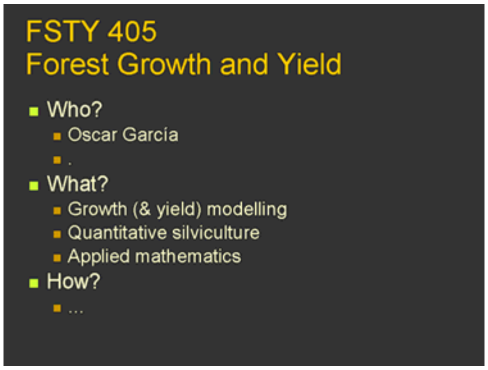
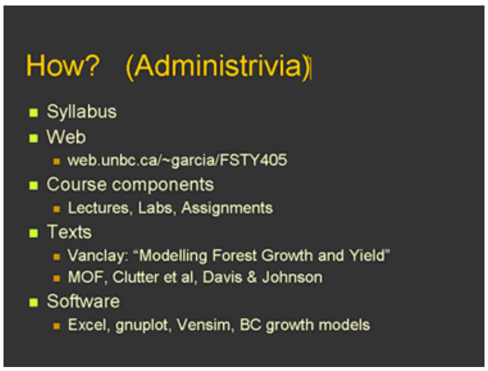
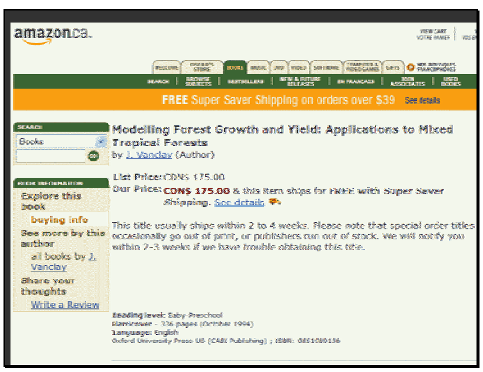
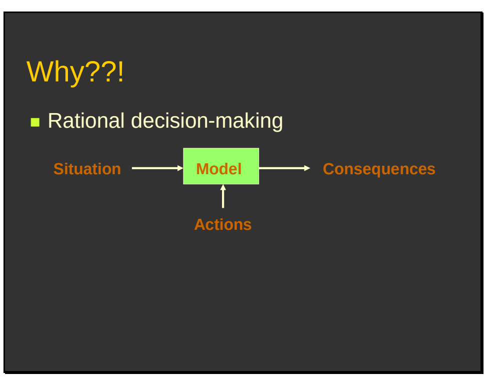


Read the Syllabus!
For the Introduction and Overview that follows read Chapter 1 of Vanclay, MoF's *"Guidelines for Developing Stand Density Management Regimes"*, and MoF's G&Y web pages.
You might also find useful *"Growth Modelling – a (Re)view"*: http://web.unbc.ca/~garcia/publ/view.pdf





Easy reading! (notice Amazon's *Reading level* rating).



Need to link actions to consequences.

BC Forestry

- Prospects
  - Expansion is over, structural changes
  - Transition old-growth → second growth
  - MPB
  - Log sizes, species mix
  - Pulp & paper: residues →roundwood
  - Changes in logging, silviculture, G&Y needs

See http://forestgrowth.unbc.ca/background.pdf

Why??!

- Rational decision-making

Situation → Model → Consequences
Actions → Model

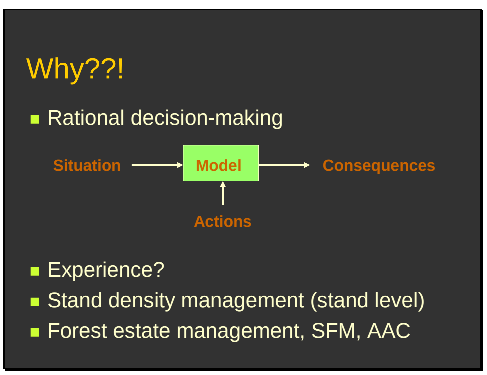
- Experience?
- Stand density management (stand level)

See MoF's *"Guidelines for Developing Stand Density Management Regimes"*.

Lodgepole pine, thinned and pruned (left), control (right).

