the game's borders by moving, left to right, from coordinate to coordinate, laying down blank spaces. (Because we, at least, defined `PAIR_BORDER` with a red background, the results are "blank" lines filled with color.) But the function next lays down some text, centering your program's `TITLE` and `AUTHOR` in the topmost border using some simple arithmetic. It then plants some instructions in the bottommost border, before turning color back off.

Now take a look at `draw_grid`. It's this function that lays down the ASCII art that represents our game's board. Similarly does it first determine your window's dimensions. It then uses those values to determine coordinates for the grid's top-left corner. (We decided that we wanted the grid roughly in the middle of your window but slightly to the left, and so we came up with those formulas by trial and error.) Rather than generate this grid character by character, this function instead lays down whole strings (using ncurses' `mvaddstr` function). Specifically, this function moves the cursor to a specific coordinate and adds a string there. It then does that again and again (in that `for` loop) in order to print most of the game's grid. (Again, we determined most of those coordinates by trial and error.) We then thought it'd be neat to remind the user of the level and board that he or she is playing, and so we constructed a string on the fly using `sprintf`, and then added it to the screen with a final call to `mvaddstr`.

Incidentally, if curious to learn more about all these ncurses functions, `man` is your friend.[11]

Next glance at `draw_logo`. Notice how it bases its own coordinates on those of the grid. Notice, too, how distorted our logo looks. That's because we had to escape some of its backslashes with backslashes of our own! Do feel free to alter the logo. You might find this site a fun time:

`http://www.network-science.de/ascii/`

[10] It's because `getmaxyx` is a macro and not an actual function that you don't need to pass in its arguments by reference.

[11] Some functions don't actually have their own man page, so you might need to execute `man ncurses`, and then look for the **Manual Page Name** for some **curses Routine Name** of interest in the table that appears roughly halfway into ncurses's own man page.

Now look at `draw_numbers`. It's this function that fills that otherwise empty grid with the numbers in `g.board`. That kind of knowledge is bound to be useful! Why all the arithmetic in that function? Admittedly, it took a bit of trial and error to get right on our part, but it simply ensures that the numbers end up where they should on the screen and not on top of the grid's own lines.

Now glance at `show_banner` and `hide_banner`. Both pretty simple, these functions exist so that you can show (and hide) messages to users. In fact, while using ncurses, do not use `printf` as well. Bad things will happen.

Speaking of `show_banner`, why don't we also peek at `show_cursor`. Recall that functions like `mvaddch` and `mvaddstr` end up moving your cursor in order to add text to the screen. That's kind of annoying if you want to use that same cursor to play the actual game. And so it's necessary to remember where the cursor should be with respect to that grid. Glance back at that global called `g` and you'll see how we do it. This `show_cursor` function relies on that `struct` to return the cursor to where it should be after screen updates.

Let's see, you needn't worry too much about `handle_signal`. Just know that when terminal windows are resized (as from 80×24 to something larger or smaller), "signals" are generated. Our code is "listening" for that signal so that we can respond to resizings by re-centering everything.

Okay, so that only leaves `log_move`, `redraw_all`, `restart_game`, and `shutdown`. Those you can handle! Take the same approach that we took here, walking through each function, pulling up man pages as needed, and only move on once you understand each function's flow.

So that's everything. Not bad for 600+ lines.

☐ Okay, a few questions for you. Create a file called `questions.txt` in `~/hacker4/` using `nano` (remember how?) and record in it your answers to the below!

i. Notice that `main` calls `strcmp`. What does it mean if `strcmp`, when passed two strings as arguments, returns `0`? (Hint: RTFM!)
ii. How would you rewrite the line below, excerpted from `main`, using keywords `if` and `else`?
```
int max = (!strcmp(g.level, "debug")) ? 9 : 1024;
```
iii. Under what circumstances might the call to `sscanf` below, excerpted from `main`, return `2` instead of 1?
```
sscanf(argv[2], " %d %c", &g.number, &c)
```
iv. What fields in `g` represent the coordinates at which the user's cursor belongs?
v. What function (that we wrote) can you call to make the cursor actually appear at those coordinates? (Hint: we told you a few paragraphs ago!)
vi. Around what line number in `main` could you add additional `case` statements to handle keystrokes besides N, R, and ctrl-L?
vii. Most n00b and l33t boards have lots of blanks. But how many blanks are in debug #1? In debug #2? And in debug #9?

