Urbanization and Economies of Scale: Topics in Network Theory

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May 12, 2009

Outline of Part I

1. Context for transportation networks
   - Motivation
   - Terms and Definitions

Outline of Part II

2. Urban Systems
   - The Modern City
   - Using software to simulate urbanization

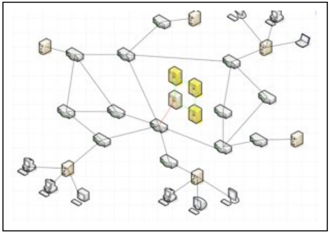
Part I

Context Setting

Flow

- Goods
- People
- Information

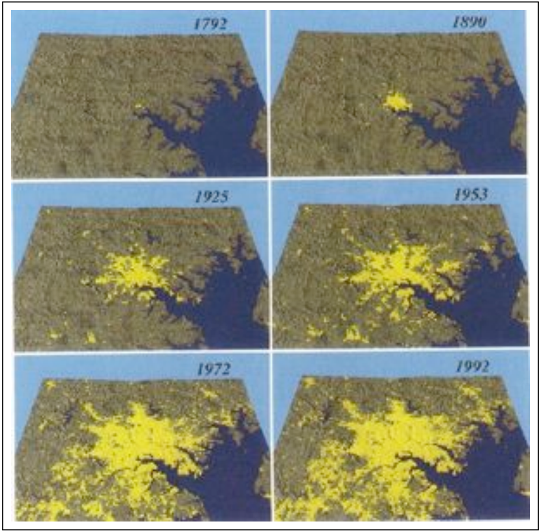
Children in Jakarta



Thanks to Shaxun

Flow

Growth



Baltimore simulated forest land cover showing 200 years of urban growth in yellow.
biology.usgs.gov

Sustainability

- How do these modes interact?
- What other systems are impacted by movement and flow?
- How are land use and transportation plans sensitive to one another?

Network Properties

Defining a network

A set of nodes or vertices joined together in pairs by lines or edges

Networks and Mathematics

Spatial Distribution Network Design Problem

Given a set of things that 'want' to move between a set of spatial points V, what's the cheapest way to get them there?

Gastner & Newman (2006) wants us to think about two specific parts of this question as applied to transportation networks:

- How do we determine the points V anyway?
- What do we mean by 'cheapest'? Does how we measure cost change the optimal structure?

(Wuellner on spacial distribution networks, 2009)

Network Properties

Cost

- Cost $= \sum_{edges(i,j)} d_{ij}$ where d_{ij} is the Euclidean distance between nodes i and j.
- Cost can be measured in travel time and can be influenced by traffic
- Let w_{ij} be the amount of traffic between i and j:
- Total Travel Cost can be calculated as $Z = \sum_{i<j} w_{ij} d_{ij}$

