Parallel Computing Notes
Topic: Halo Exchange: Game of Life

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Last Update: 10/16/17
Created: 3/1/16

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Halo Exchange Example: Conways Game of Life

Conways Game of Life

- Game of Life is a cellular automaton (CA).
- Described in 1970 Scientific American Article: http://www.ibiblio.org/lifepatterns/october1970.html
- Interesting behaviors: See: https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life
- How to do it:
  - http://www.wikihow.com/Make-the-Conway's-Game-of-Life-Cellular-Automaton
- Relevant links:
  - LifeLab: http://trevorrow.com/lifelab/index.html
  - http://www.math.com/students/wonders/life/life.html
  - http://www.cs.mcgill.ca/~rwest/link-suggestion/wpcd_2008-09_augmented/wp/c/Conway%2527s_Game_of_Life.htm
- Parallel hints:
  - http://extremecomputingtraining.anl.gov/files/2015/03/mlife-code-jul30-830.pdf
  - http://web.csc.fi/english/csc/courses/archive/material/prace-summer-school-materal/MPI-tutorial

Conways Game of Life - Overview

- Life is played on an arbitrary-sized grid of square cells.
- Each cell has two states: "dead" or "alive".
- The state of every cell changes from one "generation" to the next according to the states of its 8 nearest neighbors:
  - a dead cell becomes alive (a "birth") if it has exactly 3 live neighbors;
  - a live cell dies out if it has less than 2 or more than 3 live neighbors.
- The "game" of Life simply involves starting off with a pattern of live cells and watching it evolve.
- Even though the rules for Life are completely deterministic, it is impossible to predict whether an arbitrary starting pattern will die out, or start oscillating, or fill the grid.
- Life and other CAs provide a powerful demonstration of how a very simple system can generate extremely complicated behavior.

Source: http://trevorrow.com/lifelab/index.html

Game of Life Programming Example: using basic arrays

Conways Game of Life: using basic arrays

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode src: Basic

```
#include <stdio.h>
#define HEIGHT 25
#define WIDTH 25
#define LIFE_YES 1
#define LIFE_NO 0

// make the rest of the function calls easier to read
typedef int TableType[HEIGHT][WIDTH];

void printTable(TableType table) {
    int height, width;

    for (height = 0; height < HEIGHT; height++) {
        for (width = 0; width < WIDTH; width++) {
            if (table[height][width] == LIFE_YES) {
                printf("X");
            } else {
                printf("-");
            }
        }
        printf("\n");
    }
    printf("\n");
}

// you already have a printTable, no need for this clear was a better name
void clearTable(TableType table) {
    int height, width;
    for (height = 0; height < HEIGHT; height++)
        for (width = 0; width < WIDTH; width++)
            table[height][width] = LIFE_NO;
}
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode src: Basic

```
int getNeighborValue(TableType table, int row, int col) {
    if (row < 0 || row >= HEIGHT
        || col < 0 || col >= WIDTH
        || table[row][col] != LIFE_YES )
    {
        return 0;
    } else {
        return 1;
    }
}


int getNeighborCount(TableType table, int row, int col) {
    int neighbor = 0;

    neighbor += getNeighborValue(table, row - 1, col - 1);
    neighbor += getNeighborValue(table, row - 1, col);
    neighbor += getNeighborValue(table, row - 1, col + 1);
    neighbor += getNeighborValue(table, row, col - 1);
    neighbor += getNeighborValue(table, row, col + 1);
    neighbor += getNeighborValue(table, row + 1, col - 1);
    neighbor += getNeighborValue(table, row + 1, col);
    neighbor += getNeighborValue(table, row + 1, col + 1);