☐ Because `sudoku` has a GUI, debugging it with `gdb` can be a bit tricky, since you probably don't want `gdb`'s output messing up the GUI itself. Not a problem, though! You can actually run `sudoku` in one terminal (*i.e.*, SSH) window and `gdb` in another! So that you know how to do it, let's give it a try now.

Odds are at the moment you have just one terminal window open. Go ahead and execute the command below:

```
hostname
```

Recall that `cloud.cs50.net` is actually a cluster of servers. That command tells you the name of the specific server in the cluster that you happen to be connected to at the moment. Take note of that name.

Then SSH to `cloud.cs50.net` in a second window, logging in as needed, and execute `hostname` in that second window. If you don't see the same name, go ahead and log out in that second window and try one or more times until the names match.

Once you have two windows with connections to the same server, arrange them so that you can see (at least part of) both at once. Then, in one window, run this command:

```
./sudoku n00b 42 &
```

That ampersand (`&`) at the end of the command will tell your shell to "background" `sudoku` (*i.e.*, run it in the background, much like a minimized window in Mac OS or Windows). The implication is that you won't actually see `sudoku`'s GUI (yet), but you will see its "process ID" (aka PID), which is simply a number that uniquely identifies your running copy of `sudoku` among all the other programs running on the server at the moment. Go ahead and highlight and copy that number (or, at least, remember it). And then "foreground" (*i.e.*, maximize) `sudoku` by executing this command:

```
fg
```

You should see the game's GUI. Now, in your second terminal window, run

```
gdb ./sudoku #
```

where `#` is the number you just copied or remembered. Because you've provided a process's PID, `gdb` will proceed to "attach" itself to that process (not unlike a snail to a shell) [12] so that you can debug it remotely (*i.e.*, in a separate window). After a whole bunch of output, you should see `gdb`'s prompt. Let's go ahead and set a breakpoint in `draw_numbers`, a function you looked at earlier. Execute the command below at `gdb`'s prompt in `gdb`'s window:

```
break draw_numbers
```

[12] Okay, this is pretty unlike that.

Now, when `gdb` attached itself to `sudoku` earlier, it actually suspended (*i.e.*, paused) execution of the latter. And so we need to tell `gdb` to resume execution of `sudoku` so that you can start interacting with it again. Execute the command below at `gdb`'s prompt in `gdb`'s window:

```
continue
```

Okay, at this point in the story, both `sudoku` and `gdb` are running, each in its own window, with `gdb` "watching" `sudoku`, just waiting for the latter to hit that breakpoint in `draw_numbers`. Let's make that happen. In `sudoku`'s window, hit **N** to start a new game. Because of that `do-while` loop (and `switch`) in `main`, `restart_game` will get called, which will eventually call `draw_numbers`. Indeed, if you now look at `gdb`'s window, you should see that you've hit that breakpoint in `draw_numbers`! Go ahead and start executing `draw_numbers` line by line by executing

```
next
```

at `gdb`'s prompt again and again. You should find that, after each iteration of the inner loop in `draw_numbers`, a new number gets drawn on the board in `sudoku`'s window. Neat, eh? Anyhow, executing `next` so many times will quickly get boring, so execute

```
continue
```

as soon as you're bored; that'll tell `gdb` to finish executing `draw_numbers`. Since you yourself haven't written any code yet to debug, go ahead and quit `sudoku` now by hitting **Q** in its window. Then execute

```
quit
```

at `gdb`'s prompt in `gdb`'s window to quit `gdb` too. Phew. Feels like a lot of steps, but you'll get the hang of it before long. You will come to appreciate the power you now have!

Incidentally, if you find that `sudoku` or `gdb` isn't behaving as we've promised, odds are that you simply missed some step above or did something in the wrong order. Not to worry. Just quit both `sudoku` and `gdb`, close your terminal windows, and start fresh with two new ones!

When it comes time to chase down some bug in your own code, remember that you now have this power!

☐ The funny thing is that none of the 600+ lines we wrote actually implement Sudoku. But that's where you come in! Your challenge for this problem set is to implement a few features, among them support for actual game play! Specifically, you must implement each of the REQUIRED FEATURES below; you are welcome, but not required, to implement any of the ADD-ONS.

This problem set is perhaps more about design than anything else, so do give some thought about how best to implement some feature, given the game's framework. With that said, you are welcome to change most any aspect of our code if the change fits your design better. However, what you must not change is anything related to logging, including `log_move`. So that we can

automate some tests of your code, your program, no matter your changes, must still call our implementation of `log_move` after each keystroke from users, whether or not that keystroke actually altered the board.