Network Properties

Distance

- Euclidean distance
- Legs of air travel
- Hops an Internet packet will make

Diameter

Largest graph distance between two points

Network Properties

Vertex Degrees

The degree of a vertex is the number of edges connected to it

$\rightarrow$ A distinguishing characteristic of a network

Interstate System

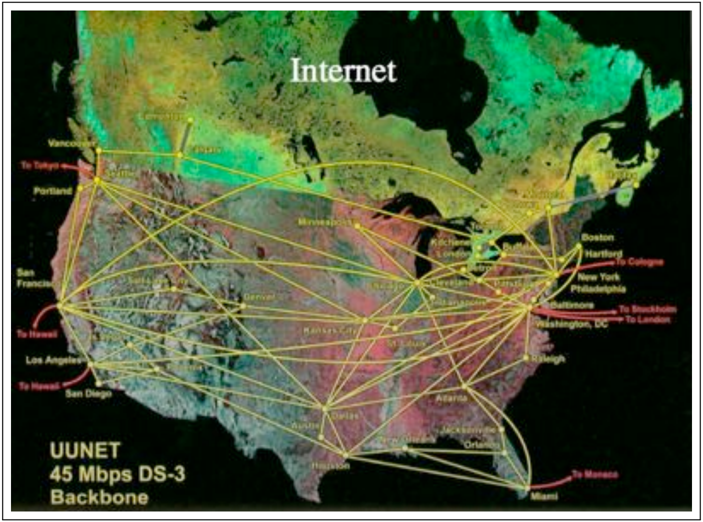
wikimedia.org

Interstate Rail System

Air Network

Gaster Slides from MAE 298, 2008

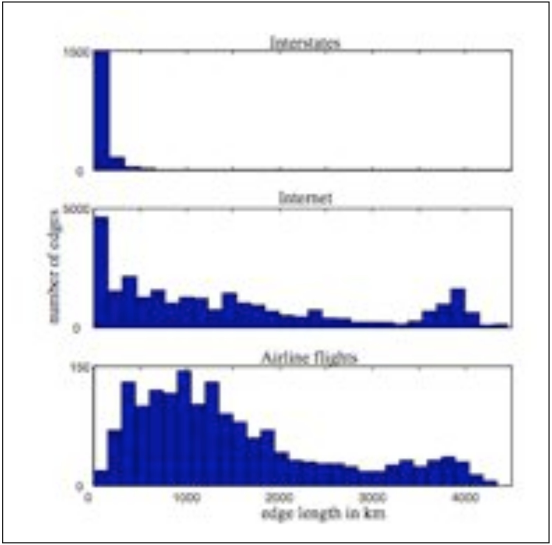
Information network: Internet



Gaster Slides from MAE 298, 2008

GOTO: http://www.akamai.com Content Delivery Networks

Counting Network Edges



Histograms of the lengths of edges in three networks (Gastner & Newman, 2006) Small worlds formed in airlines.

Zipf's Law: 1949

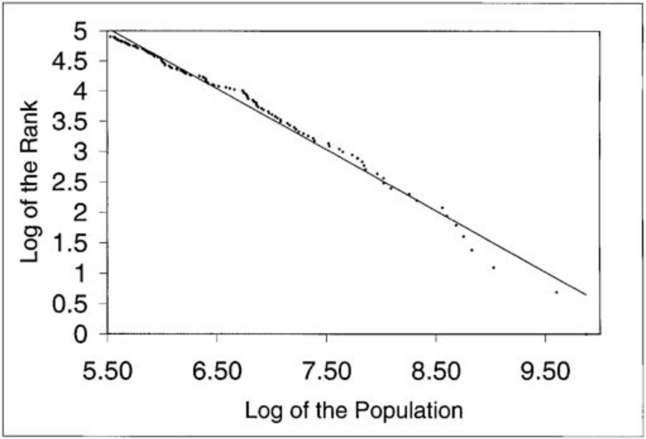


Figure: Log Size versus Log Rank of the 135 largest U. S. Metropolitan Areas in 1991 Source: Statistical Abstract of the United States [1993]

Part II

Urban Systems Analysis

2 Urban Systems

- The Modern City
- Using software to simulate urbanization

Scaling and Biological Metaphors

Organisms as metabolic engines

Characterized by energy consumption rates, growth rates, body size, and behavioral times

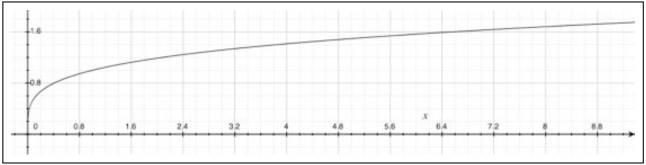
Cities as organisms

Scaling and Biological Metaphors

- A metabolic engine is a consumer of resources
- Consider biological scaling
- Almost all physiological elements scale with body mass = M

Scaling and Biological Metaphors: Generalized Case

- Consider M as a body mass
- M has a metabolic rate, B
- B is the energy required to sustain the organism
- $B \propto M^{\frac{3}{4}}$, typically the exponent is a multiple of 1/4 (or 1/(1+d) in d-dimensional space



$y = x^{3/4}$

- The metabolic rate per unit mass: $\frac{B}{M} \propto M^{\frac{-1}{4}}$

Scaling and Biological Metaphors: Examples

- $M^{1-\beta} \approx M^{1/4}$ can be used to scale physiological times (life spans, turnover time, etc.)
- $M^{1-\beta} \approx M^{-1/4}$ can be use to scale associated rates (heart rate, population growth)

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Scaling and Biological Metaphors: Generalizable Items

- Rates
- Times
- Internal structures

Bettencourt equation

Bettencourt et. al (2007) go on further to describe urban growth and decay with a power law function

