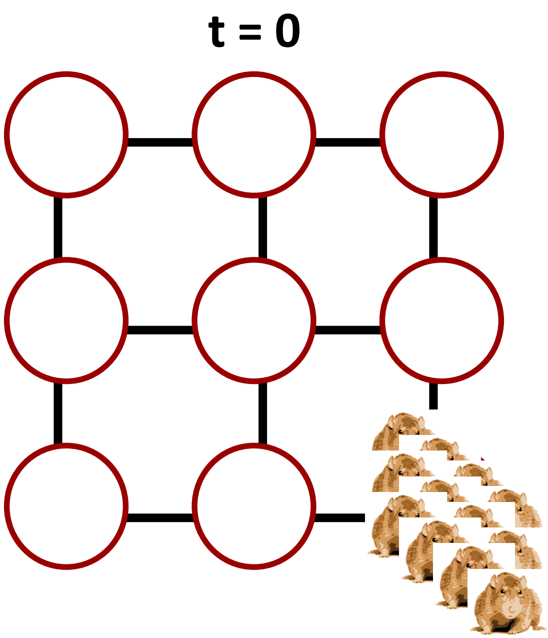
Assignment 3: GraphRats

Topics

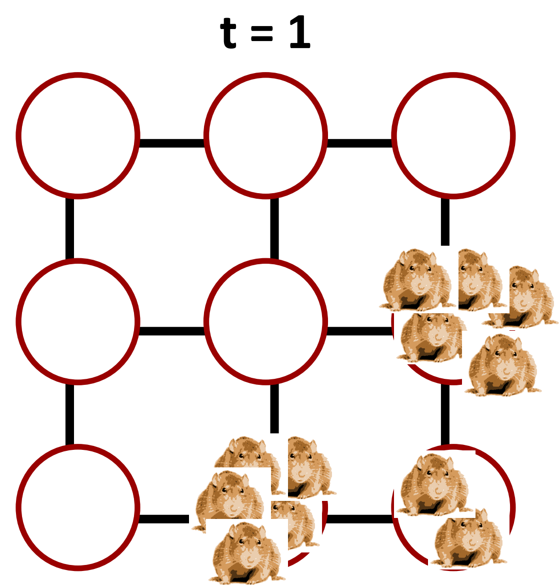
- Application
- Implementation Issues
- Optimizing for Sequential Performance
- Optimizing for Parallel Performance
- Useful Advice

Basic Idea



- **Graph**
  - K X K grid
- **Initial State**
  - Start with all *R* rats in corner

- **Transitions**
  - Each rat decides where to move next
    - Don't like crowds
    - But also don't like to be alone
  - Weighted random choice



Node Count Representation

```
t = 0
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |320|
+---+---+---+---+---+---+---+---+
```

```
t = 1.
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |142|
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |149| 29|
+---+---+---+---+---+---+---+---+
```

Simulation Example

```
t = 0
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |320|
+---+---+---+---+---+---+---+---+
```

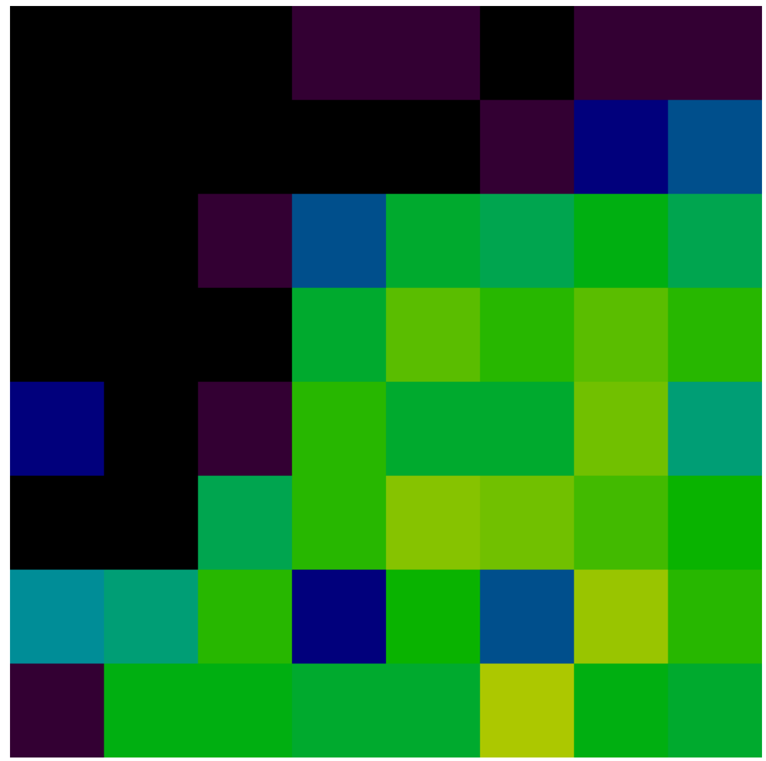
```
t = 30.
+---+---+---+---+---+---+---+---+
|   |   |   | 1 | 1 |   | 1 | 1 |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   | 1 | 2 | 3 |
+---+---+---+---+---+---+---+---+
|   |   | 1 | 3 | 7 | 6 | 8 | 6 |
+---+---+---+---+---+---+---+---+
|   |   |   | 7 | 12| 10| 12| 10|
+---+---+---+---+---+---+---+---+
| 2 |   | 1 | 10| 7 | 7 | 13| 5 |
+---+---+---+---+---+---+---+---+
|   |   | 6 | 10| 14| 13| 11| 9 |
+---+---+---+---+---+---+---+---+
| 4 | 5 | 10| 2 | 9 | 3 | 15| 10|
+---+---+---+---+---+---+---+---+
| 1 | 8 | 8 | 7 | 7 | 16| 8 | 7 |
+---+---+---+---+---+---+---+---+
```

