An Agent-Based Model of a Highway On-Ramp

Kevin I. Davidson and Dr. Keith Jones
Department of Mathematics, Computer Science & Statistics, SUNY College at Oneonta

Introduction

- **Model**: a purposeful representation of a real system (Railsback & Grimm, 2019)
- Being representations of reality, models must include certain assumptions or simplifications in their construction
- In traditional modeling, equations represent aggregate properties of systems ("top-down" approach) (Bonabeau, 2002)

Overview of agent-based modeling (ABM)

- ABM takes a "ground-up" approach; researchers indicate parameters for agent behaviors and behavior of the system is reimagined as resultant from interaction of agents (Bonabeau, 2002)
- Computing, often through ABM, allows for a more relaxed set of assumptions, thus creating models that correspond more closely to reality (Railsback & Grimm, 2019)
- ABM offers multiple benefits as compared to traditional modeling methods (Axtell & Epstein, 1996; Bonabeau, 2002):
  - Captures the growth of **emergent phenomena**; system-level phenomena whose characteristics are decoupled from the properties of their parts
  - Provides a more natural description of systems in which the behavior of individual agents is of key importance
  - Allows for flexibility of model variables, e.g., number of agents, complexity of agent behavior, and level of description
  - Allows for easy study of system dynamics without relying on equilibria
  - See Table 1 for an in-depth comparison of traditional and agent-based modeling methods (largely borrowed from Axtell & Epstein, 1996; additions from Bazghandi, 2012; Šalamon, 2011)

Table 1 *Agent-based Modeling vs. Traditional Modeling Methods*

	Traditional modeling methods	Agent-based modeling
Model structure	Series of equations describing whole system	Simulation; system results from interactions of agents
Level of focus	System	Agents
Approach	Top-down	Bottom-up
Populations	Generally homogenous	Generally heterogenous
Information access	Global	Local
Spatial component	Non-existent or inexplicit	Generally explicit
Model state	Equations are solved to determine	Reported by software

- Models may be continuous or discrete (Bazghandi, 2012)
  - **Continuous**: Passage of time is represented by continuous functions
  - **Discrete**: Time steps forward in increments called ticks
- One type of discrete model is a **cellular automata model**, in cells in a grid structure are updated mechanistically at each time step (Wolfram, 1983)
- Cellular automata grids are often **toroidal** (cells on one edge connecting to the corresponding cells on the opposite edge)

Modeling traffic systems

- For the benefits listed above, a typical application of agent-based modeling is flow management (i.e., traffic) (Bonabeau, 2002)
- Traffic itself is an emergent phenomenon (Bazghandi, 2012)
  - E.g., traffic jams flow in the opposite direction of the cars who create them
- Policymakers and researchers alike benefit from the efficiency of modeling as infrastructure changes are expensive to implement (Bazghandi, 2012)

Research question

- What behavioral strategy around on-ramps maximizes safety and efficiency?

Methods

Mesa

- Mesa is an agent-based modeling software developed using Python, a high-level programming language (Kazil et al., 2021)
- Mesa features many built-in modules helpful in developing this model:
  - **Agent class:** initializes agents with unique characteristics; includes step function to carry out agent actions at each time increment, i.e., obstacle detection, speed and lane adjustment, and movement (user-defined)
  - **Model class:** contains spatial/temporal properties of model; defines agents and adds to scheduler
  - **Single-grid:** spatial grid that returns exception if agents occupy the same square; useful for collision detection
  - **Base scheduler:** activates agents, one at a time, in order during each step
  - **Visualizer**: creates an in-browser visualization of model functioning
  - **Batch runner:** allows for multiple iterations of model to be ran at once; useful for experimentation and analysis
  - **Data collector:** stores data over iterations, allowing for analysis

The model

- The current study uses a cellular automata model on a 5x50 toroidal grid (Fig. 1)
  - This approach is simple while still allowing sufficient detail to study the dynamics we are interested in (e.g., modeling continuous movement between lanes is not necessary to detect collisions)
  - Making the ends of the grid toroidal allows for continual running of model (agents will simply return to the beginning of the lane upon reaching the end)
  - The top and bottom lanes act as buffers to prevent agents "jumping" lanes
  - Three lanes remain usable: on-ramp (second from bottom), and two highway lanes (third and fourth from bottom)

