Network Traffic Simulator

Designing an Extensible Traffic Management System Using Python

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Summary

Overview of Traffic Simulators

What is a Traffic Simulator?

- **Network**: infrastructure (real, virtual, etc) that allow the flow of objects or information
- **Traffic**: objects (or packets) that transverse the network
- **Simulation**: modeling the flow of traffic on the network over time

- Macroscopic: models flow and patterns
- Microscopic: models individual units

Existing Simulations

Figure: SUMO [1]

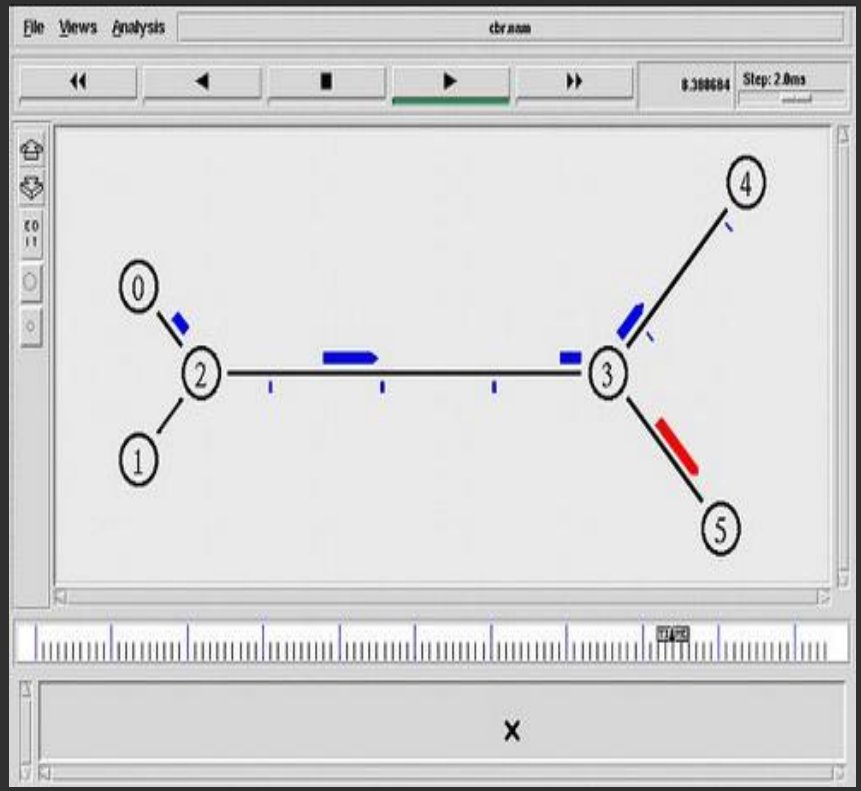


Figure: NS2 [3]