Visualizations

Text ("a" for ASCII)

```
t = 30.
+---+---+---+---+---+---+---+---+
|   |   |   | 1 | 1 |   | 1 | 1 |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   | 1 | 2 | 3 |
+---+---+---+---+---+---+---+---+
|   |   | 1 | 3 | 7 | 6 | 8 | 6 |
+---+---+---+---+---+---+---+---+
|   |   |   | 7 | 12| 10| 12| 10|
+---+---+---+---+---+---+---+---+
| 2 |   | 1 | 10| 7 | 7 | 13| 5 |
+---+---+---+---+---+---+---+---+
|   |   | 6 | 10| 14| 13| 11| 9 |
+---+---+---+---+---+---+---+---+
| 4 | 5 | 10| 2 | 9 | 3 | 15| 10|
+---+---+---+---+---+---+---+---+
| 1 | 8 | 8 | 7 | 7 | 16| 8 | 7 |
+---+---+---+---+---+---+---+---+
```

Heat Map ("h")



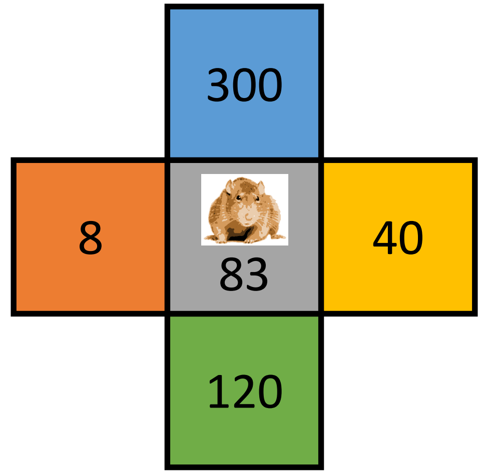
Running it yourself

```
linux> cd some directory
linux> git clone https//github.com/cmu15418/asst3-s18.git
linux> cd asst3-s18/code
Linux> make demoX
```

***X* from 1 to 10**

- **Demos**
  - 1: Text visualization, synchronous updates
  - 2: Heap-map, synchronous updates

