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A multi-model approach to large-scale multiagent transport simulation (13-3631)

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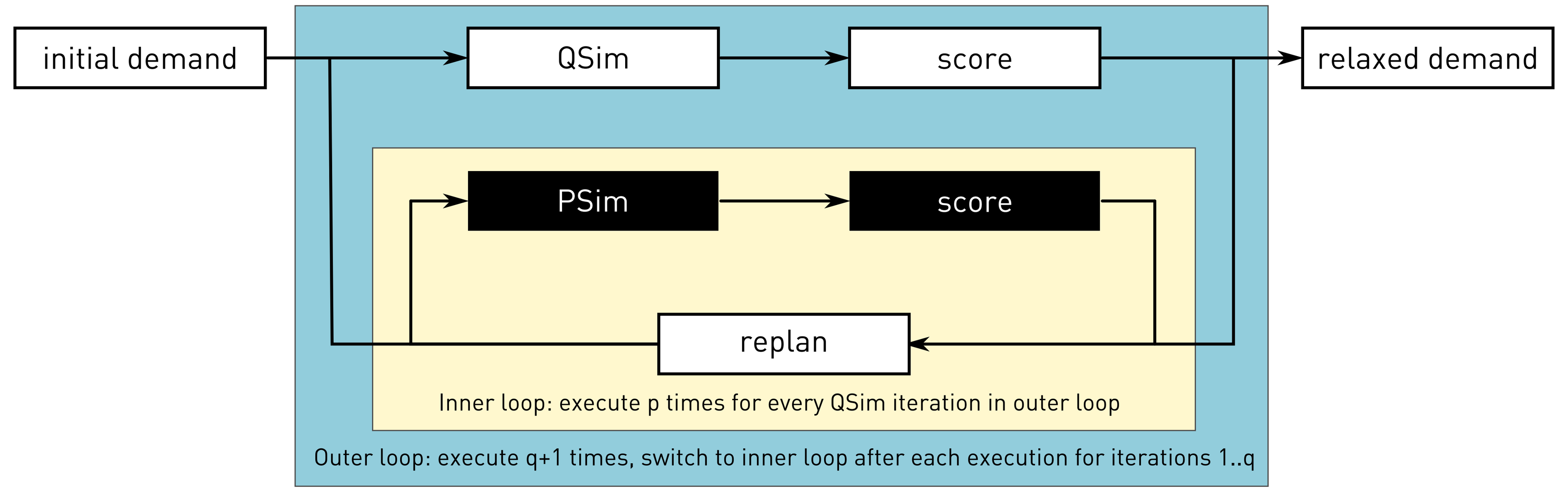
In this paper, we introduce a multi-model approach to a large-scale, activity-based, multi-agent travel demand simulation (MATSim). The greatest current performance limitation to the system is the network loading simulation, currently a queue simulation (`QSim'). In our application, the multi-model system periodically replaces the current QSim for a number of iterations with a simplified pseudo-simulation (`PSim') that runs approximately two orders of magnitude faster. PSim uses information generated in the preceding QSim iteration to produce an estimate of how well an agent day plan might perform, which allows the existing model framework to select and improve plans before executing them in a full queue simulation. We apply and evaluate the technique in a large-scale application to Zurich.



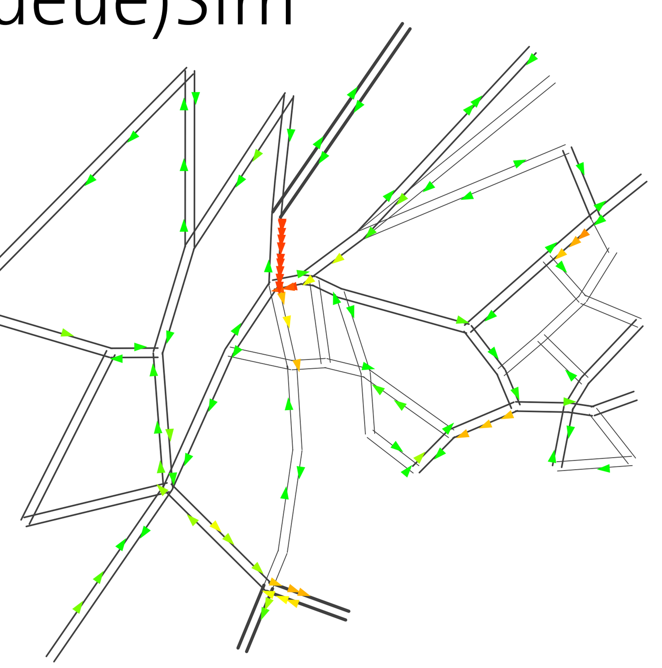
MATSim simulates the traffic produced in a transportation network by agents pursuing daily schedules of activities (plans) separated in time and space. Its principle of operation is shown by the white boxes in the image above. The system is fed with an initial demand of agent plans that are repeatedly executed in a QSim network loading. After each QSim run, plan performance is evaluated using a utility-based scoring function, rewarding time spent at activities and punishing time spent traveling or arriving late. Then, agent plans are mutated along a number of choice dimensions, such as activity start times and durations, route choice, trip transport mode, activity location choice, etc., to produce new plans for execution in the following QSim iteration. With increasing iterations, the number of plans in each agent's memory grows up to a limiting number, following which poorly performing plans are discarded. Consequently, the average score of plans improves with increasing iterations, until a steady state is reached where plan mutations produce only marginal changes in score.