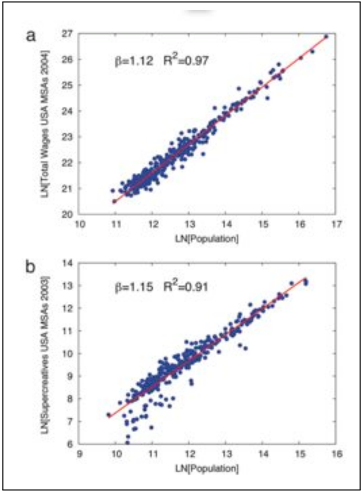
$$Y(t) = Y_0 N(t)^{\beta} \quad (1)$$

Where N is the population,
Y is material resources (such as energy or infrasturcture),
Y_0 is a normalization constant

Application to the Modern City

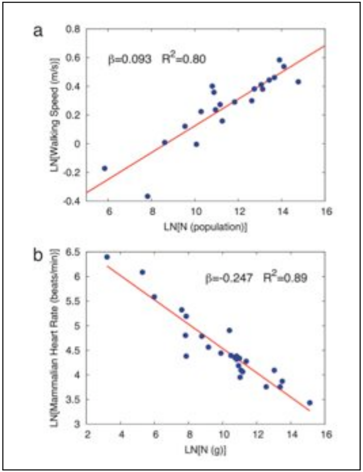
- Data collected to understand scaling of the urban metabolism
- Data is grouped by metropolitan statistical areas (MSAs), and larger urban zones (LUZs)
- The data set is applied to the scaling equation described in the previous slide

Scaling and Biological Metaphors



a)Total wages per MSA vs. metropolitan population
b) Supercreative employment per MSA vs. metropolitan population

Scaling and Biological Metaphors



a) Scaling of walking speed vs. population for cities around the world.
b) Heart rate vs. the size (mass) of organisms

Scaling exponents for urban indicators vs. city size

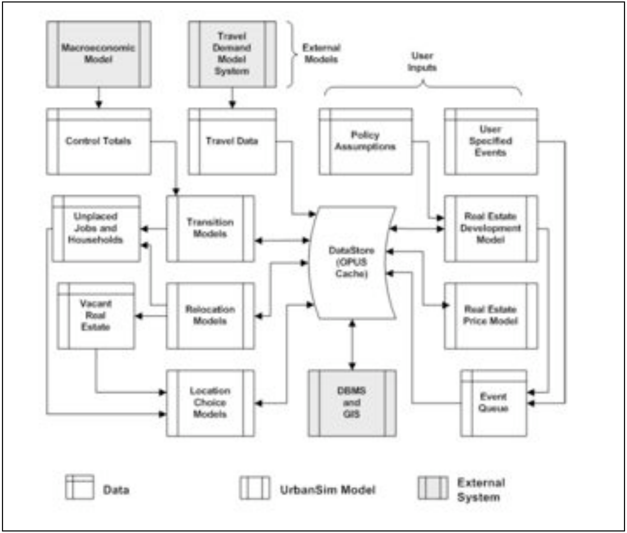
Y	β	95% CI	Adj-R^2	Observations	Country-year
New patents	1.27	[1.25,1.29]	0.72	331	U.S. 2001
Inventors	1.25	[1.22,1.27]	0.76	331	U.S. 2001
Private R&D employment	1.34	[1.29,1.39]	0.92	266	U.S. 2002
"Supercreative" employment	1.15	[1.11,1.18]	0.89	287	U.S. 2003
R&D establishments	1.19	[1.14,1.22]	0.77	287	U.S. 1997
R&D employment	1.26	[1.18,1.43]	0.93	295	China 2002
Total wages	1.12	[1.09,1.13]	0.96	361	U.S. 2002
Total bank deposits	1.08	[1.03,1.11]	0.91	267	U.S. 1996
GDP	1.15	[1.06,1.23]	0.96	295	China 2002
GDP	1.26	[1.09,1.46]	0.64	196	EU 1999–2003
GDP	1.13	[1.03,1.23]	0.94	37	Germany 2003
Total electrical consumption	1.07	[1.03,1.11]	0.88	392	Germany 2002
New AIDS cases	1.23	[1.18,1.29]	0.76	93	U.S. 2002–2003
Serious crimes	1.16	[1.11, 1.18]	0.89	287	U.S. 2003
Total housing	1.00	[0.99,1.01]	0.99	316	U.S. 1990
Total employment	1.01	[0.99,1.02]	0.98	331	U.S. 2001
Household electrical consumption	1.00	[0.94,1.06]	0.88	377	Germany 2002
Household electrical consumption	1.05	[0.89,1.22]	0.91	295	China 2002
Household water consumption	1.01	[0.89,1.11]	0.96	295	China 2002
Gasoline stations	0.77	[0.74,0.81]	0.93	318	U.S. 2001
Gasoline sales	0.79	[0.73,0.80]	0.94	318	U.S. 2001
Length of electrical cables	0.87	[0.82,0.92]	0.75	380	Germany 2002
Road surface	0.83	[0.74,0.92]	0.87	29	Germany 2002