Determining Rat Moves

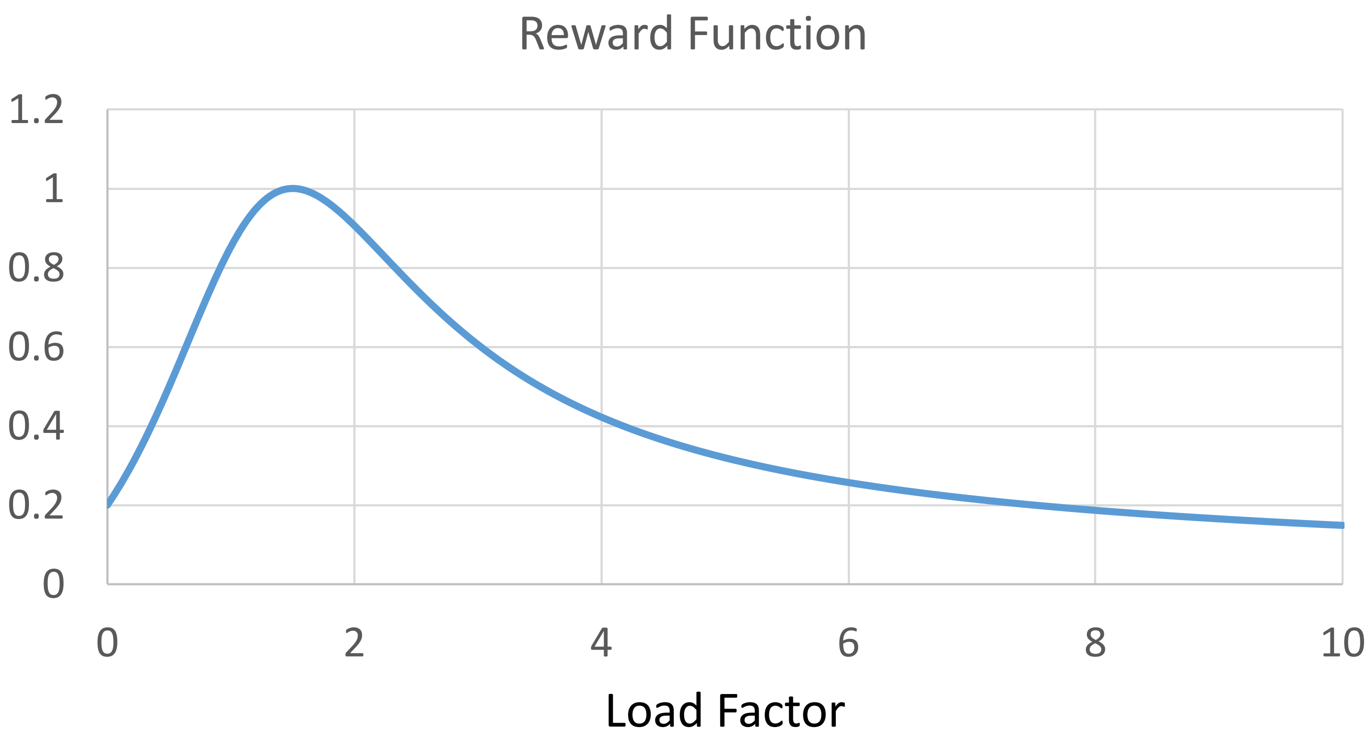


- **Count number of rats at current and adjacent locations**
  - Adjacency structure represented as graph
- **Compute reward value for each location**
  - Based on *load factor* $\boldsymbol{l}$ = count/average count
  - $\boldsymbol{l}^*$ Ideal load factor (= 1.5)
  - $\boldsymbol{\alpha}$ Fitting parameter (= 0.5)

$$\mathit{Reward}(\boldsymbol{l}) = \frac{\mathbf{1}}{\mathbf{1} + (\mathbf{log_2}\,[\mathbf{1} + \boldsymbol{\alpha}(\boldsymbol{l} - \boldsymbol{l}^*)])^{\mathbf{2}}}$$

Reward Function

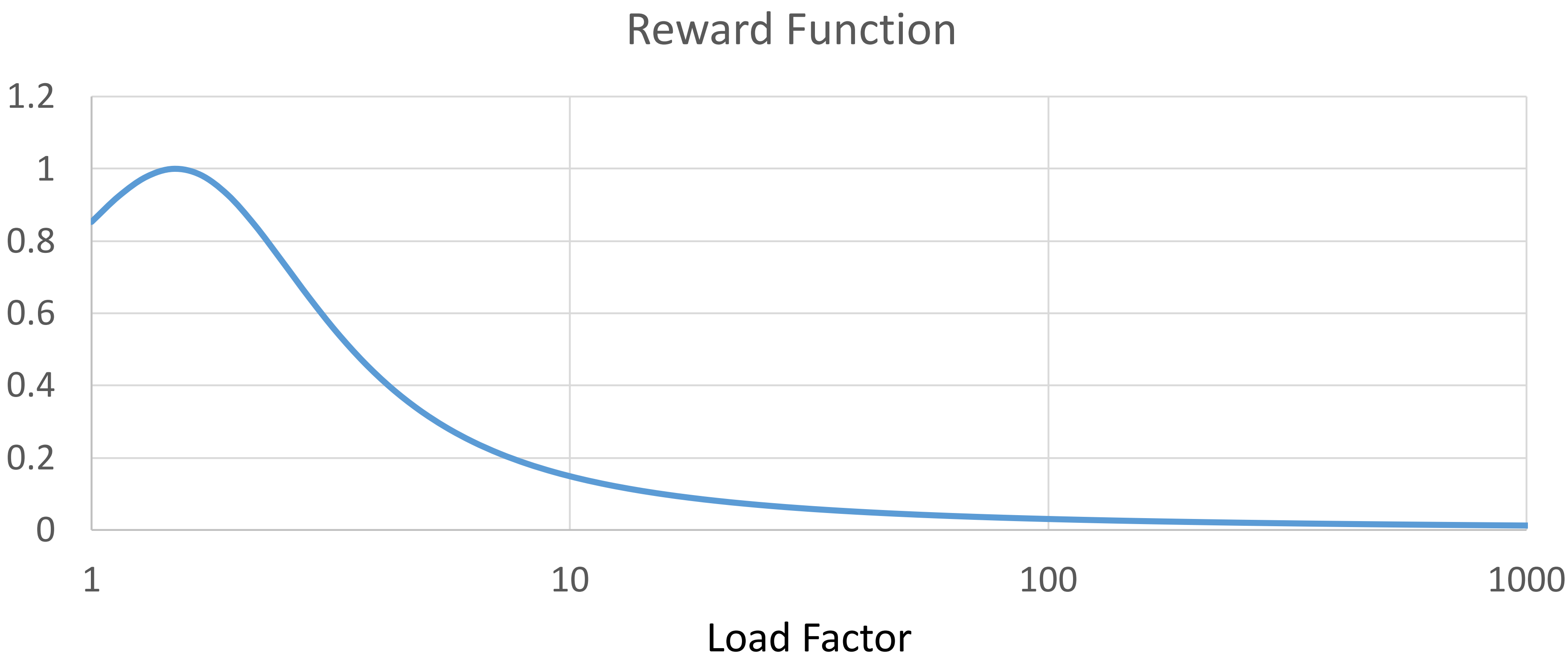
$$Reward(l) = \frac{1}{1 + (\log_2 [1 + \alpha(l - l^*)])^2}$$



