END4400 – System Dynamics

Week 2 – 16/3/2021

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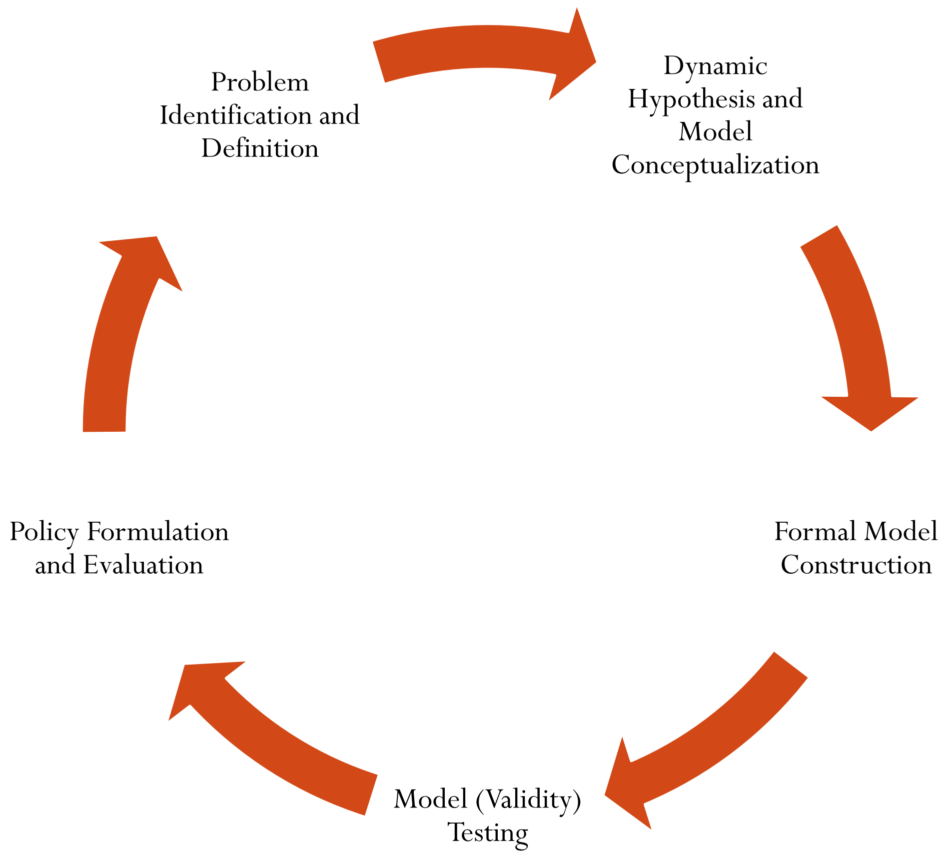
Outline

- The Modeling Process
- Structure and Behavior of Dynamic Systems
  - Principles of Systemic Feedback Approach

Steps of an SD Modeling Process

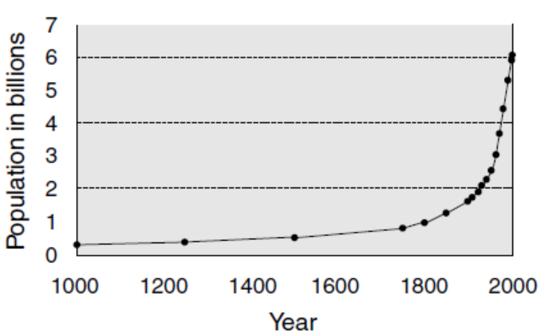
- A typical system dynamics study goes through some standard steps.
  - some variations
  - no cookbook recipe for successful modeling → no procedure you can follow to guarantee a useful model
  - a commonly-used disciplined process
- 5 step-process
  1. problem identification and definition
  2. dynamic hypothesis and model conceptualization
  3. formal model construction
  4. model credibility (validity) testing
  5. policy formulation and evaluation

