Real-Time Simulation of the German Autobahn Network

Topics

- CA–Model of Traffic Simulation
- Network Simulation

  Example: Iterative Routing
- Parallelization
- Outlook

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Starting Point

Traffic Simulation

is one of the

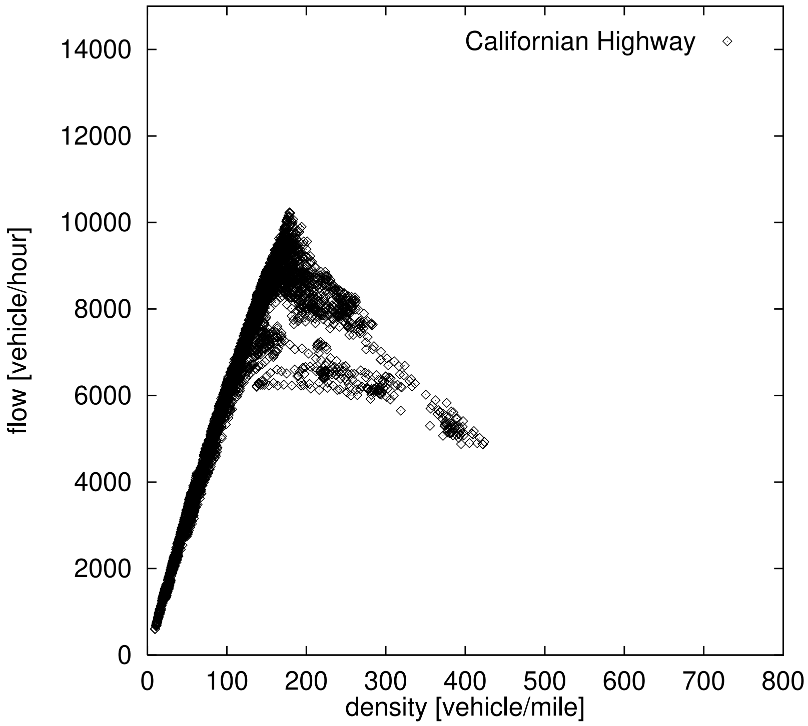
Grand Challenges

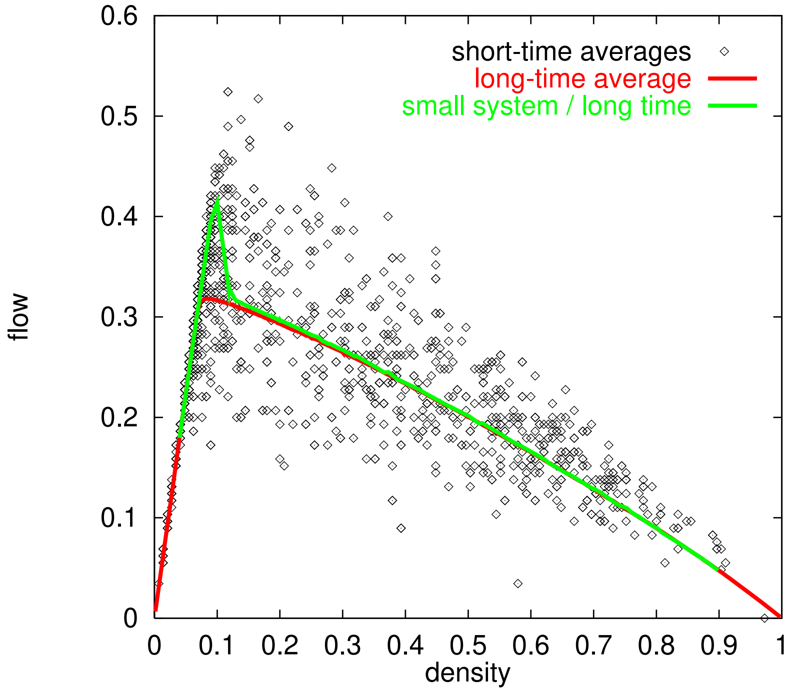
in computer simulation.

Approach

- Fast algorithms based upon
  → Cellular Automata (CA)
- Efficient implementation
  → Parallel Computers

Motivation


Californian Highway
flow [vehicle/hour]
density [vehicle/mile]
14000
12000
10000
8000
6000
4000
2000
0
0
100
200
300
400
500
600
700
800


short-time averages
long-time average
small system / long time
flow
density
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

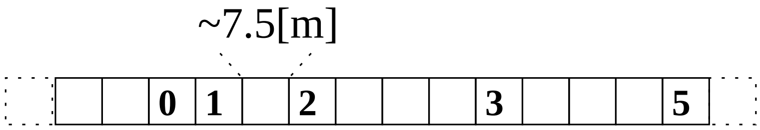
Work Groups

TRANSIMS at the Los Alamos Natl. Lab
(Nagel GK July 93 - Dec. 94)

ZPR Traffic Group
Forschungsverbund Verkehr NRW
(Rickert GK since Jan. 95)

PARAMICS in Edinburgh, Scottland

Single Lane CA
Nagel / Schreckenberg (1992)



figures denote vehicles with v=0,1,...,5

1 Accelerate:

$$v := \min(v_{max}, v + 1)$$

2 Avoid crash:

$$v := \min(gap, v)$$

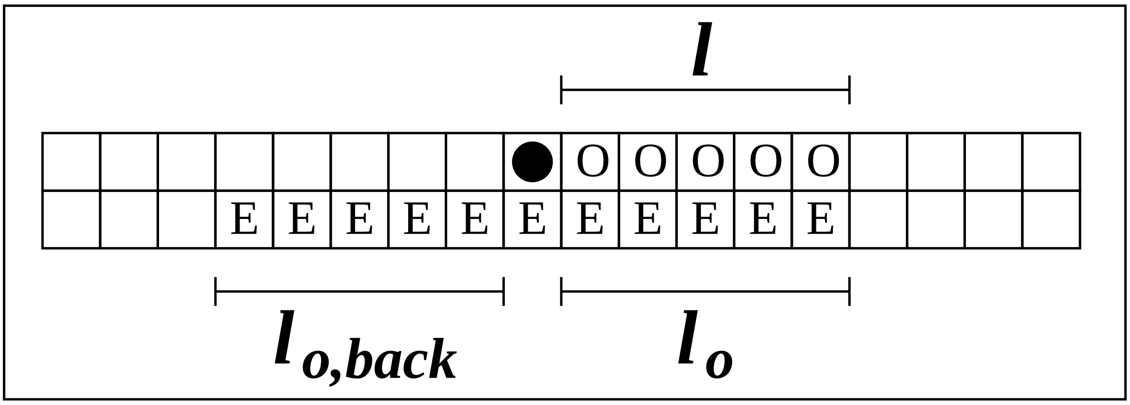
3 Randomize:

$$rand() < p_{dec} \Rightarrow v := \max(v - 1, 0)$$

Perform Parallel Update

Lane Changing Rules

l	look ahead same lane
l_o	look ahead other lane
$l_{o,back}$	look back other lane

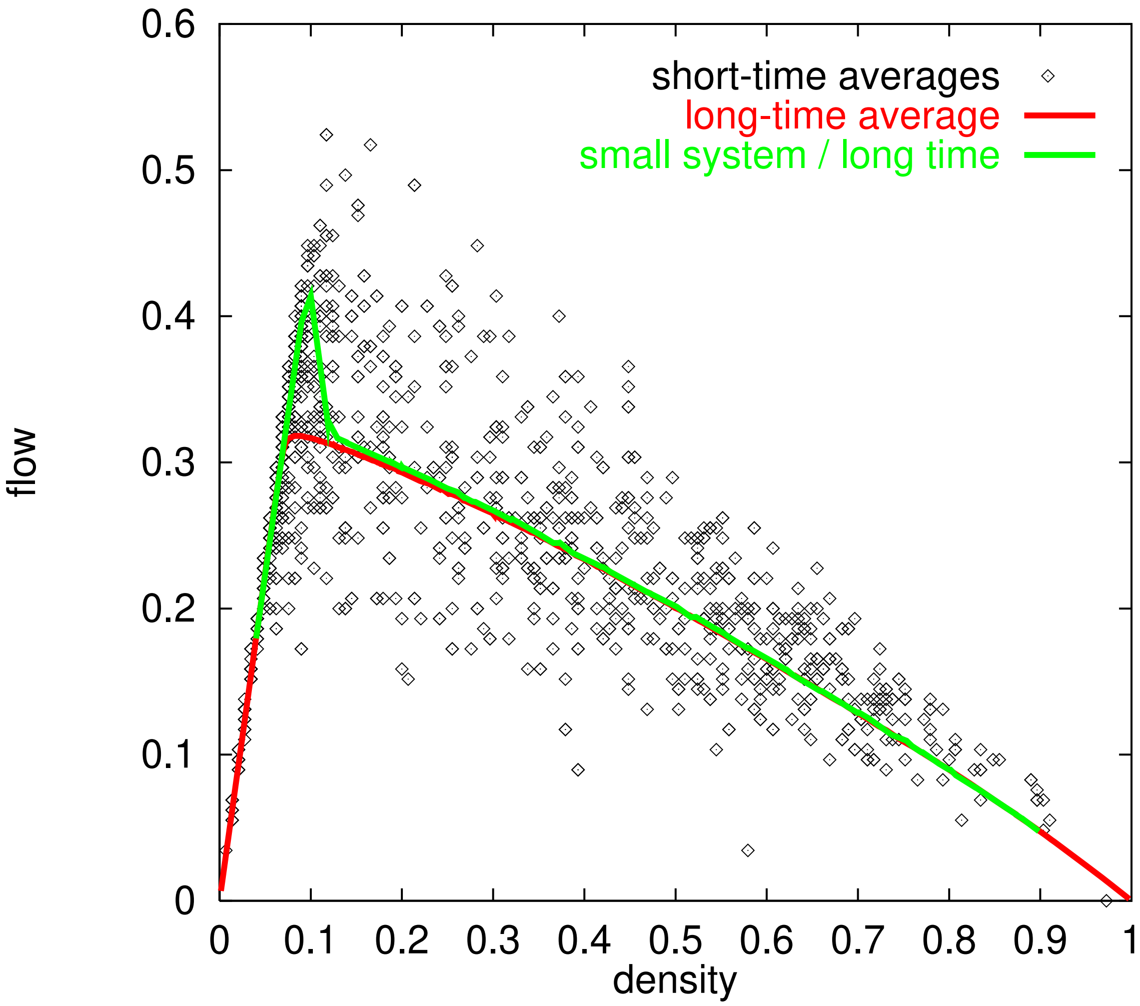


Example

symmetric	asymmetric $L \rightarrow R$	asymmetric $R \rightarrow L$
$l = v + 1$	no	yes
$l_o = v + 1$	yes	yes
$l_{o,back} = v_{max}$	yes	yes

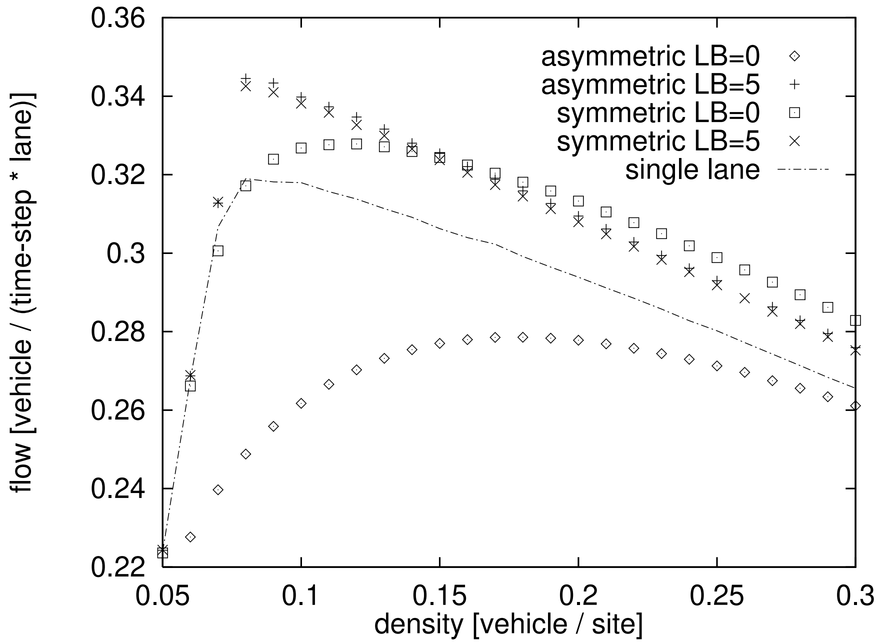
Fundamental Diagram

system setup	sites	steps
scatter	10,000	100
large	10,000	1,000,000
finite size	100	10,000