- Maximized at load factor 1.5
  - Just above average population
  - Drops for smaller loads (too few) and larger loads (too crowded)

Reward Function (cont.)

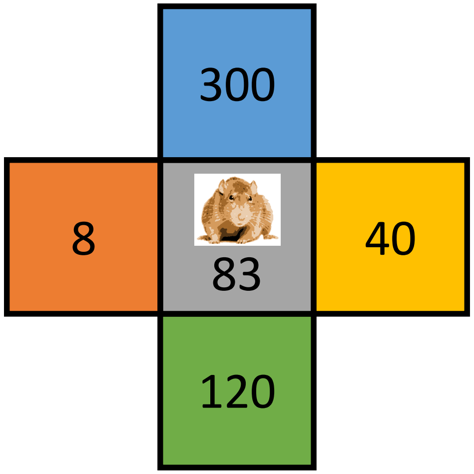
$$Reward(l) = \frac{1}{1 + (\log_2 [1 + \alpha(l - l^*)])^2}$$



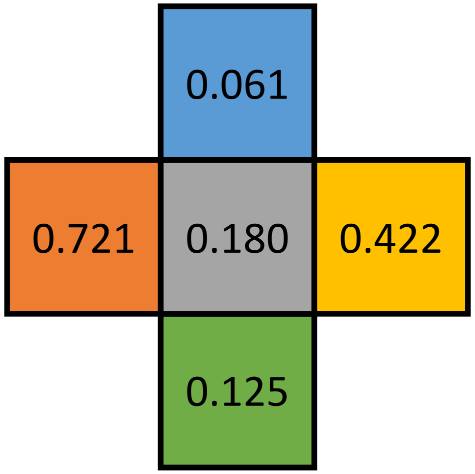
- Falls off gradually
  - *Reward*(1000) = 0.0123

Selecting Next Move

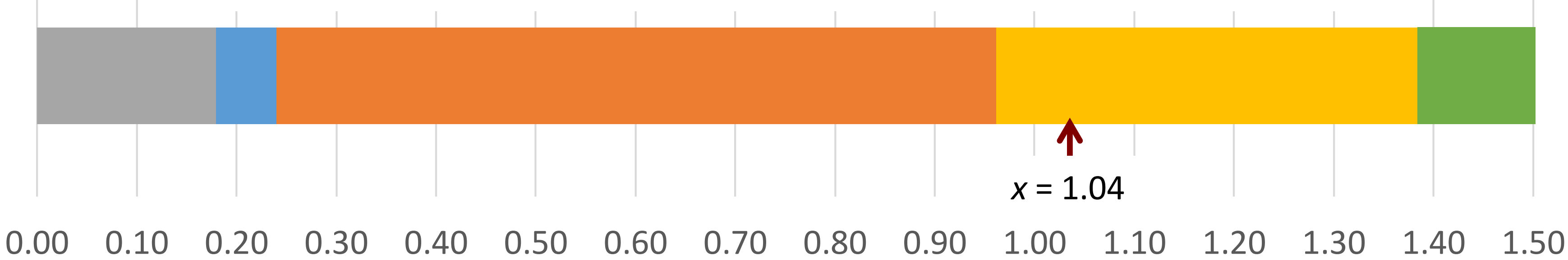
Population



Reward (avg = 10)



Weighted Choices
(node followed by row-major ordering of neighbors)



- Choose random number between 0 and sum of rewards
- Move according to interval hit

Update Models

- **Synchronous**
  - Demo 2
  - Compute next positions for all rats, and then move them
  - Causes oscillations/instabilities
- **Rat-order**
  - Demo 3
  - For each rat, compute its next position and then move it
  - Smooth transitions, but costly
- **Batch**
  - Demo 4
  - For each batch of B rats, compute next moves and then move them
  - B = 0.02 * *R*
  - Smooth enough, with better performance possibilities