Steps of an SD Modeling Process

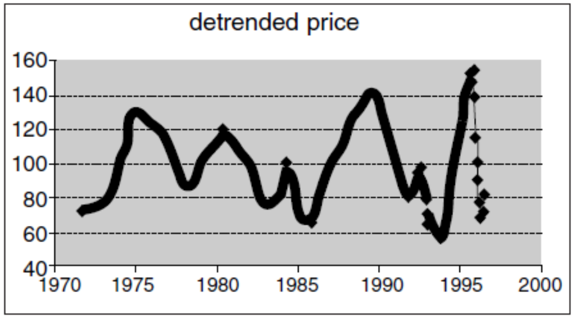


Problem Identification and Definition

- selection and articulation of a meaningful dynamic feedback problem is critical
- "dynamic" + "feedback"
- problems driven by external forces ✘
- characterized by
  - behavior patterns that may be observed in plotted data or
  - may be deduced from available qualitative information.



(a) World population growth (See "The ECOCOSM Paradox," EOLSS on-line, 2002).



(b) USA pulp prices (Deflated by CPI and all trends removed)

Problem Identification and Definition

- plot all the available dynamic data and examine the dynamic behaviors
- determine the time horizon (into the future and into the past) and basic time unit of the problem (e.g., days/months/years)
- determine the reference dynamic behavior
- write down a specific, precise statement of what the dynamic problem is

Dynamic Hypothesis and Model Conceptualization

- objective → develop a hypothesis, a theory that explains the causes behind the problematic dynamics
  - "endogenous" explanation
  - dynamic hypothesis → simulation model → hypothesis testing
  - dynamic hypothesis is also called "conceptual model"

Dynamic Hypothesis and Model Conceptualization

- examine the real problem
- list all variables playing a potential role in the creation of the dynamic(s) of concern
- identify the major causal effects and feedback loops between these variables
- construct an initial causal loop diagram and explore alternative hypotheses → more than one "model" (several dynamic hypotheses)
- add and drop variables as necessary and fine-tune the causal loop diagram.
- identify the main stock and flow variables
- finalize a dynamic hypothesis as a concrete basis for formal model construction.

Formal Model Construction

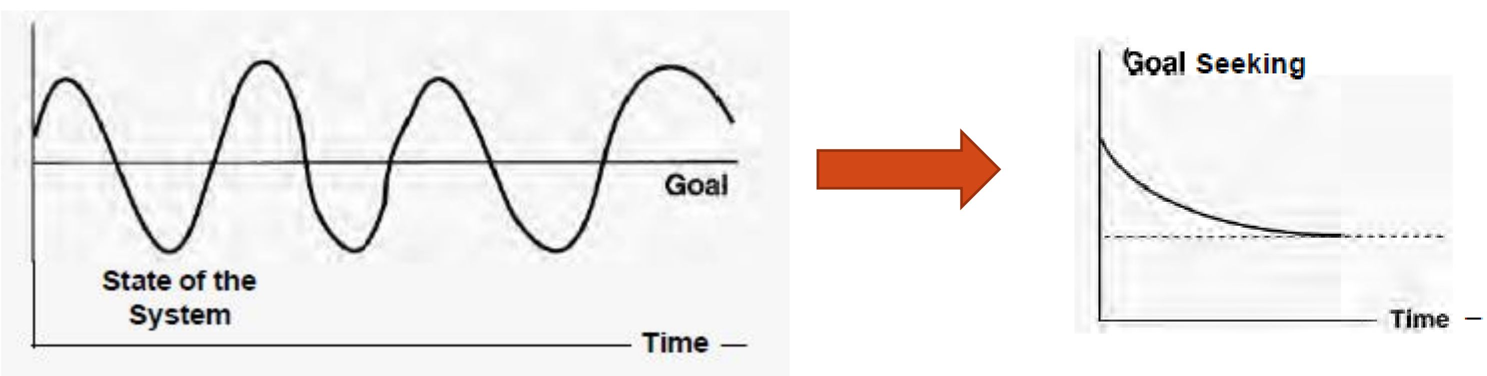
- construct the stock-flow diagram; the structure of the model
- write down mathematical formulations that describe cause-effect relations for all variables
- estimate the numerical values of parameters and initial values of state variables (i.e., stocks)