Designing a New Traffic Simulator: Architecture

Desired Network Structure

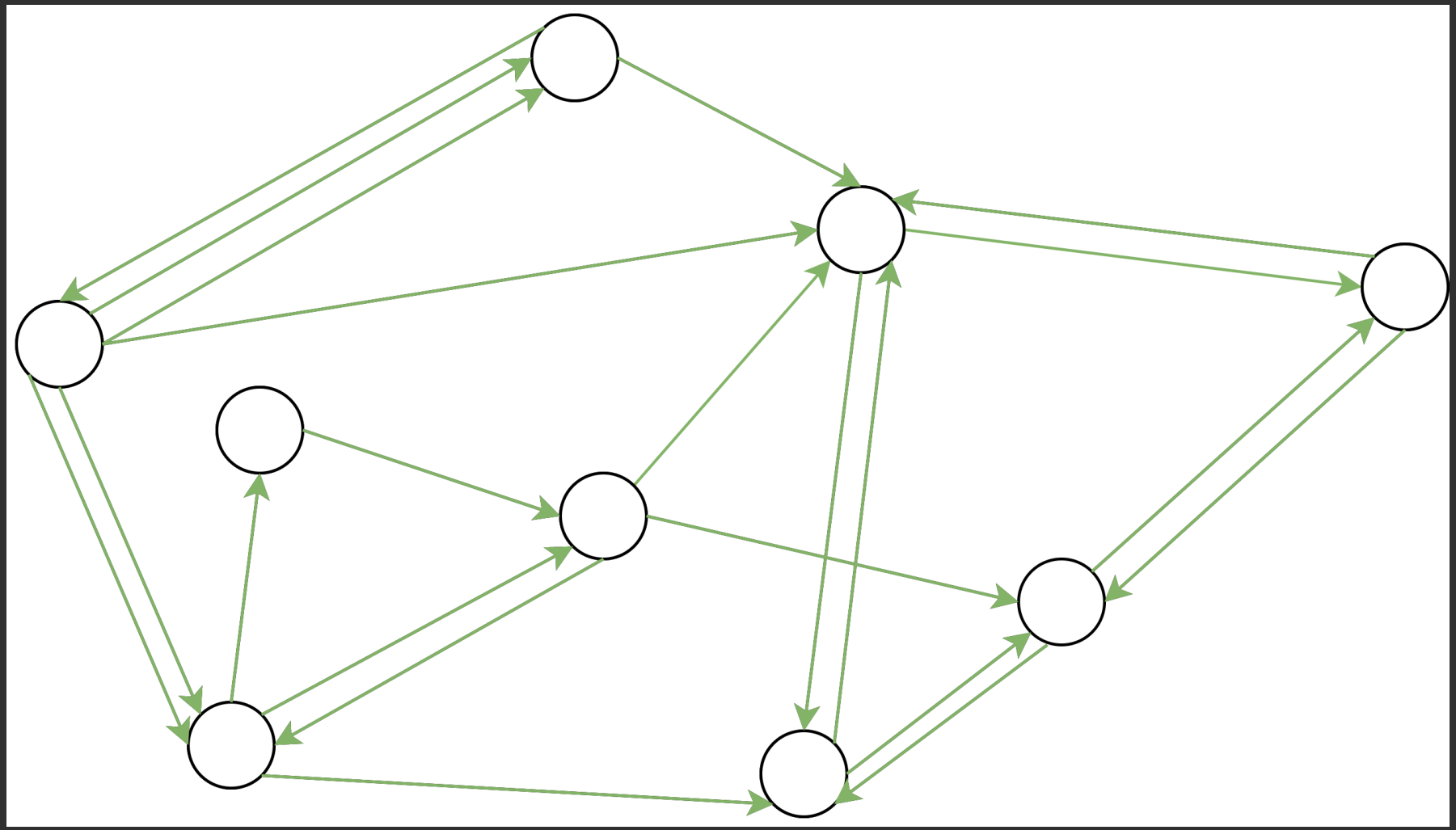


Figure: Example generalized graph network

Desired Network Structure: Highlights

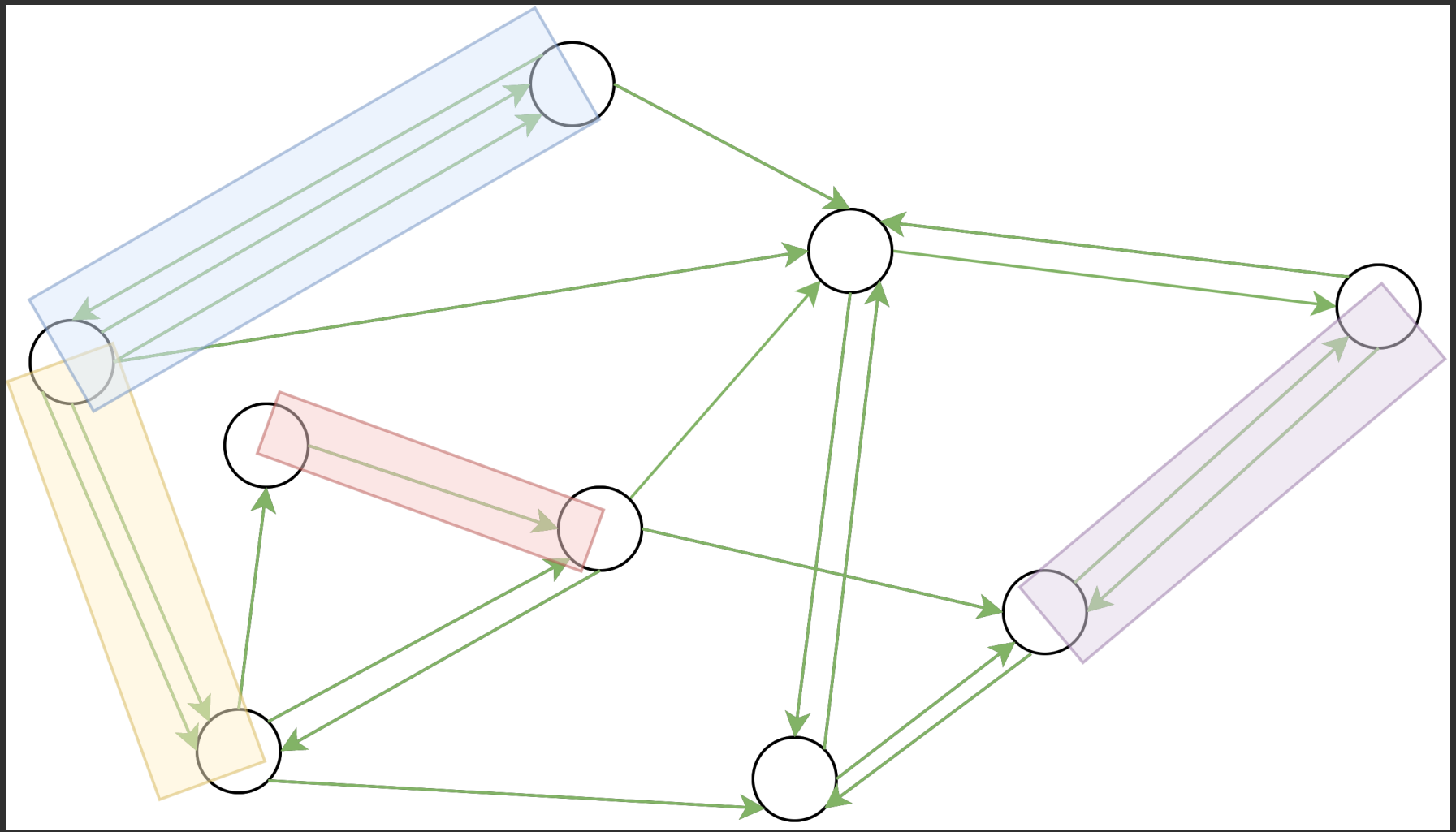
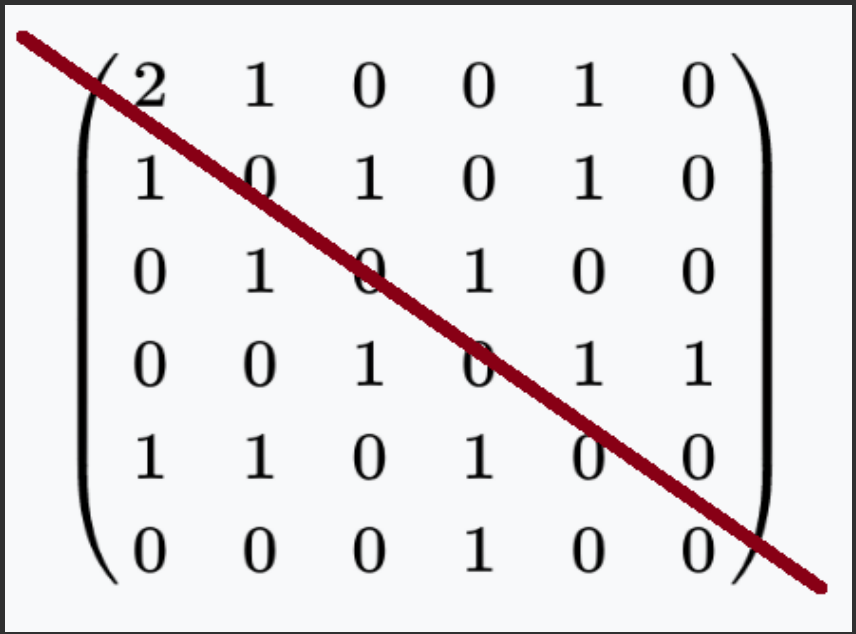


Figure: Different edge patterns have been highlighted

Desired Network Structure: Data Structures



$$\begin{pmatrix} 2 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Figure: Adjacency matrices cannot isolate individual edges

```
defaultdict(<function Network.__init__.<locals>.<lambda> at 0x00000247F
FD2DF70>, {1: <traffic_network.Node object at 0x000002478060AD60>, 2: <
traffic_network.Node object at 0x000002478060AD90>, 3: <traffic_network
.Node object at 0x000002478060AF70>, 4: <traffic_network.Node object at
 0x000002478060AF40>})
```

```
{
    "id": 2,
    "intersection_time_cost": 0,
    "stoplight_pattern": null,
    "stoplight_pattern_current_index": 0,
    "stoplight_duration": 60,
    "stoplight_delay": 10,
    "node_tick_number": 0,
    "outbound_edges": [
        5001,
        5002
    ],
    "inbound_edges": [
        5000,
        5003
    ]
},
```

Figure: Dictionary output: internal (top), human readable (bottom)