Our multi-model approach uses a simplified surrogate model of traffic conditions, basically a lookup table of link travel times during the course of the simulated day, produced after each QSim execution. These are used in a fast pseudo-simulation (PSim) to produce an expected score for each newly generated plan. After a number of iterations, the system switches back to the QSim to produce an updated set of link travel times.
Because the PSim requires no interaction between agents, it can be distributed between many computational nodes, making it well-suited to modern computer architectures.

Operation

During a QSim iteration, an agent plan is executed with all other plans on the network. Links are modeled as FIFO queues, producing congestion and increased link travel times.

Q(ueue)Sim



The queue simulation produces an event stream that describes what is happening to each agent throughout the course of the simulated day. The times recorded entering and leaving links (red lines in the event stream below) are an emergent property of the simulation, arising from the interacting queue dynamics. This event stream is processed to evaluate how much time was spent traveling vs performing activities, to produce a score for each agent plan.

Agent plans

```
<person id=1>
  <plan selected=yes>
    <act type="home" link=1 end_time="06:00:00" />
    <leg mode="car">
        <route> 6 15 20 </route>
    </leg>
    <act type="work" link=20 end_time="17:00:00" />
    <leg mode="car">
        <route> 19 16 12 1 </route>
    </leg>
    <act type="home" link=1 />
  </plan>
</person>
```

Events

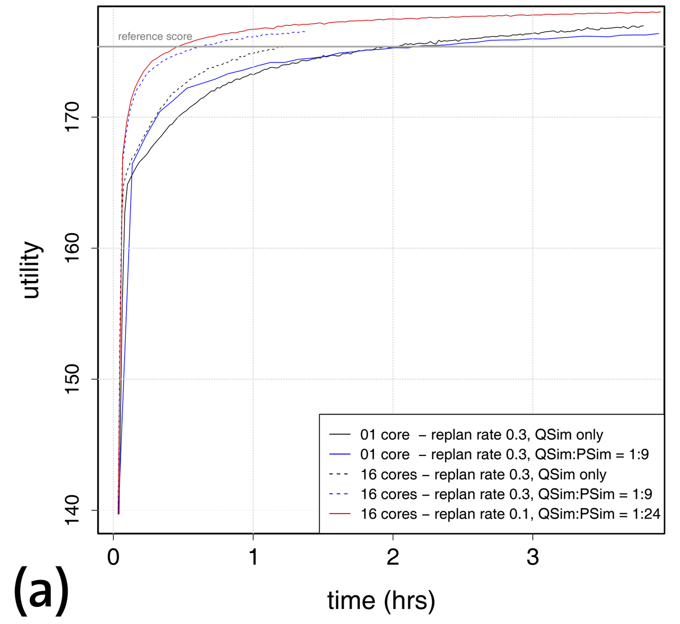
```
<event time=21600.0 type="actend" person=1 link=1 actType="home" />
<event time=21600.0 type="departure" person=1 link=1 legMode="car" />
<event time=21609.0 type="wait2link" person=1 link=1 vehicle=1 />
<event time=21610.0 type="left link" person=1 link=1 vehicle=1 />
<event time=21610.0 type="entered link" person=1 link=6 vehicle=1 />
<event time=22357.0 type="left link" person=1 link=6 vehicle=1 />
<event time=22357.0 type="entered link" person=1 link=15 vehicle=1 />
<event time=22787.0 type="left link" person=1 link=15 vehicle=1 />
<event time=22787.0 type="entered link" person=1 link=20 vehicle=1 />
<event time=23146.0 type="arrival" person=1 link=20 legMode="car" />
<event time=23146.0 type="actstart" person=1 link=20 actType="work" />
<event time=61200.0 type="actend" person=1 link=20 actType="work"  />
<event time=61200.0 type="departure" person=1 link=20 legMode="car"  />
<event time=61200.0 type="wait2link" person=1 link=20 vehicle=1  />
...........
...........
...........
```