Model (Validity) Testing

- main question;
  - “is the model an adequate representation of the real problem with respect to the study purpose?”
- structural validity
  - “is the structure of the model a meaningful description of the real relations?”
- behavioral validity
  - “are the model generated patterns similar to real patterns?”
  - reference mode vs. model-generated dynamics (in a pattern-oriented way)
- “All models are wrong, but some are useful” (George Box)

Policy Formulation and Evaluation

- a potential prior step → play with the model parameters for exploration (model analysis)
  - structured sensitivity tests
- policy development and testing → "improve" the model dynamics
  - e.g., stabilize oscillatory inventory dynamics



Policy Formulation and Evaluation

- policy → a decision rule
  - e.g., new ordering policies to alleviate oscillations
- design alternative policies and test them on the model
- implement the "best" policy

Structure and Behavior of Dynamic Systems

Principles of Systemic Feedback Approach

Principles of Systemic Feedback Approach

- deals with dynamic policy problems of systemic, feedback nature
  - interactions between system variables → "systemic"
  - the feedbacks between the managerial actions and the system's reactions → "feedback"
- purpose in SD
  - understand the reasons → develop effective policies
- the need of "systemic feedback" philosophy
  - General Systems Theory (Ludwig von Bertalanffy)
  - Feedback Control Theory (Gordon Brown)
  - Cybernetics (Norbert Wiener)
  - etc.

Principles of Systemic Feedback Approach

- SD integrates systems theory with cybernetics and feedback control theories.
- three main principles of "systemic feedback" approach:
  1. causal relationships (rather than correlations)
  2. circular causality (feedback loops)
  3. internal structure as the main cause of dynamic behavior

Principles of Systemic Feedback Approach

- **Principle 1: Causal Relationships**
  - causal relationships ✓
  - statistical correlations ✗
- an SD model is constructed through causal relationships between variables
- the purpose is not short-term predictions
- correlation-based statistical models → perfect forecast but no possibility of understanding and controlling the problems

Principles of Systemic Feedback Approach

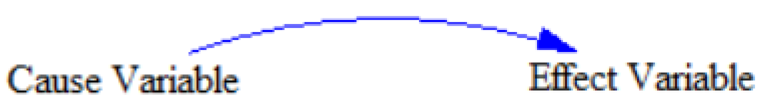
- e.g., swimsuit sales and ice cream sales are highly positively correlated $y = f(x)$

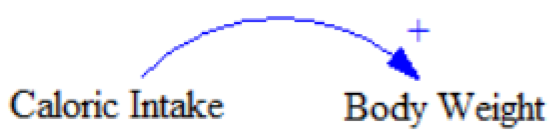
$$ice\ cream\ sales = f(swimsuit\ sales)$$

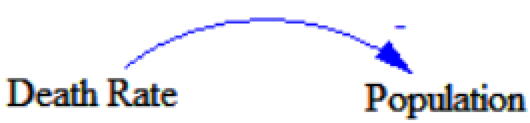
  - simple linear regression model
- to forecast ice cream demand, this model is very useful
- dynamic problem
  - a consistent decline in ice cream sales after several years of growth
  - the (correlational) model above is totally useless!
  - no causal relationship between ice cream sales and swimsuit sales

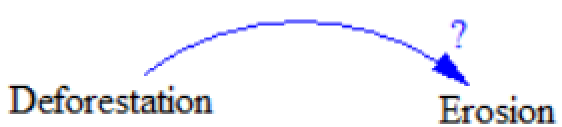
Principles of Systemic Feedback Approach

- causality → input variable (*x*) has some **causal influence** on the output variable (*y*)
  - *x* → cause variable *y* → effect variable
- examples of causal relationships;
  - an **increase** in caloric intake causes weight **gain** (+)
  - **increased** death rate causes the population to **decline** (-)
  - **increased** deforestation causes erosion to **increase** (?)



