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Project Title: Simulating a Zombie Infection Using Cellular Automata in a Parallel Computing Environment

Course: Parallel Computing (COMP H3036)

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Abstract:

This project models a Zombie Infection outbreak using Cellular Automata, implementing serial and parallel computing for the basic and latent infection scenarios. It simulates infection dynamics, analyzes performance speed-up, and evaluates population outcomes under varying conditions.

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Flowchart for Serial Simulation

1. **Start**
2. **Initialize the grid**: Populate the grid with all cells as `SUSCEPTIBLE` except one `ZOMBIE` in the center.
3. **Simulation Loop** (for each day):
   - For each cell in the grid:
     - If the cell is `SUSCEPTIBLE`:
       - Count the number of `ZOMBIE` neighbors.
       - Decide the state change based on probabilities (`SUSCEPTIBLE` → `ZOMBIE` or `REMOVED`).
     - Else: Copy the current state to the next grid.
   - Copy the `nextGrid` to `currentGrid`.
   - Every 10 days, save the grid state to a file.
4. **End of Simulation**: After completing the specified days, print completion and terminate.

Flowchart for Parallel Simulation

1. **Start**
2. **Initialize the grid**: Same as the serial version.
3. **Create threads**: Divide rows among threads.
4. **Thread Execution**:
   - For each thread:
     - Process assigned rows using the same decision logic as in the serial version.
     - Use a barrier to synchronize threads after processing rows for a day.
     - One thread updates the currentGrid from nextGrid.
5. **Repeat simulation until the last day.**
6. **Destroy threads and terminate.**

Pseudo-Code for Serial

```
BEGIN
   FUNCTION InitialiseWorld():
      FOR i FROM 0 TO GRID_SIZE-1:
         FOR j FROM 0 TO GRID_SIZE-1:
            currentGrid[i][j] = SUSCEPTIBLE
      currentGrid[GRID_SIZE/2][GRID_SIZE/2] = ZOMBIE

   FUNCTION CountZombieNeighbours(x, y):
      DEFINE dx = [-1, -1, -1, 0, 0, 1, 1, 1]
      DEFINE dy = [-1, 0, 1, -1, 1, -1, 0, 1]
      count = 0
      FOR k FROM 0 TO 7:
         nx = (x + dx[k] + GRID_SIZE) % GRID_SIZE
         ny = (y + dy[k] + GRID_SIZE) % GRID_SIZE
         IF currentGrid[nx][ny] == ZOMBIE:
            count += 1
      RETURN count

   FUNCTION DecideState(x, y):
      zombieNeighbours = CountZombieNeighbours(x,
y)
      randomValue = RANDOM(0, 1)
      IF randomValue < P_INFECT * zombieNeighbours:
         nextGrid[x][y] = ZOMBIE
      ELSE IF randomValue < P_DEATH:
         nextGrid[x][y] = REMOVED
      ELSE:
         nextGrid[x][y] = SUSCEPTIBLE

   FUNCTION CopyNextGridToCurrent():
      FOR i FROM 0 TO GRID_SIZE-1:
         FOR j FROM 0 TO GRID_SIZE-1:
            currentGrid[i][j] = nextGrid[i][j]

   FUNCTION OutputWorld(day):
      OUTPUT currentGrid TO FILE "grid_day_" + day

   MAIN:
      InitialiseWorld()
      FOR day FROM 0 TO MAX_DAYS-1:
         FOR i FROM 0 TO GRID_SIZE-1:
            FOR j FROM 0 TO GRID_SIZE-1:
               IF currentGrid[i][j] == SUSCEPTIBLE:
                  DecideState(i, j)
               ELSE:
                  nextGrid[i][j] = currentGrid[i][j]
         CopyNextGridToCurrent()
         IF day MOD 10 == 0:
            OutputWorld(day)
      PRINT "Simulation completed"
```

