Lecture #10: Understanding model behavior and sensitivity

Understanding model behavior

The main result: build up to complexity, and carry understanding with you. Understanding comes from reflecting on many well-designed simulation experiments, starting with the simple and moving to the complex. Understanding a complex model starting with the completed model is extraordinarily difficult, if not impossible.

Three kinds of parameter sensitivity:

quantitative sensitivity
behavioral sensitivity
policy sensitivity

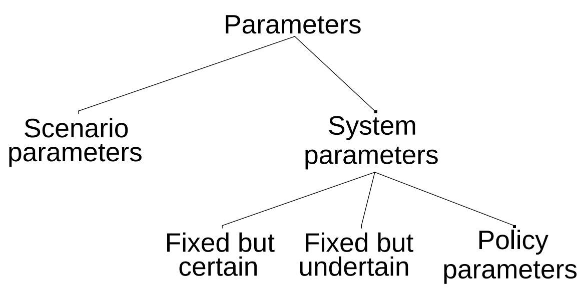
Examples:

A mass on a spring exhibits quantitative sensitivity as one varies the mass and spring constant, but no behavioral sensitivity at all: it always oscillates.

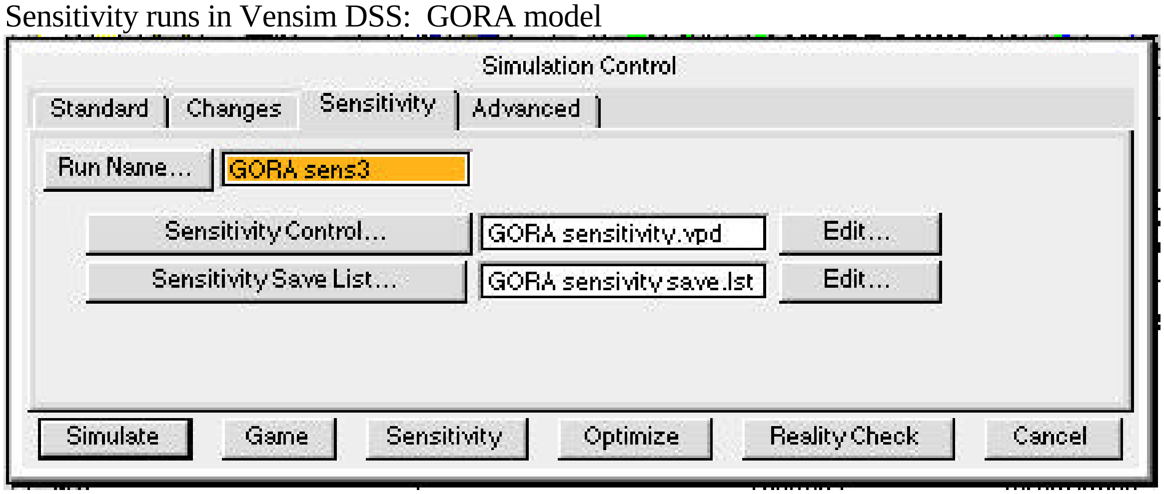
The multiplier/accelerator model exhibits quantitative and behavioral sensitivity as one varies the consumption and acceleration coefficients.

Does the multiplier/accelerator model with PID controller exhibit policy sensitivity as one varies the consumption and accleration coefficients? [Would your policy recommendations change depending on the values or range of values of the consumption and acceleration coefficients?]