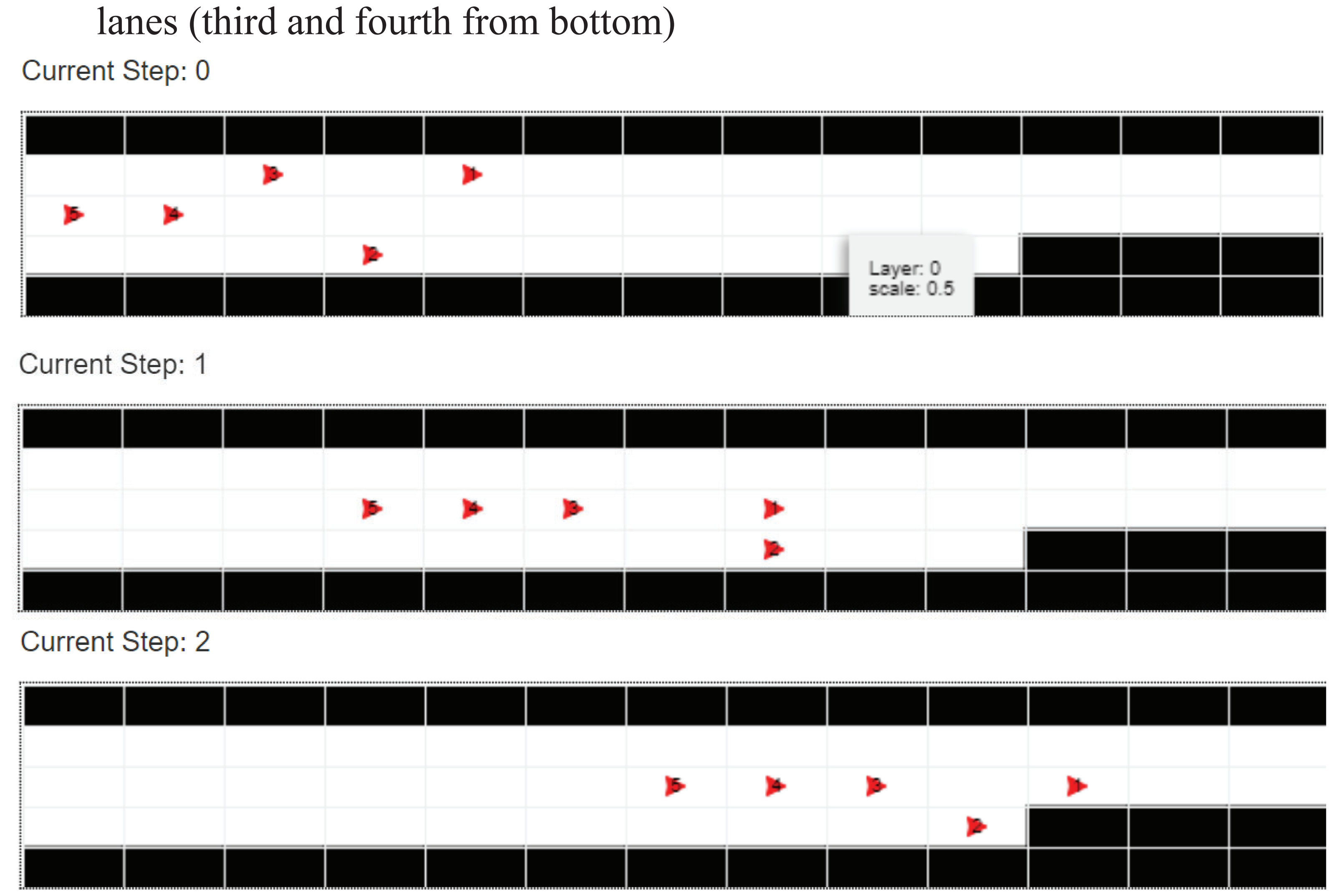
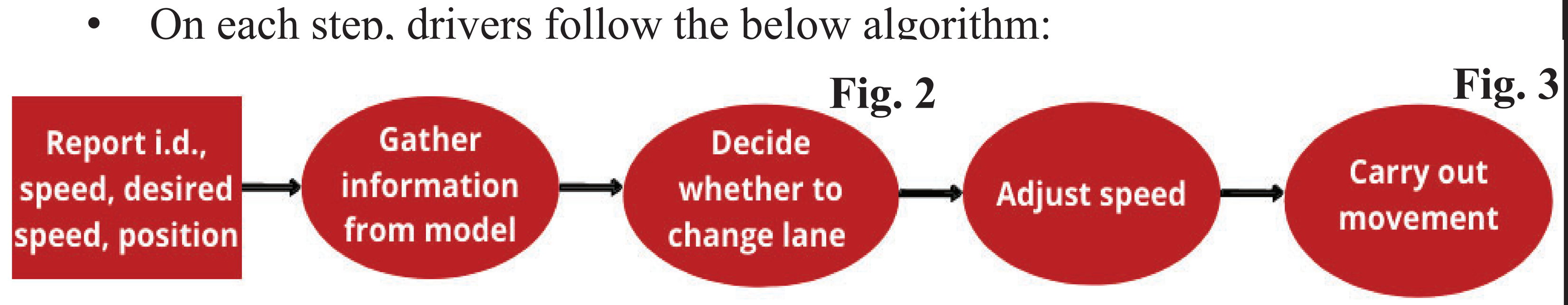