Importance of Lookback (I)

- *lookback* > 0 and lane changing improves throughput
- *lookback* ~ 0 separates symmetric and asymmetric case

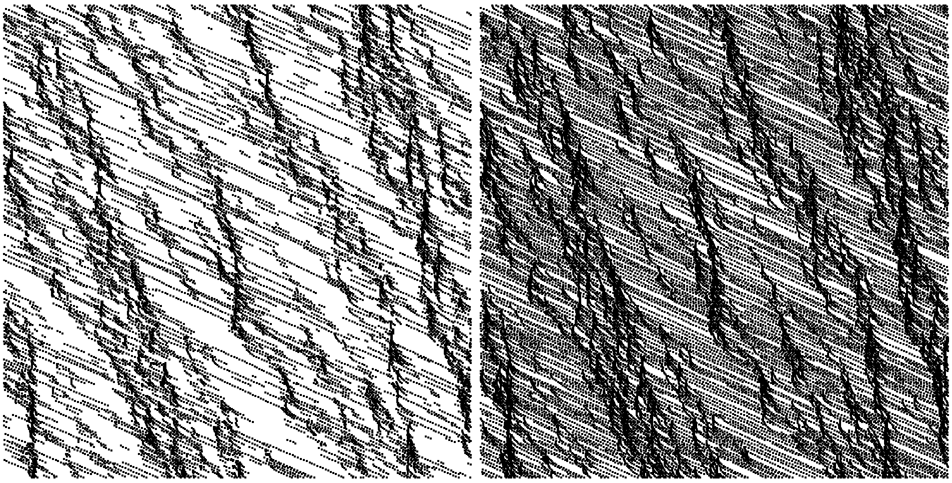


Current work by *Nagel, Latour, Schreckenberg, and Rickert* will be published in Physica A.

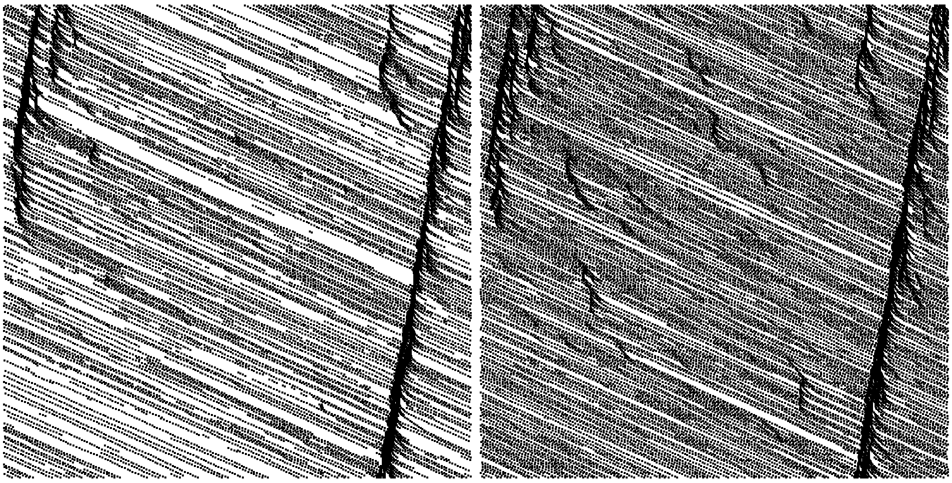
Importance of Lookback (II)

Time Space Plots

$l_{o,back} = 0$

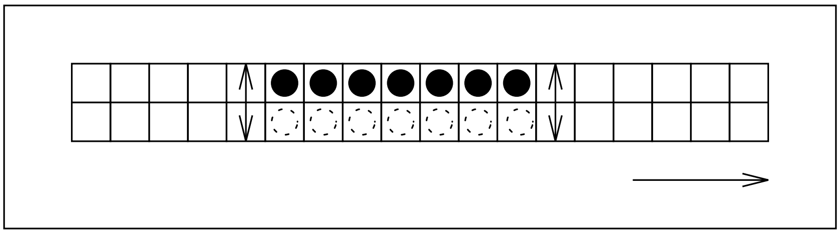


$l_{o,back} = 5$

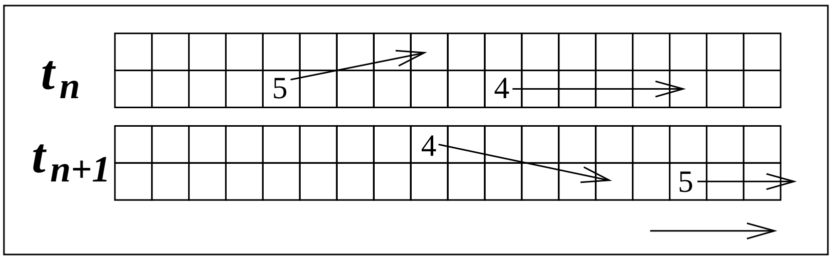


Artifacts:
Ping Pong Lane Changes

At high densities vehicles cluster:

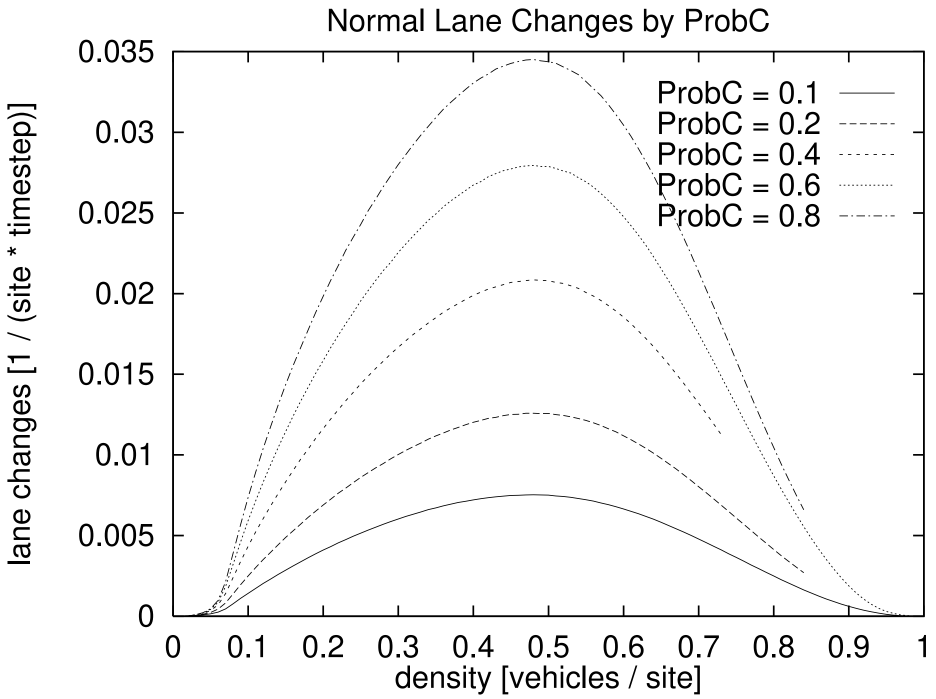


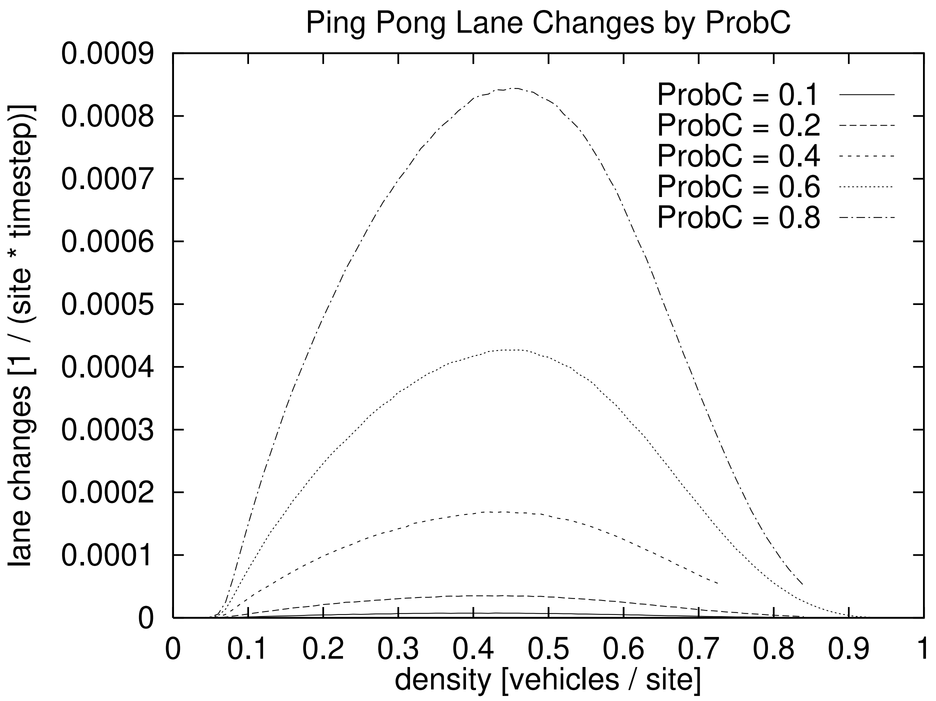
At free flow densities (asymmetric) passing often fails:



Remedy against Ping Pong:
stochasticity for lane changing

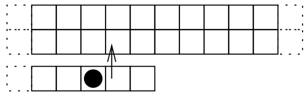
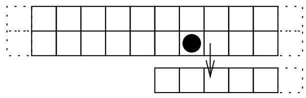
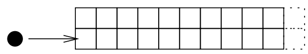
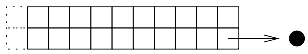
Ping Pong Lane Changes





CA Simulation Network

Building Blocks

- multilane CA
- emission point . . . . 
- absorption point . . . . 
- source . . . . 
- sink . . . . 