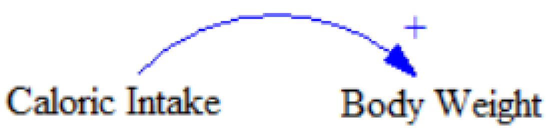






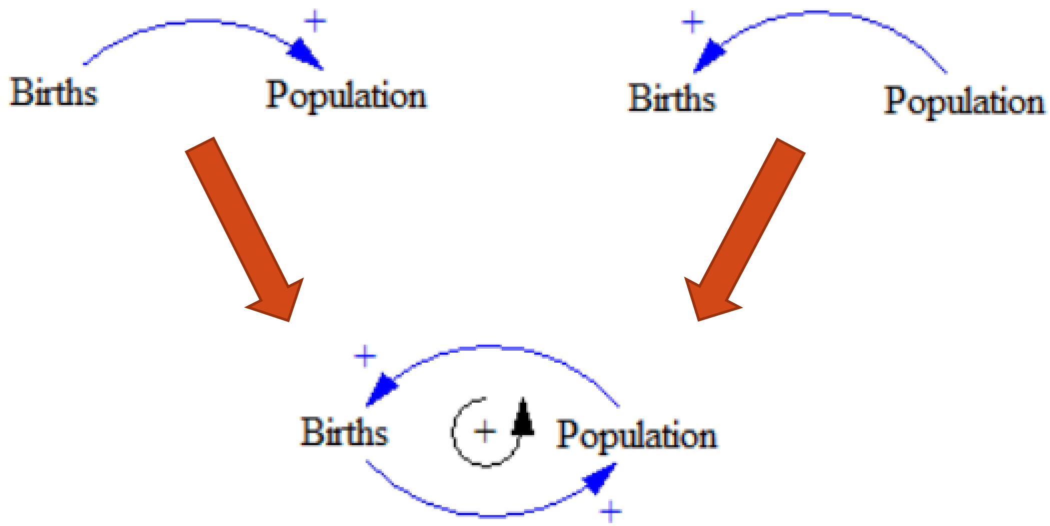
Principles of Systemic Feedback Approach

- how to detect causal relationships?
  - each causal relation in a system dynamics model is a "*ceteris paribus*" (all other things being equal) argument
  - X → Y means "other things being equal, a change in X causes a change in Y"
- causality is not a straightforward concept
  - based on either (i) real-life experience or (ii) well-established in the literature



Principles of Systemic Feedback Approach

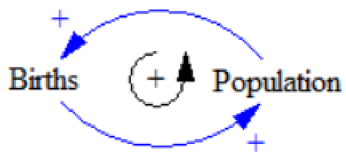
- **Principle 2: Circular (Feedback) Causality**
  - identification of feedback loops (circular causalities), *not only one-way causal relations*
  - e.g.,



  - The more births, the more people there will be
  - The more people, the more births there will be
- no obvious separation between cause and effect

Principles of Systemic Feedback Approach

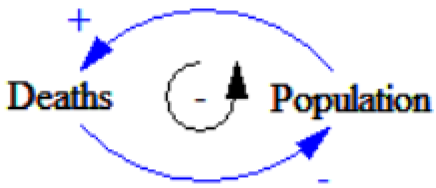
- positive (reinforcing) feedback loop



- loop polarity: +
  - "births determine population and population determines births"
  - reinforcing → exponential growth in the population

