SIMULATION OPTIMIZATION LAB

OPTIFOR FOREST RESEARCH

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汇报提纲 Contents

背景 Background

- 树木生理生态过程 Tree physiology
- 林分结构功能服务 Stand structure
- 社会生态经济系统 Soci-eco-econ-systems

理论 Theories

- 复杂度理论 The theory of complexity
- 重要度理论 The theory of importance
- 可靠度理论 The theory of reliability

方法 Methodologies

- 三阶段建模法 A three-stage modeling approach
- 平行仿真优化 Parallel simulation and optimization

复杂系统 Complex systems

Examples (Mitchell 2009)

- Biological systems
- Social systems
- Physical systems

Properties (Boccara 2004, Mitchell 2009)

- Heterogeneity, hierarchy, self-organization, openness, adaptation, memory, non-linearity, and uncertainty

Features (Wang and Kang 2012)

- Global behavior can not be deduced from that of their components;
- Global behavior can not be predicted in long term

复杂性科学 Science of complexity

- ❑ 系统工程 =〉 系统科学 =〉 复杂系统
- ❑ 从定量到定性的综合集成法 Meta synthesis
- ❑ Complexity: variables => structure/layers => flow

- Santa Fe Institute, SFI. 1984. Science of complexity.
- 钱学森, 于景元, 戴汝为 1990. 一个科学新领域--开放的复杂巨系统及其方法论. 自然杂志 13(1): 3-10.
- Filotas, E. Parrott, L., Burton, P.J. et al. 2014. Viewing forests through the lens of complex systems science. Ecosphere. Volume 5(1):1-23.

Social-Economic-Natural Ecosystems

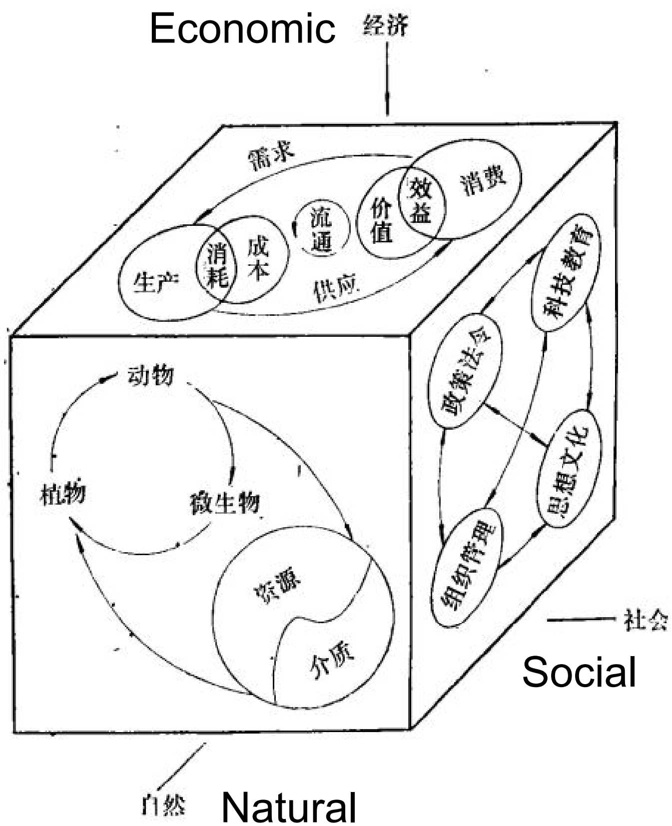
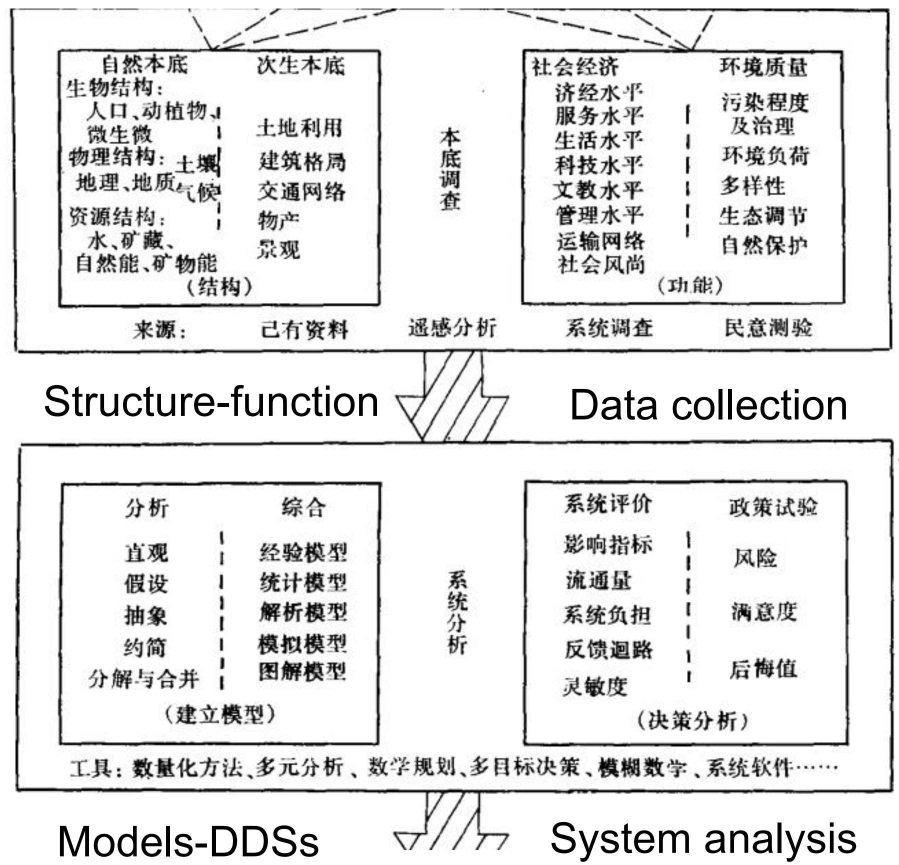


图 1　社会-经济-自然复合生态系统示意图



Source: 马世俊, 王如松 1984. 社会-经济-自然复合生态系统. 生态学报. 第4卷, 第1期. 1-9页.

