An Interactive City Simulation System

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Application of

Interactive Geometric Simulation of 4D Cities

B. Weber, P. Mueller, P. Wonka, M. Gross

Eurographics 2009

Contribution

Simulation method to generate sequences of urban configurations



- Geometric (not grid-based)
- Interactive
- Generic

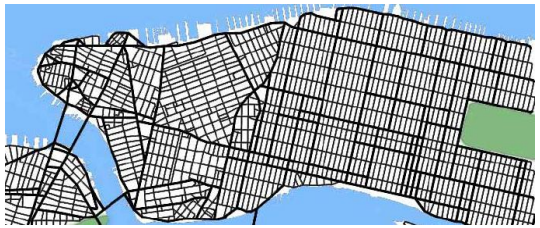
Motivation

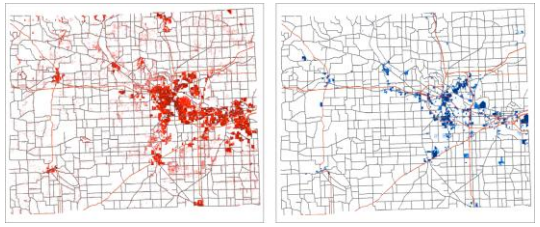
Motivation

- Dynamic content for interactive entertainment
  --→ Second Life, World of Warcraft, ..
- Educational games
  --→ Cities are very difficult to understand
- Fast and simple urban simulation tool
  --→ Visualize growth of urban environments

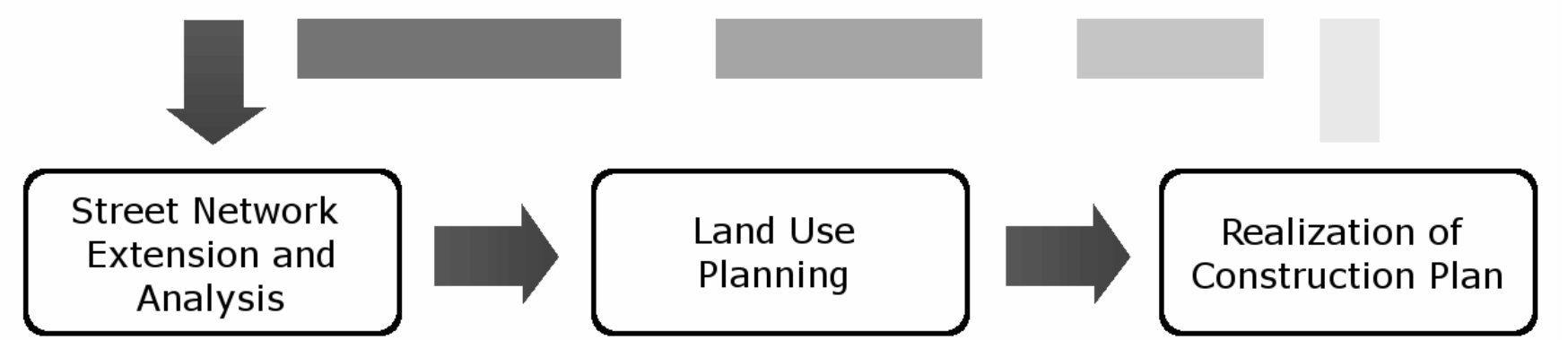
Related Work

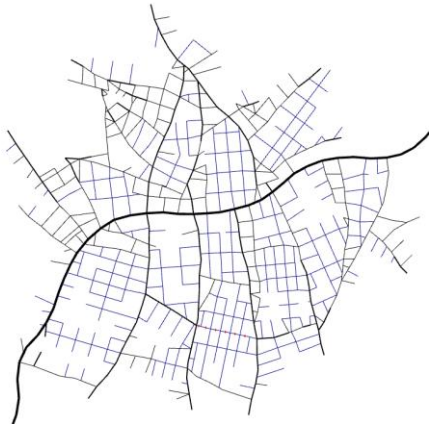
- Procedural Modeling of Cities (Parish & Mueller, SIGGRAPH, 2001)
- Procedural Modeling of Urban Land Use (Lechner et al., 2006)
- Space Syntax: Space is the machine (Hillier, Cambridge Press, 1996)
- UrbanSim (Waddell et al., 2002)