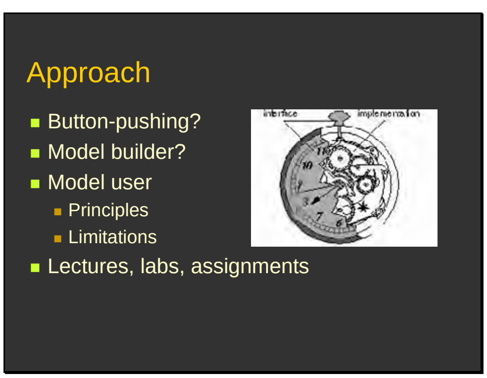
Aspen, thinned in foreground.

"Fred's Forest" demo, from BC MOF website. Note the decision variables.



Experience (trial-and-error) less useful in forestry than in other fields.

Modelling more important than in agriculture, for instance. Direct use of experiments costly or impractical.



Limited usefulness in learning to use current models: subject to change.

Not appropriate here to go into model development. Specialized subject.

Intelligent use: general understanding, fundamentals, and caveats.

Models

- A (partial) representation
  - Mental
  - Material
  - Verbal
  - Mathematical
  - Computer?
- Forest stand models. Growth {& yield} models

Used all the time. E.g., mental pictures.

Realism not a virtue. E.g., colour, pilot name, interior, not relevant in an airplane scale model for wind tunnel testing (material model).

VCR manual, example of verbal model. Empirical, predictive (no internal workings, effect of pressing button).

Mathematical language: shorthand. Advantages: a) Conciseness, les ambiguity. b) Pre-packaged arguments (rules, theorems), no need to reason from scratch every time.

“Computer models” usually implementation of a mathematical model by a computer program (simulator). Straight from ideas to computer code not advisable. There may be several computer implementations of a same model, or one program that runs several models: model ≠ simulator.

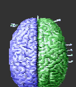
Stand (BC “polygon”) = patch of forest considered as homogeneous for a specific purpose.

An engineer thinks that his equations are an approximation to reality.

A physicist thinks reality is an approximation to his equations.

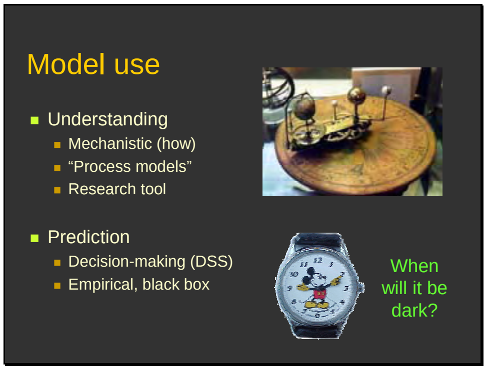
A mathematician doesn’t care.

Anonymous



All models are wrong, but some are useful.

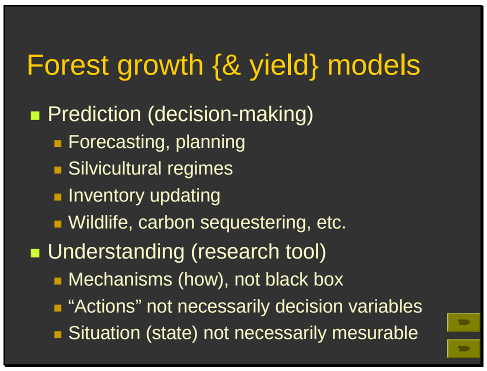
G. E. P. Box



"Models for understanding": Describe and put together current knowledge, identify gaps, test hypotheses. Mechanistic, "process models". For research. Benefits come mostly from building the model.

"Models for prediction": For decision making (decision support systems). Can be empirical, must match observation and produce good future projections.

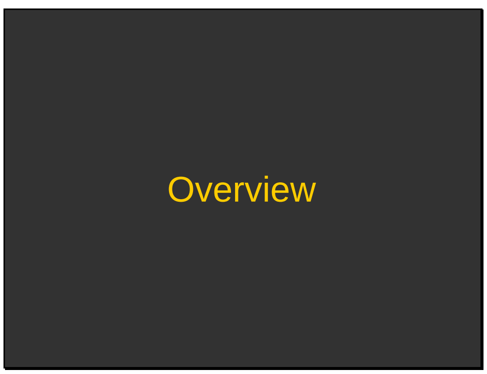
Overlaps.