Ecological & physiological processes

Production ecology

- GPP = resource supply
  *fraction of resource acquired
  *resource use efficiency

Nutrient,

- Availability, acquisition and NUE (Nutrient Use Efficiency)

Light,

- Availability, absorbtion, and LUE (Light Use Efficiency)

Water,

- Avialability, use, and WUE (Water Use Efficiency)

Structure-functional complexity

Forrester (2017)

- Changes in stand structure and APAR
- Changes in LUE and C partitioning
- The influence of stand density on WUE

Seidel et al. (2019)

- Tree-level vs. Stand-level structural complexity
- Tree architecture and forest structure
- Large-crowned, highly-complex tree individuals as key elements of stand structural complexity

森林复杂系统 Complex forest systems

Complex forest systems are characterized by

- (1) heterogeneity,
- (2) self-organization,
- (3) adaptation,
- (4) hierarchy,
- (5) non-linearity
- (6) openness,
- (7) memory,
- (8) uncertainty.

(1) Complexity

(2) Importance

(3) Reliability

Complexity scales and methodologies

Low complex 小系统

e.g. whole-stand models, 3-5 variables

- Dynamic programming
- Model linkages

Medium complex 大系统

e.g. process models, 30-50 variables

- Non-linear programming
- Bayesian networks

High complex 巨系统

e.g. transportation systems, 1000-10000+ variables

- ACP methodology
- Complex ecological networks

Applications of Bayesian networks

Aspen regeneration

- Hass TC, 1991. A Bayesian belief network advisory system for aspen regeneration. Forest Science, 37(2):627-654.
- Hass TC, Mowrer HT, Shepped WD,1994. Modeling aspen stand growth with a temporal Bayes network. AI Applications, 8(1):15-28.

District ranger decision making

- Hass TC, 1992. A Bayesian network of district ranger decision making. AI Applications, 6(3):72-88.

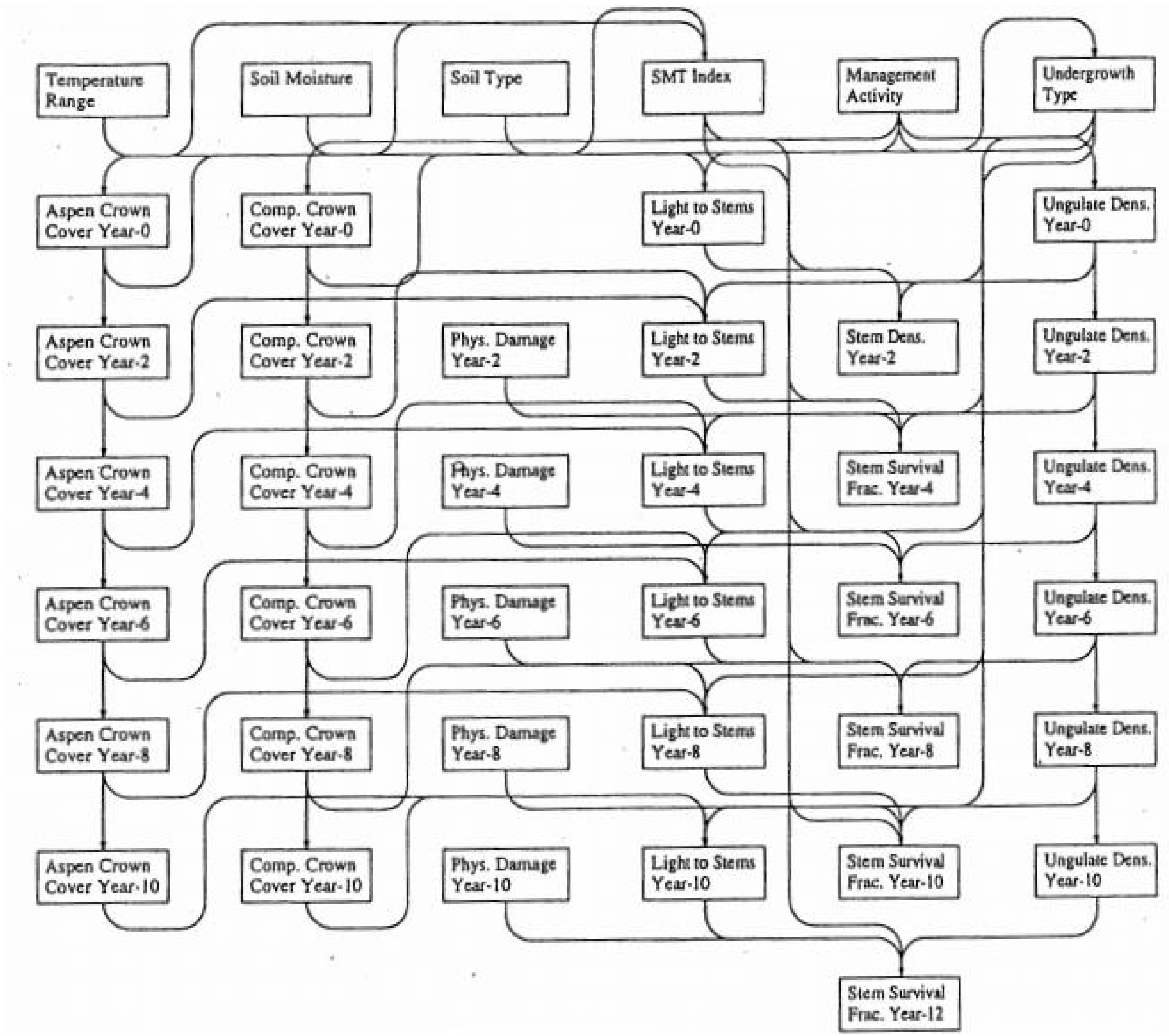
Regeneration with a Bayes network

Nontemporal variables (unaffected by time)

- Temperature Range,
- Soil Moisture, Soil Type, SMT Index,
- Management Activity,
- Undergrowth Type, and Year-2 Stem Density.

Temporal variables (time dependent)

- Crown cover, CCC, light availability, and ungulate density at time t, 0-12 yrs.
- Snow, wind damage, insect attacks, and disease at t, 2-12 yrs.
- The fraction of stem survives the time period for t, 4-12 yrs.