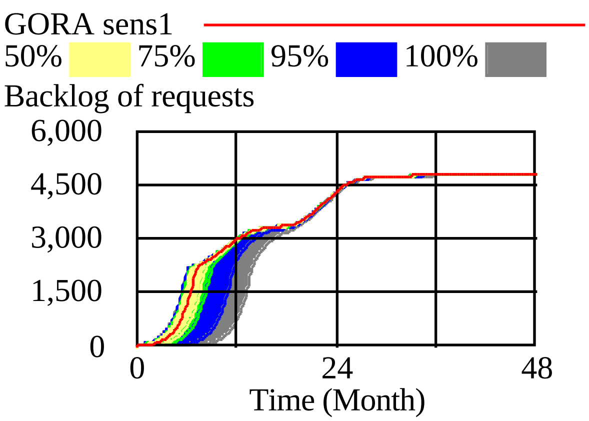
Distinguish between scenario parameters and system parameters:

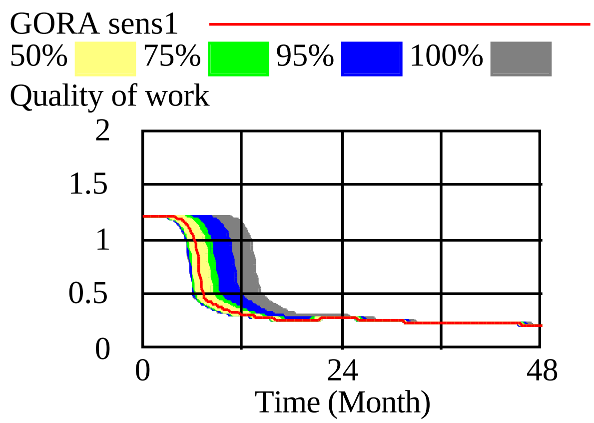


Sensitivity runs in Vensim DSS: GORA model

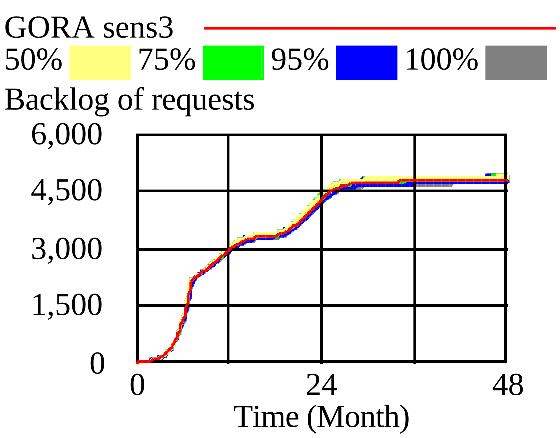


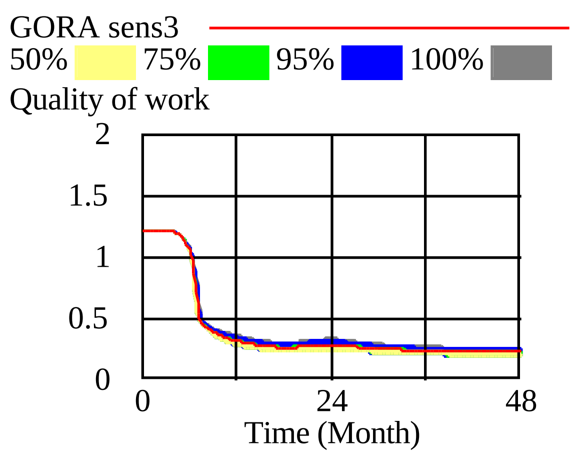
Vary ‘New requests from advertising’ from 0 to 200 (uniformally distributed): Get differing early behavior, but converges to same equuilibrium:

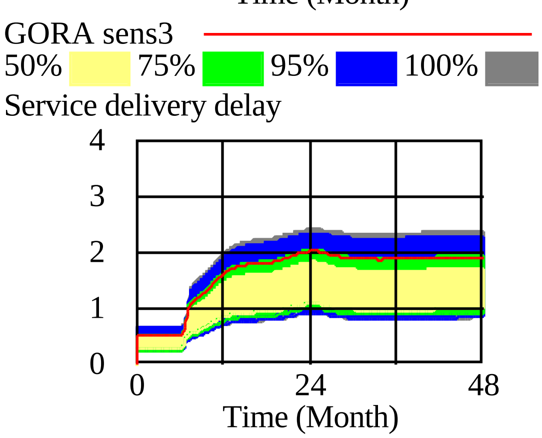




Vary ‘Normal productivity’ from 300 to 1000 (uniformally distributed) (as if testing varying levels of technology):