Data sources are shown in SI Text. CI, confidence interval; Adj-R^2, adjusted R^2; GDP, gross domestic product.

Introduction to Land Use Modeling Software

- Software package
- Built by team at University of Washington
- Open source software used for simulating growth of metropolitan regions
- Series of discrete choice models is run to determine the final land use outputs

UrbanSim: Land Use Modeling Package



UrbanSim Model Components and Data Flow

Key Features of the System

- Simulates key decision makers and choices that impact urban development
- Accounts for land, structures, and occupants
- Urban development simulated as dynamic process over time and space
- Incorporates governmental policy assumptions
- Returns disaggregate information by parcel
- Simulates development and redevelopment

Key Features of Implementation

- Linux, Mac OS, and Windows compatible
- Code predominantly implemented in Python
- Open source and downloadable
- User interface focusses on model configuration, data management, and scenario evaluation
- Object oriented programming
- Results are GIS compatible
- Binary files used for reading and writing, can be converted to shapefile, database, etc.

Discrete Choice Equations

Utility Function

$$U_i = V_i + \epsilon_i$$

$V_i = \beta x_i$ is a linear-in-parameters function and β is a vector of k estimator coefficients

Probability Function

$$P_i = \frac{e^{V_i}}{\sum_j e^{V_j}}$$

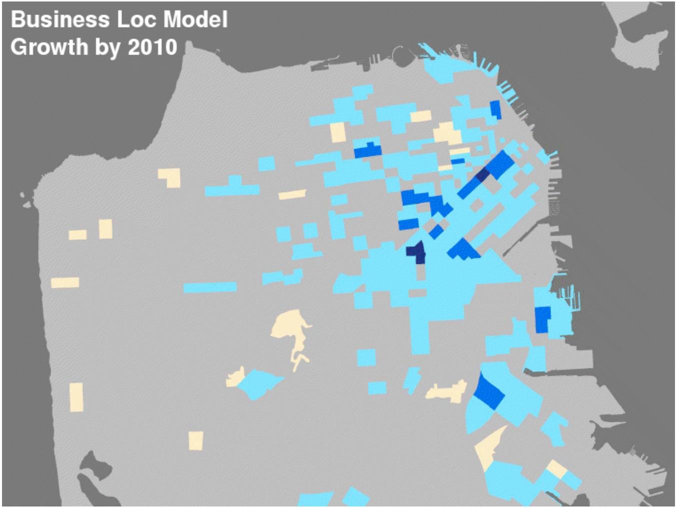
j is an index over all possible alternatives

Sub-model routines

- Real estate price model
- Building transition model
- Household transition model creates and removes households and updates the set of persons accordingly. It is based on random sampling and is driven by macroeconomic predictions.
- Business transition model
- Household relocation choice model
- Household location choice model

  determines households for moving, using a logit model.
- Business relocation model
- Business location choice model

Business Growth in San Francisco



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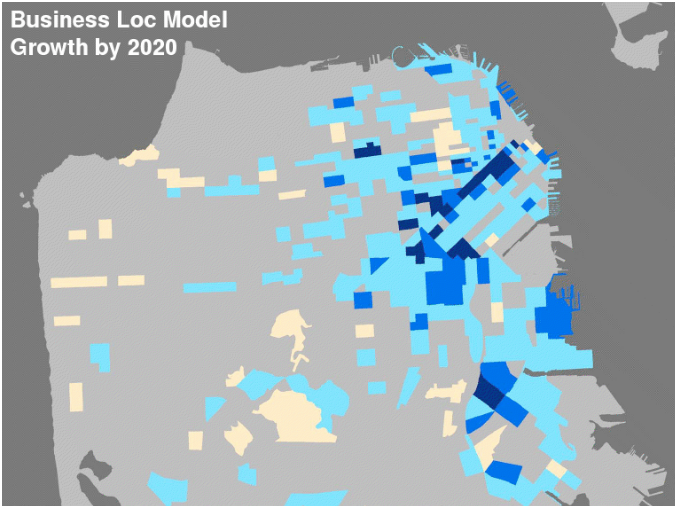