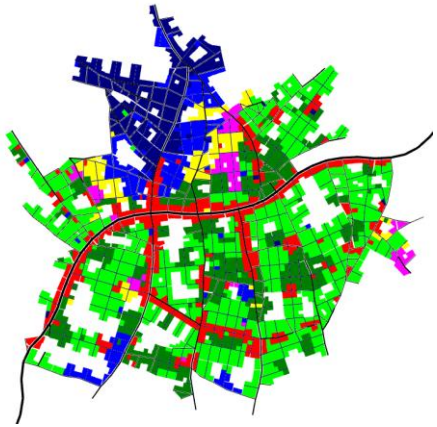




System Outline

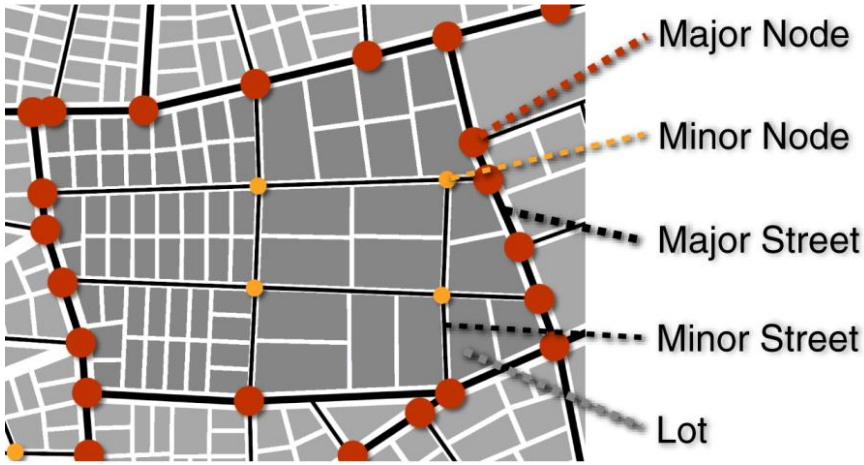


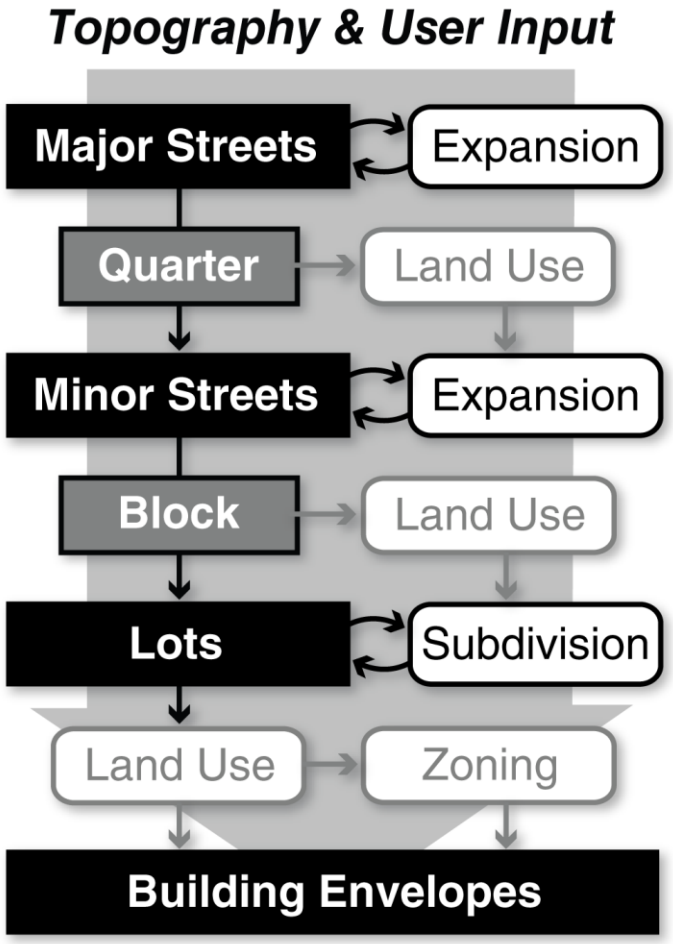




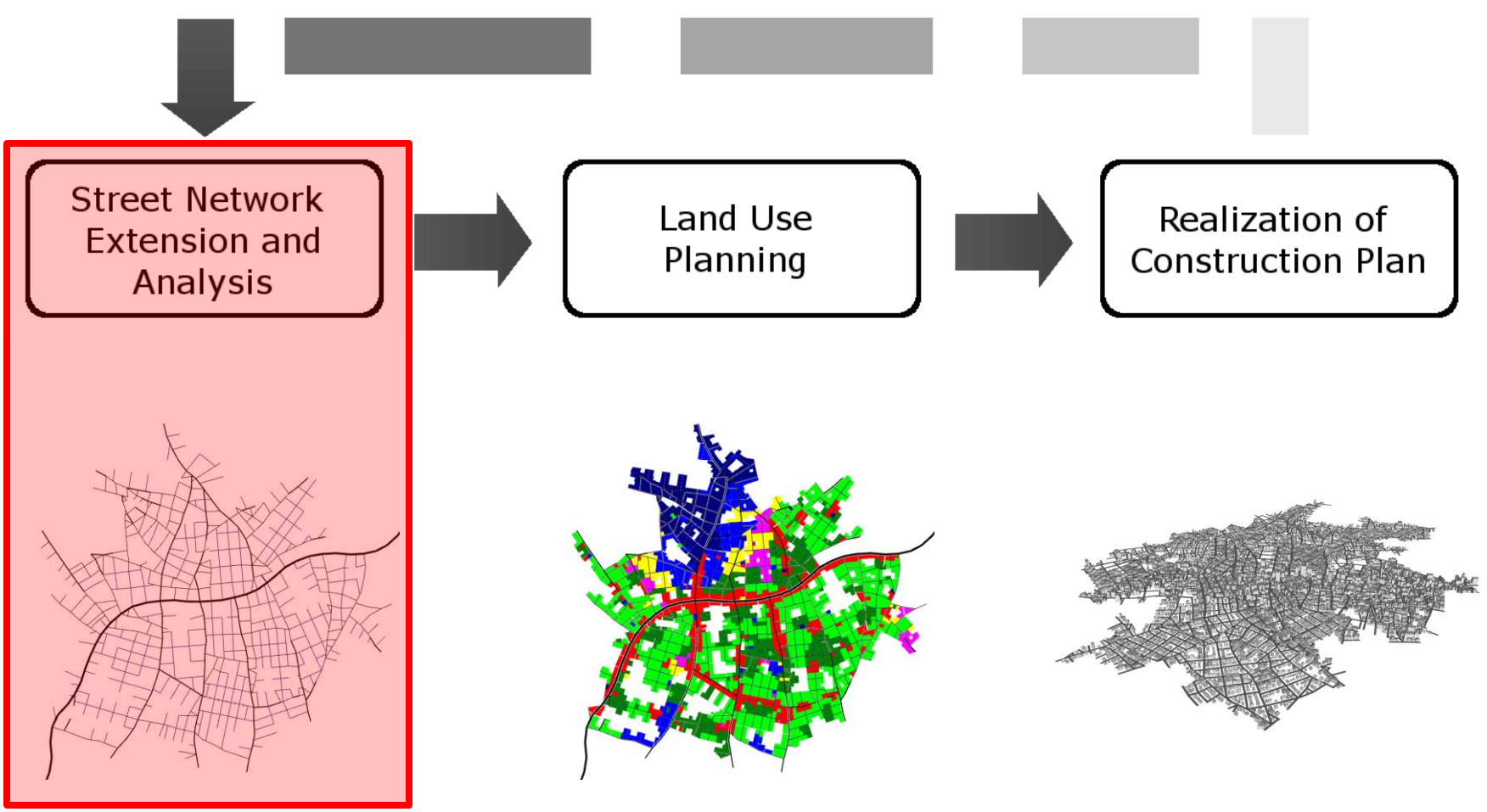
System Overview

City Hierarchy Definition





System Outline

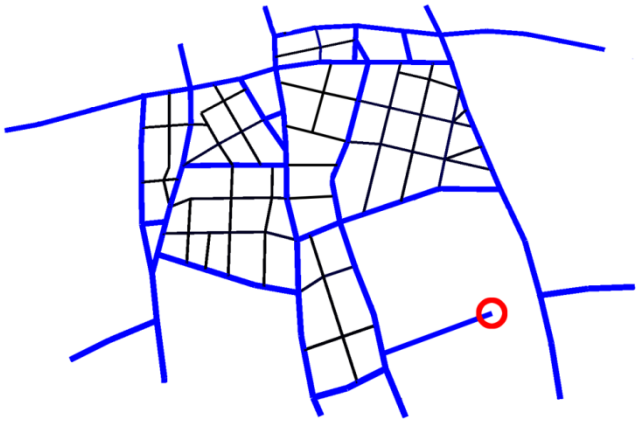


Street Expansion (I)

1. Node sampling

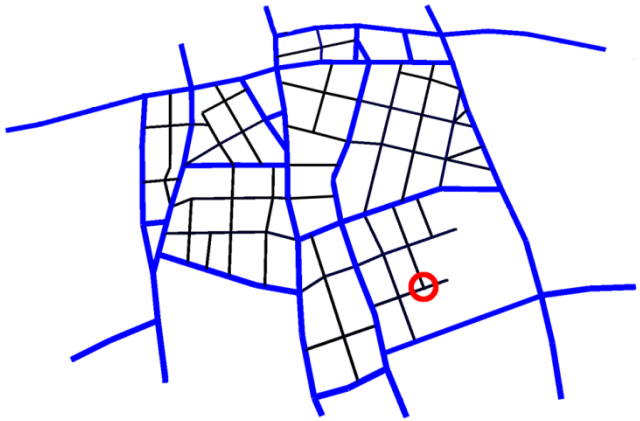
Major street expansion

- Random sampling
- Higher probability near *growth centers*



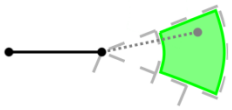
Minor street expansion

- Sample all nodes within the quarter

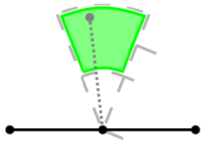


Street Expansion (II)

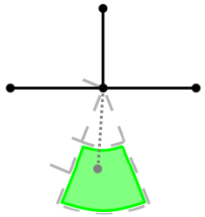
2. Street proposal



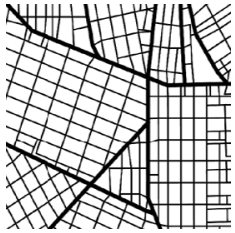
Valence 1



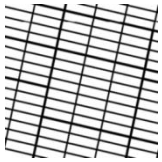
Valence 2



Valence 3



Organic



Raster

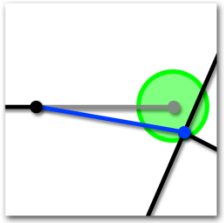
Radial

...