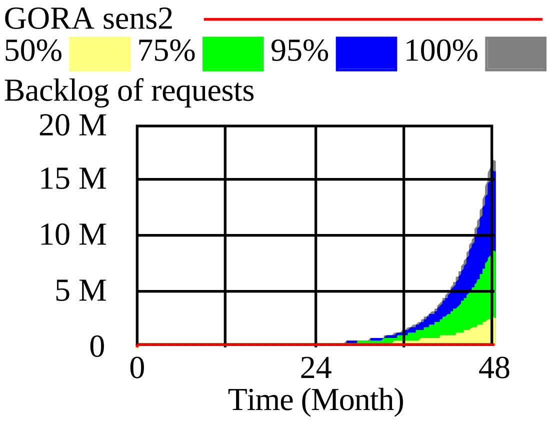


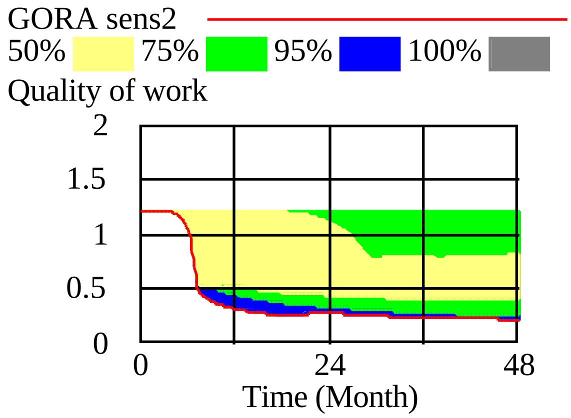


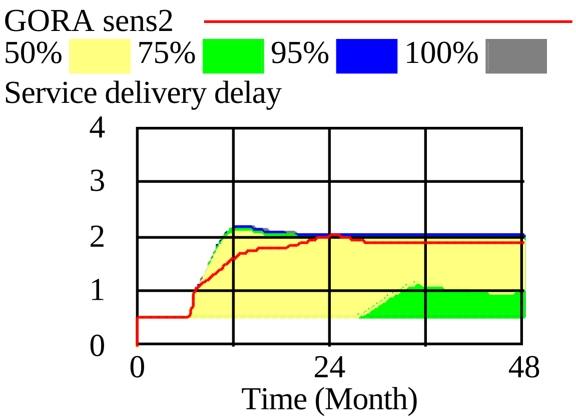


The main behavior of the model is not changed, but the size of the delivery delay varies over the whole run.

Vary ‘Price’ from 0 to 100 (uniformally distributed): Get very different behavior:







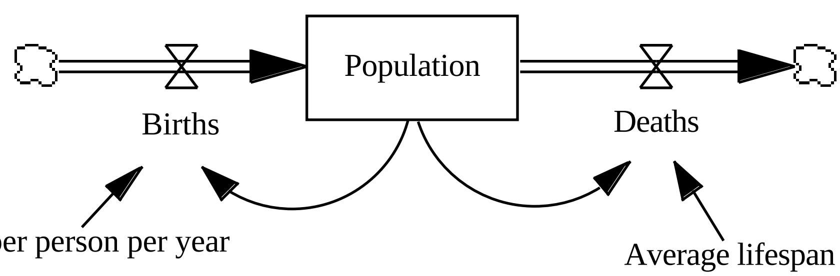
Behavior varies dramatically throughout, apparently shifting from limited growth to sustained exponential growth, with low service delivery delay and high quality.