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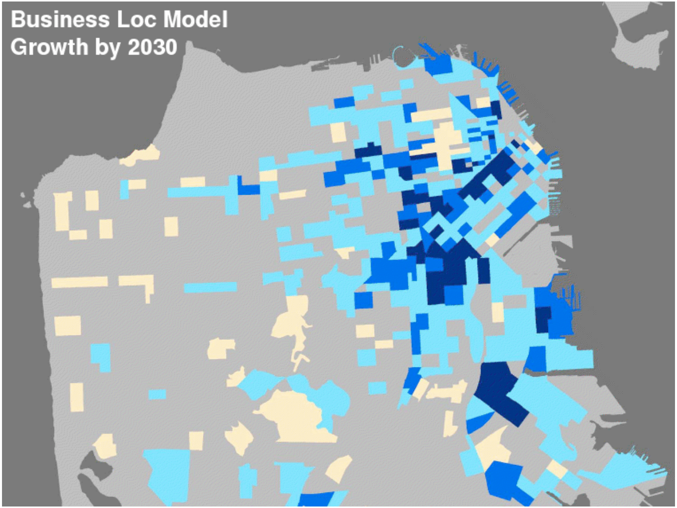

A Quick Video Presentation of UrbanSim

Goto: http://www.youtube.com/watch?v=nmBnRAde5Xw

Population Growth in San Francisco

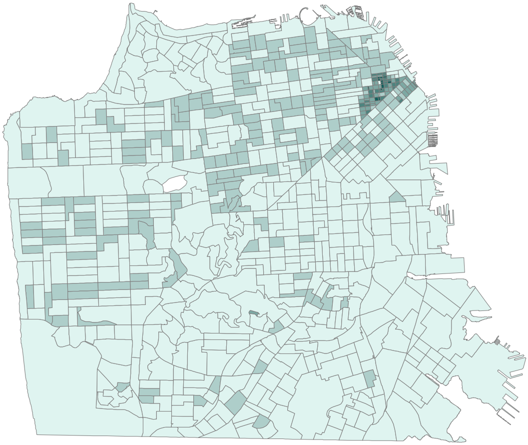

Figure: Year 2001

Population Growth in San Francisco

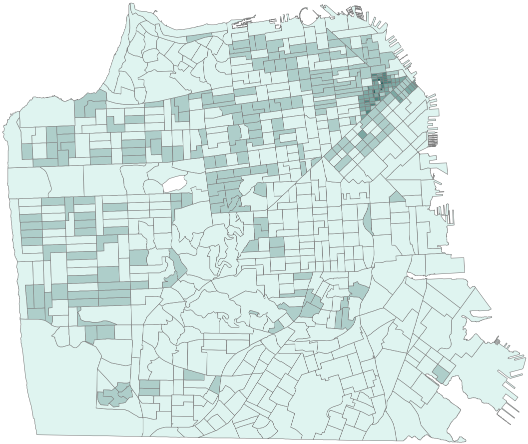

Figure: Year 2010

Population Growth in San Francisco