Network Software Components

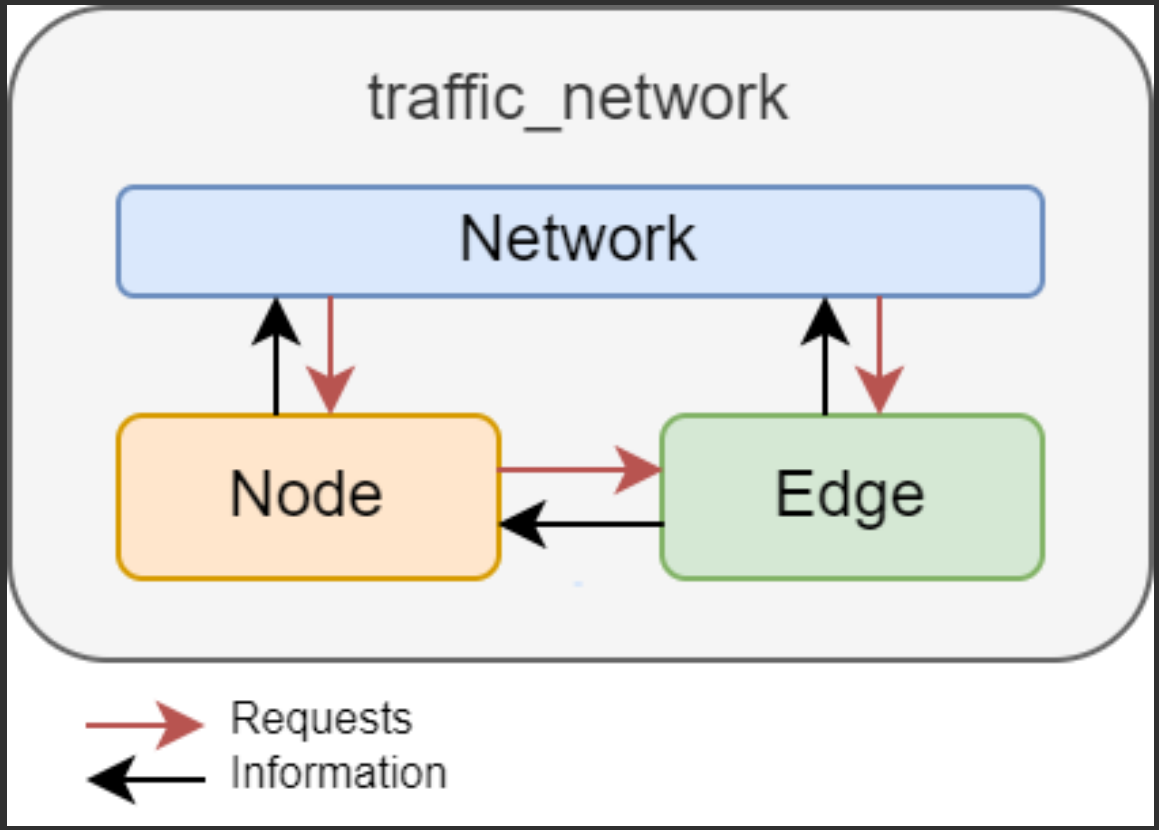


Figure: Network software module and class components

Desired Traffic Structure: Cars

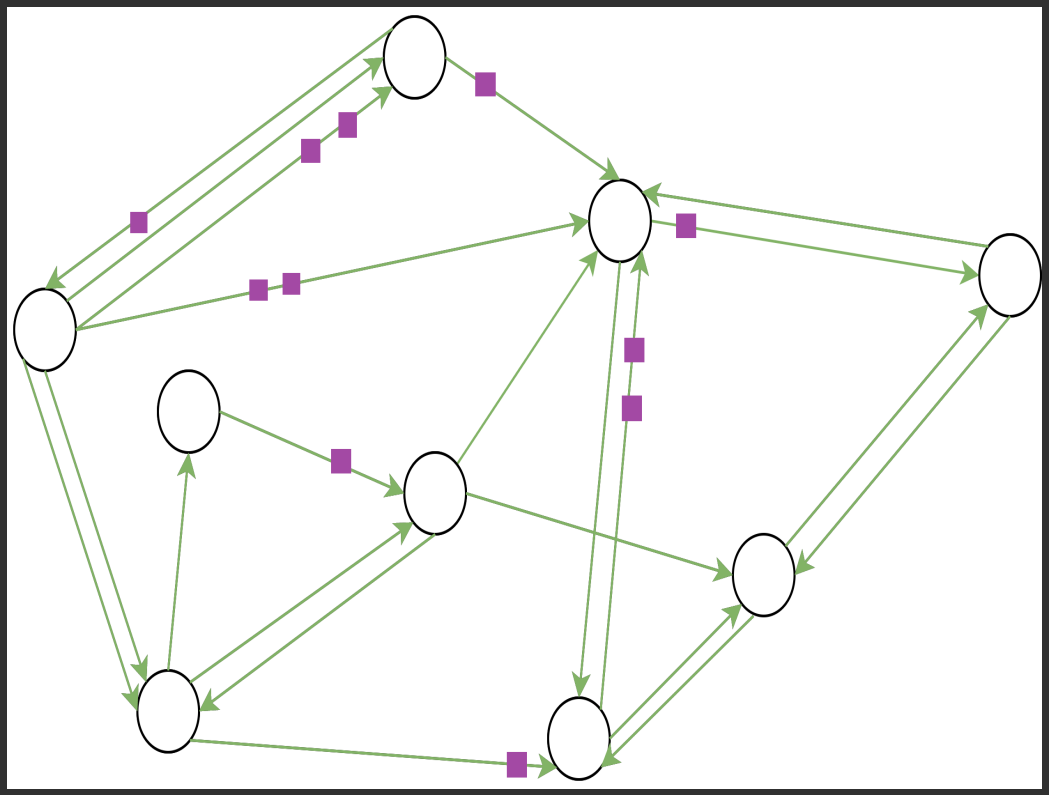


Figure: Cars (purple squares) moving along the network

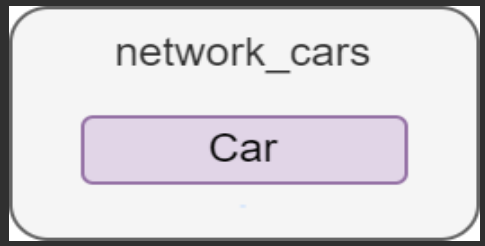


Figure: Car software module and class component