    return neighbor;
}
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode src: Basic

```
// code to load test data
void loadTestData(TableType table) {
    // toggle
    table[3][4] = LIFE_YES;
    table[3][5] = LIFE_YES;
    table[3][6] = LIFE_YES;

    // glider
    table[10][4] = LIFE_YES;
    table[10][5] = LIFE_YES;
    table[10][6] = LIFE_YES;
    table[11][6] = LIFE_YES;
    table[12][5] = LIFE_YES;
}
```

```
void loadGliderData(TableType table) {
    int r,c;
    r=HEIGHT/2;
    c=WIDTH/2;
    // ***
    // *..
    // .*.
    table[r][c] = LIFE_YES;
    table[r][c+1] = LIFE_YES;
    table[r][c+2] = LIFE_YES;

    table[r+1][c] = LIFE_YES;

    table[r+2][c+1] = LIFE_YES;
}
```

```
// Load Rabbits pattern:: (stabilizes at time 17331)
// A 9-cell {methuselah} found by Andrew Trevorrow in 1986.
//    *...***
//    ***..*.
//    .*.....
//
//  place in center
//
void loadRabbitData(TableType table) {
    int r,c;
    r=HEIGHT/2;
    c=WIDTH/2;
    // rabbits
    table[r][c] = LIFE_YES;
    table[r][c+4] = LIFE_YES;
    table[r][c+5] = LIFE_YES;
    table[r][c+6] = LIFE_YES;

    table[r+1][c] = LIFE_YES;
    table[r+1][c+1] = LIFE_YES;
    table[r+1][c+2] = LIFE_YES;
    table[r+1][c+5] = LIFE_YES;

    table[r+2][c+1] = LIFE_YES;
}
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode src: Basic

```
void calculate(TableType tableA) {
    TableType tableB;
    int neighbor, height, width;

    for (height = 0; height < HEIGHT; height++) {
        for (width = 0; width < WIDTH; width++) {
            neighbor = getNeighborCount(tableA, height, width);
            // change this arund to remove the ? : notation
            if (neighbor==3) {
                tableB[height][width] = LIFE_YES;
            } else if (neighbor == 2 && tableA[height][width] == LIFE_YES) {
                tableB[height][width] = LIFE_YES;
            } else {
                tableB[height][width] = LIFE_NO;
            }
        }
    }
    // used to be swap
    for (height = 0; height < HEIGHT; height++) {
        for (width = 0; width < WIDTH; width++) {
            tableA[height][width] = tableB[height][width];
        }
    }
}
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode src: Basic

```
main(int argc, char *argv[]) {

    TableType table;
    char end;
    int stab, pop;
    int generation = 0;

    clearTable(table);
    //askUser(table);
    //loadTestData(table);
    loadGliderData(table);
    //loadRabbitData(table);
    //loadRpentominoData(table);
    printTable(table);

    do {
         calculate(table);
         printTable(table);
         printf("Generation %d\n", ++generation);
         printf("Press q to quit or 1 to continue: ");
         scanf(" %c", &end);
      } while (end != 'q') ;
    return 0;
}
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: Dreamincode Output

```
======================================

    #      # #
           # #
  ###       #
    #   ### #
# #                #
        #### ## ## #
             #  ###
   # #########  ##
#  # ##        # ###
 ## ## ## ## # #
 ##  #     # #   ###
##      #   ##
  ##    ###  ##   #
 ####   #
#  # ####
## # # #
####    #### # #  ##
# # #      # #  ###
# ###     #### # ##
           # #
======================================
```

Source: http://www.dreamincode.net/forums/topic/73284-the-game-of-life-in-source-c/

Conways Game of Life: using structs and objects

Conways Game of Life: using structs and objects

Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway%27s-game-code-c.html

GOL Programming Example: using structs and objects

```
#include <stdio.h>
#include <stdlib.h>

#define ROWS 20
#define COLS 20

#define GETCOL(c) (c%COLS)
#define GETROW(c) (c/COLS)

#define D_LEFT(c)   ((GETCOL(c) == 0) ? (COLS-1) :  -1)
#define D_RIGHT(c)  ((GETCOL(c) == COLS-1) ? (-COLS+1) :  1)
#define D_TOP(c)    ((GETROW(c) == 0) ? ((ROWS-1) * COLS) : -COLS)
#define D_BOTTOM(c) ((GETROW(c) == ROWS-1) ? (-(ROWS-1) * COLS) : COLS)


typedef struct _cell
{
    struct _cell *neighbour[8];
    char curr_state;
    char next_state;
}cell;


typedef struct
{
    int rows;
    int cols;
    cell* cells;
} world;
```

Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway%27s-game-code-c.html

GOL Programming Example: using structs and objects

```
void evolve_cell(cell *c)
{
    int count=0, i;
    for (i=0; i<8; i++)
    {
        if (c->neighbour[i]->curr_state) count++;
    }
    if (count == 3 || (c->curr_state && count == 2)) c->next_state = 1;
    else c->next_state = 0;