Pseudo-Code for Parallel (Pthreads)

```
BEGIN

   FUNCTION InitialiseWorld():

      SAME AS SERIAL VERSION

   FUNCTION CountZombieNeighbours(x, y):

      SAME AS SERIAL VERSION

   FUNCTION DecideState(x, y):

      SAME AS SERIAL VERSION

   FUNCTION OutputWorld(day):

      SAME AS SERIAL VERSION

   FUNCTION SimulateZombieInfectionParallel(data):

      DEFINE startRow = data.startRow

      DEFINE endRow = data.endRow

      FOR day FROM 0 TO MAX_DAYS-1:

         FOR i FROM startRow TO endRow:

            FOR j FROM 0 TO GRID_SIZE-1:

               IF currentGrid[i][j] == SUSCEPTIBLE:

                  DecideState(i, j)

               ELSE:

                  nextGrid[i][j] = currentGrid[i][j]

         WAIT FOR BARRIER

         IF IS_MAIN_THREAD():

            COPY nextGrid TO currentGrid

            IF day MOD 10 == 0:

               OutputWorld(day)

         WAIT FOR BARRIER

   MAIN:

      InitialiseWorld()

      DEFINE threads[THREADS]

      DEFINE threadData[THREADS]

      rowsPerThread = GRID_SIZE / THREADS
```

END	FOR i FROM 0 TO THREADS-1: threadData[i].startRow = i * rowsPerThread threadData[i].endRow = (i + 1) * rowsPerThread - 1 CREATE THREAD threads[i] USING SimulateZombieInfectionParallel(threadData[i]) FOR i FROM 0 TO THREADS-1: JOIN THREAD threads[i] PRINT "Parallel simulation completed" END

Source Code

Serial Source Code	Parallel Source Code (Pthreads)

#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#define GRID_SIZE 1000
#define MAX_DAYS 1000
#define SUSCEPTIBLE 0
#define ZOMBIE 1
#define REMOVED 2
#define P_INFECT 0.3
#define P_DEATH 0.1
 	
int currentGrid[GRID_SIZE][GRID_SIZE];
int nextGrid[GRID_SIZE][GRID_SIZE];
 	
// Initialize the grid with all cells as SUSCEPTIBLE and one ZOMBIE
 	
void initialiseWorld() {
for (int i = 0; i < GRID_SIZE; i++) {
for (int j = 0; j < GRID_SIZE; j++) {
currentGrid[i][j] = SUSCEPTIBLE;
}
}
currentGrid[GRID_SIZE / 2][GRID_SIZE / 2] = ZOMBIE;
}
	#include <stdio.h>
	#include <stdlib.h>
	#include <pthread.h>
	#include <time.h>
	#include <bits/pthreadtypes.h>
	#define GRID_SIZE 1000
	#define MAX_DAYS 1000
	#define THREADS 8
	#define SUSCEPTIBLE 0
	#define ZOMBIE 1
	#define REMOVED 2
	#define P_INFECT 0.3
	#define P_DEATH 0.1
	
	int currentGrid[GRID_SIZE][GRID_SIZE];
	int nextGrid[GRID_SIZE][GRID_SIZE];
	pthread_barrier_t barrier;
	
	typedef struct {
	int startRow;
	int endRow;
	} ThreadData;
	