3. Adaption

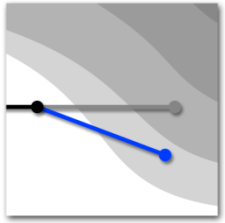
Intersect

Extend



Snap

Obstacle

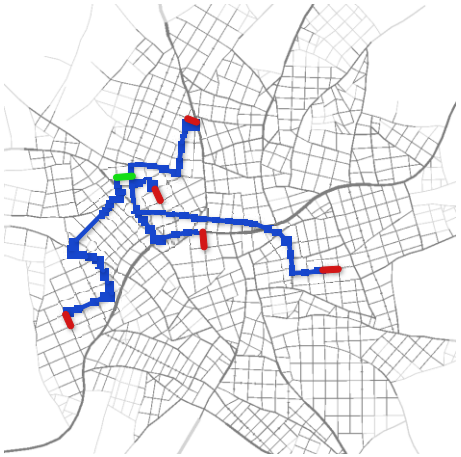


Adapt

Traffic Simulation (I)

Goal: Compute traffic at every street

- Needed for street width estimation and land use simulation
- Incremental algorithm
- Distribute trips across the city
- Account/discount traffic along trips



Trip generation

- New trips from *new* streets
- Update a small part of all trips

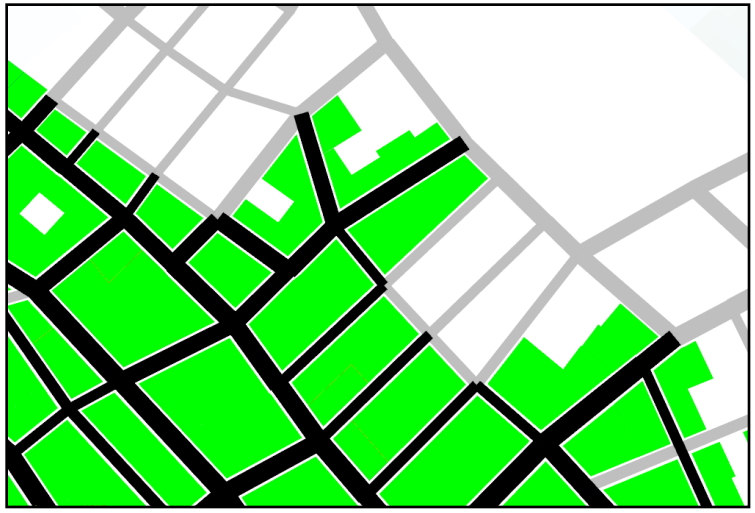
Traffic Simulation (II)

Shortest paths

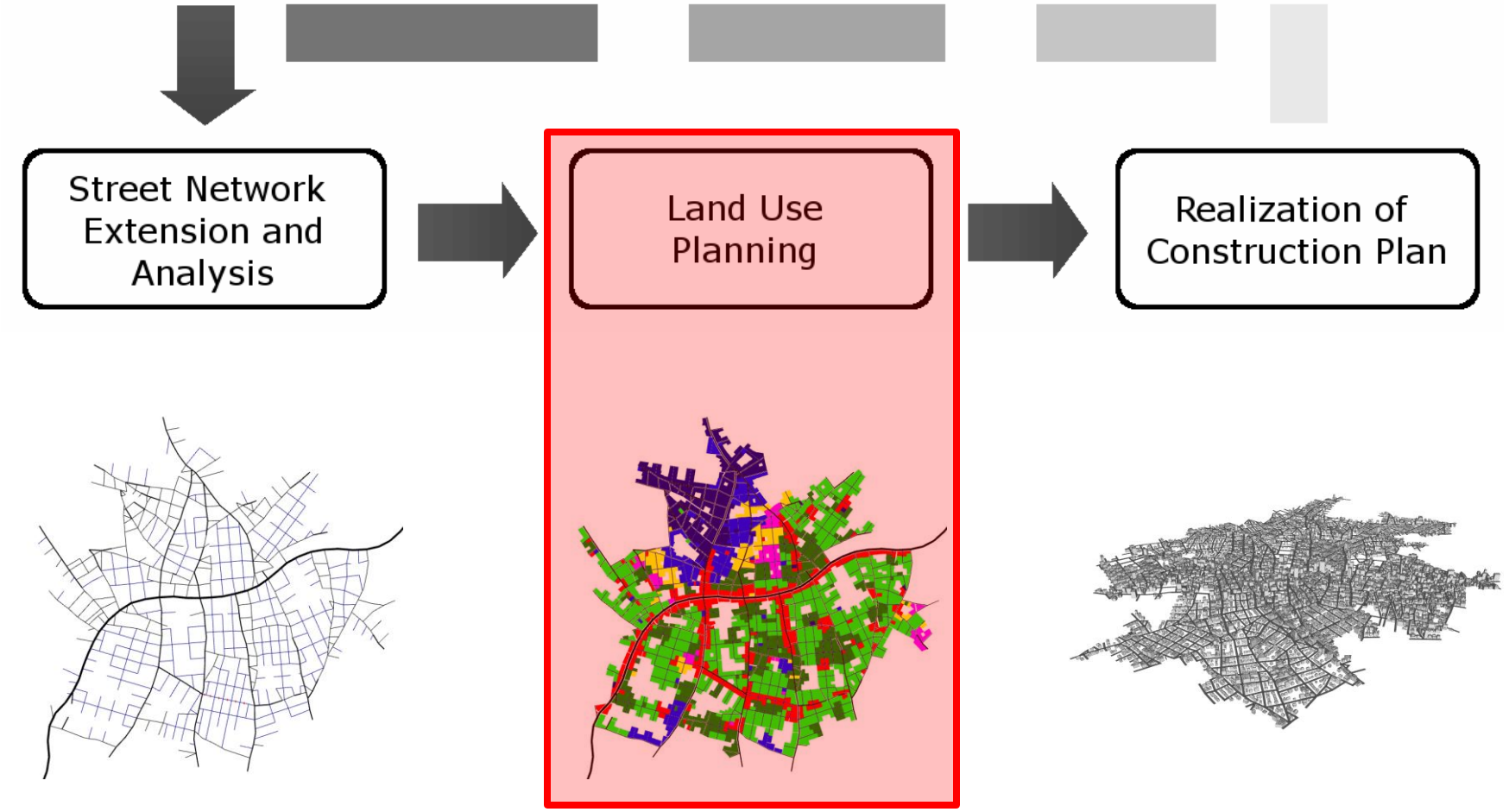
- Find shortest path along each trip
- Space Syntax motivated cost function: 90° turn ~ 500 m
- Efficient implementation with incremental all-pair-shortest-path algorithm

Built vs. planned streets

- Avoid needless streets
- Build if traffic above a threshold
- Leads to realistic city borders