}


void update_world(world *w)
{
    int nrcells = w->rows*w->cols, i;
    for (i=0; i<nrcells; i++)
    {
        evolve_cell(w->cells+i);
    }
    for (i=0; i<nrcells; i++)
    {
        w->cells[i].curr_state = w->cells[i].next_state;
        if (!(i%COLS)) printf("\n");
        printf("%c",w->cells[i].curr_state ? '#' : ' ');
    }
    printf("\n");
}
```

Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway%27s-game-code-c.html

GOL Programming Example: using structs and objects

```
world* init_world()
{
    world* result = (world*) malloc(sizeof(world));
    result->rows = ROWS;
    result->cols = COLS;
    result->cells = (cell*) malloc(sizeof(cell) * COLS * ROWS);

    int nrcells = result->rows * result->cols, i;

    for (i = 0; i < nrcells; i++)
    {
        cell* c = result->cells + i;

        c->neighbour[0] = c+D_LEFT(i);
        c->neighbour[1] = c+D_RIGHT(i);
        c->neighbour[2] = c+D_TOP(i);
        c->neighbour[3] = c+D_BOTTOM(i);
        c->neighbour[4] = c+D_LEFT(i)   + D_TOP(i);
        c->neighbour[5] = c+D_LEFT(i)   + D_BOTTOM(i);
        c->neighbour[6] = c+D_RIGHT(i)  + D_TOP(i);
        c->neighbour[7] = c+D_RIGHT(i)  + D_BOTTOM(i);

        c->curr_state = rand() % 2;
    }
    return result;
}
```

Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway%27s-game-code-c.html

GOL Programming Example: using structs and objects

```
int main()
{
    srand(3);
    world* w = init_world();