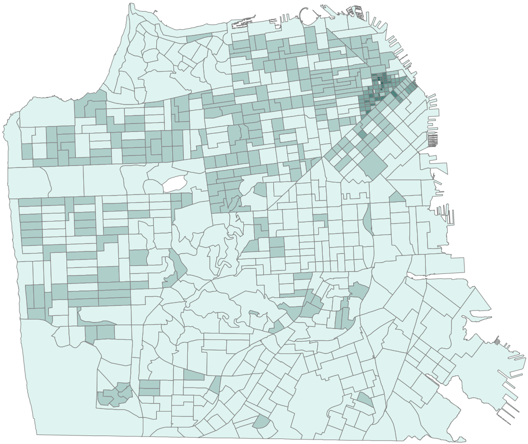

Figure: Year 2020

Population Growth in San Francisco

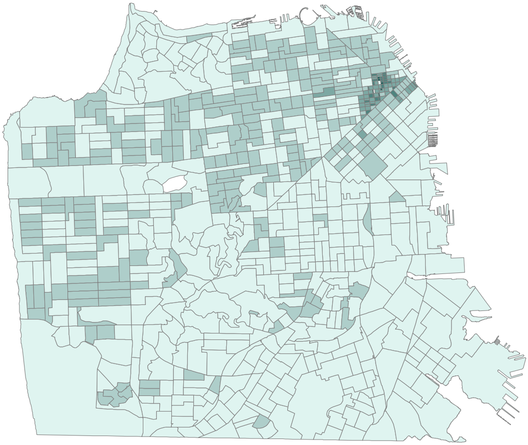

Figure: Year 2030

Employment Growth in San Francisco

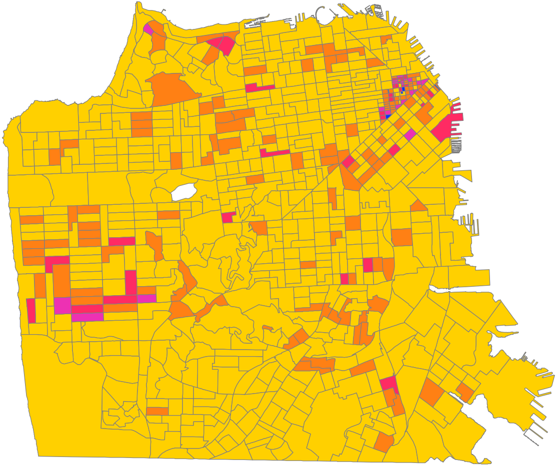

Figure: Year 2001

Employment Growth in San Francisco

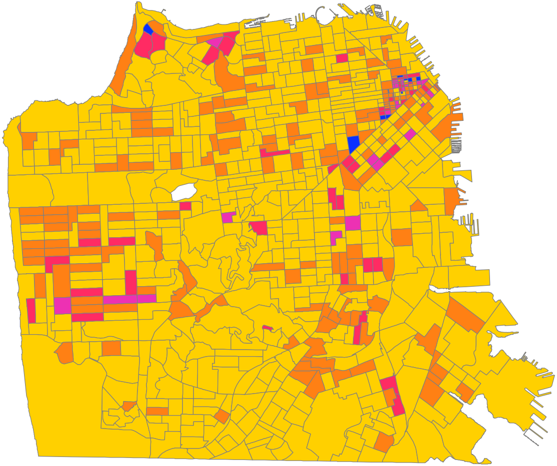

Figure: Year 2010

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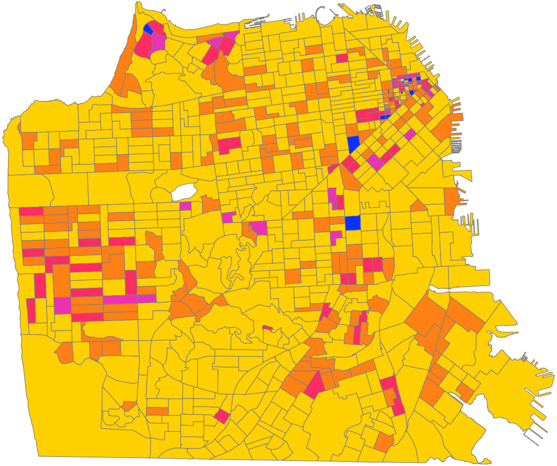