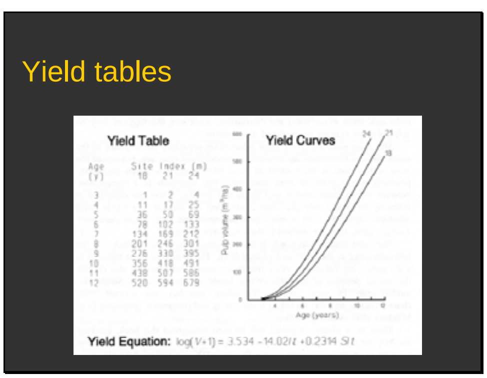
“G&Y” somewhat redundant, closely related.

Long-term forecasting for planning at forest, regional and national levels, e.g. timber supply, AAC. Stand-level evaluation of silvicultural prescriptions (initial density, thinning, pruning, rotation age, etc.). Estimating current condition from last measurements.

Examples of research models (plant architecture) taken from http://algorithmicbotany.org/vmm-deluxe/Section-08.html.



Big picture. Details later.

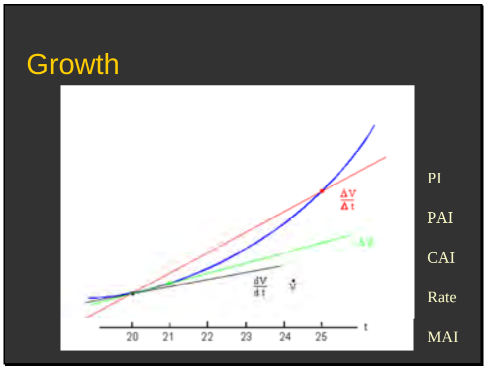


Yield tables (or curves, functions) oldest (late 1700's) and simplest. Good enough in many situations (e.g. VDYP for AAC in BC)

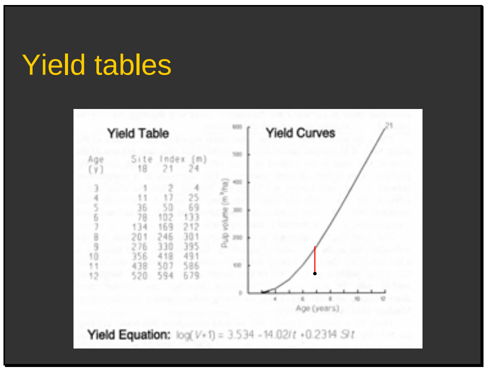
Even-aged stands.

Volume ("yield") and usually mean dbh, height, trees per hectare, etc., over age. For various site qualities.

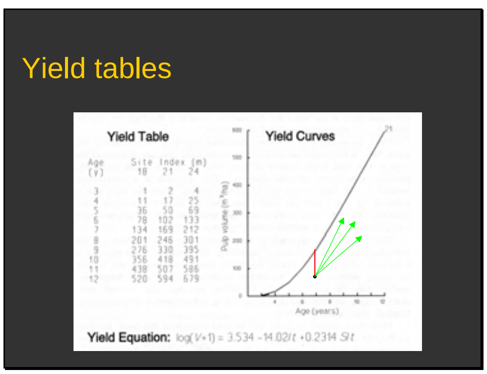
From cross-sectional data: point (or short interval) observations from many stands at various ages, no need to wait full rotation.



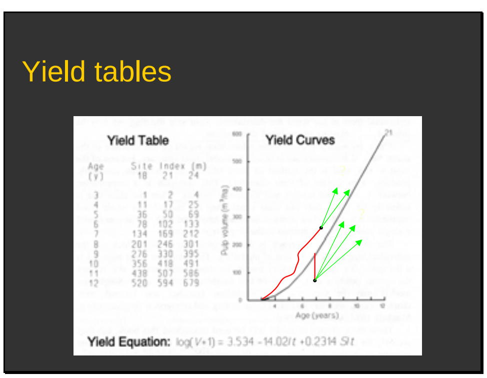
Growth = change in size
Periodic (PAI), annual (CAI), "instantaneous"
Growth rate = slope
Change in other variables, not necessarily “growth”, also important. E.g., trees per hectare (“mortality”).
Mean annual increment (MAI) is the average growth from 0 up to a given age, i.e., MAI = V/t
See the interactive MAI demo in the website.
Some ambiguity in notation: ΔV may mean $V(t+1) - V(t)$, or $V(t+\Delta t) - V(t)$.