P(seudo)Sim

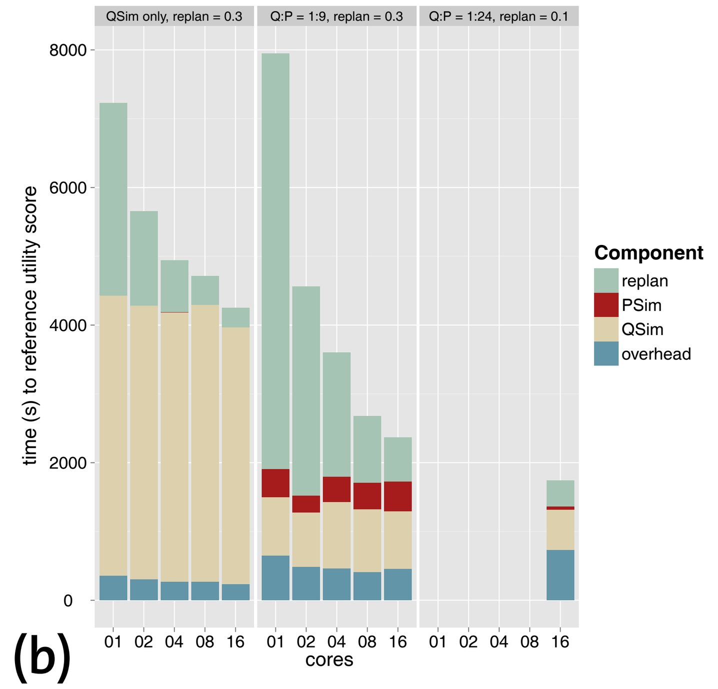
Link 6		...	Link 15		...
Time of day	Travel time	...	Time of day	Travel time	...
0:00:00	412	...	0:00:00	252	...
0:15:00	412	...	0:15:00	252	...
...	...	...	...	...	...
5:30:00	501	...	5:30:00	287	...
5:45:00	645	...	5:45:00	321	...
6:00:00	723	...	6:00:00	363	...
6:15:00	786	...	6:15:00	428	...
...	...	...	...	...	...

PSim operates by reading a travel time for each link in an agent's route, at the appropriate time of day interval (TODI), from a lookup table. This table is produced after each QSim iteration, averaging the recorded agent travel times for each link, for each TODI.

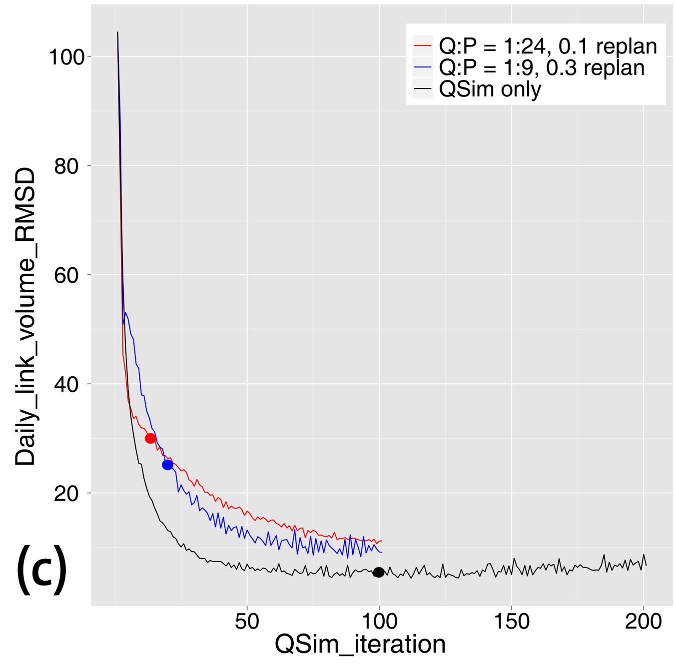
PSim produces an event stream for each agent, similar to that produced by QSim. It runs much faster than QSim, and therefore allows the rapid mutation and evaluation of plans before execution in QSim. PSim performance scales linearly with increasing compuational cores.