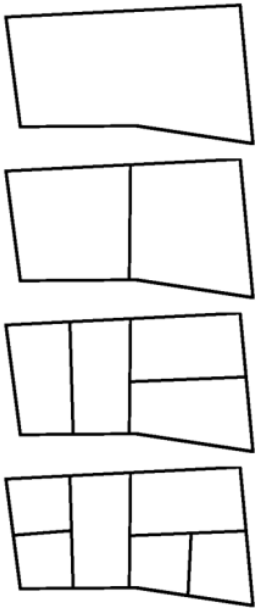


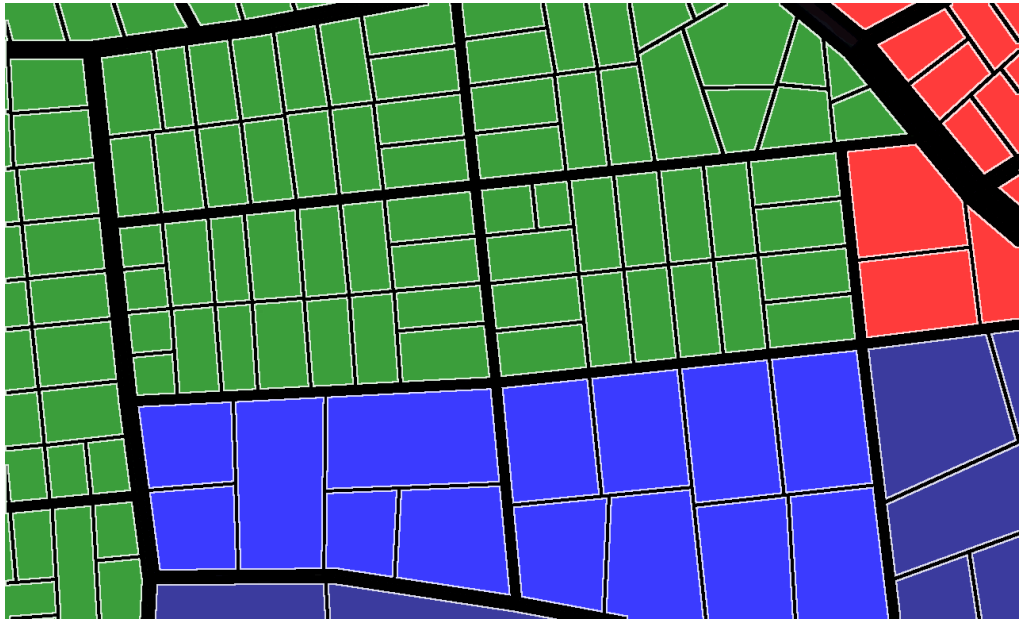
System Outline



Lot Subdivision

- Do splits until the area is below a threshold
- Threshold is land use dependent
- Block land use is computed similar as lot land use (next slide)





Land Use Simulation

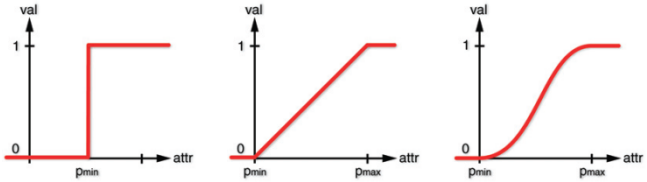
Generic system

- A designer can define a set of land use types
- Land use type = convex combination of valuation functions

$$lot[i].luv = \sum_j \lambda_j \cdot valuation_j(lot[i])$$

Valuation functions

- Return values between 0 and 1
- Choose mapping function, lot attribute and range



X

Traffic, Elevation, Slope, cluster, influence, centerdist, forestdist, waterdist

X

$$\rho_{min}, \rho_{max}$$

Land Use Simulation (II)

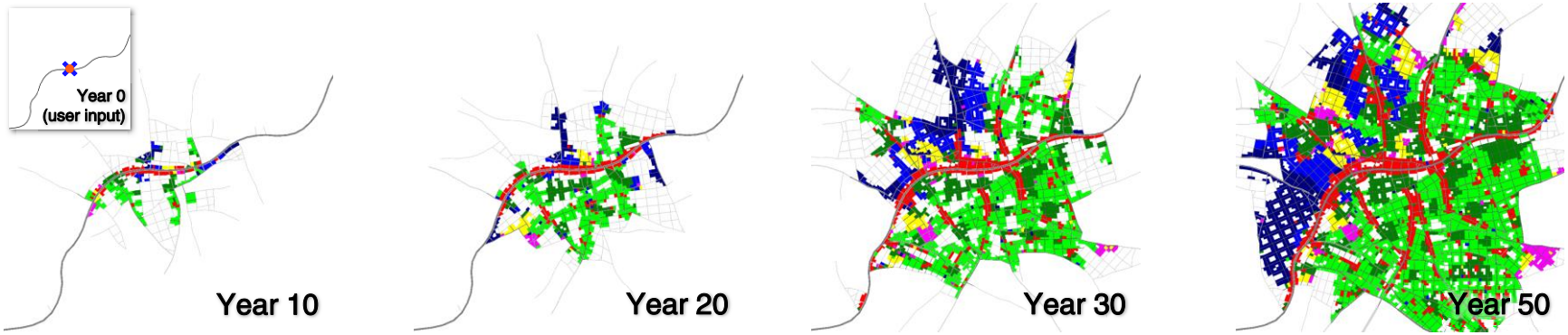
Optimize the value of the urban configuration

$$\lambda_{local} \cdot \underbrace{\frac{\sum_{\forall i} lot[i].area \cdot lot[i].luv}{\sum_{\forall i} lot[i].area}}_{\text{average of weighted luv}} - \lambda_{global} \cdot \underbrace{\sum_{t \in T} \left(\frac{percent_t - goal_t}{scale} \right)^2}_{\text{squared land use percentage deviation}}$$

Optimization

- Similar to Simulated Annealing
- Pick random lots and assign random land use types
- Also accept negative changes with small probability