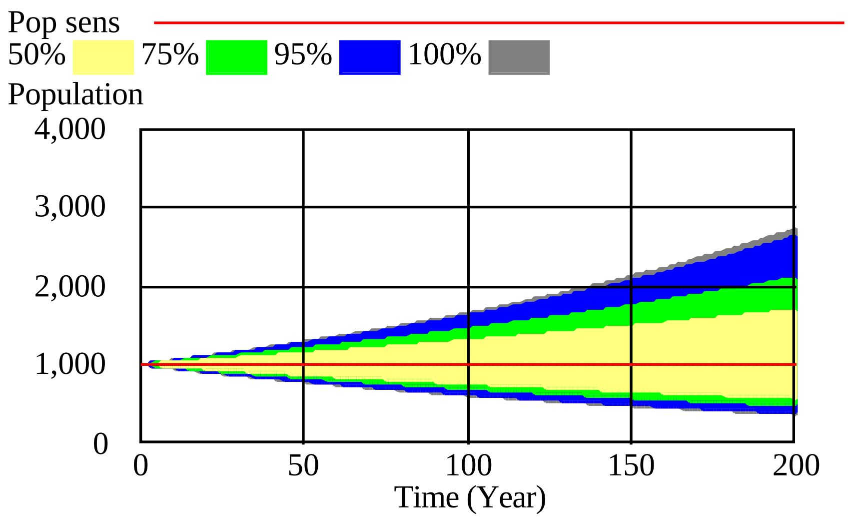
===> Price is a sensitive policy lever; Advertizing changes the timing of growth, but not the nature of it nor the final equilibrium condition; Productivity (technology)

The basic problem of model sensitivity in nonlinear models:

Basins of attraction; bifurcations as loop dominance shifts.

<u>Example</u>: Population model, with Average lifespan = 66.7 years (= 1/.015) and Births per person per year = 0.01 to 0.02:



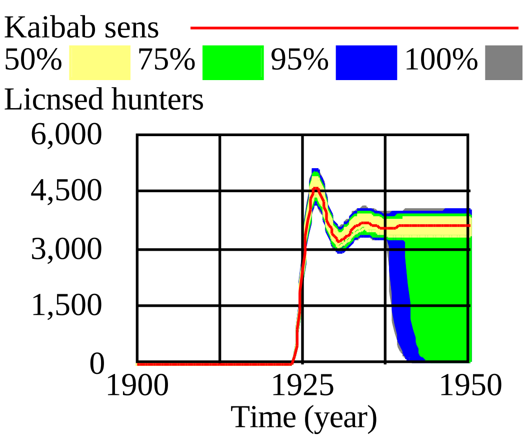


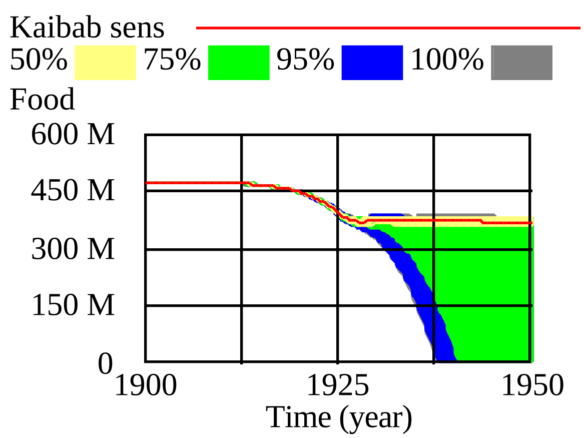
Behavior varies from exponential decay to exponential growth -- two very different behaviors depending on the relative strength of the two loops in the model.