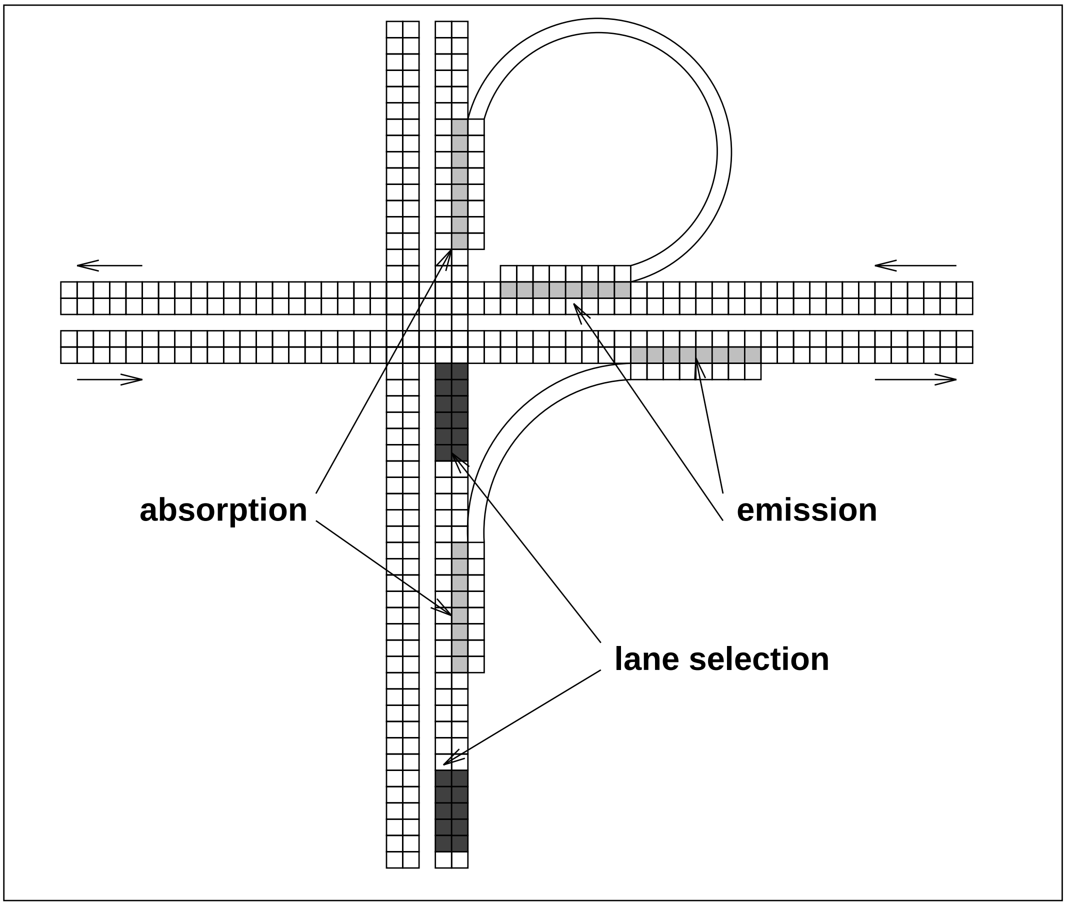
Composite Elements

- net terminator (node degree = 1)
- ramp (node degree = 2)
- intersection (node degree = 3,4)

CA Routeplan Execution

Vehicles

- behave like 'classical' CA on segments
- have individual route plans
- are absorbed/emitted to follow route



Example: Iterative Routing

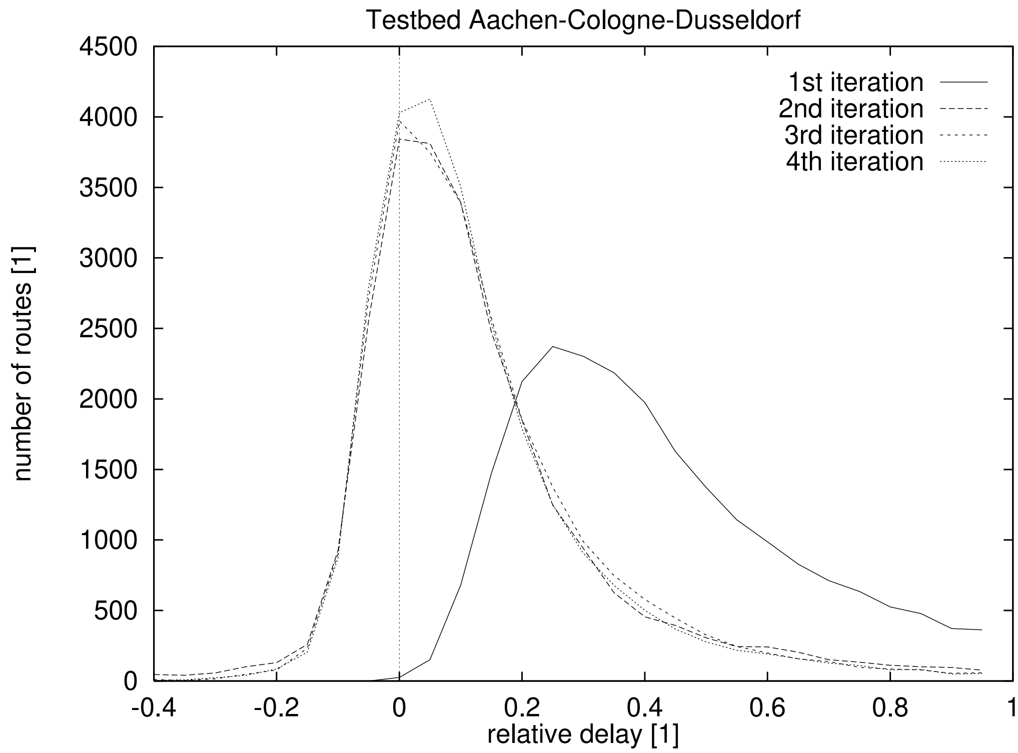
- Input: time-dependent origin-destination matrix
- Output: consistent set of route plans and edge weights

Iteration of Route Planning

1. preload edge weights (e.g. free–flow–velocity)
2. compute route plans for OD-matrix (e.g. shortest paths with Dijkstra)
3. simulate route plans while storing actual time-dependent edge weights
4. goto 2

Routing Example

For low densities ($\varrho = 0.05$) the process converges after the first iteration.



Questions:

Parameter space of convergence?

Quality of prediction?

Parallelization

- traffic network is assigned to a graph of vertices and edges handled by the Parallel Toolbox:

  vertices correspond to terminators, ramps, and intersections

  edges correspond to bidirectional CA multilane segments

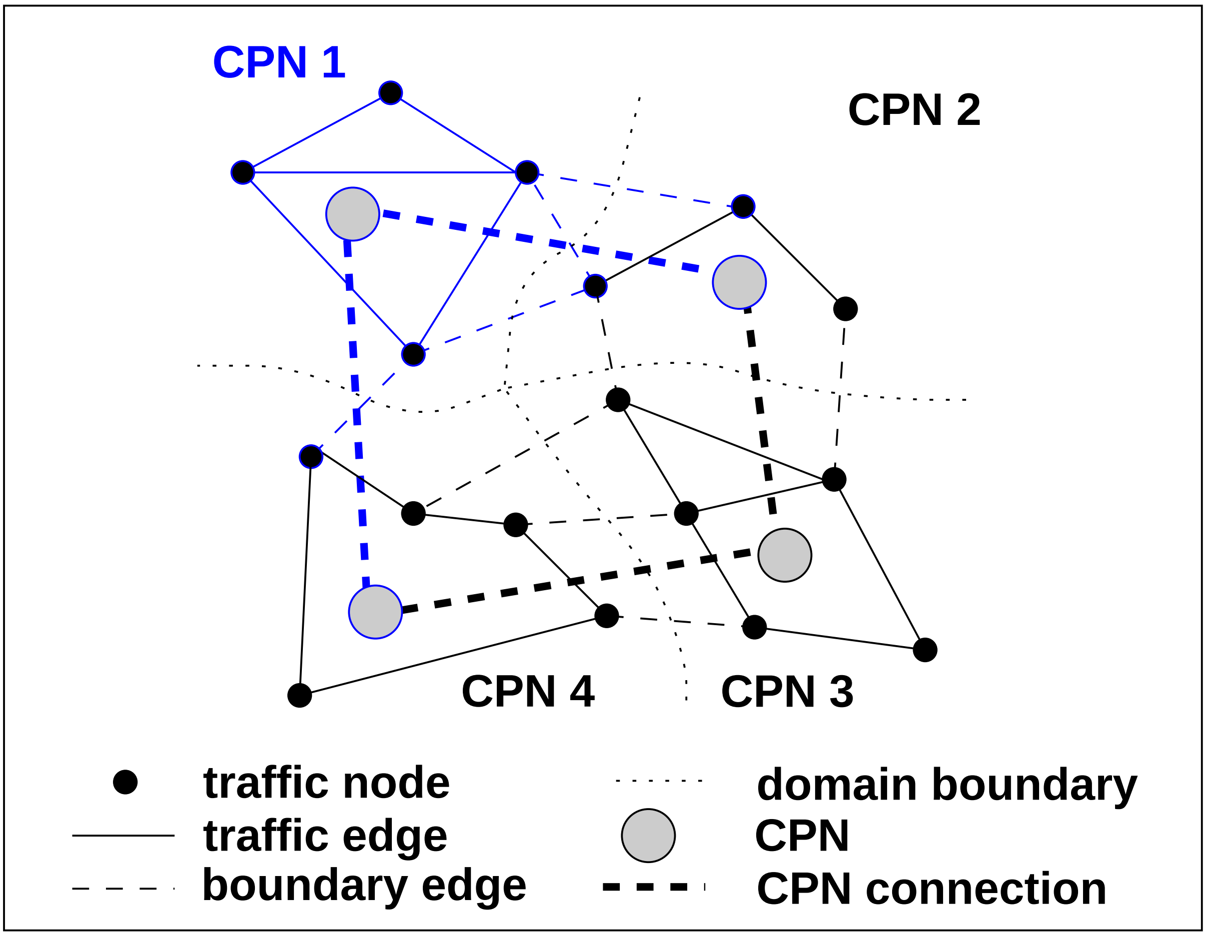
- initial geometric distribution of vertices (domain decomposition)

- inter-CPN edges handled by exchange of boundaries

- dynamic load balancing

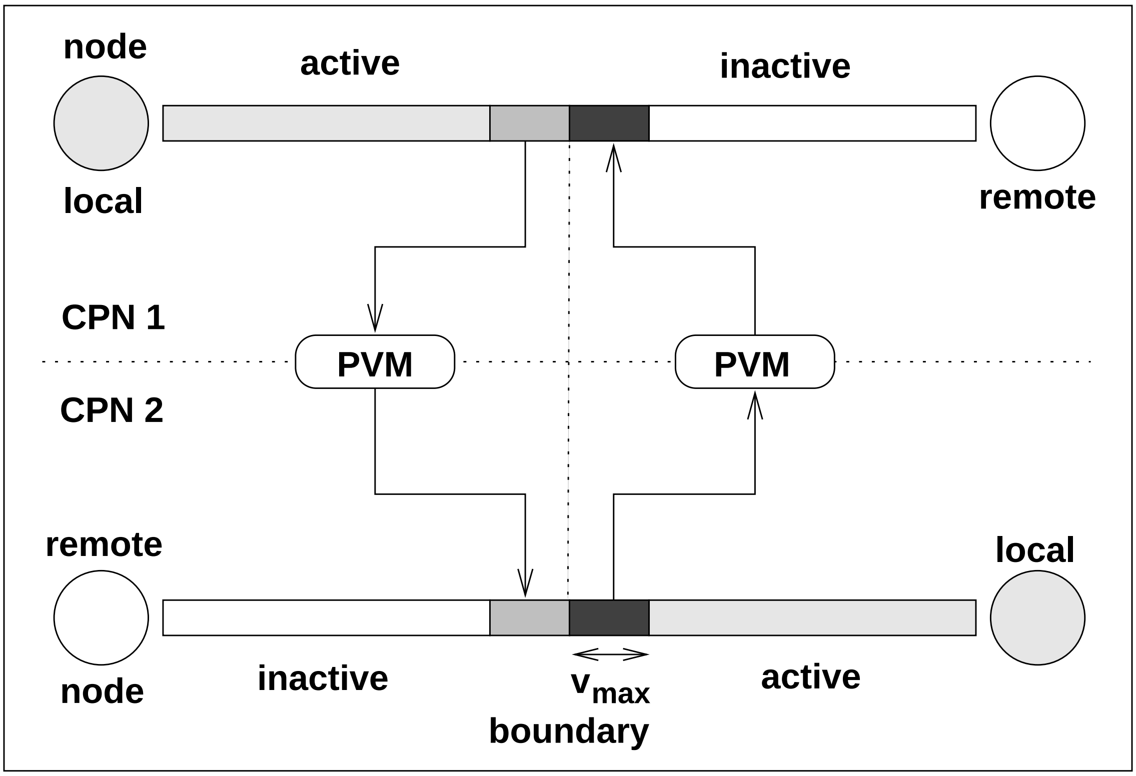
Domain Decomposition

- master CPN has a full copy of inactive network (mainly for graphics)
- each slave CPN has an local active sub network and some inactive dummies