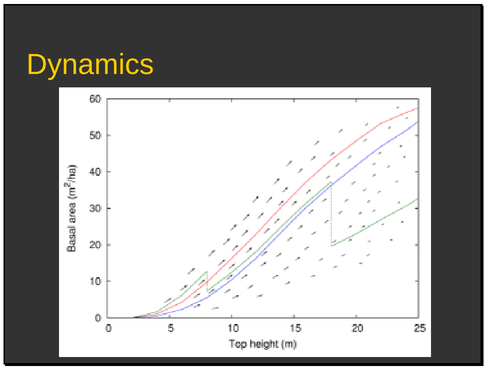
Run into trouble if we deviate from the predicted trend. E.g. through a thinning.



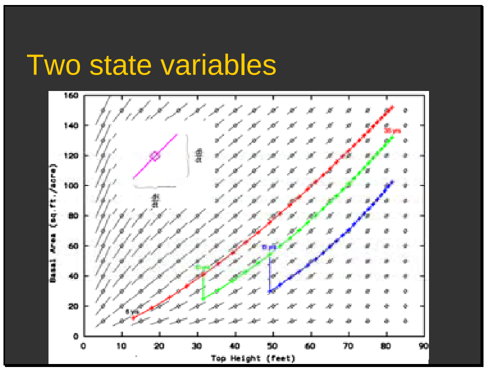
Which way?



Even without treatments, stand may deviate from predictions due to weather, etc.
How to predict future of an existing stand?
Various adjustments and modifications have been proposed.
Better (when the yield tables are not sufficient) is to think in terms of growth rates, instead of the accumulated yield.

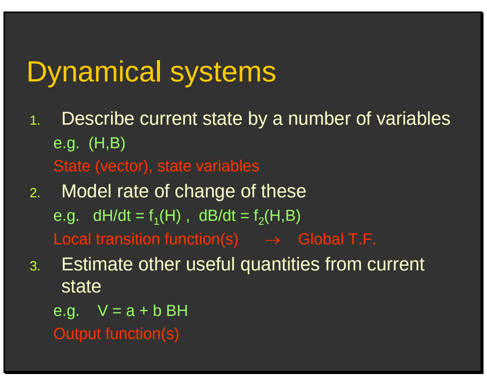


Growth rates associated to any point (state). They generate trajectories.
Think of fluid flow and streamlines.



Based on Clutter's 1963 model (Vanclay, p.28).

PSP data, with thinnings (purple lines)
Axes: blue = top height, green= basal area, red = average spacing
See the VRML dynamic graphics demo in the website (VRML viewer required).



General, for any system evolving in time.
More generally, rate functions can also include (continuous) inputs. Inputs such as temperature and precipitation often used in research (process) models, rarely in forest management decision-support stand models.

Vectors

- (H, B) = $\mathbf{x}$
  $\mathbf{x} = (x_1, x_2, \ldots, x_n)$
- V = a + b BH = f (B, H)
  = f ($\mathbf{x}$)
- $\Delta H = f_1(H)$
  $\Delta B = f_2(B, H)$ → $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x})$

Shorthand.

Dynamical Systems

state input

$d\mathbf{x}/dt = \mathbf{f}(\mathbf{x}, \mathbf{u})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x}, \mathbf{u})$

(continuous or discrete time)

- E.g., stand:
  $\mathbf{x}$ = (H, B, N) , $\mathbf{u}$ null or weather
- E.g. tree:
  $\mathbf{x}$ = dbh, $\mathbf{u}$ = “growing space”
- E.g. forest estate model:
  $\mathbf{x} = \{s_{ki}\}$, s_{ki} = area in forest type k, age class i

Dynamical Systems

state input

$d\mathbf{x}/dt = \mathbf{f}(\mathbf{x}, \mathbf{u})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x}, \mathbf{u})$

(continuous or discrete time)

- E.g., Physics: $\mathbf{x} = (x, y, z, v_x, v_y, v_z)$
  v_x = velocity = dx/dt
  Newton: F = ma, a = acceleration = dv/dt
  Therefore,
  $dx/dt = v_x$
  ...
  $dv_x/dt = F_x/a$
  ...