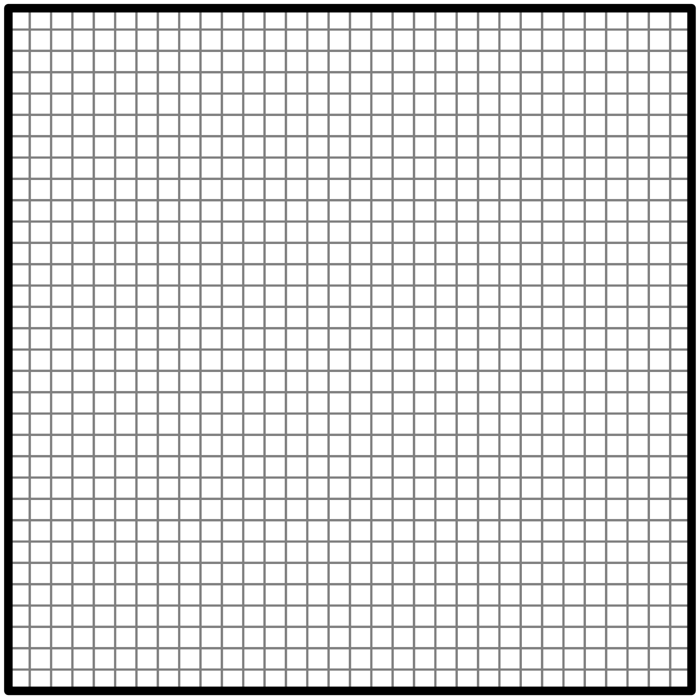
What We Provide

- **Python version of simulator**
  - Demo 4
  - Very slow
- **C version of simulator**
  - Faster, but still too slow
  - Demo 5: 8X8 grid, 320 rats
  - Demo 6: 160X160 grid, 1,024,000 rats
    - That’s what we’ll be using for benchmarks!
    - You’ll have to be patient using the starter code
- **Generate visualizations by piping C simulator output into Python simulator**
  - Operating in visualization mode
  - See Makefile for examples

Correctness

- **Simulator is Deterministic**
  - Global random seed
  - Random seeds for each rat
  - Process rats in fixed order
- **You Must Preserve Exact Same Behavior**
  - Python simulator generates same result as C simulator
  - Use `regress.py` to check
  - Don’t rely only on the small cases it currently checks

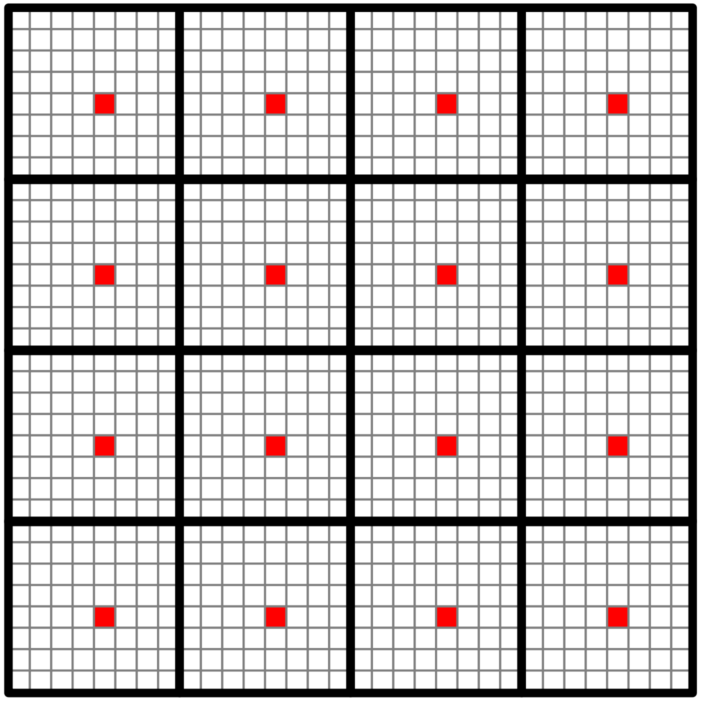
Graphs: Grid (Demo 6)



Highly regular
Low degree
Rats spread slowly

- k X k nodes, each with nearest neighbor connectivity
- Max degree = 4
- k = 160: 25,600 nodes 101,760 edges