	// Initialize the grid with all cells as SUSCEPTIBLE and one ZOMBIE

```
// Output the grid to a file for visualization

void outputWorld(int day) {
    char filename[50];
    sprintf(filename, "grid_day_%d.txt", day);
    FILE *file = fopen(filename, "w");
    for (int i = 0; i < GRID_SIZE; i++) {
        for (int j = 0; j < GRID_SIZE; j++) {
            fprintf(file, "%d ", currentGrid[i][j]);
        }
        fprintf(file, "\n");
    }
    fclose(file);
}

// Count the number of neighboring ZOMBIE cells
int countZombieNeighbours(int x, int y) {
    int dx[] = {-1, -1, -1, 0, 0, 1, 1, 1};
    int dy[] = {-1, 0, 1, -1, 1, -1, 0, 1};
    int count = 0;
    for (int k = 0; k < 8; k++) {
        int nx = (x + dx[k] + GRID_SIZE) % GRID_SIZE;
        int ny = (y + dy[k] + GRID_SIZE) % GRID_SIZE;
        if (currentGrid[nx][ny] == ZOMBIE) {
            count++;
        }
    }
    return count;
}

// Decide state change for SUSCEPTIBLE cells

void decide_S_to_ZorR(int x, int y) {
    int zombieNeighbors = countZombieNeighbours(x,
y);
    float randomValue = rand() / (float)RAND_MAX;
    if (randomValue < P_INFECT * zombieNeighbors) {
        nextGrid[x][y] = ZOMBIE;
    } else if (randomValue < P_DEATH) {
        nextGrid[x][y] = REMOVED;
    } else {
        nextGrid[x][y] = SUSCEPTIBLE;
    }
}

// Copy the nextGrid into currentGrid

void copyNextGridToCurrent() {
    for (int i = 0; i < GRID_SIZE; i++) {
        for (int j = 0; j < GRID_SIZE; j++) {
            currentGrid[i][j] = nextGrid[i][j];
        }
```

```
void initialiseWorld() {
    for (int i = 0; i < GRID_SIZE; i++) {
        for (int j = 0; j < GRID_SIZE; j++) {
            currentGrid[i][j] = SUSCEPTIBLE;
        }
    }
    currentGrid[GRID_SIZE / 2][GRID_SIZE / 2] = ZOMBIE;
}

// Output the grid to a file for visualization
void outputWorld(int day) {
    char filename[50];
    sprintf(filename, "grid_day_%d.txt", day);
    FILE *file = fopen(filename, "w");
    for (int i = 0; i < GRID_SIZE; i++) {
        for (int j = 0; j < GRID_SIZE; j++) {
            fprintf(file, "%d ", currentGrid[i][j]);
        }
        fprintf(file, "\n");
    }
    fclose(file);
}

// Count the number of neighboring ZOMBIE cells
int countZombieNeighbours(int x, int y) {
    int dx[] = {-1, -1, -1, 0, 0, 1, 1, 1};
    int dy[] = {-1, 0, 1, -1, 1, -1, 0, 1};
    int count = 0;
    for (int k = 0; k < 8; k++) {
        int nx = (x + dx[k] + GRID_SIZE) % GRID_SIZE;
        int ny = (y + dy[k] + GRID_SIZE) % GRID_SIZE;
        if (currentGrid[nx][ny] == ZOMBIE) {
            count++;
        }
    }
    return count;
}

// Decide state change for SUSCEPTIBLE cells
void decide_S_to_ZorR(int x, int y) {
    int zombieNeighbors = countZombieNeighbours(x,
y);
    float randomValue = rand() / (float)RAND_MAX;

    if (randomValue < P_INFECT * zombieNeighbors) {
        nextGrid[x][y] = ZOMBIE;
    } else if (randomValue < P_DEATH) {
        nextGrid[x][y] = REMOVED;
    } else {
        nextGrid[x][y] = SUSCEPTIBLE;
    }
}
```

```
    }
}

// Simulate the zombie infection for multiple days

void simulateZombieInfection() {
    for (int day = 0; day < MAX_DAYS; day++) {
        for (int i = 0; i < GRID_SIZE; i++) {
            for (int j = 0; j < GRID_SIZE; j++) {
                if (currentGrid[i][j] == SUSCEPTIBLE) {
                    decide_S_to_ZorR(i, j);
                } else {
                    nextGrid[i][j] = currentGrid[i][j];
                }
            }
        }
        copyNextGridToCurrent();
        if (day % 10 == 0) {
            outputWorld(day);
        }
    }
}

int main() {
    srand(time(NULL));
    initialiseWorld();
    simulateZombieInfection();
    printf("Simulation completed.\n");
    return 0;
}
```

```
// Thread function to process rows for simulation
void *simulateZombieInfectionParallel(void *arg) {
    ThreadData *data = (ThreadData *)arg;

    for (int day = 0; day < MAX_DAYS; day++) {
        for (int i = data->startRow; i <= data->endRow; i++)
{
            for (int j = 0; j < GRID_SIZE; j++) {
                if (currentGrid[i][j] == SUSCEPTIBLE) {
                    decide_S_to_ZorR(i, j);
                } else {
                    nextGrid[i][j] = currentGrid[i][j];
                }
            }
        }

        pthread_barrier_wait(&barrier);

        if (data->startRow == 0) { // Main thread updates
the current grid
            for (int i = 0; i < GRID_SIZE; i++) {
                for (int j = 0; j < GRID_SIZE; j++) {
                    currentGrid[i][j] = nextGrid[i][j];
                }
            }
            if (day % 10 == 0) {
                outputWorld(day);
            }
        }

        pthread_barrier_wait(&barrier);
    }

    return NULL;
}

int main() {
    pthread_t threads[THREADS];
    ThreadData threadData[THREADS];
    pthread_barrier_init(&barrier, NULL, THREADS);

    initialiseWorld();

    int rowsPerThread = GRID_SIZE / THREADS;
    for (int i = 0; i < THREADS; i++) {
        threadData[i].startRow = i * rowsPerThread;
        threadData[i].endRow = (i == THREADS - 1) ?
GRID_SIZE - 1 : (i + 1) * rowsPerThread - 1;
        pthread_create(&threads[i], NULL,
simulateZombieInfectionParallel, &threadData[i]);
    }

    for (int i = 0; i < THREADS; i++) {
```