Dynamical Systems

Local transition function:

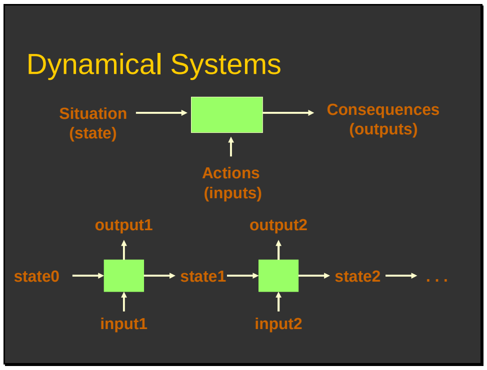
$d\mathbf{x}/dt = \mathbf{f}(\mathbf{x})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x})$ (no input, for simplicity)

Integration ↓ or iteration $\mathbf{x}(t+\Delta) = \mathbf{x}(t) + \mathbf{f}(\mathbf{x}(t))$

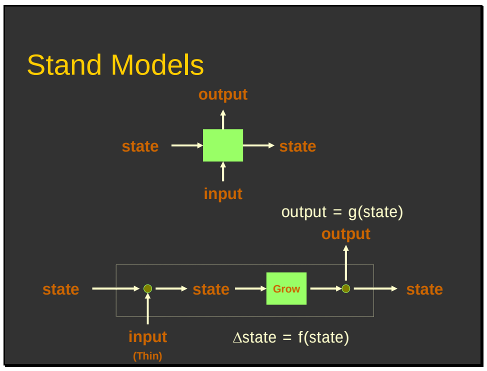
Global transition function:

$\mathbf{x}_1 = \mathbf{F}(\mathbf{x}_0, t_1 - t_0)$

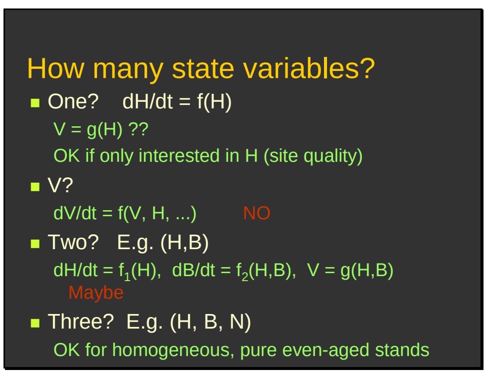
This article might or might not help to understand the state-space approach: http://web.unbc.ca/~garcia/publ/time-p.pdf



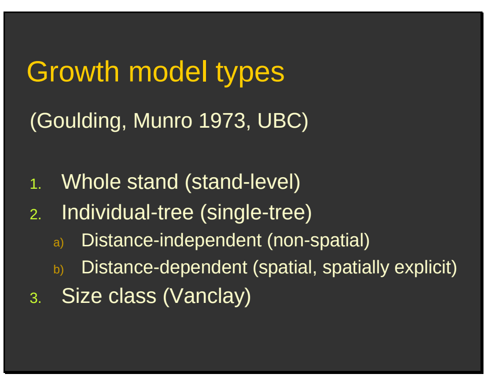
Break-up into time intervals.



Growth models can be simpler:
Inputs are usually point actions, instantaneous changes, rather than continuous time functions.
Outputs functions of current state.
“Guts” of the model just needs to describe change of state (transition).



State detail must be sufficient for:
a) Estimating rates
b) Estimating outputs of interest



Growth model types

- Continuous $d\mathbf{x}/dt$
- Discrete $\Delta\mathbf{x}$, $\mathbf{x}(t+\Delta)$

- Deterministic $\mathbf{f}(\mathbf{x}$, known $\mathbf{u})$
- Stochastic $\mathbf{f}(\mathbf{x}$, random $\mathbf{u})$

Data

- PSP, stem analysis
- Estimation
- Validation, implementation, etc.

Program

- Site
- Yield tables
- Distance dependent
- Distance independent
- Whole stand
- Data, etc.