Figure: Year 2020

Employment Growth in San Francisco

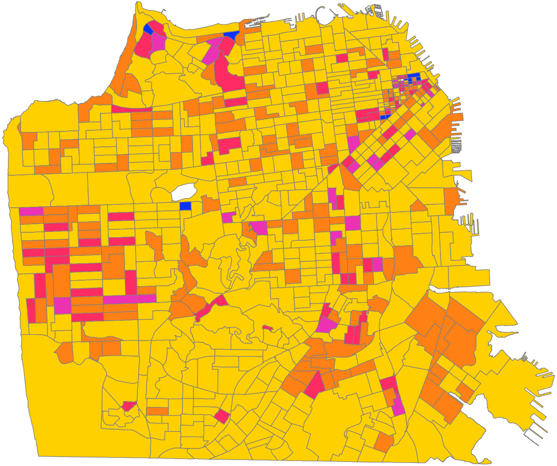
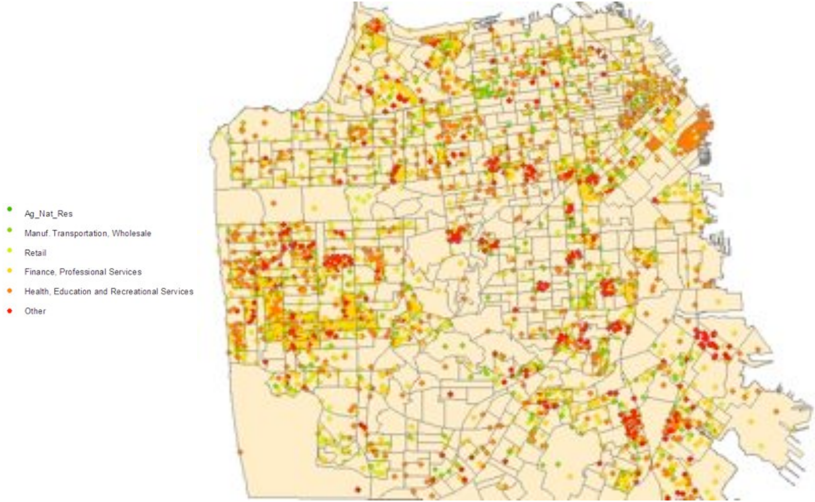


Figure: Year 2030

Jobs by Sector in San Francisco



Year 2001

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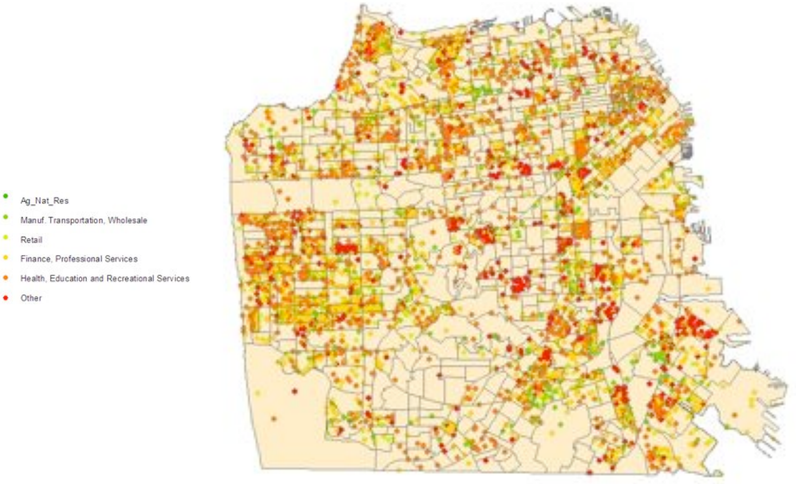

Year 2010

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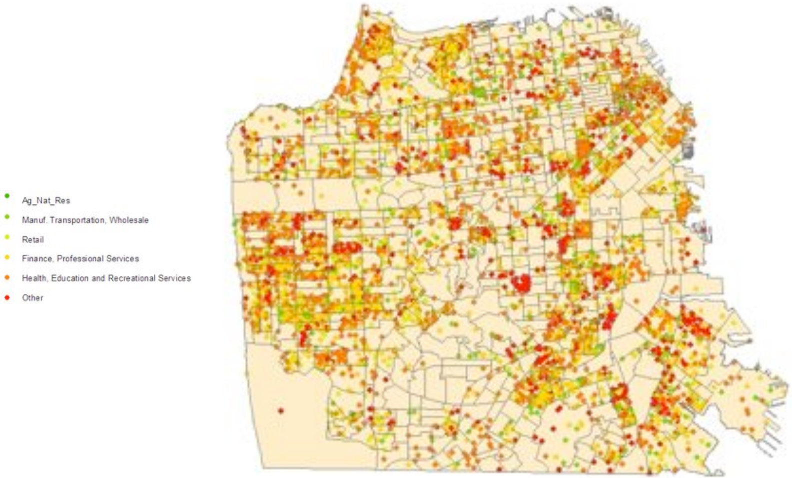