	`        pthread_join(threads[i], NULL);`
	`    }`
	
	`    pthread_barrier_destroy(&barrier);`
	`    printf("Parallel simulation completed.\n");`
	`    return 0;`
	`}`

Cellular Automata Model

States

Each cell in the grid represents an individual, categorized into the following states:

1. **SUSCEPTIBLE (S):** Healthy individuals vulnerable to infection.
2. **ZOMBIE (Z):** Infected individuals actively spreading the infection.
3. **REMOVED (R):** Individuals who died naturally or were removed after infection.
4. **INFECTED (I) (Optional):** Transition state before becoming a zombie.

Transition Rules

The state of each cell evolves based on interactions with its neighbors according to these rules:

1. **SUSCEPTIBLE → ZOMBIE:**
   - Trigger: Neighboring ZOMBIE cells.
   - Probability: **P_infect** (e.g., 30%).
2. **SUSCEPTIBLE → REMOVED:**
   - Trigger: Natural death.
   - Probability: **P_death** (e.g., 10%).
3. **SUSCEPTIBLE → INFECTED → ZOMBIE (Optional Latent Model):**
   - Trigger: Infection followed by a delay (e.g., 3 steps).
   - Transition: **P_infect** applies first, then a fixed time leads to ZOMBIE.
4. **ZOMBIE → REMOVED:**
   - Trigger: External factors or resource depletion.
   - Occurs after a fixed number of steps.

Grid Representation

- **Structure:** 2D grid (e.g., 1000x1000 cells).
- **Boundary Conditions:** Periodic (neighbors wrap around edges).
- **Time Steps:** Discrete iterations where all cells update synchronously.