Temperature Range
Soil Moisture
Soil Type
SMT Index
Management Activity
Undergrowth Type
Aspen Crown Cover Year-0
Comp. Crown Cover Year-0
Light to Stems Year-0
Ungulate Dens. Year-0
Aspen Crown Cover Year-2
Comp. Crown Cover Year-2
Phys. Damage Year-2
Light to Stems Year-2
Stem Dens. Year-2
Ungulate Dens. Year-2
Aspen Crown Cover Year-4
Comp. Crown Cover Year-4
Phys. Damage Year-4
Light to Stems Year-4
Stem Survival Frac. Year-4
Ungulate Dens. Year-4
Aspen Crown Cover Year-6
Comp. Crown Cover Year-6
Phys. Damage Year-6
Light to Stems Year-6
Stem Survival Frac. Year-6
Ungulate Dens. Year-6
Aspen Crown Cover Year-8
Comp. Crown Cover Year-8
Phys. Damage Year-8
Light to Stems Year-8
Stem Survival Frac. Year-8
Ungulate Dens. Year-8
Aspen Crown Cover Year-10
Comp. Crown Cover Year-10
Phys. Damage Year-10
Light to Stems Year-10
Stem Survival Frac. Year-10
Ungulate Dens. Year-10
Stem Survival Frac. Year-12

Empirical parameters

Hynynen et al. (2002)

- Routine inventory data
- Updating empirical growth models

模型校正步骤如下：

(1) 计算Bias=ln(H)-ln(H*),

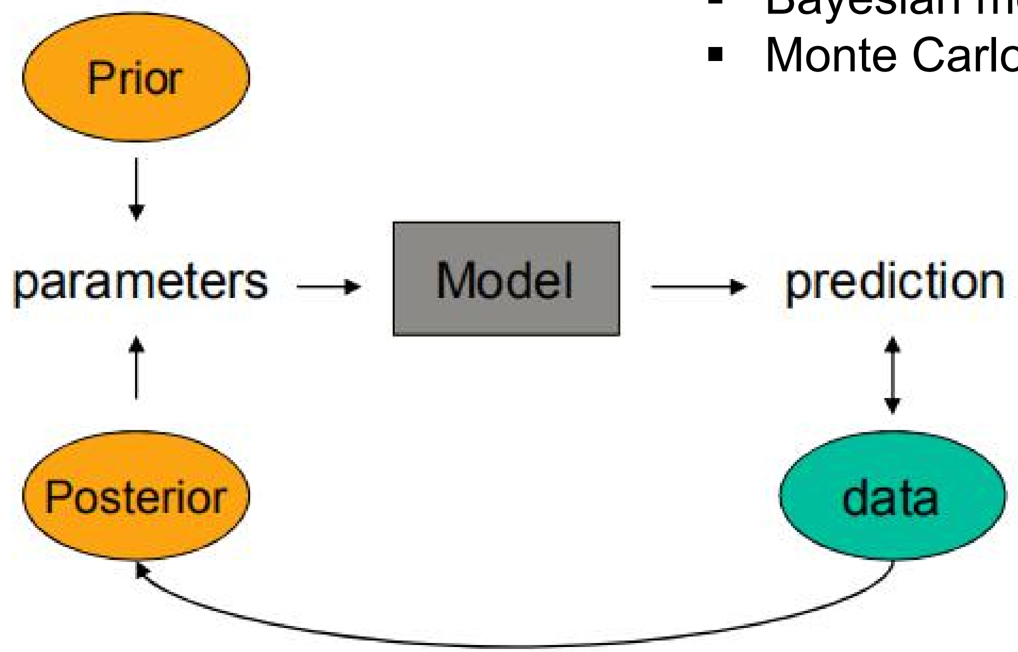
(2) 计算H*(cal)=exp(ln(H*)+Bias*)，

(3) 计算校正后树高H(cal)=Cratio*H^exp(Bias*)，

where Cratio=H(obs)_mean/H(cal)

Process parameters (Mäkelä 2011)

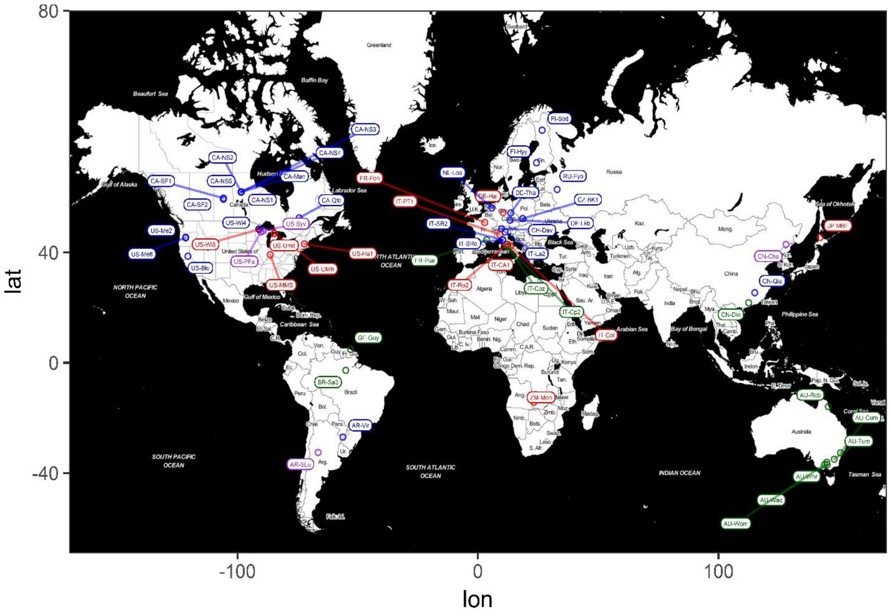
- Calibration
- Bayesian method
- Monte Carlo simulation



Data for calibrating the PRELES model

Eddy covariance data (55 sites)

- DBF(13)
- EBF(12)
- ENF(26)
- MF(4)