Alright, get to it! Here's your menu of features. Know that we've enumerated the REQUIRED FEATURES in the order in which they should probably be implemented.

REQUIRED FEATURES

☐ At the moment, the cursor is "stuck" in the board's center. Enable users to move that cursor up, down, left, and right by way of their keyboard's arrow keys. You're welcome to support other keys for movement as well, but you must support `KEY_UP`, `KEY_DOWN`, `KEY_LEFT`, and `KEY_RIGHT`, constants that represent the characters fed to ncurses' `getch` function when arrow keys are pressed. (See `getch`'s man page for even more constants.) You should only allow the user to move his or her cursor to coordinates where there are actual numbers or blanks (*i.e.*, the cursor should "hop over" one-character lateral gaps between cells as well as the innermost crossbars that make up the grid's lines), but you should find that the arithmetic already implemented in `show_cursor` helps with that! Even though you might be tempted to make the cursor hop over numbers that came with the board (*i.e.*, that cannot be changed), resist the temptation; allow the cursor to be in any one of those 81 cells.

☐ Enable the user to replace any blank with a number by moving his or her cursor over that blank and then hitting a number from 1 to 9.

☐ Enable the user to change a number that he or she already inputted back to a blank by hitting any of 0, a period, `KEY_BACKSPACE`, or `KEY_DC` or to some other number from 1 to 9 by hitting that number.[13] But do not allow the user to alter numbers that "came with" the board.

☐ Any time the user changes the board, check whether the game has been won. If so, display a congratulatory banner and prevent the user from changing the board further.

☐ Any time the user changes the board, check whether he or she has inserted a number where it does not belong at the moment (because that same number already exists in the same column or row or 3×3 box). If so, display a banner warning the user of the problem that disappears the moment the user changes the board again (unless the change is also a problem, in which case the user should again be warned).

☐ Add to the game a **[H]int** feature, whereby hitting H fills in a blank (with a correct number) on behalf of the user each time that it's called during play.[14]

[13] Know that `KEY_BACKSPACE` and `KEY_DC` generally map to a keyboard's Backspace and Delete keys, respectively, if they're actually present. Don't worry if your own Backspace and/or Delete keys don't seem to work, even though you're listening for `KEY_BACKSPACE` and `KEY_DC`; some keyboards send different codes altogether.

[14] Afraid the boards' solutions are not in those `.bin` files, in case you're wondering!

ADD-ONS (IMPLEMENT ZERO (0) OR MORE OF THESE)
Make clear in the comments atop `sudoku.c` which of these features you implemented, if any.

- ☐ In addition to displaying a congratulatory banner, turn all 81 numbers green when the game has been won.
- ☐ In addition to warning the user of obvious mistakes with a banner, turn the column, row, or 3×3 box with the error red until the mistake is corrected.
- ☐ Enable the cursor to "wrap around" from the top row to bottom, bottom to top, left to right, or right to left if the user presses `KEY_UP`, `KEY_DOWN`, `KEY_LEFT`, or `KEY_RIGHT`, respectively, one too many times.
- ☐ Display numbers that "came with" the board in a different color than those that the user has inputted.
- ☐ Keep track (in seconds) of the amount of time that the user has been playing the current board and allow the user to show or hide that clock at any time by hitting T. Be sure to stop the clock the moment the game has been won.
- ☐ Allow the user to undo the last change made to the board by hitting U or ctrl-Z.

☐ Don't forget about `help.cs50.net`! If you'd like to play with the staff's own implementation of `sudoku`, you may execute the below.

```
~cs50/pub/solutions/hacker4/sudoku
```

Sanity Checks.

Before you consider this problem set done, best to ask yourself these questions and then go back and improve your code as needed! Do not consider the below an exhaustive list of expectations, though, just some helpful reminders. The checkboxes that have come before these represent the exhaustive list! To be clear, consider the questions below rhetorical. No need to answer them in writing for us, since all of your answers should be "yes!"