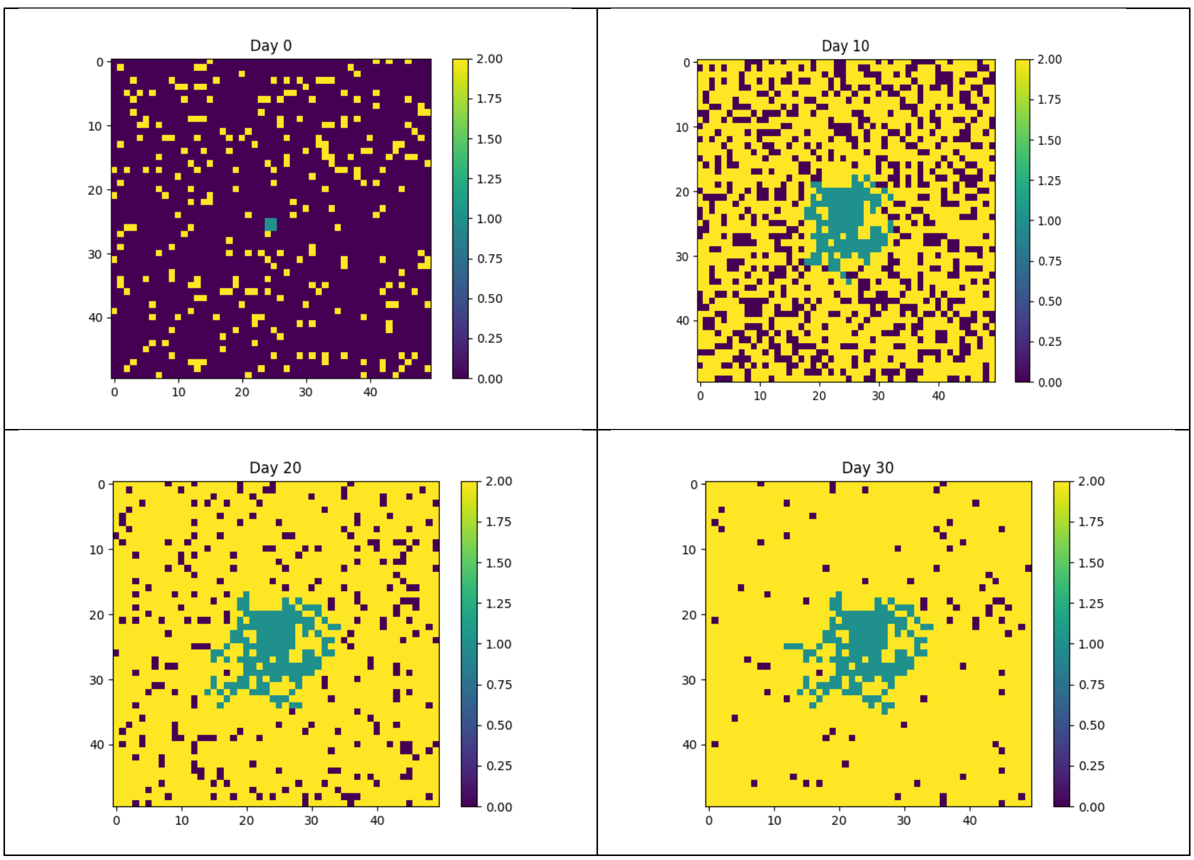
Model Justification

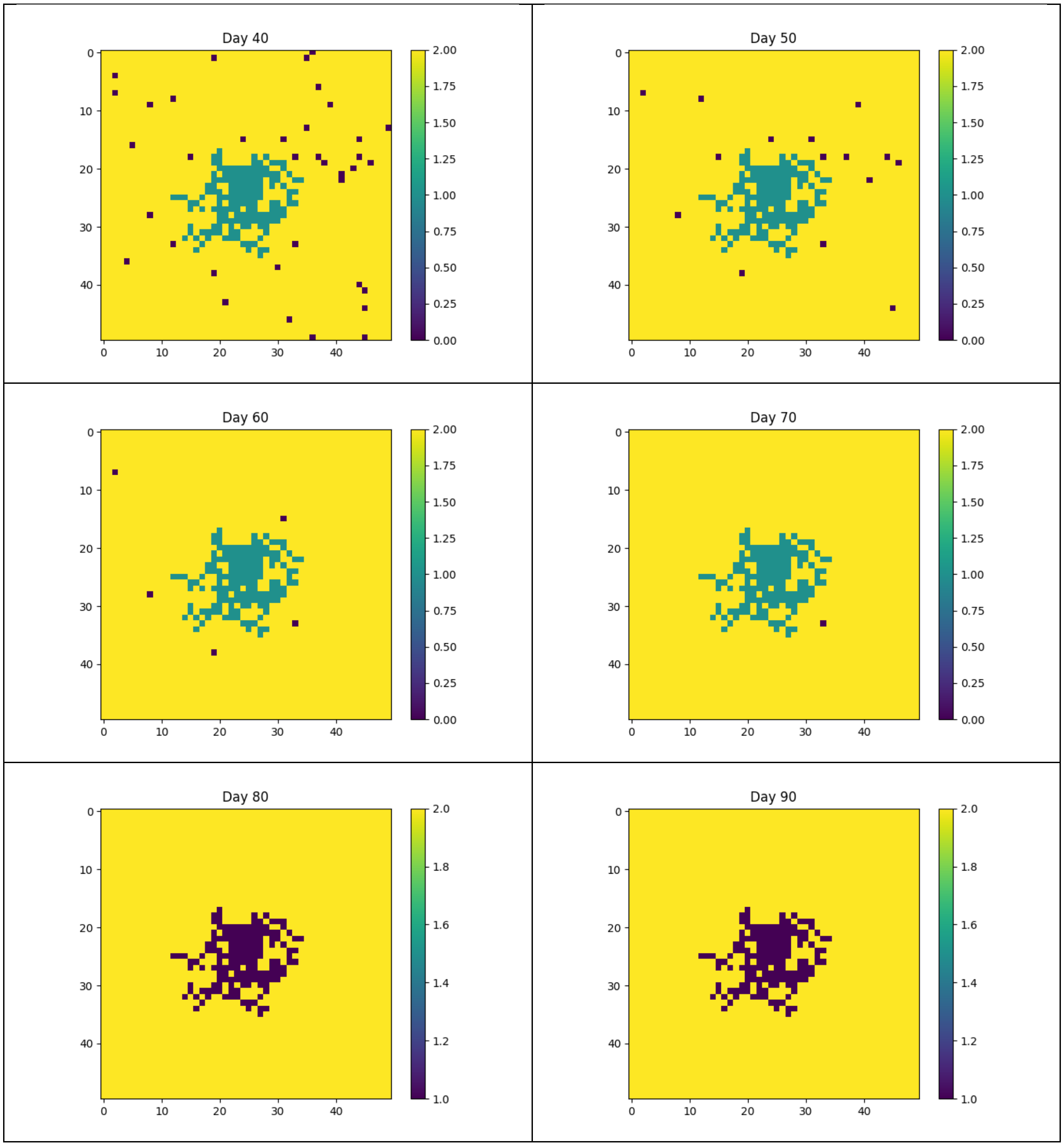
- **States and Rules:** Capture realistic infection dynamics with flexibility for parameter tuning.
- **Probabilities:** Add variability for simulating different outbreak scenarios.
- **Grid Design:** Ensures scalability and avoids boundary artifacts.