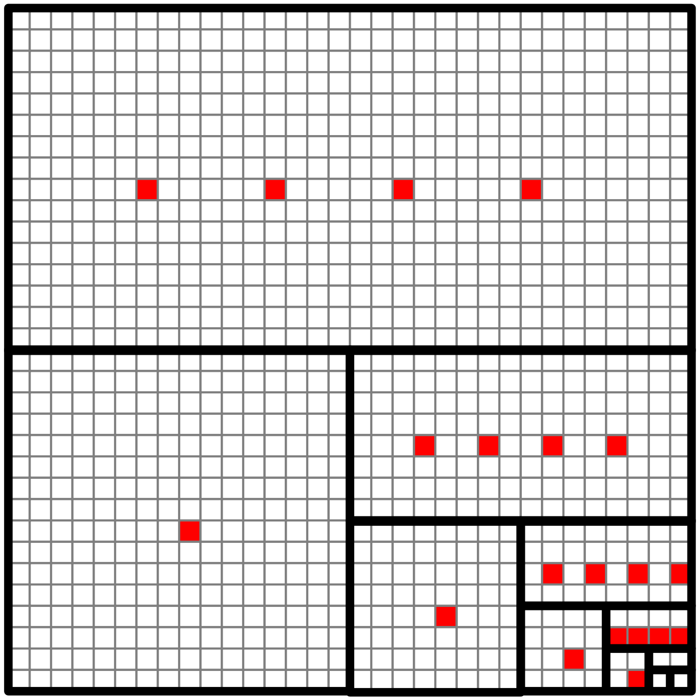
Graphs: Tiled (Demo 7)



Globally regularly, locally irregular
Low/medium degree degree
Rats spread quickly within tile, slowly between tiles
Hub nodes typically have high rat counts

- **Smaller d X d regions, each with *hub* node**
  - Node with edge to every other node in region
  - Regions connected only by nearest-neighbor edges at border
  - Maximum degree = d^2-1 (= 99 for benchmark graph)
- **k = 160, d = 10: 25,600 nodes 152,850 edges**

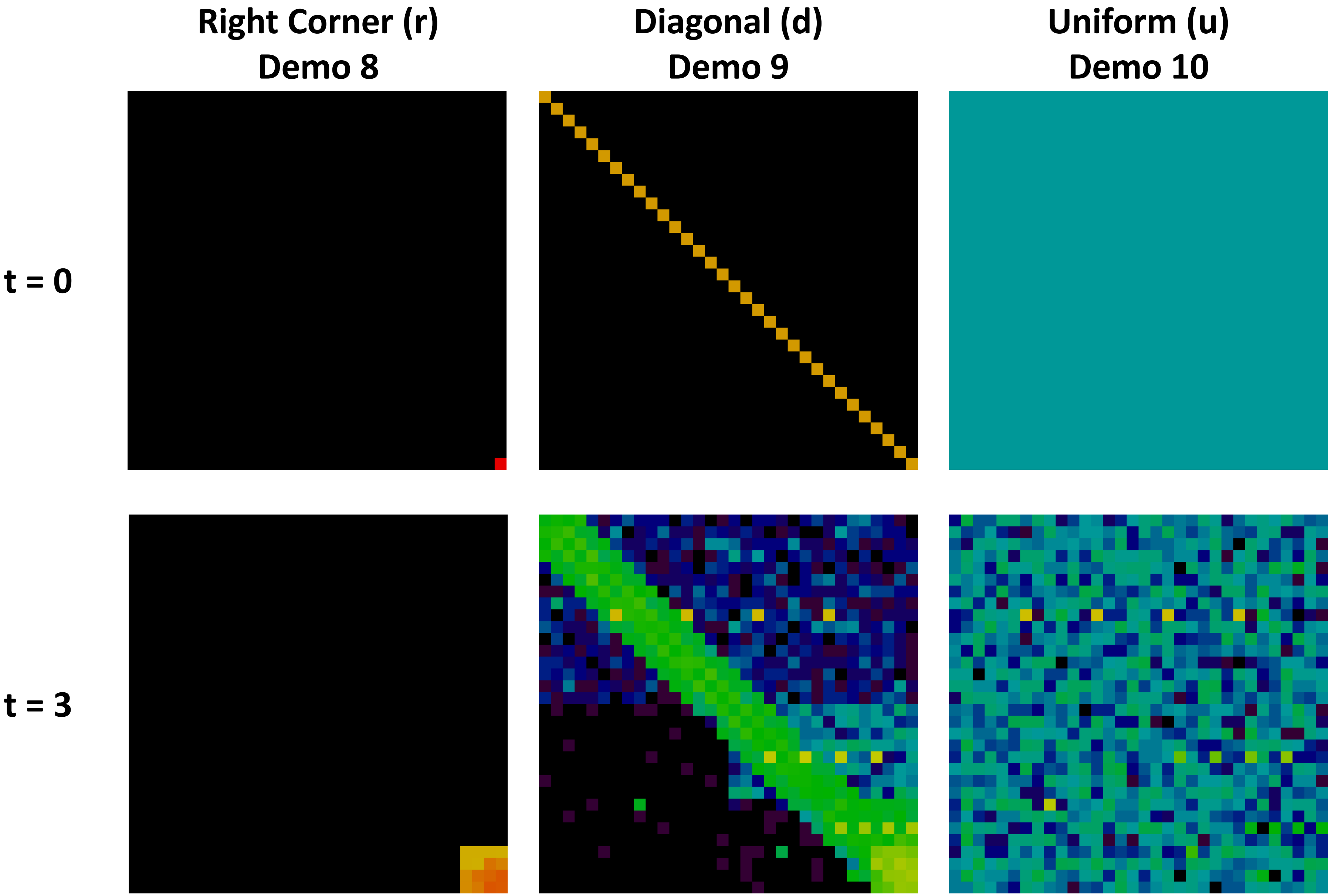
Fractal Graph (Demo 8)