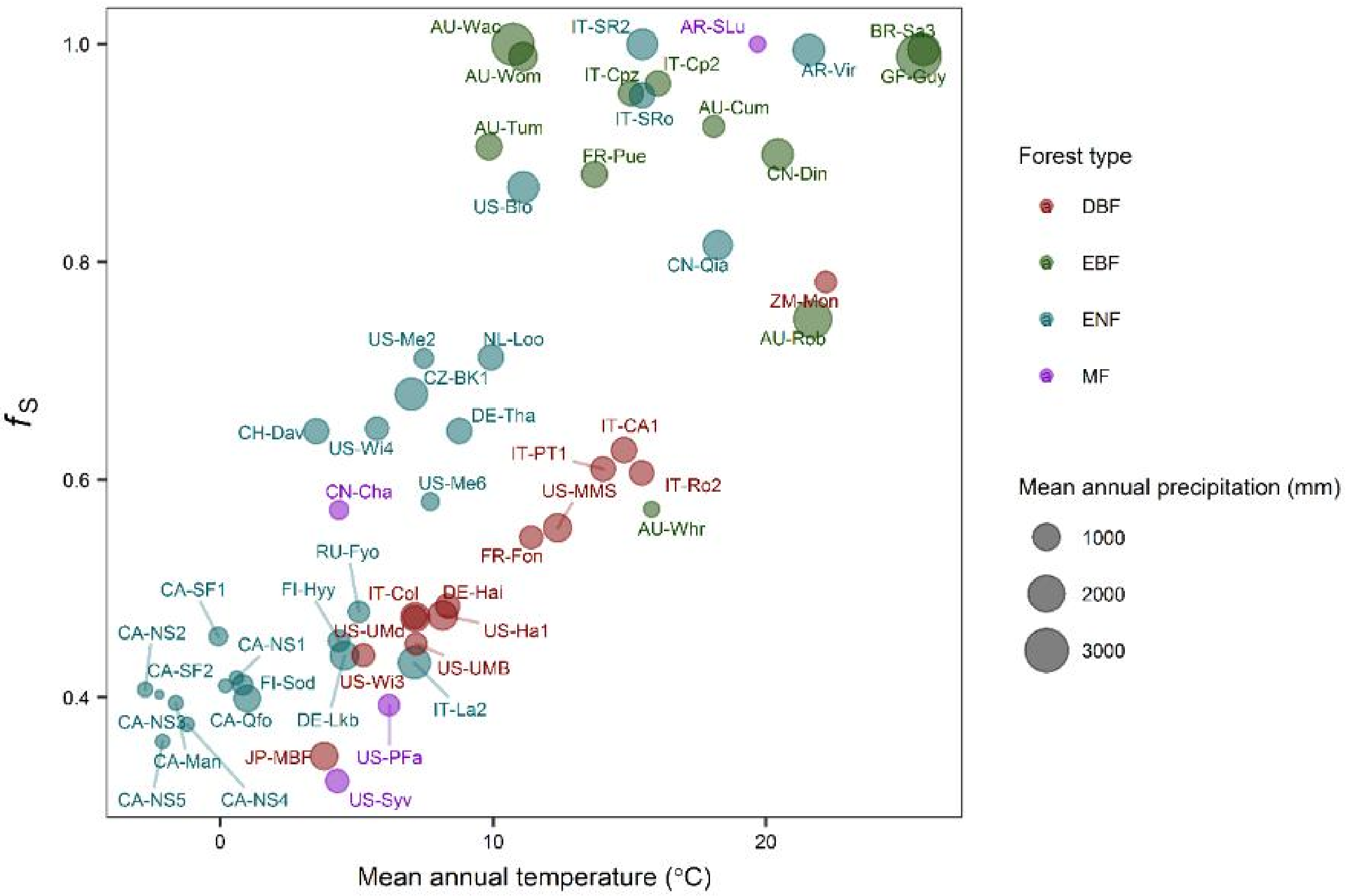


MODIS fAPAR data

MODIS Collection 6
Official Name: MOD15A2H
Platform: Terra
Spatial Resolution: 500m
Temporal Granularity: 8 Day

MODIS Collection 5
Official Name: MOD15A2
Platform: Terra
Spatial Resolution: 1000m
Temporal Granularity: 8 Day

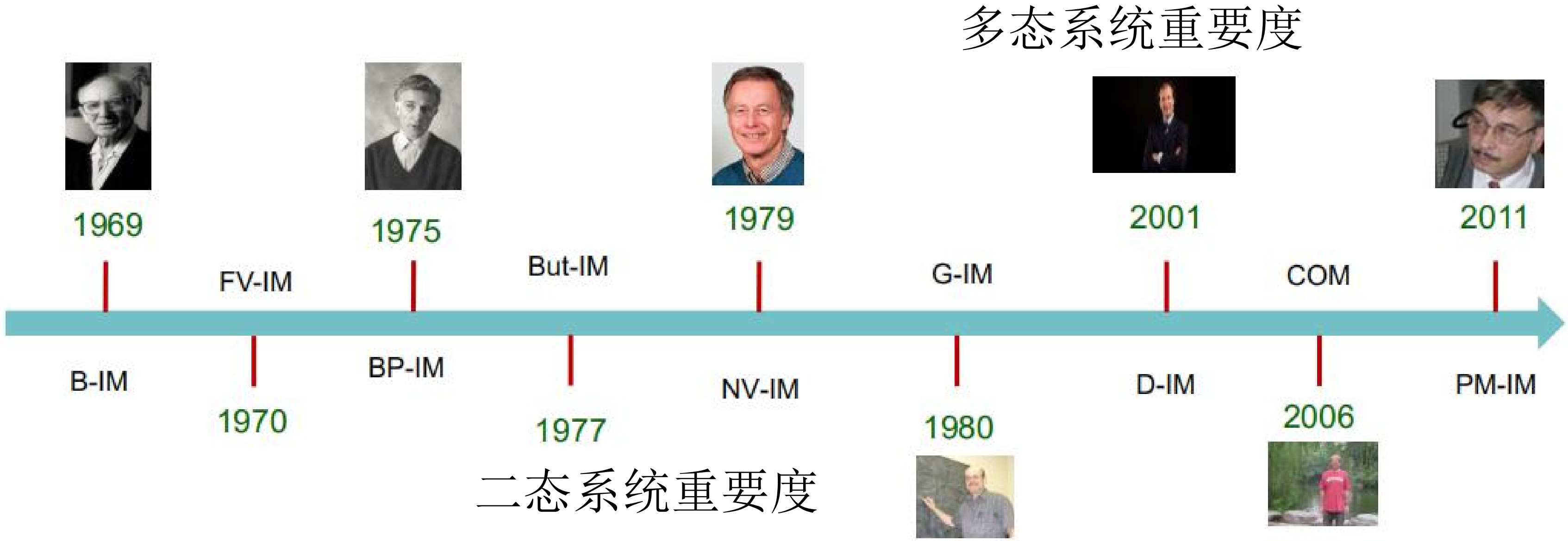
Temp. accli. modifier (Tian et al. 2019)



The theory of importance (Si 2015)

$$I_i^{IIM}(t) = -\frac{\partial R_S \quad t}{\partial R_i \quad t} * \frac{dR_i \quad t}{dt}, \quad I_{i\to k}^{IIM}(t) = \sum_{i=1}^{k} -\frac{\partial R_S \quad t}{\partial R_i \quad t} * \frac{dR_i \quad t}{dt}$$

$$I_m^{IIM}(i) = P_{im} * \lambda_{m,0}^{i} \sum_{j=1}^{M} a_j \left[P(\Phi(m_i, X) = j) - P(\Phi(0_i, X) = j) \right]$$



The theory of importance, con't

- 重要度研究的数学基础：偏微分
- 重要度研究是系统优化，灵敏度分析，可靠性设计，风险分析，及资源配置的主要数学工具
- 重要度：
  - 结构重要度，
  - 概率重要度，
  - 周期重要度
- 综合重要度：(Si et al. 2014. SAS软件研究所采用)
  - 系统单元对时间的导数=>时间对系统可靠性的影响
  - 随机过程与重要度结合=>时间累积和过程变化对系统可靠性的影响

Sensitivity analysis

- *p* input parameter
- *Y* output

How do small changes in input propagate to results?