Speed-up Analysis:

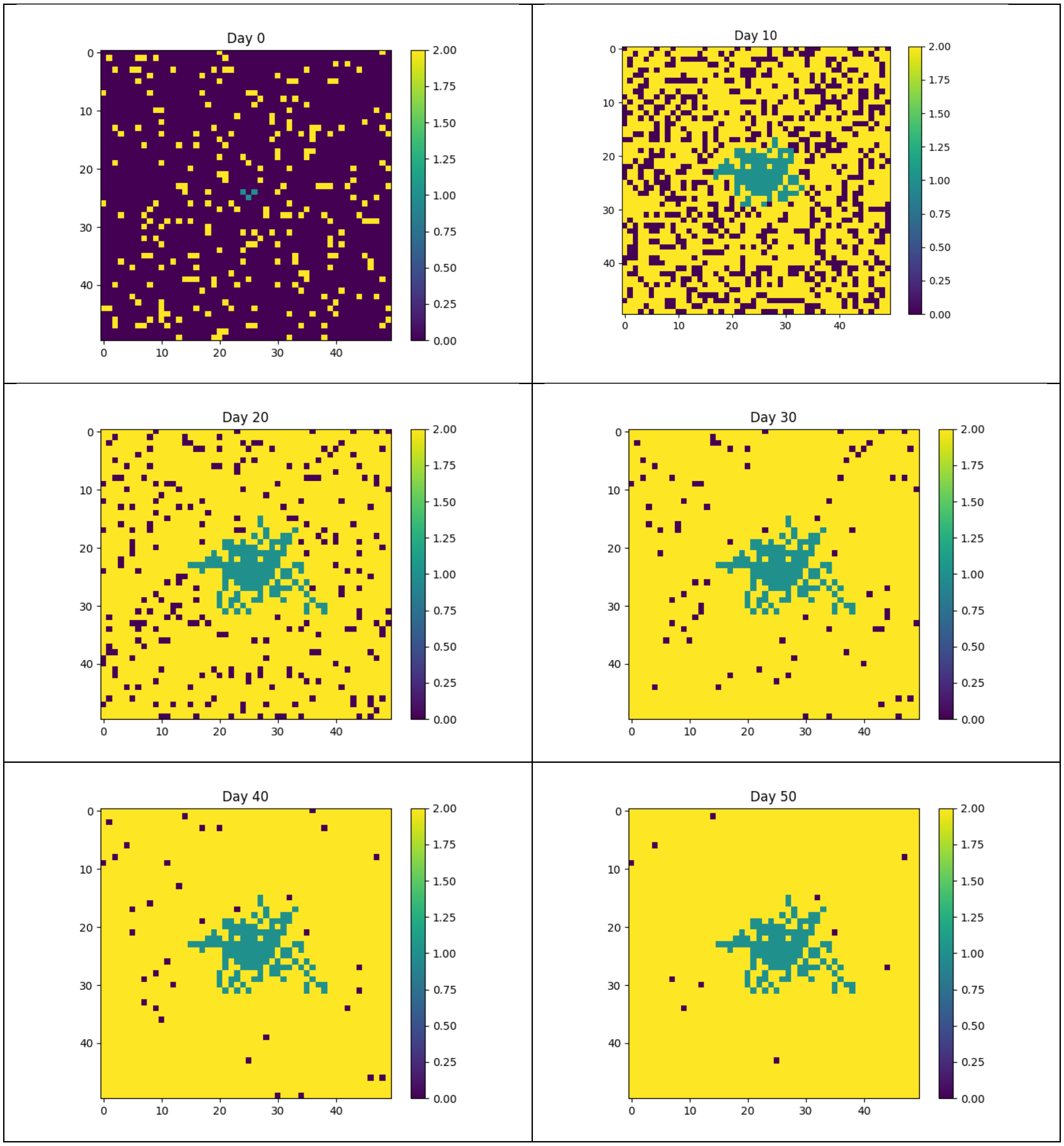
Threads	Parallel Real Time (s)	Serial Real Time (s)	Speed-up (Real Time)
8	10.029	9.4	0.937281883
4	10.314	9.4	0.911382587
2	10.727	9.4	0.876293465