Complete Software Architecture

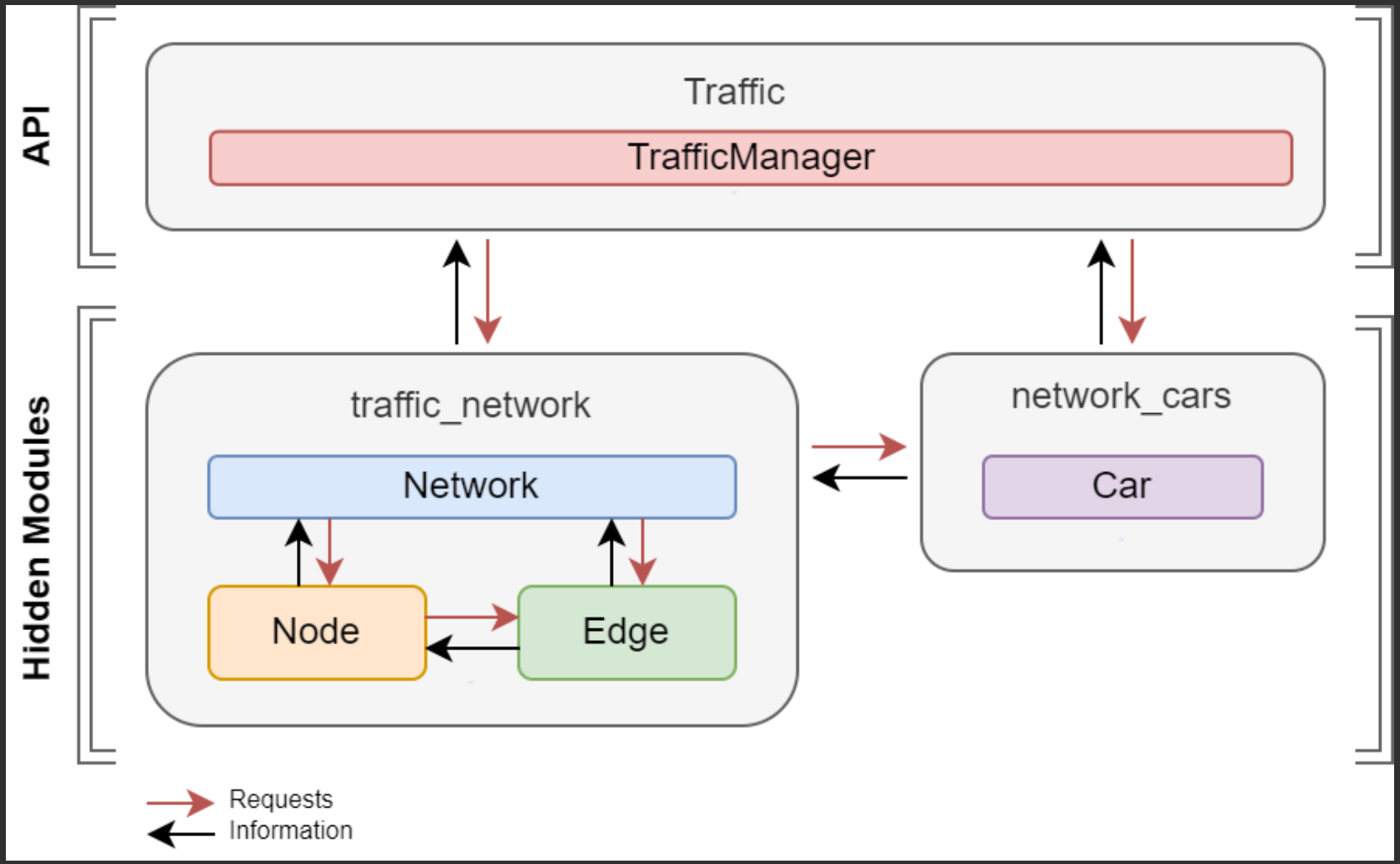


Figure: Module Interaction

Full Software Ecosystem

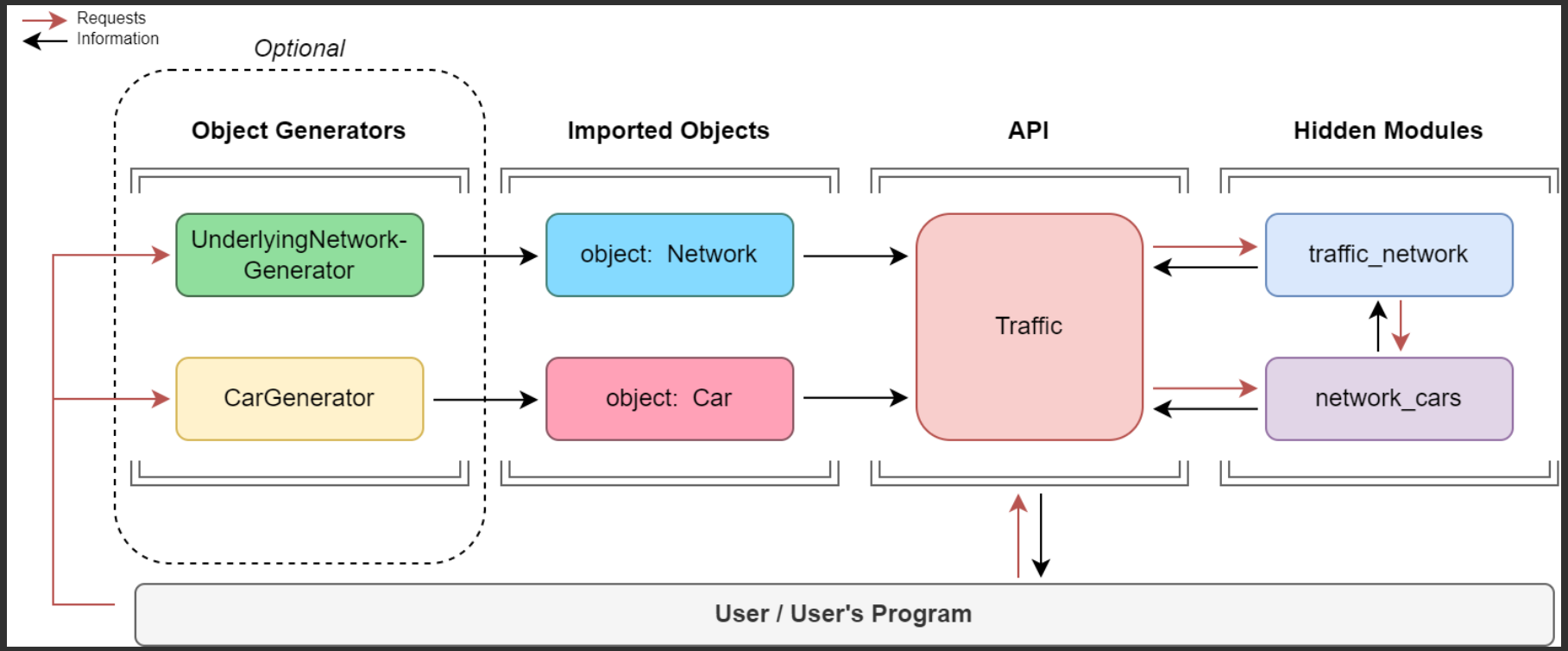


Figure: Module Interaction, including user and generators

Designing a New Traffic Simulator: Movement

Car Movement along Edges