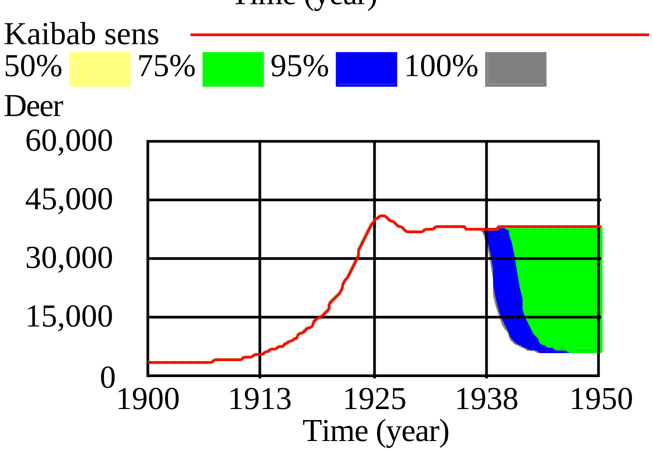
The behavior ‘bifurcates’ at Births per person per year = .015.

A secondary problem of model sensitivity:

Model sensitivity varies as parameter values near the borders of basins of attraction.
Example: Kaibab model with hunters policy implemented. Here the desired deer population is set at 30600, and randomness is activated in food regeneration and kills per hunter.







The potential for a desired deer population of 30600 to collapse is not observable from a deterministic run (the red line in the graphs), but collapse occurs in some 25 percent of these runs, suggesting in a reality parameterized like this collapse would likely occur.

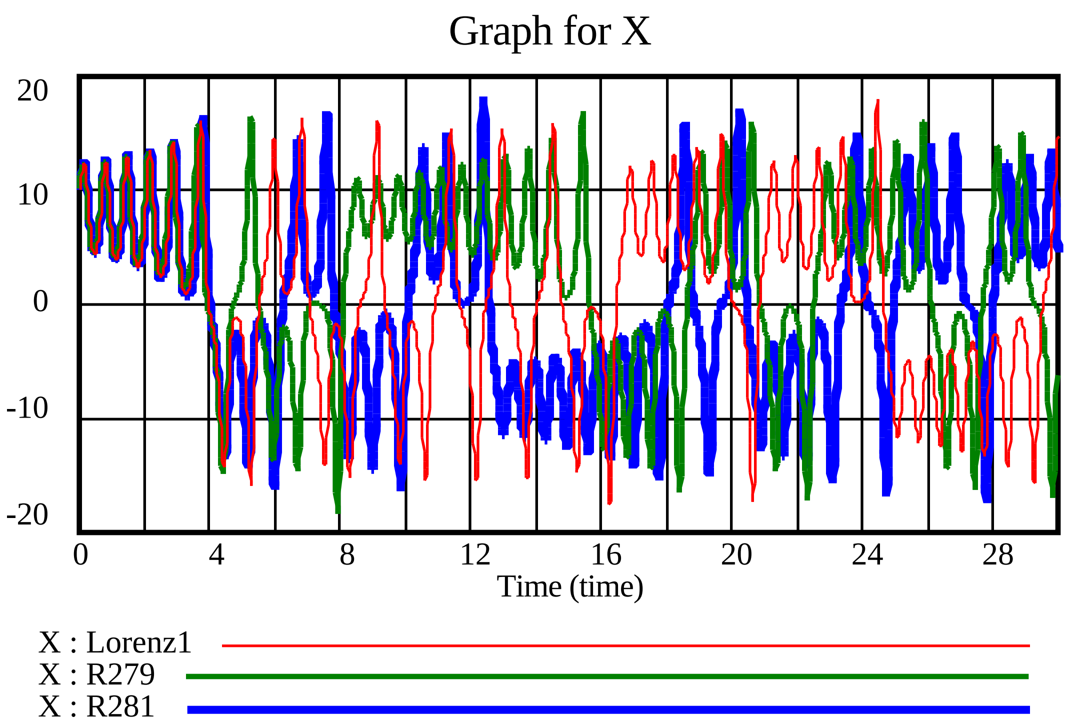
Appropriate tests for such loop dominance/bifurcation sensitivity include