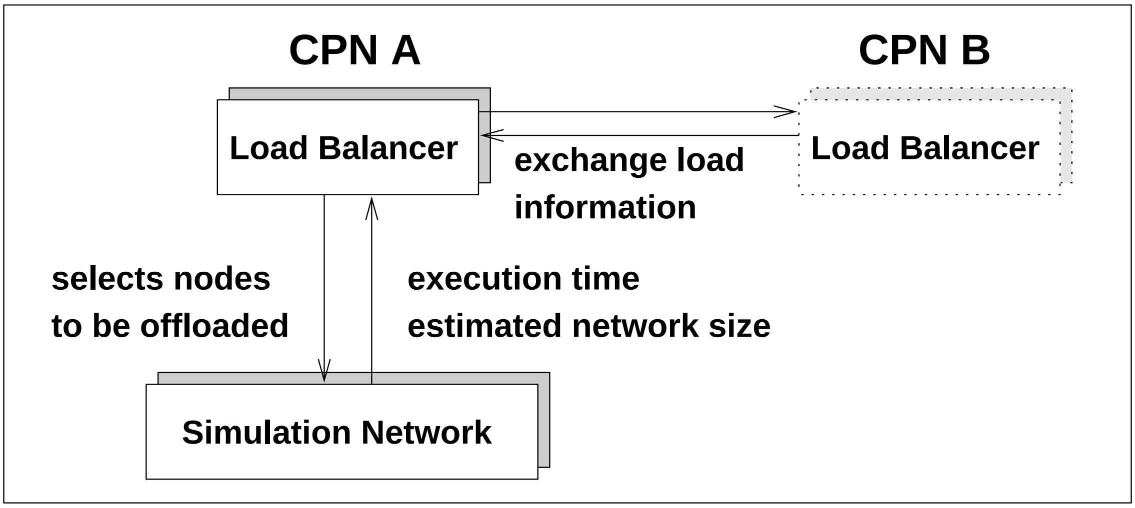


Boundaries

- inter-CPN edges are duplicated with different active ranges
- boundary information is transferred through message passing (PVM)



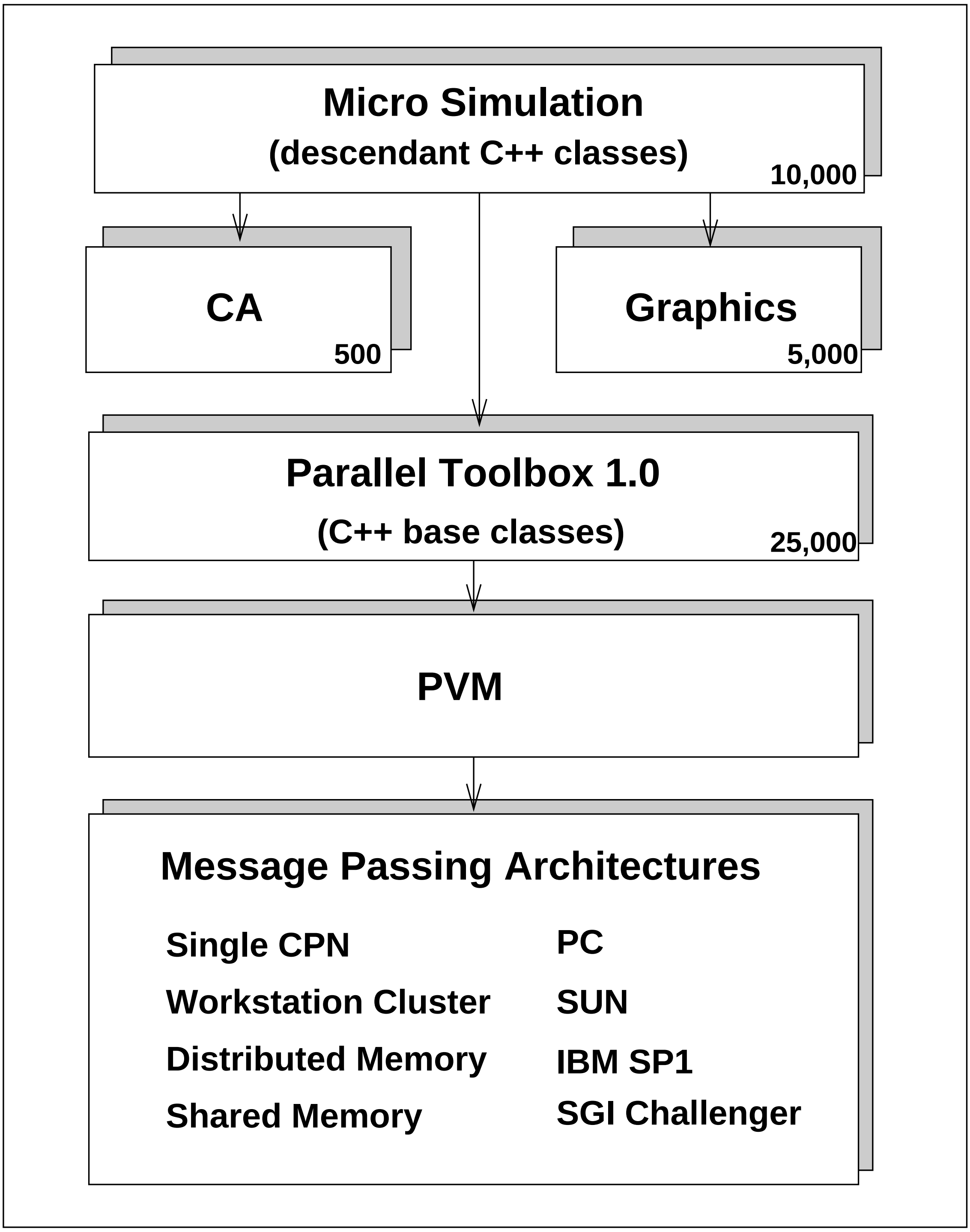
Load Balancing



Topology is offloaded

- with local synchronization only
- along common boundaries
- preferring vertices furthest from the center (keep 'nice' shape)
- optionally maintaining one connected component per CPN