- ☐ Did you create `questions.txt` and answer those questions?
- ☐ Did you get all four arrow keys to work?
- ☐ Can a user reach all 81 cells on the board via those arrow keys?
- ☐ When the user moves his or her cursor, does it hop over the game's grid (*i.e.*, lines) automatically?
- ☐ Can the user change blanks to numbers as well as numbers to other numbers?
- ☐ Can the user change numbers (that he or she inputted) back to blanks?
- ☐ Are you detecting when the game's been won?
- ☐ Are you preventing the user from moving the cursor once the game's been won?
- ☐ Are you warning the user with a banner when he or she inputs a number where it doesn't belong?
- ☐ Did you get hints to work?
- ☐ Are all of your files where they should be in `~/hacker4/`?

As always, if you can't answer "yes" to one or more of the above because you're having some trouble, do drop by office hours or turn to `help.cs50.net`!

How to Submit.

In order to submit this problem set, you must first execute a command on `cloud.cs50.net` and then submit a (brief) form online; the latter will be posted after lecture on Wed 10/6.

☐ SSH to `cloud.cs50.net`, if not already there, and then submit your code by executing:

```
~cs50/pub/bin/submit hacker4
```

You'll know that the command worked if you are informed that your "work HAS been submitted." If you instead encounter an error that doesn't appear to be a mistake on your part, do try running the command one or more additional times.

☐ Anytime after lecture on Wed 10/6 but before this problem set's deadline, head to the URL below where a short form awaits:

`http://www.cs50.net/psets/4/`

If not already logged in, you'll be prompted to log into the course's website.

Once you have submitted that form (as well as your source code), you are done!

This was Problem Set 4.

Puzzle 1 (Medium, difficulty rating 0.55)

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

Puzzle 2 (Easy, difficulty rating 0.39)

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

Puzzle 3 (Hard, difficulty rating 0.75)

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

Puzzle 4 (Medium, difficulty rating 0.49)

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

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Puzzle 5 (Hard, difficulty rating 0.61)

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

Puzzle 6 (Medium, difficulty rating 0.53)

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

Puzzle 7 (Medium, difficulty rating 0.47)

	1			5			2	
		5	6			1	8	
	6	7			9			5
1			7				6	
	3						7	
	9				1			8
6			8			2	1	
	2	9			3	6		
	7			2			9	

Puzzle 8 (Hard, difficulty rating 0.71)

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

Puzzle 9 (Easy, difficulty rating 0.35)

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

Puzzle 10 (Easy, difficulty rating 0.43)

6		4	9		7		8	
9	8							3
					3			4
		5		3	9	8		
	9			7			3	
		8	5	6		7		
4			3					
2							4	8
	6		2		5	9		7

Puzzle 11 (Medium, difficulty rating 0.56)

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

Puzzle 12 (Easy, difficulty rating 0.35)

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

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Puzzle 13 (Medium, difficulty rating 0.50)

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

Puzzle 14 (Medium, difficulty rating 0.53)

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

Puzzle 15 (Easy, difficulty rating 0.37)

			4				1	5
	9	5	6	2				
		2	8					9
			5	8				1
	6		2		1		3	
4				9	6			
9					8	3		
				4	2	9	8	
6	2				3			

Puzzle 16 (Very hard, difficulty rating 0.84)

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

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Puzzle 17 (Hard, difficulty rating 0.60)

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

Puzzle 18 (Medium, difficulty rating 0.48)

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

Puzzle 19 (Medium, difficulty rating 0.48)

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

Puzzle 20 (Hard, difficulty rating 0.65)

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

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Puzzle 21 (Easy, difficulty rating 0.40)

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

Puzzle 22 (Hard, difficulty rating 0.61)

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

Puzzle 23 (Easy, difficulty rating 0.45)

			4	6		8		
						7		3
6		7			8		5	
	5	4	7	2			8	
3								5
	6			4	5	2	9	
	7		5			6		9
2		6						
		3		7	2			

Puzzle 24 (Hard, difficulty rating 0.60)

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

Puzzle 25 (Medium, difficulty rating 0.56)

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

Puzzle 26 (Medium, difficulty rating 0.50)

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

Puzzle 27 (Medium, difficulty rating 0.47)

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

Puzzle 28 (Medium, difficulty rating 0.46)

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

Puzzle 29 (Easy, difficulty rating 0.42)

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

Puzzle 30 (Easy, difficulty rating 0.28)

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

Puzzle 31 (Easy, difficulty rating 0.40)

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

Puzzle 32 (Easy, difficulty rating 0.44)

5					1	7		6
		7		8			3	
8			7				5	
6		9	1					
		8	3	7	6	5		
					9	1		8
	9				7			2
	1			9		8		
3		5	2					7