Year 2020

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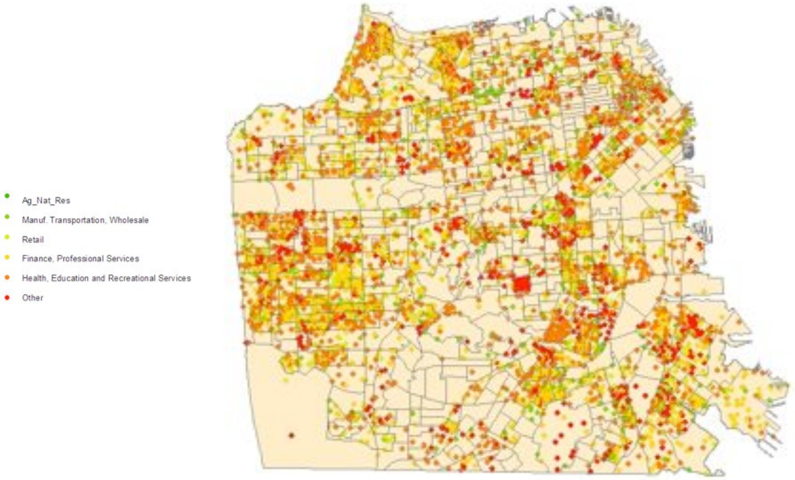
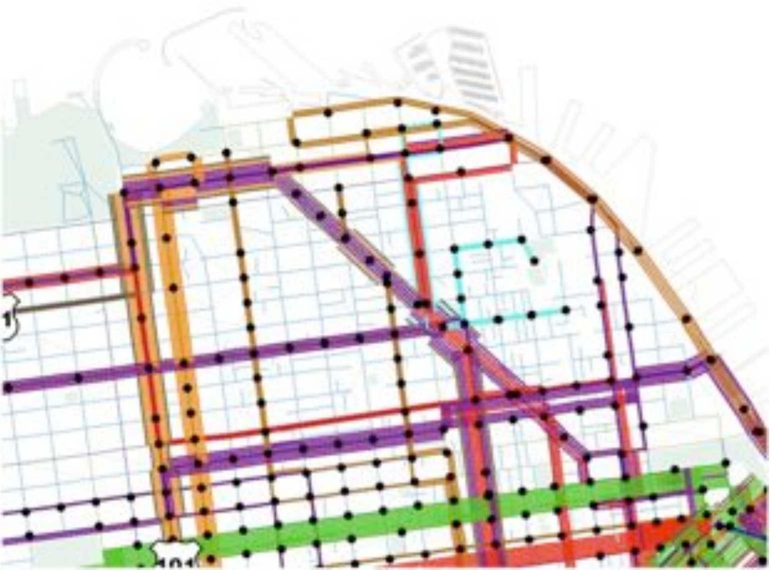


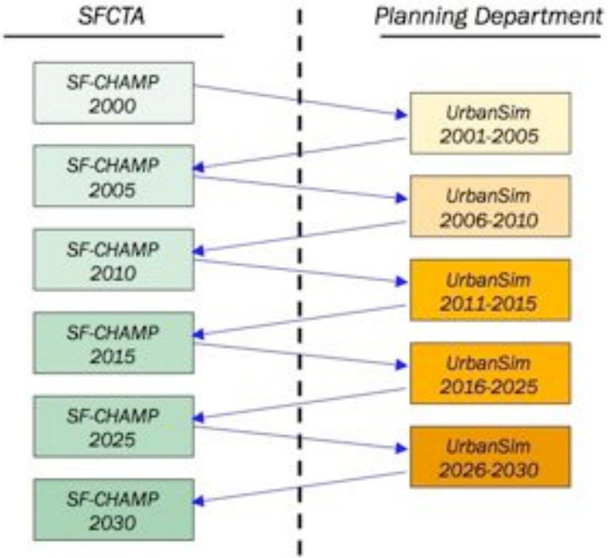
Year 2030

Activity Based Modeling Scenario: Auto Networks

Activity Based Modeling Scenario: Transit Networks



What to do with land use forecasts?



What to do with land use forecasts?

Next Steps

- Land use model validation
- Solidify key links between network theory and urban modeling
- Further quantify the urban metabolism for long term planning
- Generalize for generic metropolitan implementation