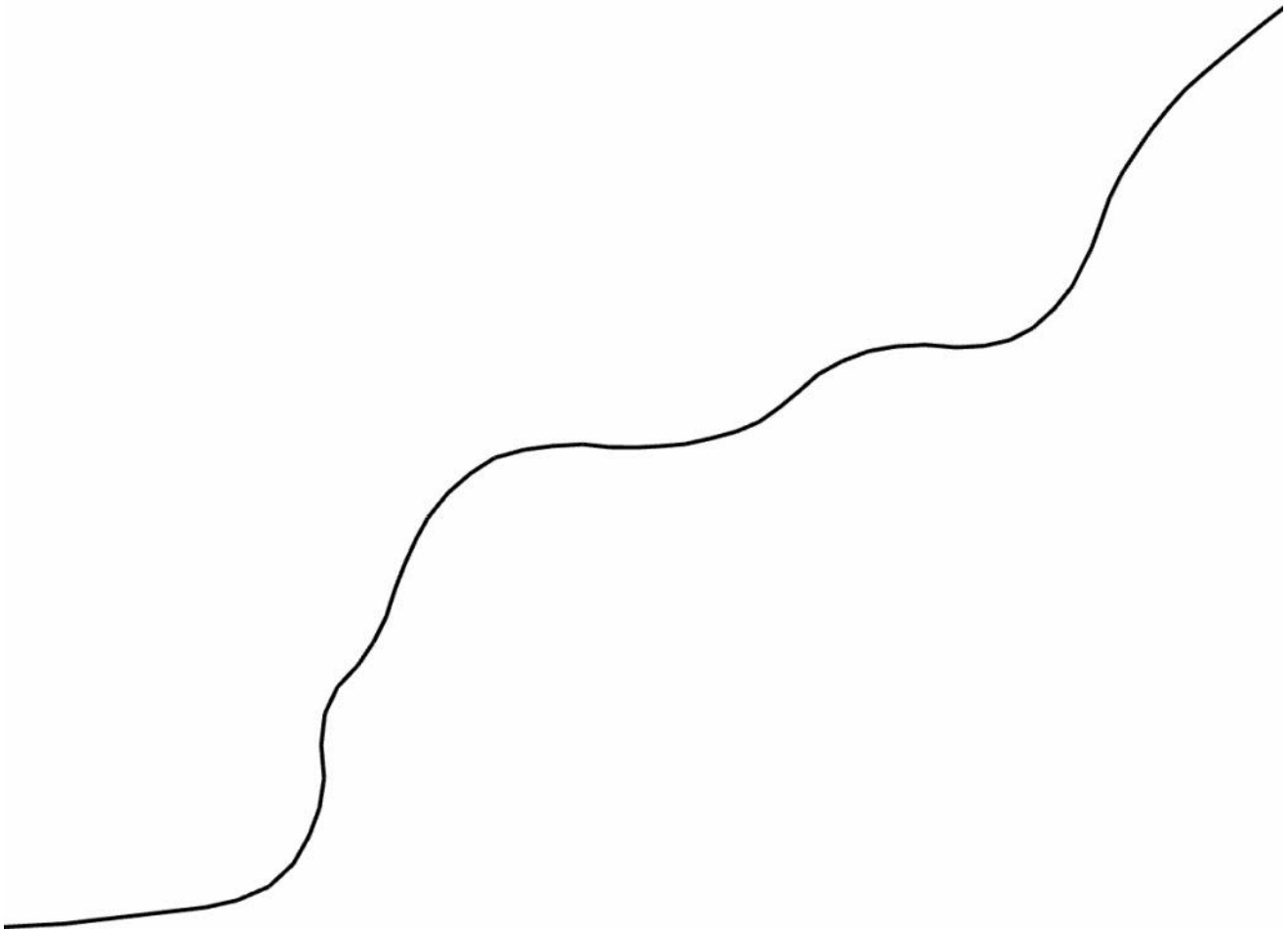
Example: Streets & Lots



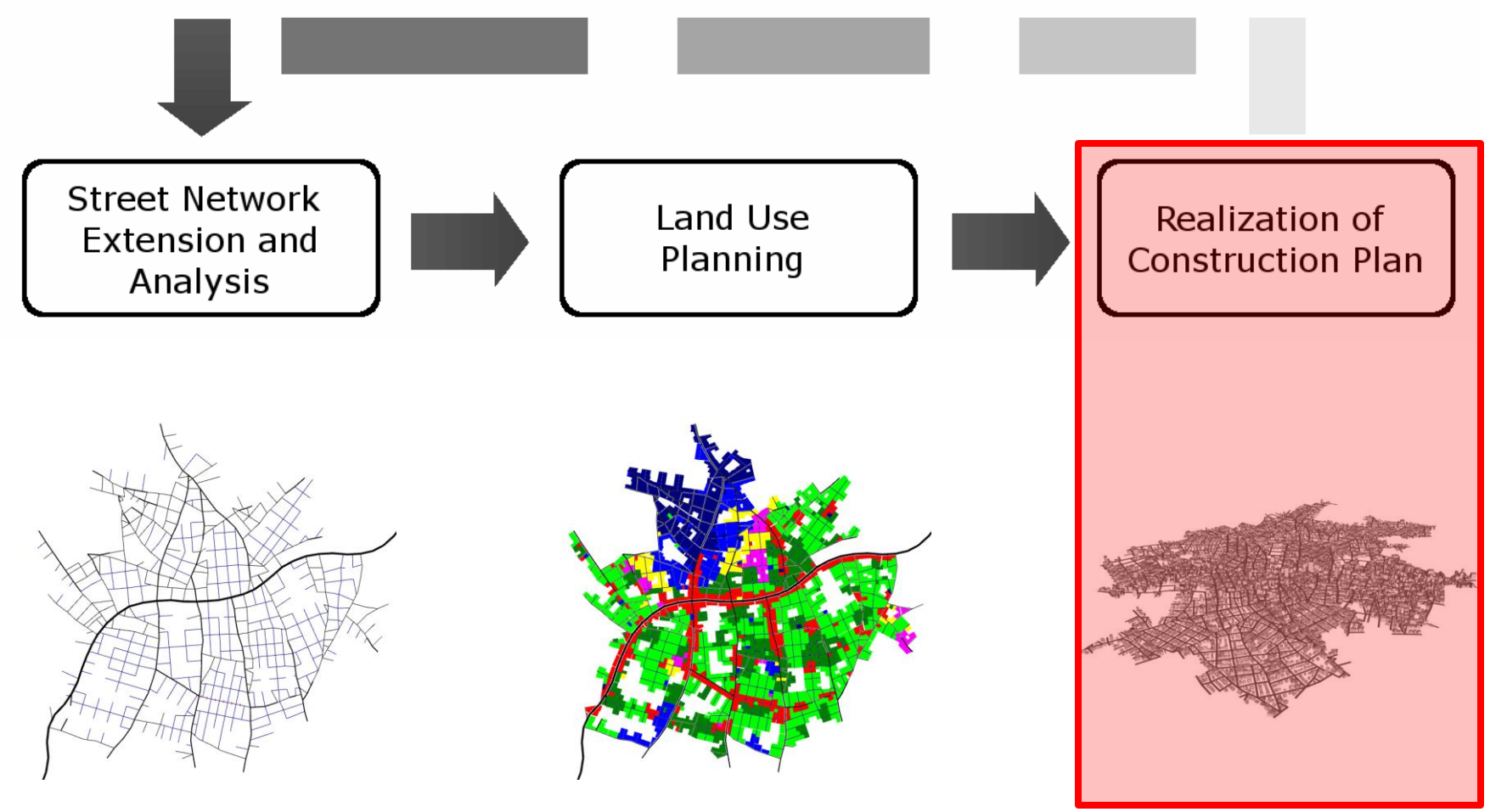
- User start configuration
- One growth center
- Planned streets: light gray

Land Use Type	Description	%
Low. D. Residential	One or two family houses	40
High D. Residential	Blocks, apartments, condos	20
Low. D. Industrial	Service industry, offices	8
High D. Industrial	Heavy industry	10
Commercial	Retail sales, offices, inns	15
Parks	Recreation, memorials	4
Public Buildings	Schools, communal, transp.	3

Streets & Lots Video



System Outline



Building Construction & Substitution

Construction

- Build on empty lots with a fixed probability p_{con}

Substitution

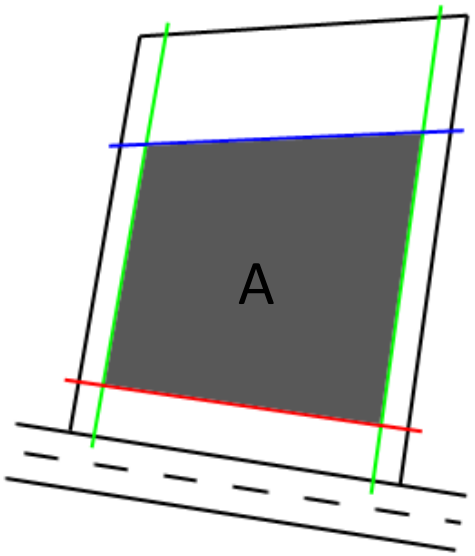
- Replace existing building with a probability dependent on
  - Building age
  - Value difference between the existing and a potential new building

$$p_{sub} = f_1(lot[i].age) + f_2(\Delta_{price})$$

Building Envelope Generation

Envelope Area

- Setback ranges for each land use
- Front, side and back setbacks are stochastically sampled

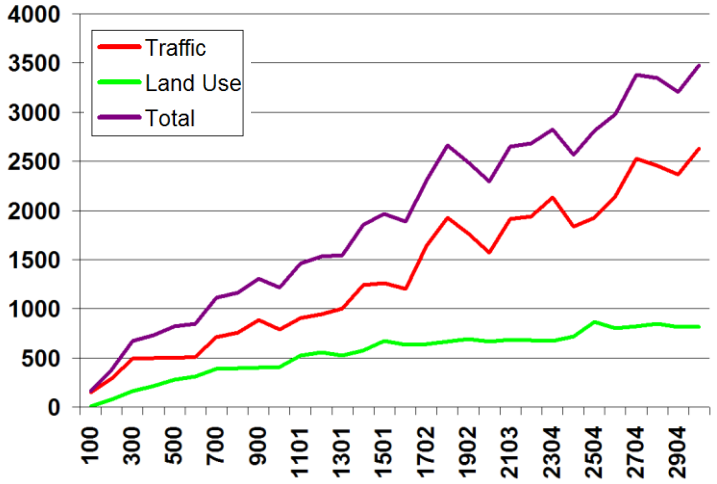


Envelope Height

- $$lot[i].nFloors = \frac{lot[i].price \cdot margin_{lot[i].lut}}{A}$$
- $$lot[i].price = lot[i].area \cdot avgprice[t] \cdot \frac{lot[i].luv}{\sum_{\forall j} lot[j].luv / n}$$