- Sensitivity S = $\partial Y/\partial p$

What is the relative importance of different components?

- Relative sensity S_R = $\partial Y/\partial p * p/Y$

Calculating complex dynamic models

- *p,* input parameter
- *Y,* output
- Δp , a very small change
- S(t), sensitivity function

$$S(t) = \partial Y(t,p)/\partial p \approx (Y(t,p+\Delta p) - Y(t,p)) / \Delta p$$

Uncertainty problem

- p, input parameter
- Y, output
- Δp , error/uncertainty in p

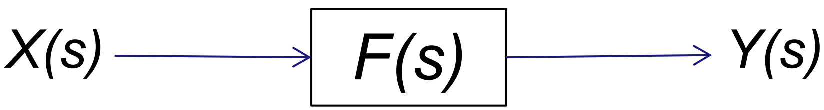
Uncertainty $U = \partial Y/\partial p * \Delta p$

- Total uncertainty is additive
- How does uncertainty/error in input information propagate to results?
- What is the significance of different sources of error/uncertainty?

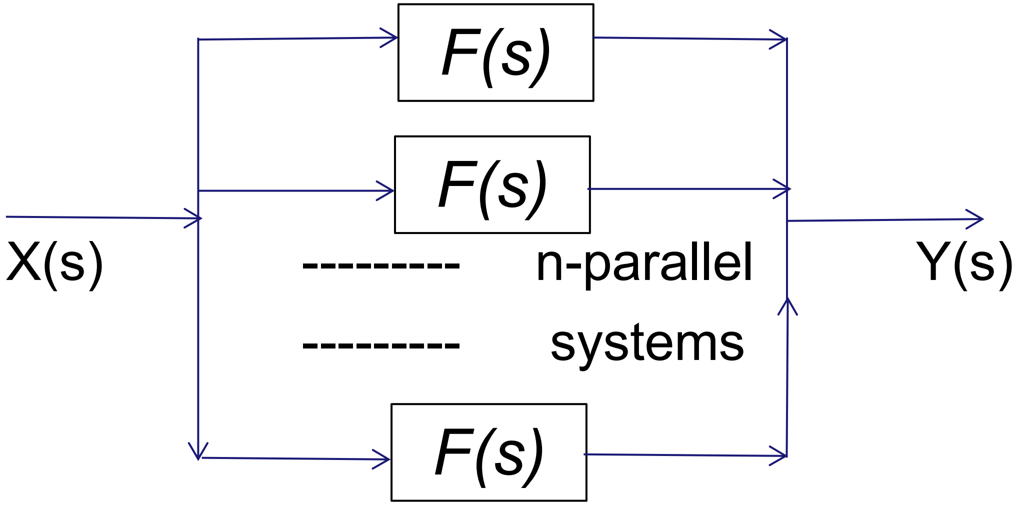
Stochastic processes 随机过程

- 泊松过程
  - 单一变量 λ 决定了某一时间内事件的发生率
- 更新过程
  - 事件间隔是独立的且为同分布随机变量
- 交替更新过程
  - 事件时间在两分布中不断交替变换
- 非齐次泊松过程
  - 事件发生时间为非稳态序列
- 连续时间马尔科夫链
  - 通过时间区间 (0,S] 上的转置，生成服从指数分布的事件时间 T 以及为离散值的过程状态X(t)