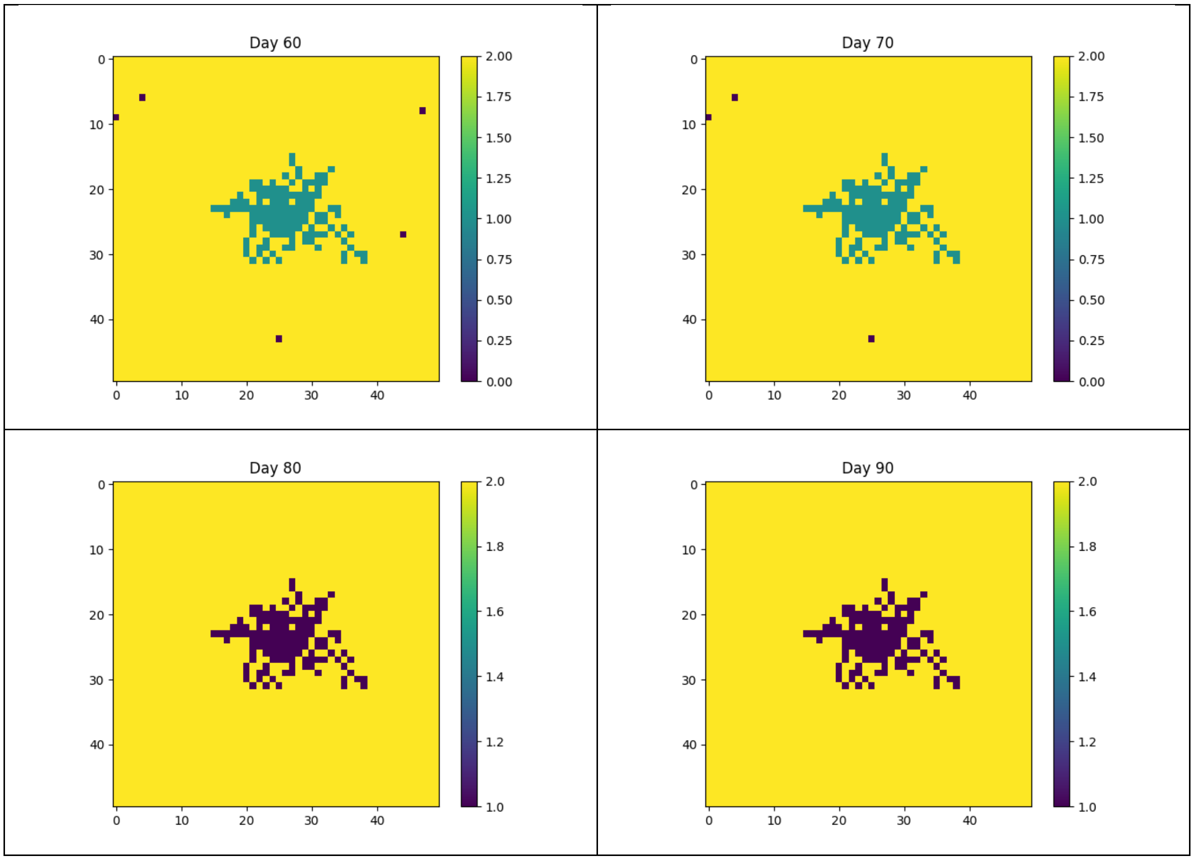
Simulation Analysis for Serial




Day 40
Day 50
Day 60
Day 70
Day 80
Day 90

Simulation Analysis for Parallel (Pthread)





Day 60
Day 70
Day 80
Day 90