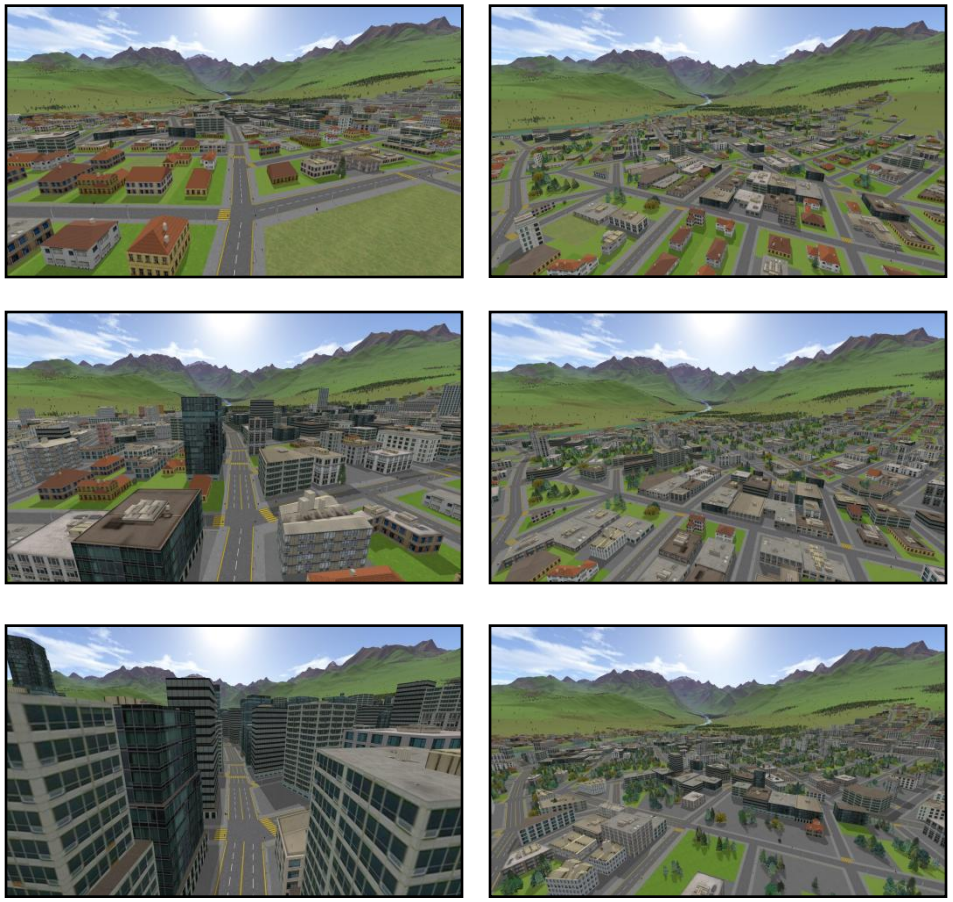
Results – Typical City Growth

- Simulation of typical city growth phenomena
- Simulation time grows linearly with city size (per time step)



Low-high density

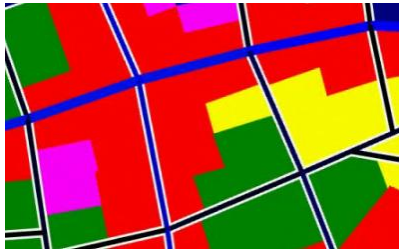
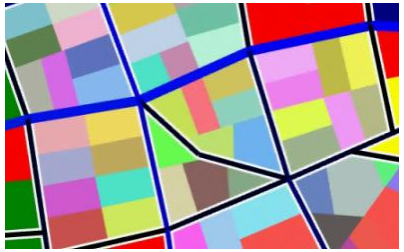
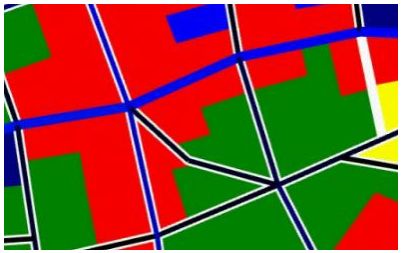
Sustainable dev.