The theory of reliability



■ a simple system 开环串联系统



■ n-parallel systems 闭环并联系统

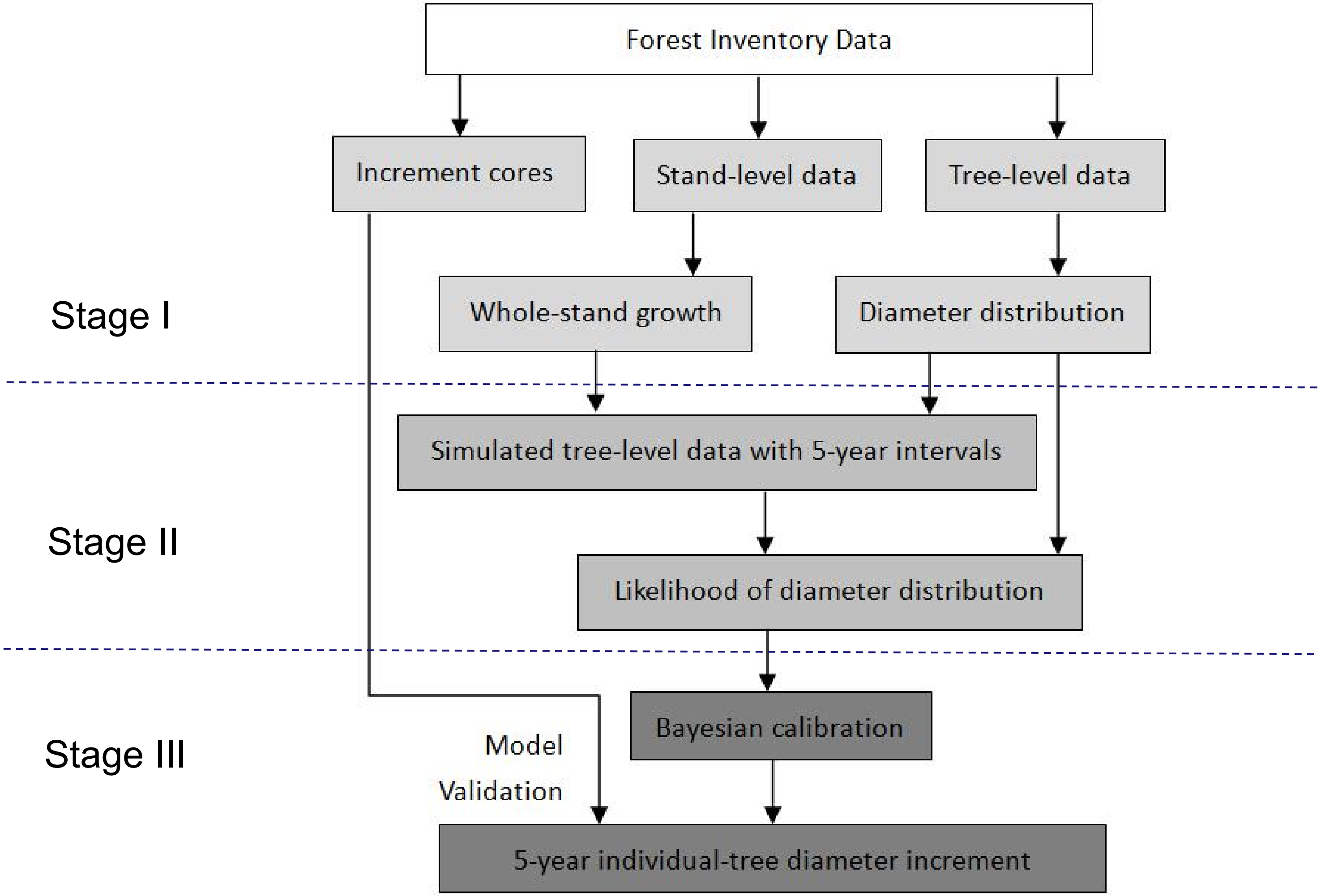
Control of error

- 钱学森 1954. 工程控制论. 麦格劳希尔出版公司. USA

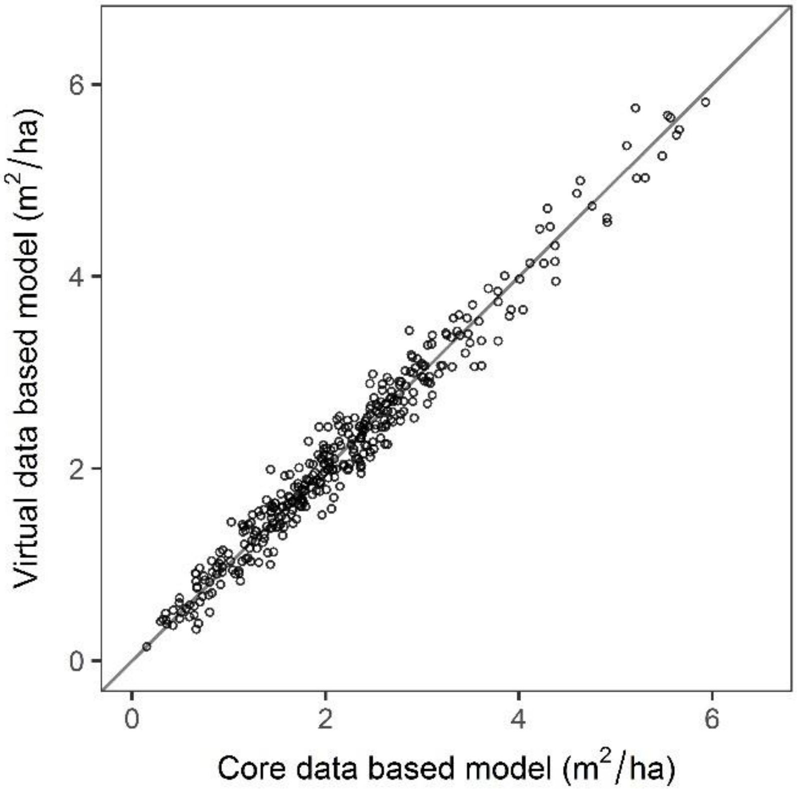
- Reliability by duplication
- Method of multiplexing
- Error in executive component
- Error of multiplexing systems

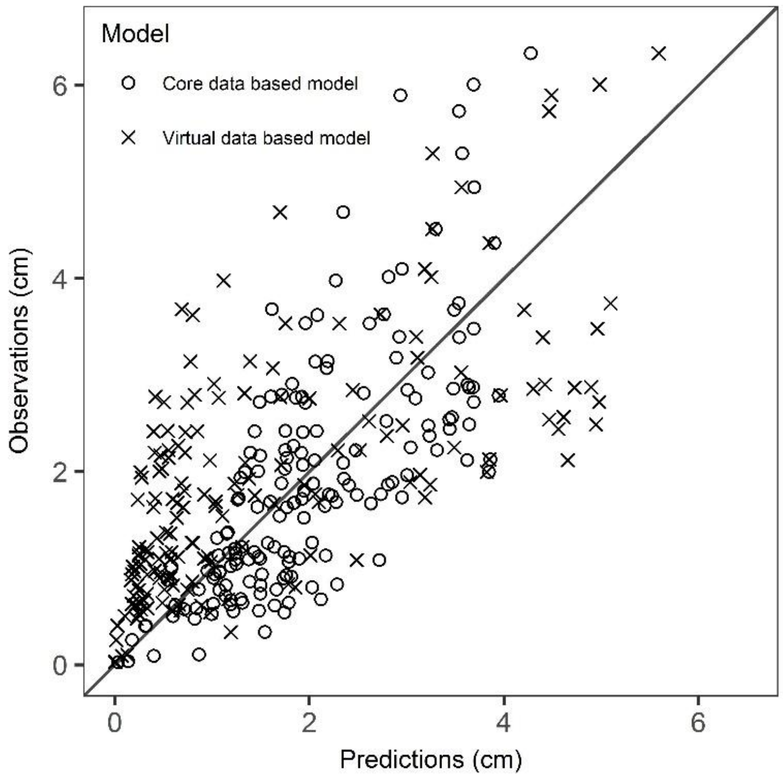
“This particular method of synthesizing a reliable system out of unreliable elements is called the method of multiplexing by von Neumann.” -- 钱学森 Hsue-shen Tsien

三阶段建模法 (Tian & Cao 2019)



Simulated Δd (Tian & Cao 2019)