Puzzle 33 (Easy, difficulty rating 0.43)

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

Puzzle 34 (Easy, difficulty rating 0.38)

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

Puzzle 35 (Easy, difficulty rating 0.41)

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

Puzzle 36 (Very hard, difficulty rating 0.86)

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

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Puzzle 37 (Easy, difficulty rating 0.44)

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

Puzzle 38 (Easy, difficulty rating 0.45)

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

Puzzle 39 (Hard, difficulty rating 0.67)

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

Puzzle 40 (Hard, difficulty rating 0.61)

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

Puzzle 41 (Medium, difficulty rating 0.50)

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

Puzzle 42 (Medium, difficulty rating 0.48)

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

Puzzle 43 (Easy, difficulty rating 0.35)

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

Puzzle 44 (Very hard, difficulty rating 0.78)

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

Puzzle 45 (Medium, difficulty rating 0.53)

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

Puzzle 46 (Easy, difficulty rating 0.35)

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

Puzzle 47 (Medium, difficulty rating 0.48)

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

Puzzle 48 (Hard, difficulty rating 0.60)

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

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Puzzle 1 (Medium, difficulty rating 0.55)

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

Puzzle 2 (Easy, difficulty rating 0.39)

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

Puzzle 3 (Hard, difficulty rating 0.75)

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

Puzzle 4 (Medium, difficulty rating 0.49)

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

Puzzle 5 (Hard, difficulty rating 0.61)

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

Puzzle 6 (Medium, difficulty rating 0.53)

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

Puzzle 7 (Medium, difficulty rating 0.47)

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

Puzzle 8 (Hard, difficulty rating 0.71)

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

Puzzle 9 (Easy, difficulty rating 0.35)

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

Puzzle 10 (Easy, difficulty rating 0.43)

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

Puzzle 11 (Medium, difficulty rating 0.56)

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

Puzzle 12 (Easy, difficulty rating 0.35)

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

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Puzzle 13 (Medium, difficulty rating 0.50)

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

Puzzle 14 (Medium, difficulty rating 0.53)

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

Puzzle 15 (Easy, difficulty rating 0.37)

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

Puzzle 16 (Very hard, difficulty rating 0.84)

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

Puzzle 17 (Hard, difficulty rating 0.60)

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

Puzzle 18 (Medium, difficulty rating 0.48)

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

Puzzle 19 (Medium, difficulty rating 0.48)

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

Puzzle 20 (Hard, difficulty rating 0.65)

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

Puzzle 21 (Easy, difficulty rating 0.40)

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

Puzzle 22 (Hard, difficulty rating 0.61)

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

Puzzle 23 (Easy, difficulty rating 0.45)

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

Puzzle 24 (Hard, difficulty rating 0.60)

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

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Puzzle 25 (Medium, difficulty rating 0.56)

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

Puzzle 26 (Medium, difficulty rating 0.50)

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

Puzzle 27 (Medium, difficulty rating 0.47)

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

Puzzle 28 (Medium, difficulty rating 0.46)

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

Puzzle 29 (Easy, difficulty rating 0.42)

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

Puzzle 30 (Easy, difficulty rating 0.28)

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

Puzzle 31 (Easy, difficulty rating 0.40)

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

Puzzle 32 (Easy, difficulty rating 0.44)

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

Puzzle 33 (Easy, difficulty rating 0.43)

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

Puzzle 34 (Easy, difficulty rating 0.38)

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

Puzzle 35 (Easy, difficulty rating 0.41)

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

Puzzle 36 (Very hard, difficulty rating 0.86)

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

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Puzzle 37 (Easy, difficulty rating 0.44)

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

Puzzle 38 (Easy, difficulty rating 0.45)

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

Puzzle 39 (Hard, difficulty rating 0.67)

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

Puzzle 40 (Hard, difficulty rating 0.61)

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

Puzzle 41 (Medium, difficulty rating 0.50)

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

Puzzle 42 (Medium, difficulty rating 0.48)

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

Puzzle 43 (Easy, difficulty rating 0.35)

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

Puzzle 44 (Very hard, difficulty rating 0.78)

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

Puzzle 45 (Medium, difficulty rating 0.53)

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

Puzzle 46 (Easy, difficulty rating 0.35)

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

Puzzle 47 (Medium, difficulty rating 0.48)

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

Puzzle 48 (Hard, difficulty rating 0.60)

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

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