Highly irregular
Widely varying degrees
Rats spread quickly through regions
Hub nodes typically have high rat counts

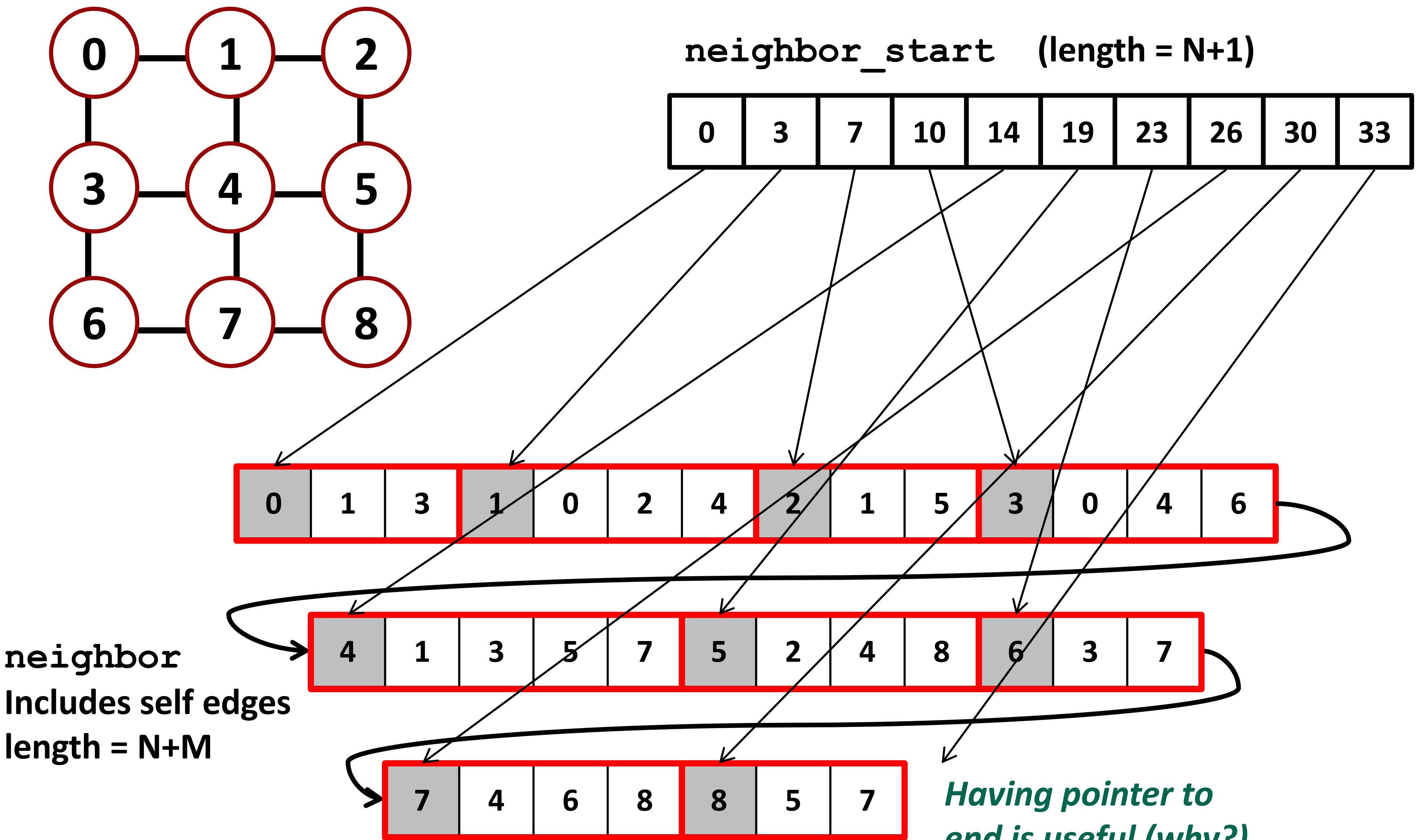
- **Regions of varying size**
  - Some have 4 hub nodes, others 1
  - Maximum degree = $k^2/2-1$ (= 12,799 for benchmark graph)
- **k = 160: 25,600 nodes 254,940 edges**