Principles of Systemic Feedback Approach

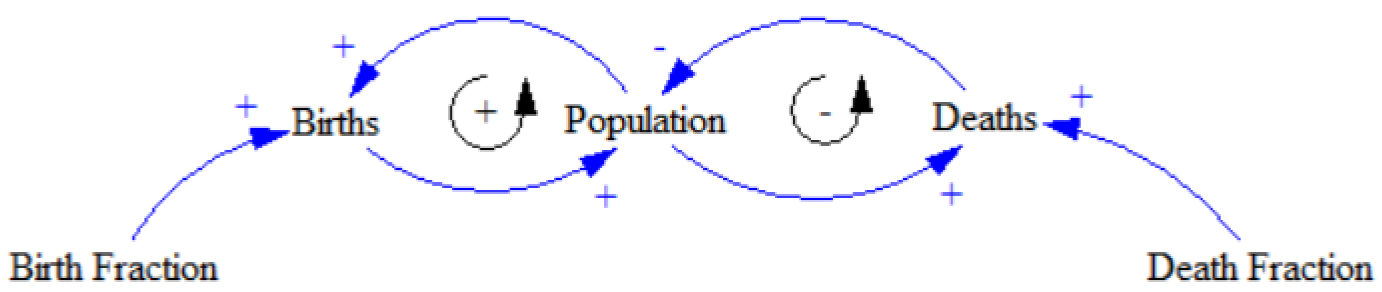
- negative (balancing) feedback loop



- loop polarity: -
  - balancing → seeks a "balance" (in the population)

Principles of Systemic Feedback Approach

- feedback loops are the "engines" of a system
  - building blocks
- there are many positive and negative feedback loops in a system
  - interact with each other → dynamics of concern
- all the causal relationships and feedback loops are shown in causal-loop diagrams



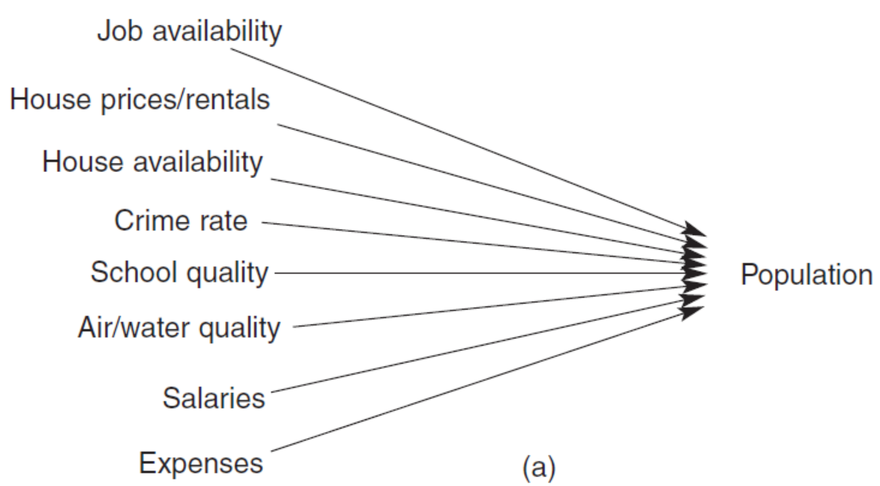
Principles of Systemic Feedback Approach

- **Principle 3: Internal Structure as the Main Cause of Dynamic Behavior**
- structure → totality of the relationships that exist between system variables
- the interaction between feedback loops and variables drive the (undesired) behavior
  - "the structure causes the behavior of the system"
  - understand the causes of an undesirable behavior and try to improve it

Principles of Systemic Feedback Approach

- e.g., population dynamics of a city → a strong early growth followed by stagnation
  - a growth-and-decline type behavior
- a static and exogenous model:

Population = f(Job availability, Salaries, Expenses, House prices, House availability, Crime rate, School quality, Air/water quality. . .)