Figure 1 *Visualization of Model*

The agents

- **Roadblocks**: initialized with ID, position; remain stationary during steps
- **Drivers**: initialized with ID, speed, desired speed, and position
  - On each step, drivers follow the below algorithm:



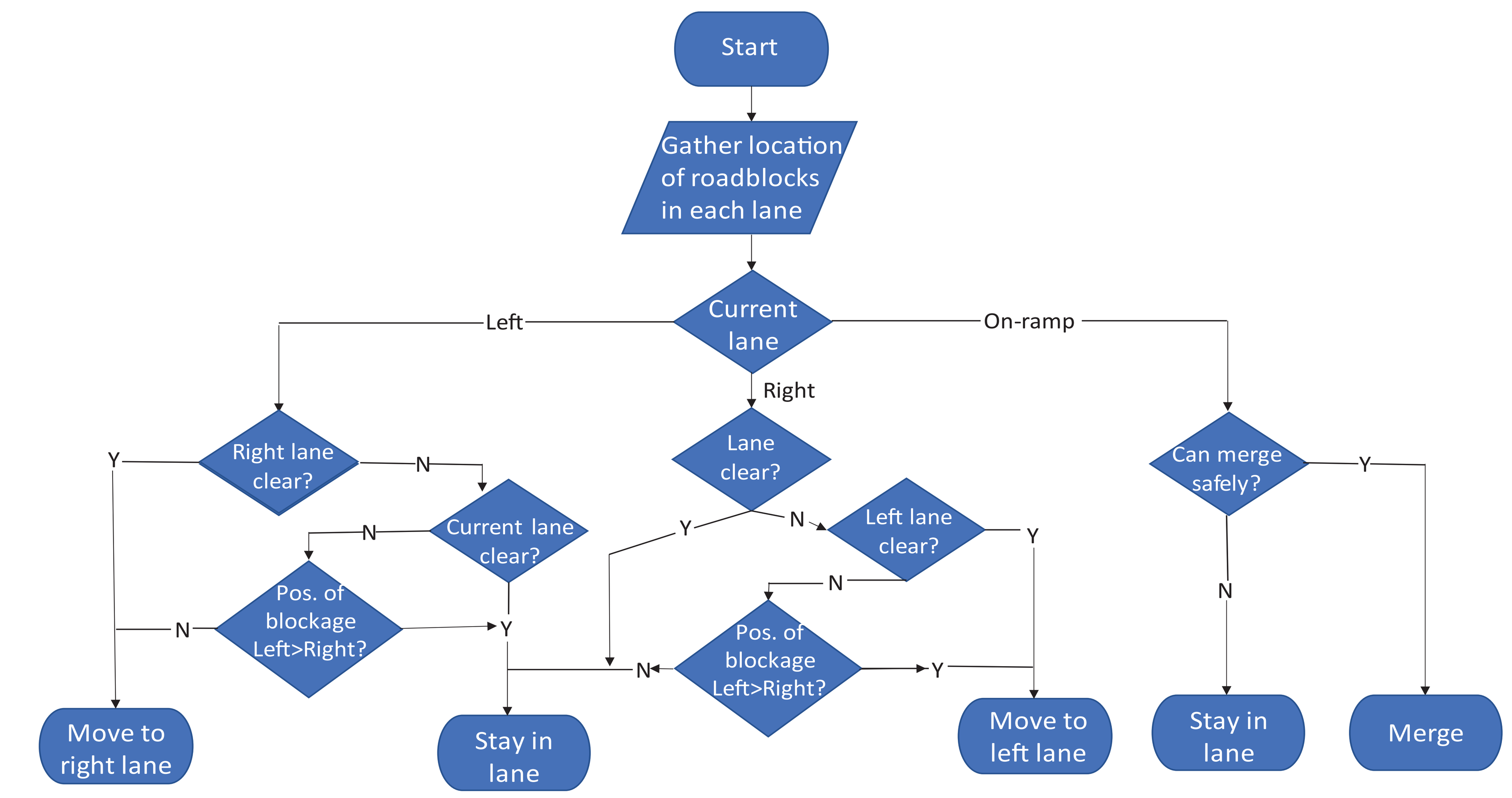


Figure 2 *Decision Tree for Agent Lane-changing Function*

- Drivers display preference for middle lane, and merge as soon as safely possible
  - Agents move forward one square at a time for collision detection
  - Speed adjustments are made prior to movement
  - Movement is carried out by built-in Mesa function

```
def move(self, newlane):
    if self.speed == 0:
        return

    if newlane != self.pos[1]: #Changes lanes
        new_position = (self.pos[0], newlane)
        print("Moving to: " + str(new_position))
        self.model.grid.move_agent(self, new_position)

    for i in range (self.speed): #Moves forward
        new_position = (self.pos[0]+1, self.pos[1])
        print ("Moving to: " + str(new_position))
        self.model.grid.move_agent(self, new_position)

    return
```

Figure 3 *Agents' Move Function*

Planned analyses

- While previous studies have examined physical characteristics of roadways, the purpose of this study is to examine behavior
- The effect of drivers slowing down, changing lanes, both, or neither in response to merging cars will be compared for their effect on safety and efficiency