    while (1)
    {
        printf("\n=======================================\n");
        //system("cls");
        update_world(w);
        getchar();
    }
}
```

Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway%27s-game-code-c.html

Conways Game of Life: using structs and objects

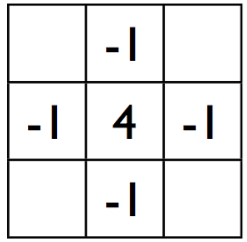
Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway

GOL Programming Example: using structs and objects

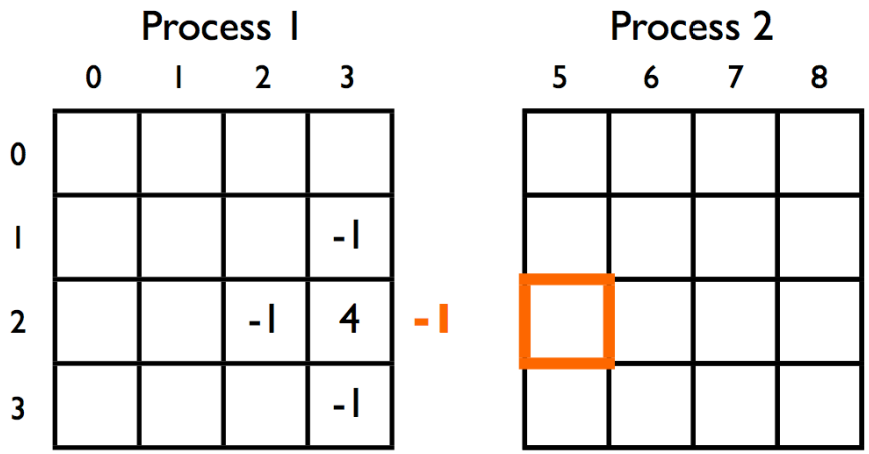
Source: http://cboard.cprogramming.com/c-programming/138126-recomposing-conway

Game of Life Using MPI Halo Exchange

MPI Halo Exchange



(a) 5-Point Stencil

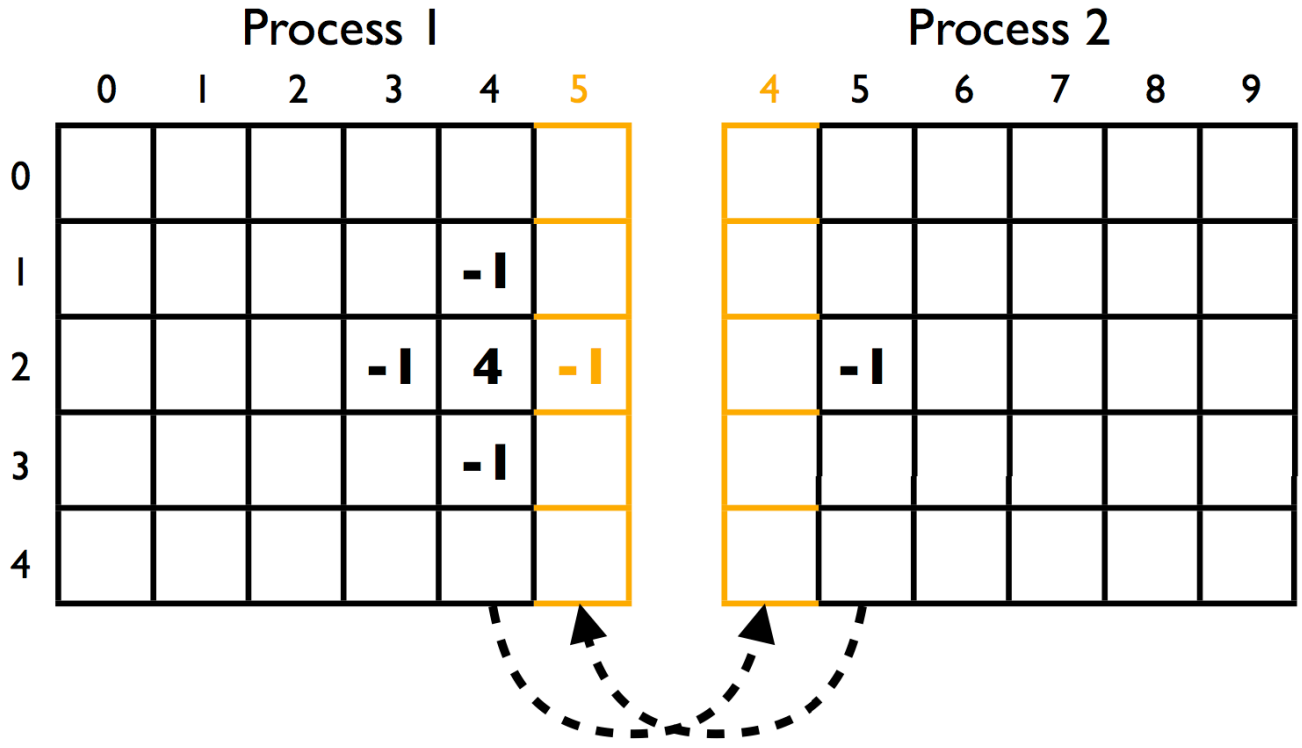


(b) Stencil that needs a cell from its neighbor

Stencil computation in geometrically decomposed grids.

Source: F. B. Kjolstad and M. Snir, Ghost Cell Pattern, in Proceedings of the 2010 Workshop on Parallel Programming Patterns

MPI Halo Exchange



Ghost Cell Layout: Each chunk receives a vector of ghost cells from neighboring chunks.

Source: F. B. Kjolstad and M. Snir, Ghost Cell Pattern, in Proceedings of the 2010 Workshop on Parallel Programming Patterns

Deadlock-freeI Halo Exchange

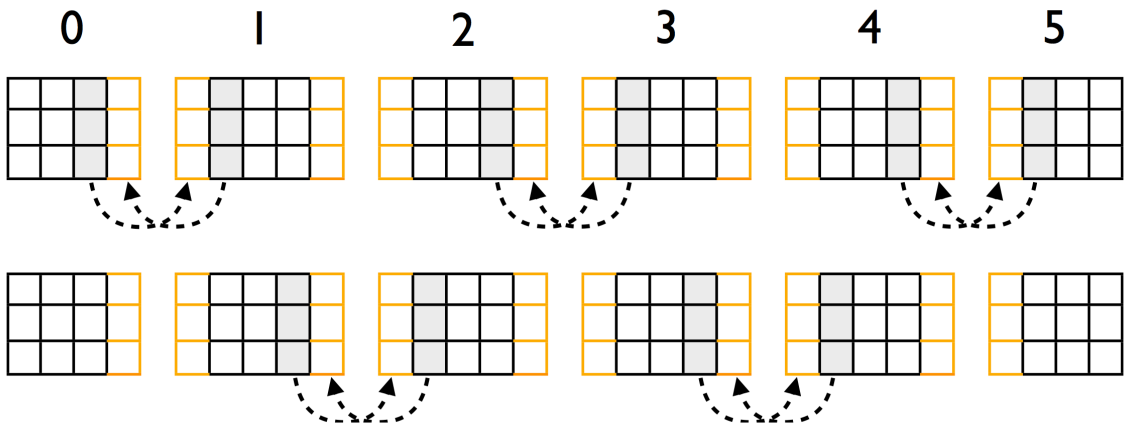


Figure 5: Deadlock-free border exchanges