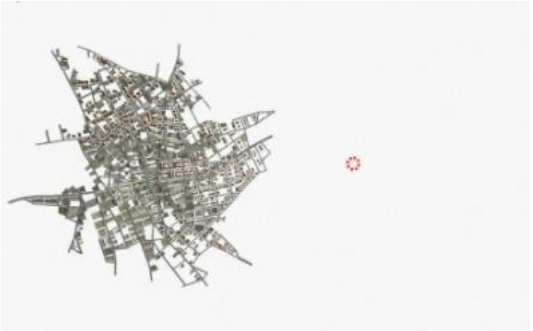
Results – Interactive Editing

All parameters, streets, lots and buildings can be changed *during* simulation

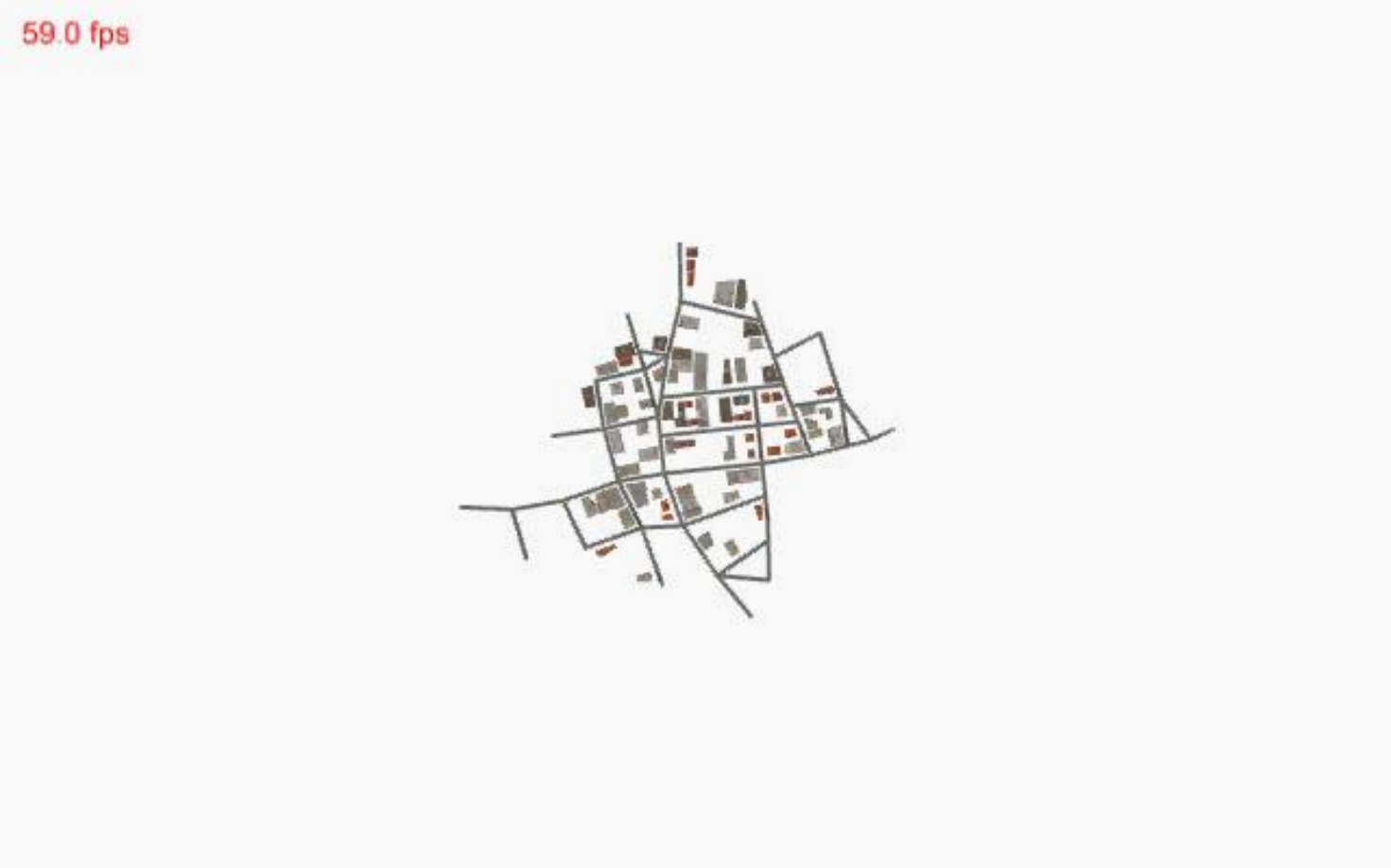
- Land use and street editing

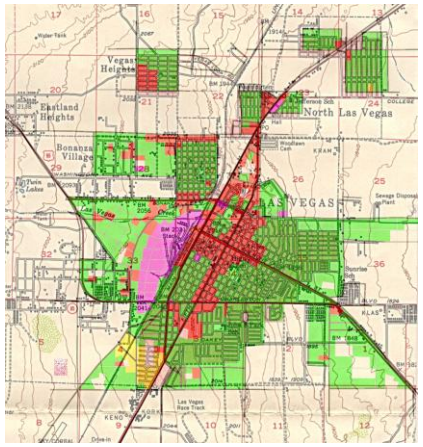
- Growth centers

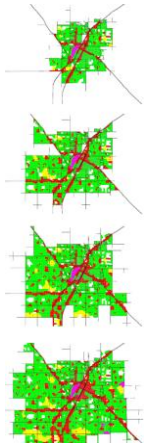


Growth Center Video



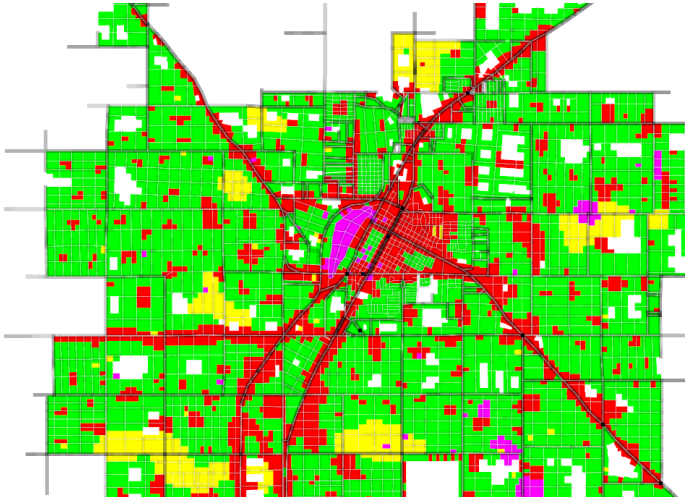
Results - Las Vegas 1950 - 1975



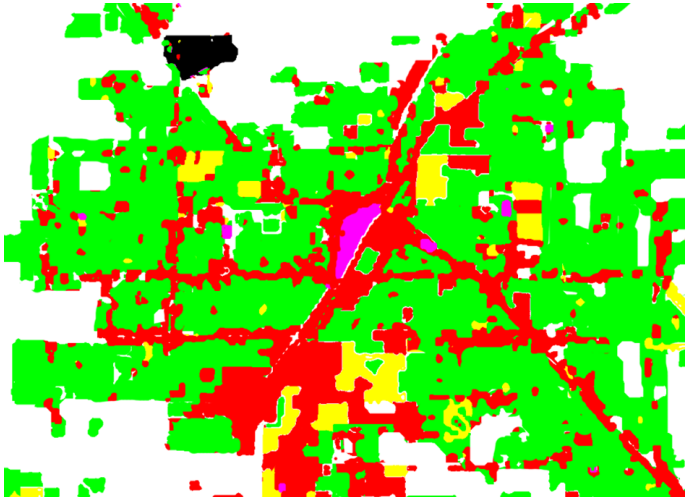


Analysis using texture similarity metric
(Wei et al. 2008)

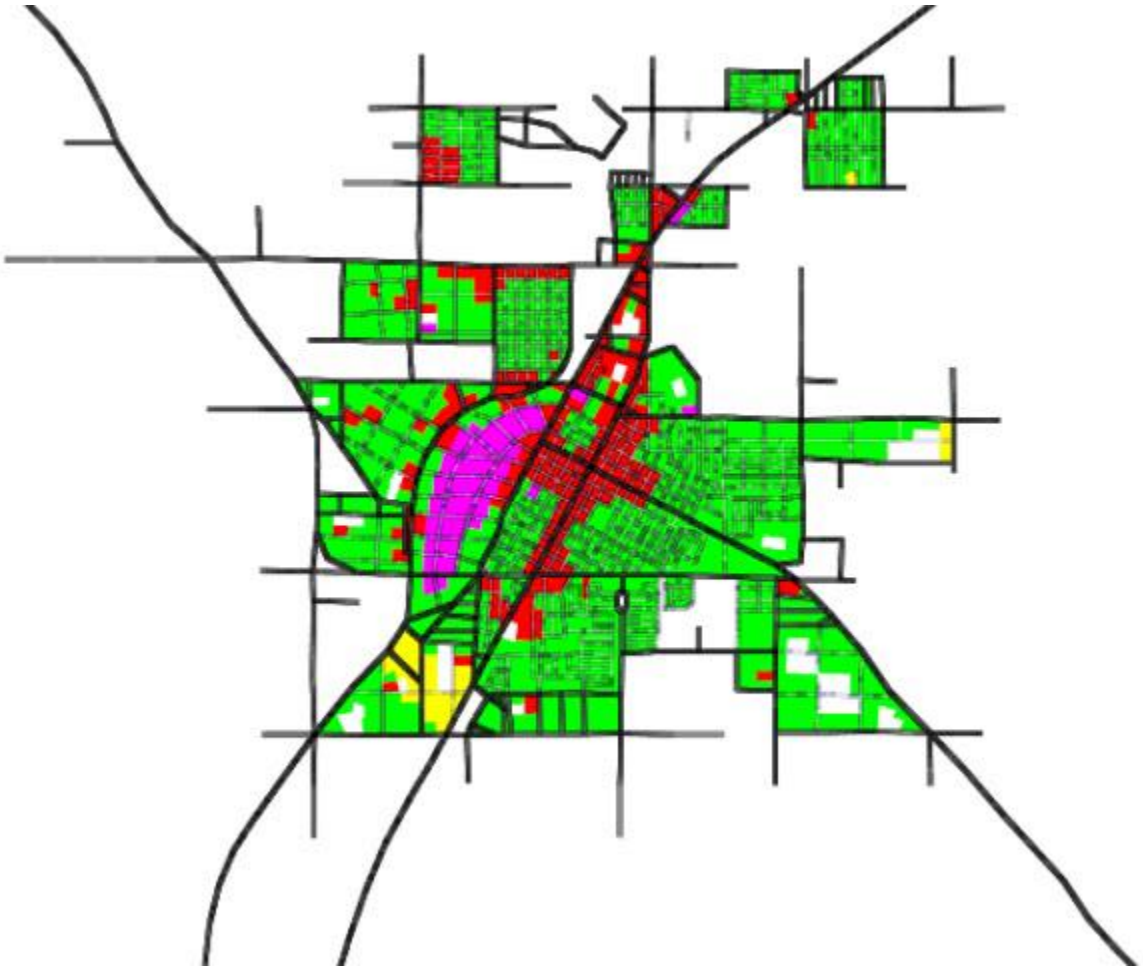
Neighborhood size	4	8	12	16	25
Similarity (IS, GT)	0.99	0.93	0.87	0.82	0.74
Similarity (GT, IS)	0.98	0.92	0.86	0.8	0.72



vs.