- Specifically, the average number of model steps before a collision (safety) and the gap between the actual speed and desired speed of drivers (efficiency) will be calculated and compared between iterations
- It is hypothesized that the more predictable behavior of maintaining lane and speed will lead to a safer and more efficient roadway

References

Bazghandi, A. (2012). Techniques, Advantages and Problems of Agent Based Modeling for Traffic Simulation. *International Journal of Computer Science Issues*, *9*(1).

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, *99*(suppl_3), 7280–7287. https://doi.org/10.1073/pnas.082080899

Epstein, J. M., & Axtell, R. (1996). *Growing Artificial Societies: Social Science from the Bottom Up (Complex Adaptive Systems)*. A Bradford Book.

Kazil, J., Masad, D., & Crooks, A. (2016). Mesa: Agent-based modeling in Python 3+Version (8.9). *PyPi*. Retrieved March 30, 2022, from https://pypi.org/project/Mesa/.

Railsback, S. F., & Grimm, V. (2019). *Agent-Based and Individual-Based Modeling: A Practical Introduction* (2nd ed.). Princeton University Press.

Šalamon Tomáš. (2011). *Design of agent-based models: Developing computer simulations for a better understanding of social processes*. Bruckner.

Wolfram, S. (1983). Cellular Automata. *Los Alamos Science*.