```
void exchange ? horizontal borders () {
     if (x coord % 2 == 0) {
          exchange east border ();
          exchange west border ();
     }
     else   {
          exchange west border ();
          exchange east border ();
     }
}
```

Source: F. B. Kjolstad and M. Snir, Ghost Cell Pattern, in Proceedings of the 2010 Workshop on Parallel Programming Patterns

A few GOL Notes and observations

General GOL Rules:

- Any live cell with fewer than two live neighbors dies, as if caused by under-population.
- Any live cell with two or three live neighbors lives on to the next generation.
- Any live cell with more than three live neighbors dies, as if by over-population.
- Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.

Game of Life: Patterns

- GOL has many different "patterns"
- You build patterns by setting cells on/off on the grid.
- Lexicon (list) of patterns:
  `https://www.mathworks.com/moler/exm/exm/lexicon.txt`
- some good examples:
  `http://www.math.cornell.edu/~lipa/mec/lesson6.html`

Game of Life: Rabbit Pattern

- The Rabbit pattern is a Methuselah pattern
  - A methuselah is any 'small' pattern which takes a 'long time' to 'finish' or stabilize
  - http://www.conwaylife.com/wiki/Methuselah
  - http://www.radicaleye.com/DRH/methuselahs.html
  - stable: A pattern is said to be stable if it is a parent of itself.
- List of long lived Methuselahs: `http://www.conwaylife.com/wiki/List_of_long-lived_methuselahs`

Game of Life: Rabbit Pattern

- Rabbits: Initial pattern contains a "male" and a "female" rabbit, using total of 9 active cells.
- The initial pattern is the first generation.
- Rabbits pattern:: A 9-cell Methuselah found by Andrew Trevorrow in 1986.

```
*...***
***..*.
.*.....
```

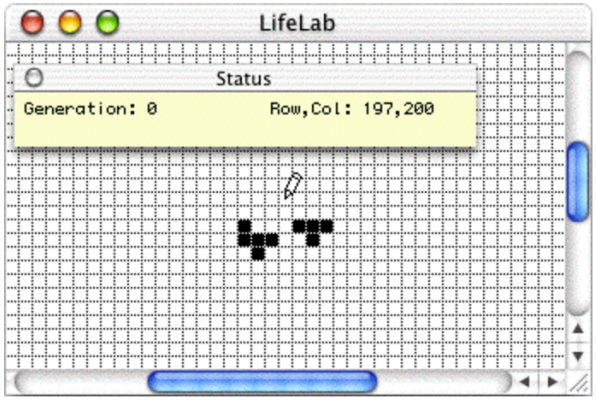
- Predecessor (Trevorrow in October 1995) has the same number of cells and lasts two generations longer.

```
..*.*
**
.**.***.
```

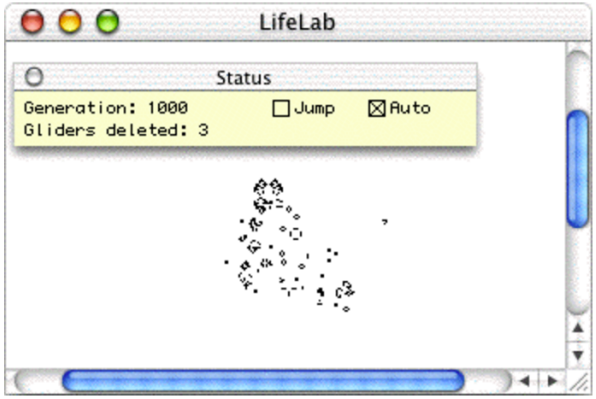
- The rabbit pattern stabilizes at 17331 generations, and a live population of 1744.

Visual Example: LifeLab Rabbit Test Case

The initial pattern has 9 live cells. The male rabbit is on the left. :)
[scale = 8 pixels per cell]



fter 1000 generations the pattern has expanded into a number of active regions.
The escaping glider on the right is about to be deleted.
[scale = 1 pixel per cell]



lifelab rabbit.

Source: `http://trevorrow.com/lifelab/index.html`

Game of Life: Hints on the rabbit pattern

- Run the model until the generations "stabilize":
  for rabbit pattern, live population = 1744, after 17331 generations
- Observe live population # as a function of generation #:
  Hint: this will be affected by the board dimensions.
- Grid/Board: Game of Life based on infinite space
  - For rabbit pattern, you need to have enough generations to reach a live population of 1744.
    Hint: you only need to run at most 18,000 generations.
  - You need a grid of cells *large* enough to achieve stability for the Methuselah patterns.
  - "Basic" game of life example – function below kills all life on the edges