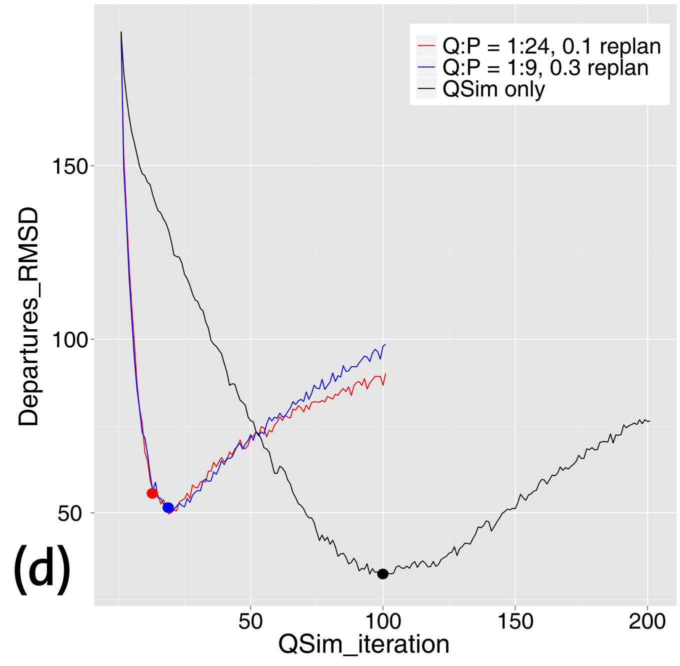
(a)



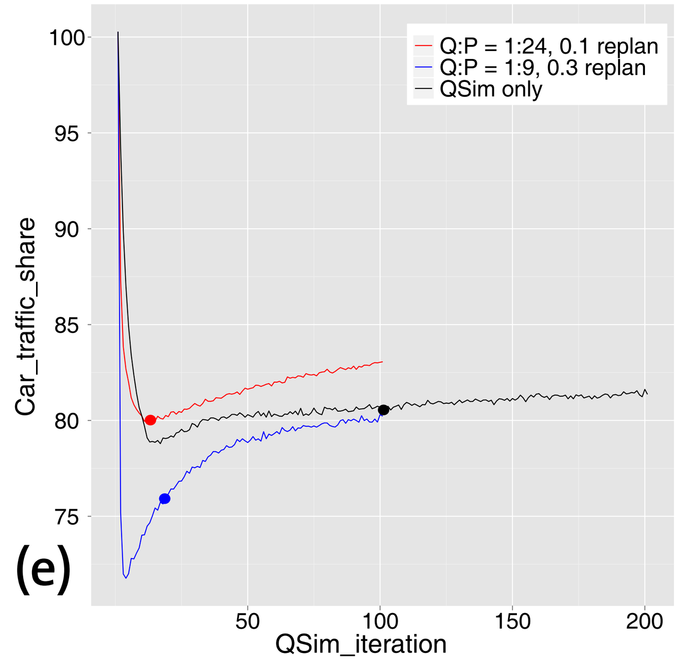
(b)



(c)



(d)



(e)

Results

We used the MATSim development scenario of Swiss car traffic crossing or operating within a 30km radius circle around Bellevue, Zurich, to test the multi-model approach. The scenario contains 67,239 agents traveling in a network of 60,518 links.
The following re-planning modules were used in equal measure, with the total replanning rate (proportion of agents replanned) varied as part of the experimental setup: activity start time and duration adjustment; re-routing using travel times from the previous iteration; subtour mode choice - switches the mode of transport of a randomly selected subtour to car/public transport; secondary activity location choice: shopping and leisure activities are switched to a randomly chosen location from a set of qualifying facilities.

We compared simulation runs for performance as well as solution quality against a 100 iteration QSim-only reference run, with a total replanning rate of 30% (black line in figures a, c-d). We varied the number of PSim iterations between Qsim iterations (Q:P ratio), as well as the overall replanning rate, and the number of computational cores committed to PSim and replanning operations.

Figures (a) and (b) show that the time needed in the multi-model approach to attain the simulation score of the Qsim-only run after 100 iterations (reference score) rapidly decreases with increasing computational cores. Interestingly, decreasing the overall replanning rate and increasing the number of PSim iterations produces the most dramatic reduction in simulation wall-clock time.

Figures (c), (d) and (e) characterize solution quality at the QSim iteration producing the reference score (coloured dots) and beyond, in comparison with the reference run.
Figure (c) shows that daily link volumes differ by approximately 20 vehicles per link from the reference run. Figure (d) shows that hourly departures differ by approximately 25 from the reference. Figure (e) shows that lowering the replanning rate, and consequently the number of random mode switches occuring after PSim iterations, produces a car mode share comparable to that of the reference run. All three figures highlight the importance of understanding the relative contribution of replanning modules to the system state, as well as the need for a large number of iterations to produce a stable system state, especially when using a combination of replanning modules.

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