States (Fractal Graph)



Graph Representation

N node, M edges



Sample Code

- From sim.c
- Compute reward value for node

```
/* Compute weight for node nid */
static inline double compute_weight(state_t *s, int nid)
{
    int count = s->rat_count[nid];
    return mweight((double) count/s->load_factor);
}
```

- Simulation state stored in `state_t` struct
- Reward function computed by `mweight`

Sample Code

- From sim.c
- Compute sum of reward values for node

```
/* Compute sum of weights in region of nid */
static inline double compute_sum_weight(state_t *s, int nid)
{
    graph_t *g    = s->g;
    double sum    = 0.0;
    int eid;
    int eid_start = g->neighbor_start[nid];
    int eid_end   = g->neighbor_start[nid+1];
    int *neighbor = g->neighbor;
    for (eid = eid_start; eid < eid_end; eid++) {
        sum += compute_weight(s, neighbor[eid]);
    }
    return sum;
}
```

Sample Code

- **Compute next move for rat**

```
static inline int next_random_move(state_t *s, int r)
{
    int nid            = s->rat_position[r];
    random_t *seedp = &s->rat_seed[r];
    double tsum        = compute_sum_weight(s, nid);
    graph_t *g         = s->g;
    double val         = next_random_float(seedp, tsum);
    double psum        = 0.0;
    int eid;
    int eid_start      = g->neighbor_start[nid];
    int eid_end        = g->neighbor_start[nid+1];
    int *neighbor      = g->neighbor;
    for (eid = eid_start; eid < eid_end; eid++) {
        psum += compute_weight(s, neighbor[eid]);
        if (val < psum) {
            return neighbor[eid];
        }
    }
}
```

Sequential Efficiency Considerations

- **Consider move computation for rat at node with degree D**
  - How many (on average) iterations of loop in `next_random_move`?
  - How many calls are made to `mweight`?
- **Suppose there are X rats in batch at single node with degree D**
  - How many (on average) iterations of loop in `next_random_move`?
  - How many calls are made to `mweight`?

Finding Parallelism

- **Sequential constraints**
  - Must complete time steps sequentially
  - Must complete each batch before starting next
- **Sources of parallelism**
  - Over nodes
    - Computing reward functions
  - Over rats (within a batch)
    - Computing next moves
    - Updating node counts

Performance Targets

- **Mega-Rats Per Second (MRPS)**
  - R rats running for S steps
  - Requires time T
  - MRPS = 10^{-6} * R * S / T
- **Runs**
  - 5 combinations of graph/initial state
  - Compute geometric mean of MRPS's
- **Target performance**

	1 Thread	12 Threads	Speedup
Synchronous	32	256	8.0
Batch	20	70	3.5

Some Suggestions

- **Focus initially on sequential performance**
  - But think of ways that will allow parallelism
  - Simple ideas / data structures generally work best
  - Use timing to guide optimizations
- **Synchronous mode easier to make fast**
  - Both sequentially and parallel
- **Machines**
  - Can develop on any machine
    - GHC machines work well
  - Performance will be evaluated on Latedays machines
    - Batch submission process
    - These have different characteristics from GHC machines when measuring parallel performance

Instrumenting Your Code

- **How do you know how much time each activity takes?**
  - Create simple library using cycletimer code
  - Bracket steps in your code with library calls
  - Use macros so that you can disable code for maximum performance

```
START_ACTIVITY(ACTIVITY_NEXT);
#pragma omp parallel for schedule(static)
for (ri = 0; ri < local_count; ri++) {
    int rid = ri + local_start;
    s->rat_position[rid] = fast_next_random_move(s, rid);
}
FINISH_ACTIVITY(ACTIVITY_NEXT);
```

Evaluating Your Instrumented Code

1 thread

```
         194 ms       1.0 %    startup
        2077 ms      11.1 %    compute_weights
        4029 ms      21.6 %    compute_sums
       11733 ms      62.8 %    find_moves
         651 ms       3.5 %    set_ops
           3 ms       0.0 %    unknown
+++     25600   t         40    u        400     b        1        18.70      21.91
```

12 threads

```
         192 ms       3.2 %    startup
         426 ms       7.0 %    compute_weights
         940 ms      15.5 %    compute_sums
        3168 ms      52.3 %    find_moves
        1325 ms      21.9 %    set_ops
           2 ms       0.0 %    unknown
+++     25600   t         40    u        400     b        12       6.06       67.55 ( 3.08X)
```

- Can see which activities account for most time
- Can see which activities limit parallel speedup

Some Logos

GraphLab
Carnegie Mellon

GraphChi: Going small with GraphLab

GraphRats
Carnegie Mellon University