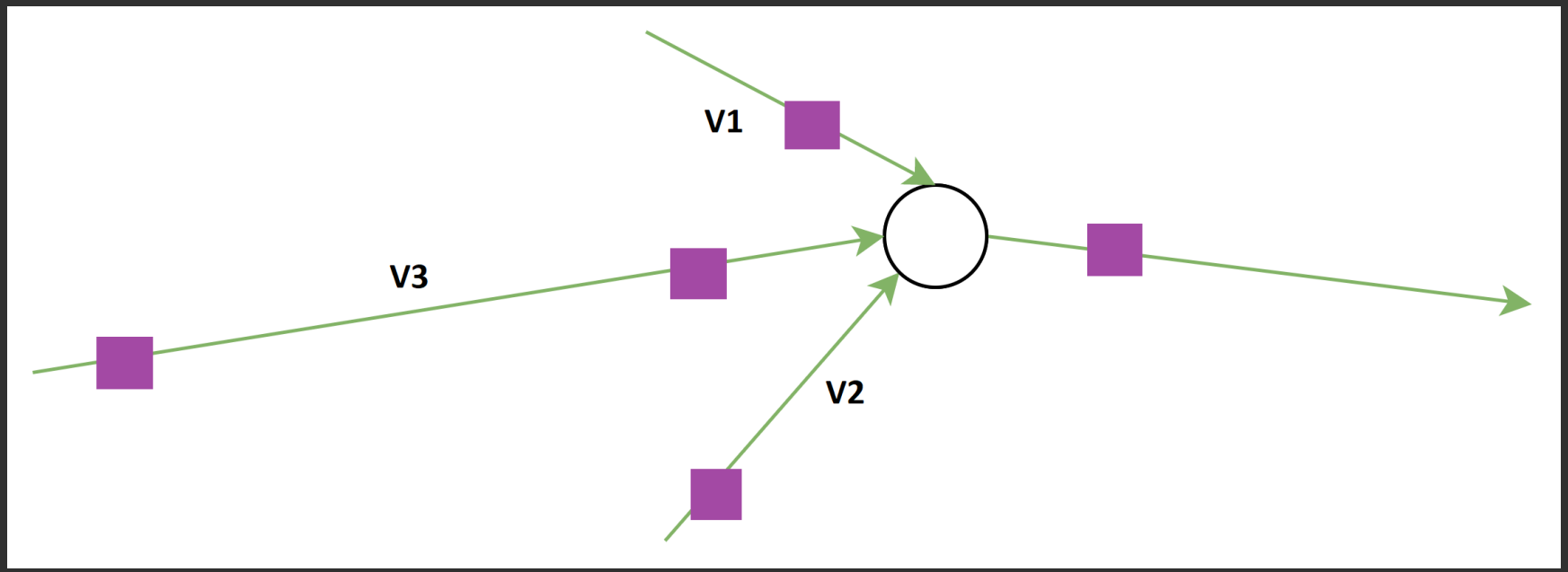


Figure: Several cars' positions at a moment in time

Movement Considerations

- Does a car have "room" to move?
- How far does a car go on to the following edge?
- What if the two edges have different speeds?
- What if cars from two (or more!) different inbound edges want to move onto the same new edge?
- Are cars allowed to change their path?

Movement Procedure

- One unit of simulation time is a tick
- The entire system ticks:
  TrafficManager $\rightarrow$ ||: Network $\rightarrow$ Node $\rightarrow$ Edge $\rightarrow$ Car :||
- Each car per tick has a maximum "potential" energy that can be utilized to move

What happens on a tick?