```
int getNeighborValue(TableType table, int row, int col) {
    if (row < 0 || row >= HEIGHT  || col < 0 || col >= WIDTH
           || table[row][col] != LIFE_YES )
    {
        return 0;
    } else {
        return 1;
    }
}
```

Game of Life: Small Test Case

The next slide contain snippets of the test case run below. You can find the full file on tuckoo in /COMP705

```
################################################################
#  test case data for a 50x50 grid -- just as an example
#  codes are named for grid size
#  args passed include:
#        - name of the pattern
#         - max number of generations
################################################################

[gidget:ga1meoflife/ser/basic] mthomas% ./gameoflife.v2.50x50
   Error: Not enough arguments, argv= 1
   Usage: gameoflife <pattern test number> <max #generations>
       Where lextype='0'(rabbit);'1'(test);'2'(glider) '3'(Rpentimono);

################################################################
#    correct usage
################################################################
[gidget:gameoflife] mthomas% ./gameoflife.50x50 0 50
```

```
####################################
# the 'dots' are dead/null.
####################################
| ............................................... |
| ............................................... |
| ............................................... |

[ dead cell rows ]

| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ........................X...XXX.................. |
| ........................XXX..X.................. |
| .........................X....................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |


[ dead cell rows ]

| ............................................... |
| ............................................... |
| ............................................... |
| ............................................... |
```

Game of Life: Small Test Case

```
####################################
# my code only prints out initial board and final board
####################################

Pattern: Rabbit, Board[50][50], #MaxGenerations= 50
Rabbit Gens= 0: livepop=759003527, locations= 156520352,
Rabbit Gens= 2: livepop=13, locations= 6
Rabbit Gens= 3: livepop=15, locations= 14
Rabbit Gens= 4: livepop=20, locations= 11


[ dead cell rows ]


Rabbit Gens= 40: livepop=40, locations= 42
Rabbit Gens= 41: livepop=41, locations= 39
Rabbit Gens= 42: livepop=47, locations= 34
Rabbit Gens= 43: livepop=43, locations= 38
Rabbit Gens= 44: livepop=40, locations= 37
Rabbit Gens= 45: livepop=35, locations= 33
Rabbit Gens= 46: livepop=37, locations= 38
Rabbit Gens= 47: livepop=30, locations= 27
Rabbit Gens= 48: livepop=27, locations= 23
Rabbit Gens= 49: livepop=36, locations= 23
Rabbit Gens= 50: livepop=28, locations= 32
```

Game of Life: Small Test Case

```
####################################
# final board for 50 generations.
####################################
Rabbit Gens= 50: livepop=28, locations= 32
|--------------------------------------------------|
| .................................................. |
| .................................................. |

[ dead cell rows ]

| .................................................. |
| .................................................. |
| .................................................. |
| .................................................. |
| ..................XXXX.X.XX....................... |
| ..................XXX...X...X..................... |
| ..................X..........X...XX.............. |
| ..................XX....X...X....XX.............. |
| ..................XX...X.XX....................... |
| ..................X................................ |
| .................................................. |
| .................................................. |
| .................................................. |

[ dead cell rows ]

| .................................................. |
| .................................................. |
| .................................................. |
| .................................................. |
|--------------------------------------------------|
Generation run completed for lexicon: Rabbit
Final State:
Rabbit Gens= 50: livepop=28, locations= 32,
Telapsed in seconds: 2.113000e-03 seconds
```

Game of Life: Hints on the rabbit pattern

- Correct Result: 1744 live cells after 17331 generations
- Grid dimensions must be large enough to reach 1744 live cells. hint: a 50x50 grid is too small, and 10000x100000 is too large.
- Choose enough generations to reach a live population of 1744.
- Rabbit locations: Try starting in the center of the grid.
- Print out a range of generations (eg 17320 to 17350) to see if you get close
- Time your code.
- Write your code so that you can load different patterns such as the glider, and the space ship. See: `http://www.math.cornell.edu/~lipa/mec/lesson6.html`
- You can turn in these test cases which demonstrate portions of your working code.