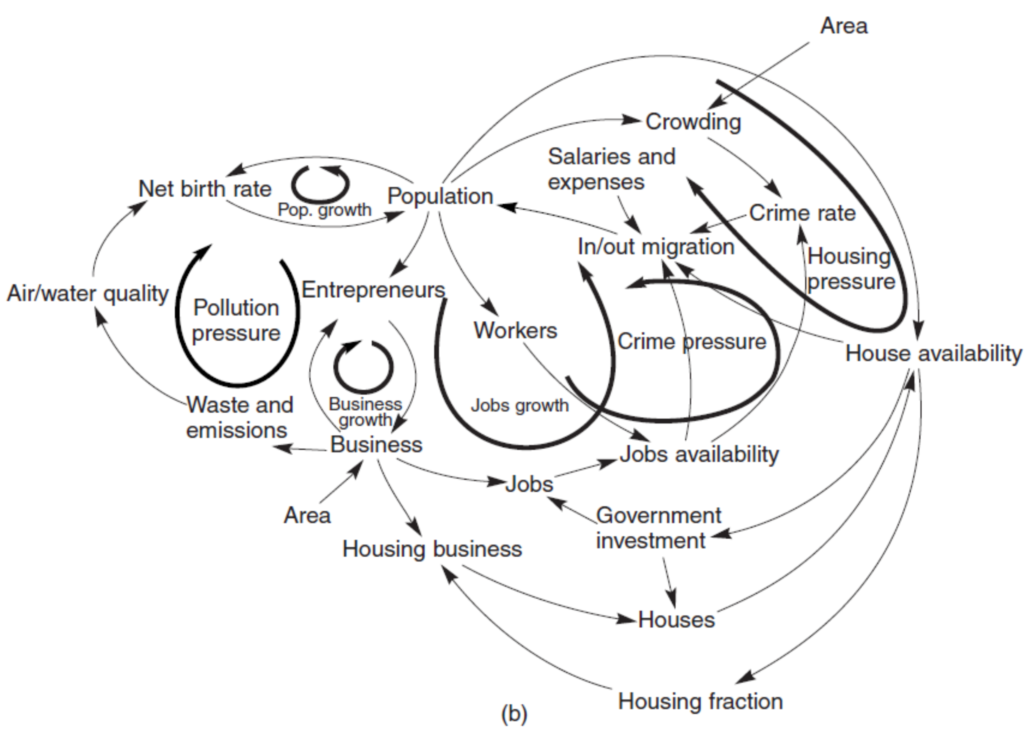
Principles of Systemic Feedback Approach

Population = f(Job availability, Salaries, Expenses, House prices, House availability, Crime rate, School quality, Air/water quality. . .)

- strict assumptions:
  - all inputs are independent (are not influenced by each other of by the output - *population*)
- obviously not a causal model
- however, it may perfectly predict the population for a given set of inputs!
- cannot understand the reasons behind the behavior of the population

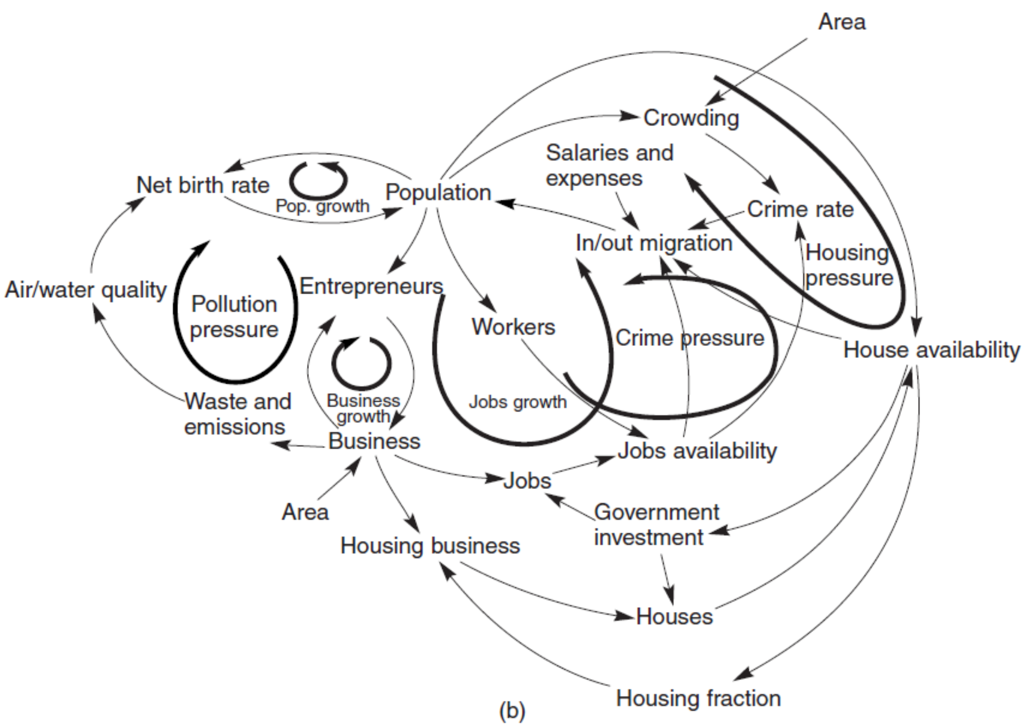
Principles of Systemic Feedback Approach