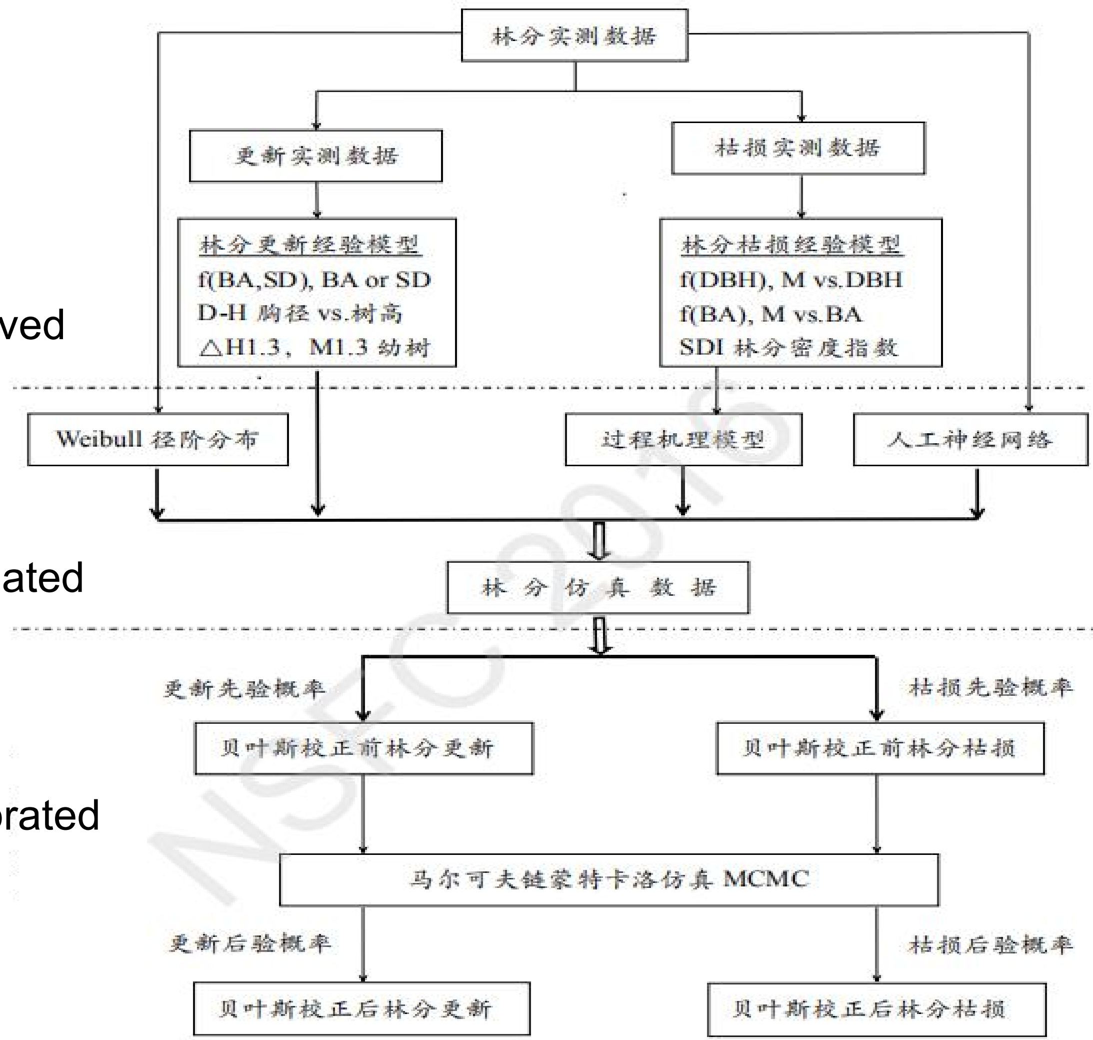


Modeling regeneration and mortality

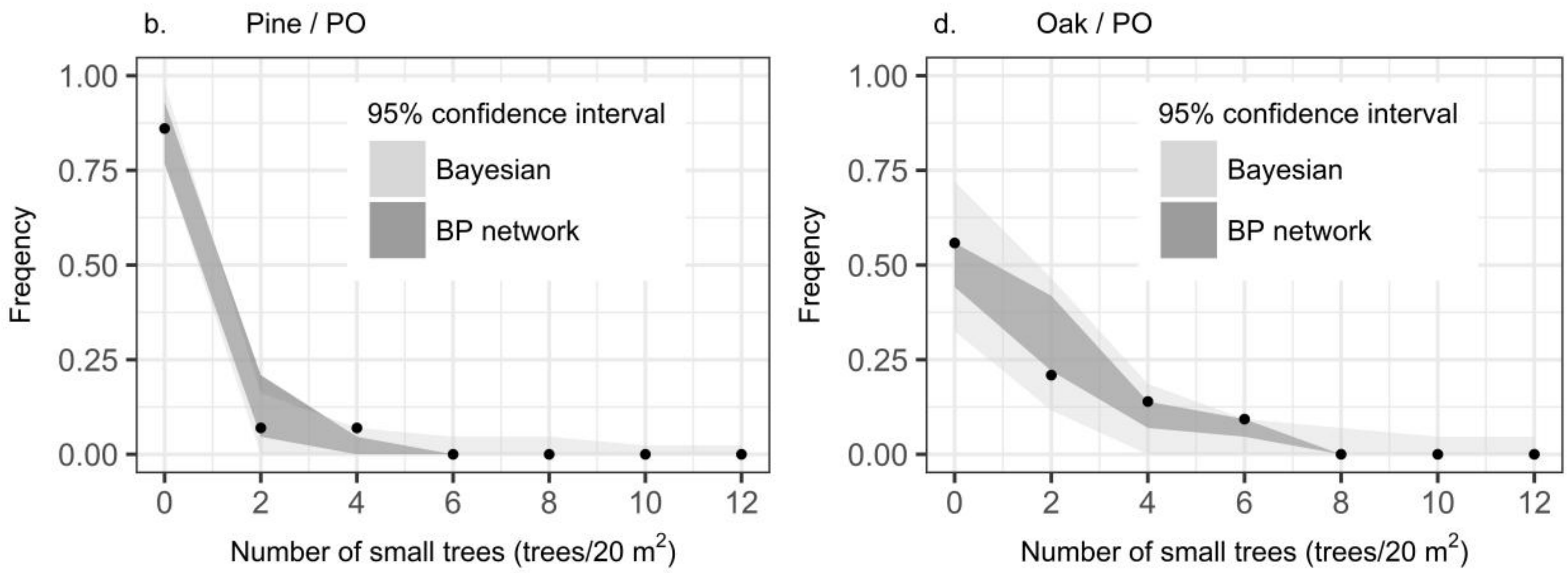
Stage I: observed

Stage II: simulated

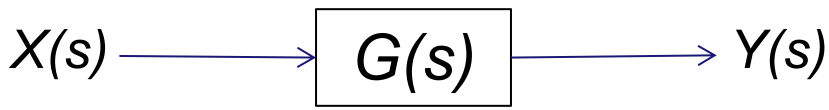
Stage III: calibrated



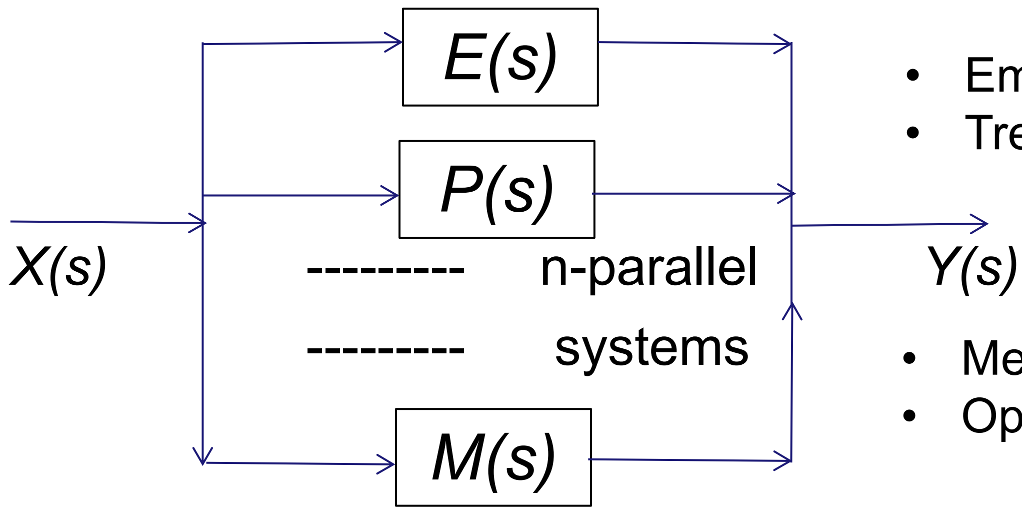
Simulated regener. (Wang & Cao 2019)



Parallel forest simulation systems



- traditional open-loop systems 开环林分生长模型



- Empirical / Process
- Tree- / Stand-level

- Measurement
- Optimal control

- n-parallel simulation systems 闭环林分平行仿真系统

ACP Methodology (王飞跃等 2012)

人工系统 **A**rtificial systems

- simulation/mathematical models describing the main features of real world;
- Calibration of the artificial systems the to the real ones;

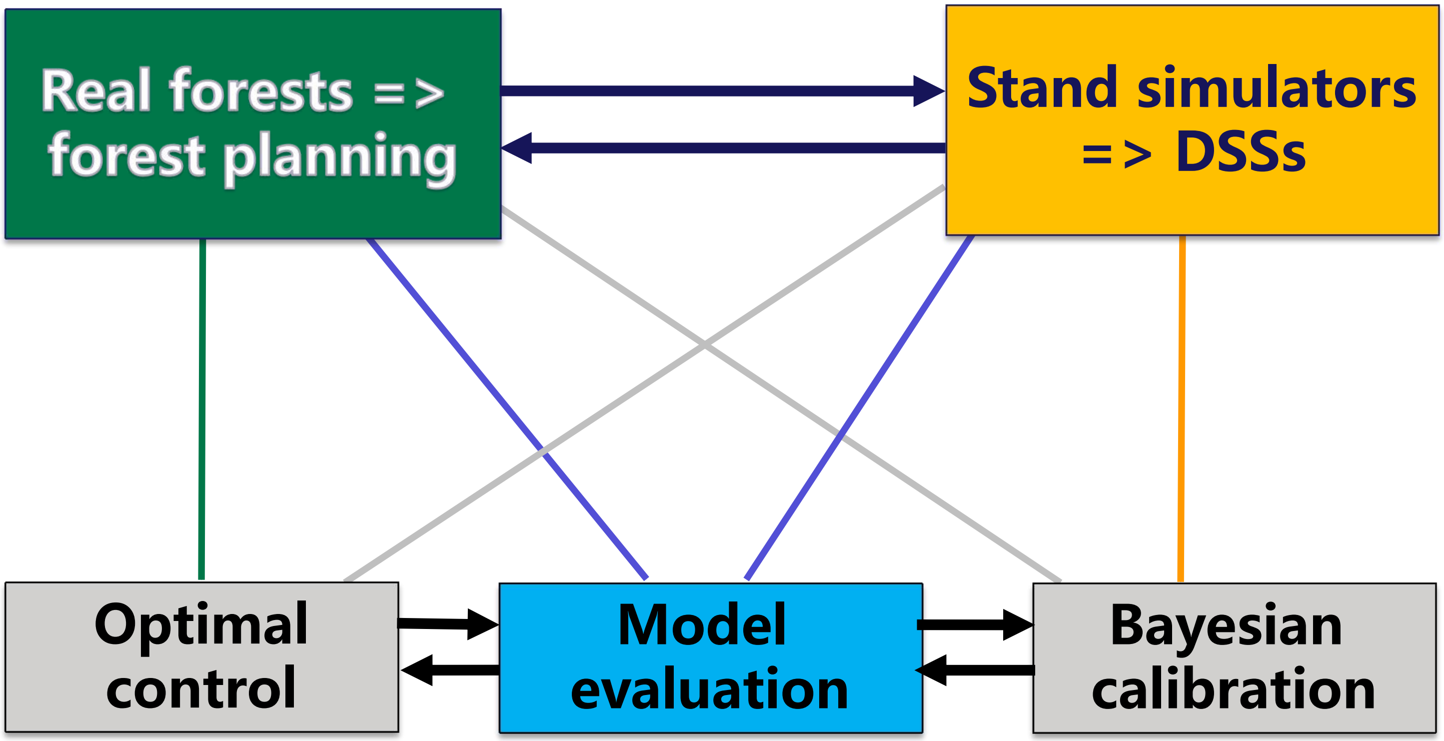
计算实验 **C**omputational experiments

- Test on the artificial/virtual systems;

平行执行 **P**arallel execution

- Management and control of real systems by referring to the virtual ones

Dual closed-loop forest systems



Modified from Wang and Kang (2012)

References 参考文献

- Bazaraa, M.S., Sherali, H.D. & Shetty, C.M. 1993. Nonlinear Programming: Theory and Algorithms. 2nd Edition. John Wiley & Sons, Inc.
- Boccara, N. 2010. Modeling Complex Systems. 2nd Edition. Springer. New York.
- Law, A.M. 2007. Simulation Modeling and Analysis. 4th Edition. The McGraw-Hill Companies, Inc. 北京: 清华大学出版社, 2009.9
- Pretzsch, H., Forrester, D.I. & Bauhus, J. 2017. Mixed-Species Forests: Ecology and Management. Springer-Verlag GmbH Germany.
- Tsien, H.S., 1954. Engineering Cybernetics. McGraw Hill Book company Inc. New York.
- 张连文, 郭海鹏, 2006. 贝叶斯网引论. 北京. 科学出版社.

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