- **TrafficManager Tick**: tell Network to move cars as far as energy allows and advance timestamp by one tick
- **Network Tick**: tell (shuffled) Nodes to tick
- **Node Tick**: tell (shuffled) outbound edges to tick
- **Edge Tick**: tell cars to move as much as possible***
- **Car Tick**: calculate remaining potential

Node Tick and Edge Tick

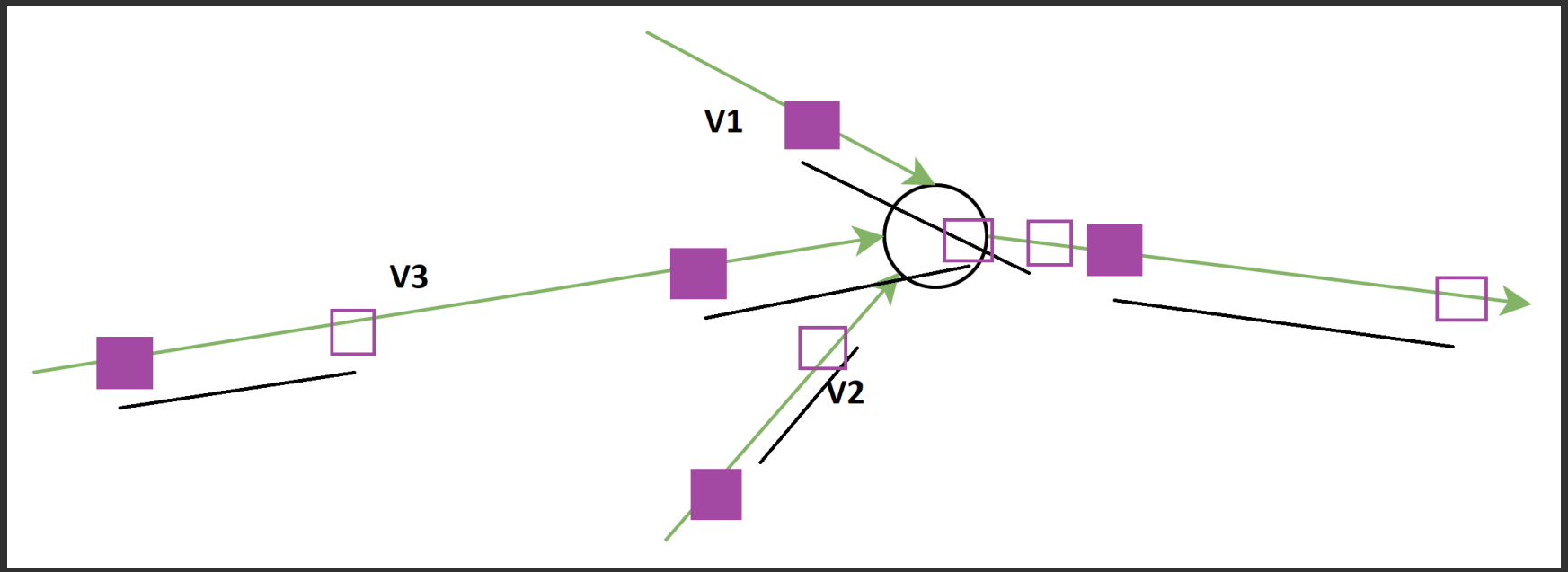


Figure: Eligible maximum travel distance per car has been mapped

Node Tick

- Check all inbound edges for cars eligible to move onto the next edge
- Place these eligible cars onto the start of the next edge in their path (if possible)
- If cars change edges, tell the old edge to forget the car and the map the car to its new edge

Edge Tick

- Try to move the car its maximum tick potential
- If it runs into another car, halt it there
- If it completes its route, remove it from the network
- If it reaches the end of the edge, wait: it will be transfered on the next node tick

Movement Procedure Recap

- The entire system ticks:
  TrafficManager $\rightarrow$ ||: Network $\rightarrow$ Node $\rightarrow$ Edge $\rightarrow$ Car :||
- Each car per tick has a maximum "potential" energy that can be utilized to move
- **If no more movement is possible on the current tick, the tick is complete. Output simulation state data.**

Next Steps

Software Improvement

- Subclasses for different car types (max tick potential, route types, etc)
- Reduce computation: flag complete and/or empty nodes and edges to be ignored on subsequent passes of the same global tick
- More efficient route calculation

User Experience / Simulation Improvement

- Create a visualizer (vis.js or D3.js)
- Add functions (delete nodes/edges)
- Congestion metrics backed by research (or user feedback)
- Snapshot improvements (logs or deltas instead of full dump)

References I

1. (DLR), G. A. C. *et al.* *SUMO User Documentation.* https://sumo.dlr.de/docs/index.html. 2022.
2. Lopez, P. A. *et al.* Microscopic Traffic Simulation using SUMO. *2018 21st International Conference on Intelligent Transportation Systems (ITSC)* (2018).
3. Singh, A. *Install NS2 (Network Simulator) on Ubuntu 18.04.* https://www.absingh.com/ns2/. 2022.

Questions?