- randomness in key scenario parameters
- lots of simulations runs, with reflection and awareness of the border effect

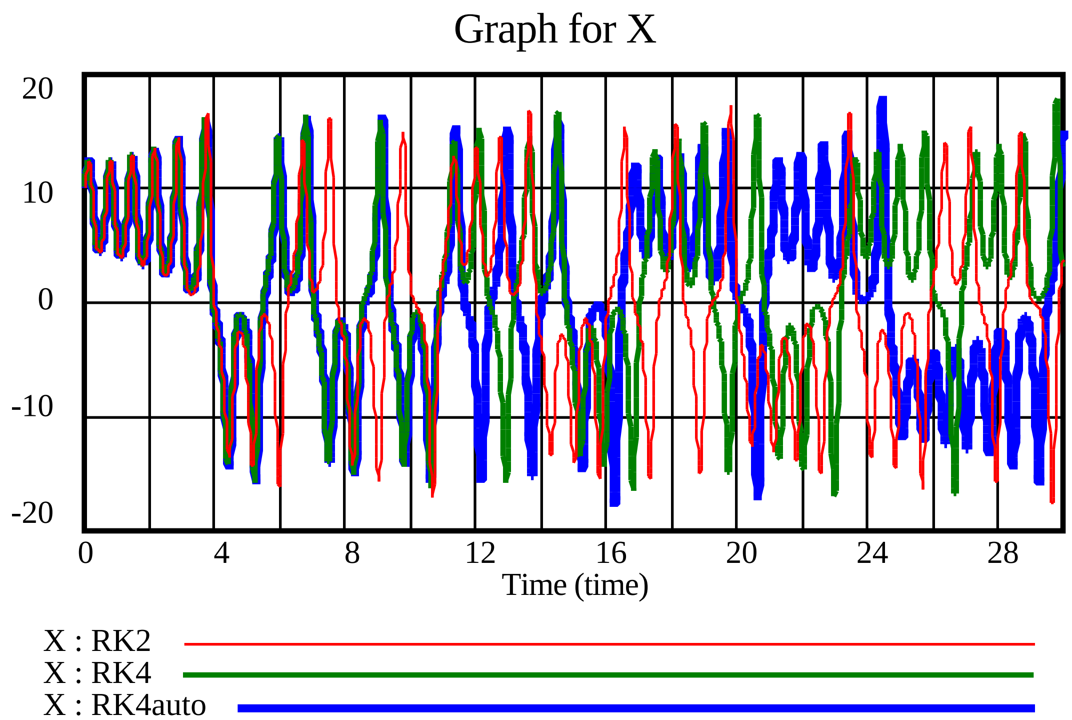
The final problem of model sensitivity: chaotic models. These models contain regions of parameter space in which the model shows extreme sensitivity to parameter values, DT, and simulation method.

Example: Lorenz model.

Three runs of the Lorenz model: R=27.9, 28.0, 28.1



Three runs of the Lorenz model (R=28.0): Runge-Kutta second and fourth order, and "Runge-Kutta 4 auto" (Runge-Kutta fourth order with automatic adjustment of the Time Step to keep integration inaccuracies within a specified tolerance):



Here only the method of integration has changed, yet the runs are completely different halfway through.

More advanced issues in sensitivity testing

More than one parameter to test ---> Latin hypercube designs (which Vensim DSS supports)

HYPERSENS: Andrew Ford (1990). "Estimating the Impact of Efficiency Standards on the Uncertainty of the Northwest Electric System." *Operations Research* 38: 580-597. In *Modelling for Management,* vol II, 49-68.

Taguchi methods: S.M. Phadke, 1989, *Quality Engineering Using Robust Design,* Englewood Cliffs: Prentice-Hall;

Taguchi methods applied: Clemson, B., Tang, Y., & Unal, R. (1995). Efficient Methods for Sensitivity Analysis. *System Dynamics Review,* 11(1), 31-49.