Current Application Structure



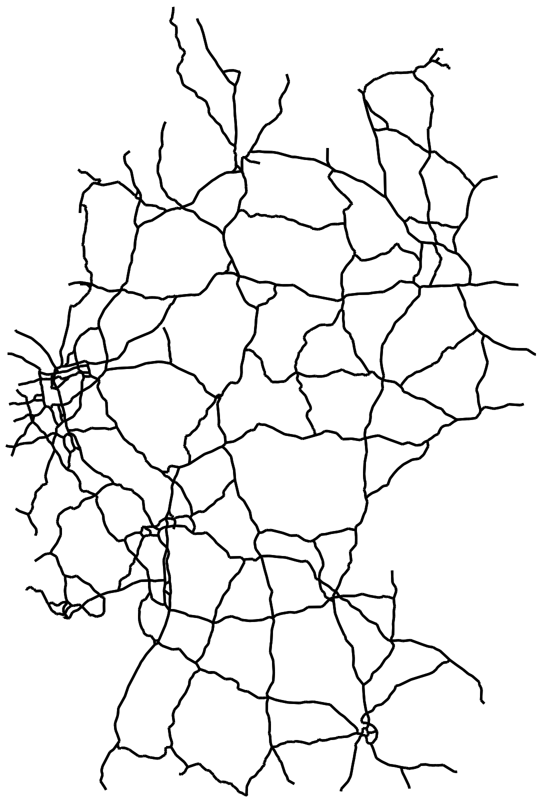
German Autobahn Network

3300 nodes, 3400 edges

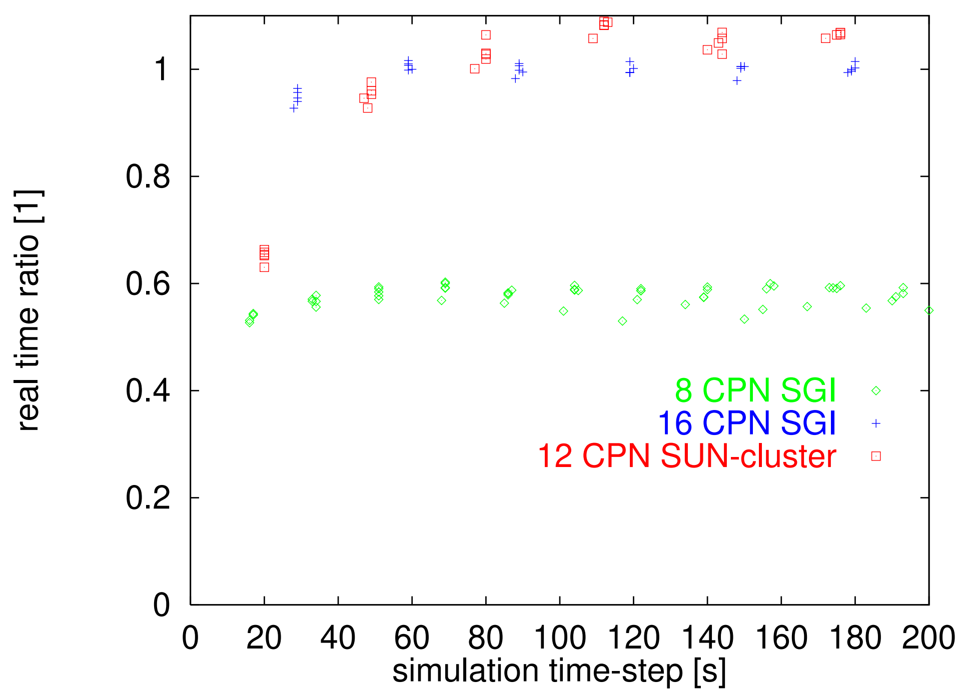
$\sim 75,000$ kilometer (lane corrected)

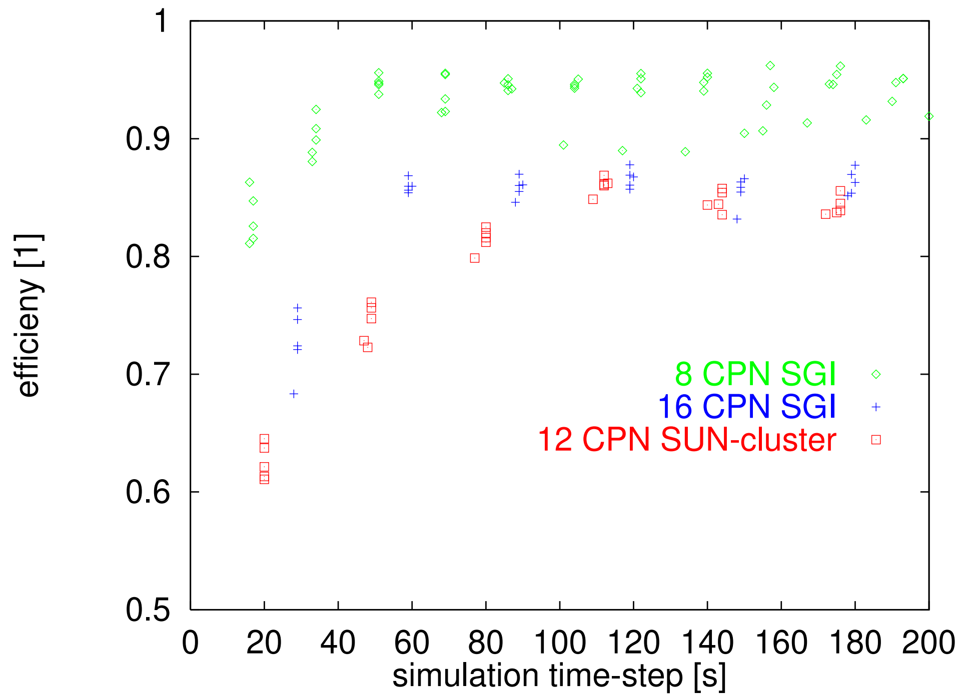
10,000,000 sites

1,000,000 vehicles with routeplans



Performance for Map FRG





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Outlook

- Traffic CA
  - include vehicle types
  - produce more realistic multilane fundamental diagrams
  - study net behaviour
- Network Simulation
  - online rerouting
  - examine stability of routing
- Dynamic Load Balancing
  - fewer boundaries
  - global corrections
  - workstation clusters