Las Vegas Video



Limitations & Future Work

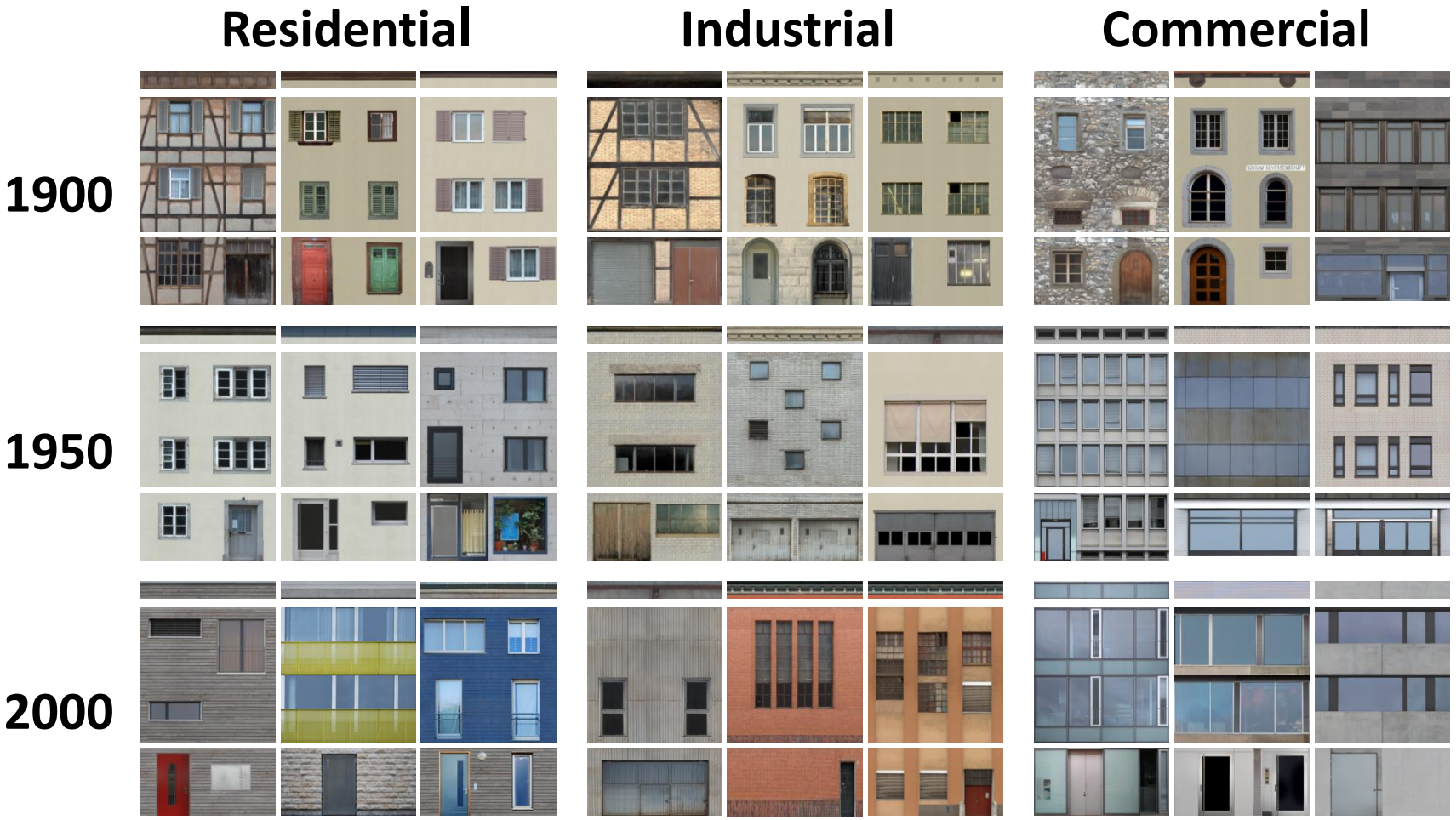
- Effect of parameter change is difficult to predict
- Traffic Simulation is the bottleneck of the system
- APSP memory consumption: O(n^2)
- Lots are only created within quarters
- Lot subdivision is done only once per block
  ⇢ Do merge and splits during simulation

Future Work & Applications

Integration into **CityEngine**, a procedural city modeling software (www.procedural.com)

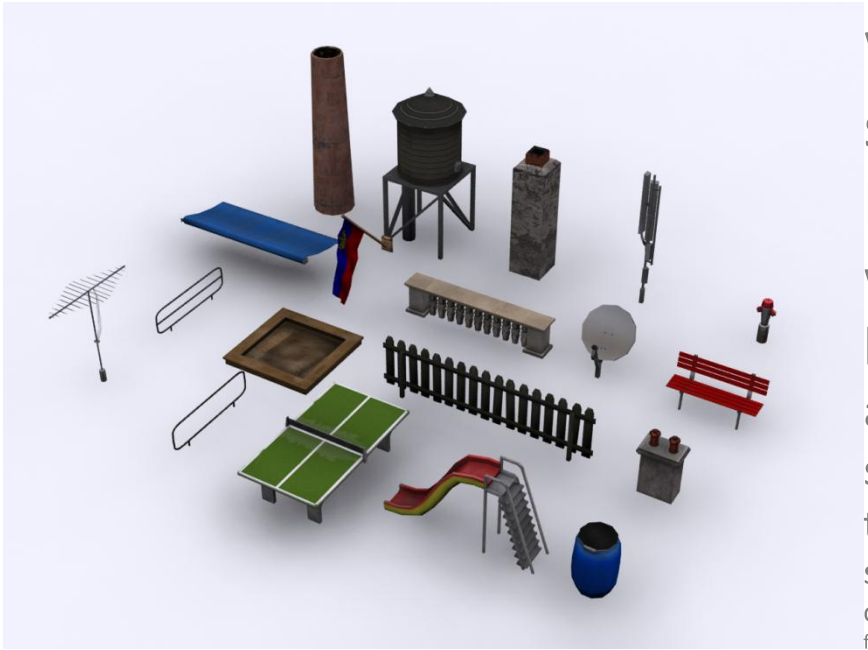
Application in TRAIN FEVER, a public transport simulation game (www.train-fever.com)

Example Facade Textures



Example City Assets

- Priority list of assets
- Sorted by ‚typicalness‘



Tree, chimney, lamp, antenna, sun curtain, newspaper box, hydrant, waste bin, water barrel, fence, satellite dish, traffic sign, traffic light, playground, park bench, water tank, barrier, cable, telephone box, mail box, telephon pylon, advertising pillar, watch, solar panel, swimming pool, sandbox, parasol, table tennis table, fountain, public toilet, bicycle stand, flag, statue, handrail, balustrade, wall, hedge, garden, security camera, information sign, ashtray, flower box, power box, lighting arrester, bird‘s nest, fire escape, tubes, …

Example City Video

Acknowledgments

Thanks to

- Urban Weber
- Andreas Ulmer, Procedural Inc.
- Michael Haerdi
- Manu Oehler
- NSF and NGA