- dynamic feedback model
- no clear distinction between inputs and outputs
  - "jobs availability"



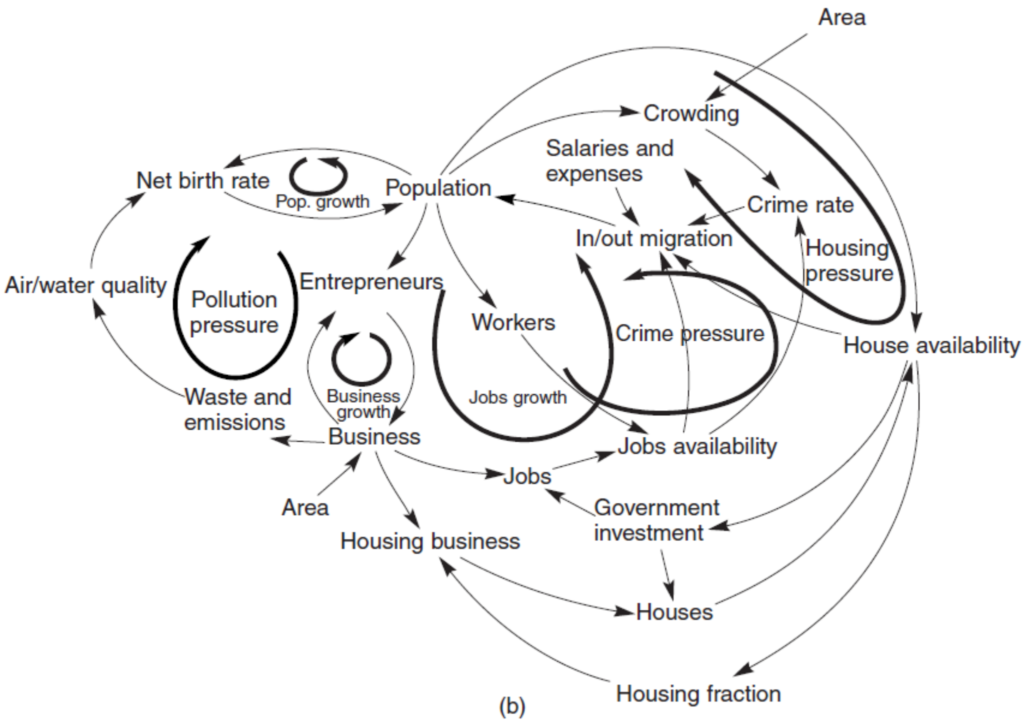
- population → entrepreneurs → business → jobs → jobs availability → in/out migration → population
- "jobs growth" is responsible for the initial increase in the population

Principles of Systemic Feedback Approach



- population → entrepreneurs → business → waste and emissions → air/water quality → net birth rate → population
- “pollution pressure” is one of the loops responsible for the decline after growth

Principles of Systemic Feedback Approach



- endogenous theory about the problem
- dynamics are internally determined

Basic Definitions (System, Problem, Model)

- Homework: Read Section 2.4 of Barlas (2002)
- Reference

Barlas, Y. "System Dynamics: Systemic Feedback Modeling for Policy Analysis" in Knowledge for Sustainable Development - An Insight into the Encyclopedia of Life Support Systems, UNESCO-EOLSS Publishers, Paris, Oxford, UK. 2002, pp.1131-1175.

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