WORKSHOP
System Dynamics Modeling in Epidemiology

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Welcome and Workshop Overview

- 3 hours, 1 ice breaker, 4 hands-on exercises, some didactics, 1 short break, short post-workshop evaluation
- Handouts
  - Agenda
  - GitHub repository with instructions for downloading all conference materials
  - Stella Architect® software download instructions
  - *Words Commonly Used in SDM* (Quick Reference)
  - *Causal Loop Diagramming* | *Model Conceptualization Exercise*
  - Post-workshop evaluation form
- GitHub repository:

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Learning Objectives

1. Understanding systems theory and the potential utility of SDM for research and action in epidemiology
2. Applying basic concepts of systems thinking: Drawing ‘balancing’ and ‘reinforcing’ loops
3. Creating, running and evaluating simple system dynamics models.

By the end of the workshop, participants will appreciate how system dynamics modeling is a novel, ‘mixed methods’ research methodology well-suited to understanding and addressing diverse, complex problems in epidemiology, public health, and medicine.

My Professional Research Foci: Three Aims

1. Participatory action research to develop and sustain high quality community-based systems of care
2. Capacity-building to reduce global health disparities, with a focus on reducing cancer burden
3. Applying systems thinking and system dynamics modeling to address complex health care problems

<u>Modeling projects</u>: HIV prevention and care, diabetes self-care, cancer screening policies, mental health services, school wellness programming, family planning and maternal health

What’s your problem?

ICE BREAKER

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Systems Theory

Hallmark

- Identifying feedback structures (‘cybernetics’)
- Understanding how things change (‘causality’)

General assumption

- Problems in natural and human systems have dynamic complexity
- Natural and human systems are ‘goal-seeking’ (i.e., gravitate towards a dynamic equilibrium; a state of homeostasis, sustainability, balance, stability)

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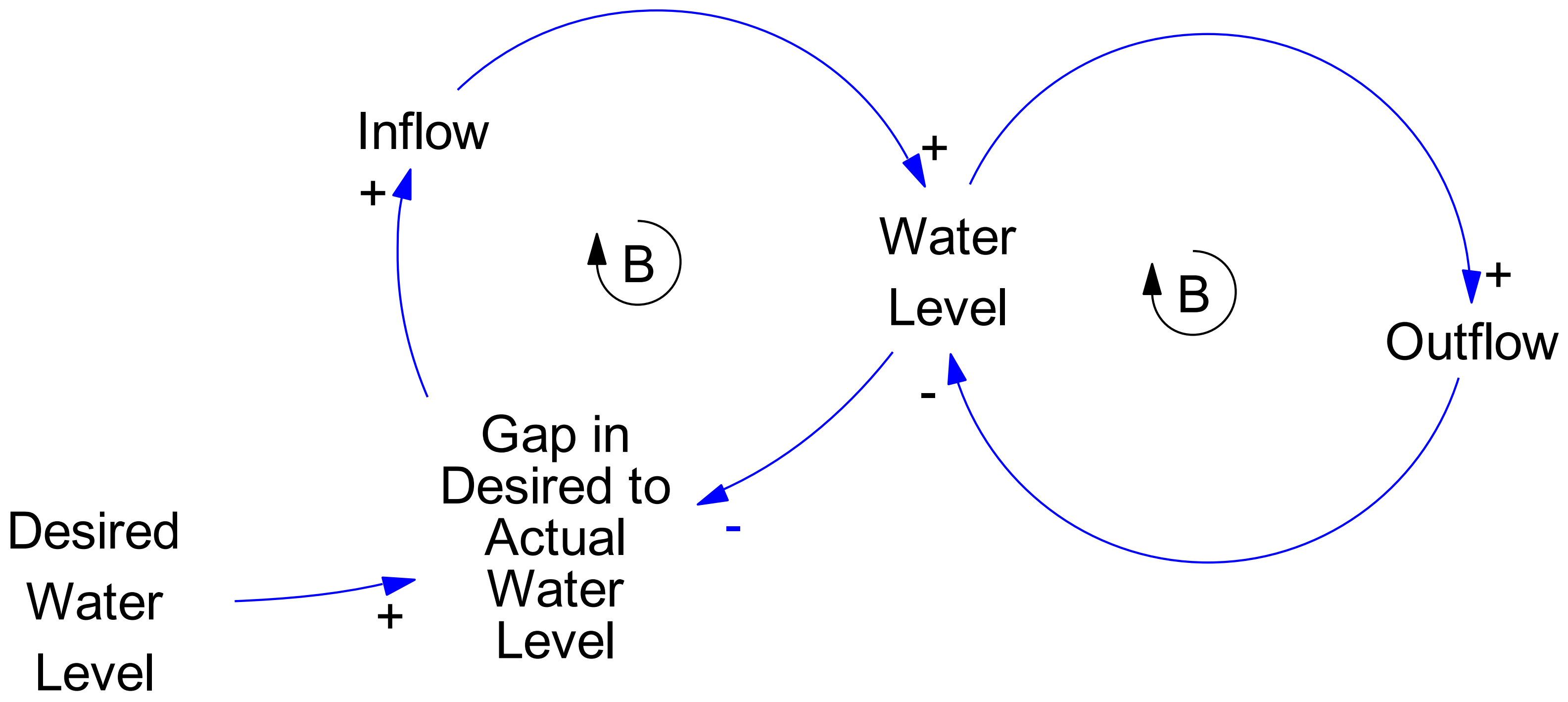
Systems Theory: Feedback Concepts from Engineering

- Engineers characterize two kinds of feedback loops: ‘reinforcing’ and ‘balancing’
- <u>Reinforcing feedback loop</u>: Characteristically tends to amplify a change in any one of its elements <u>over time</u>.
  - Moving away from equilibrium
  - Instability
- <u>Balancing feedback loop</u>: Adjusts to counteract a change in any one of its elements <u>over time</u>.
  - Coming to equilibrium
  - A steady state: Homeostasis

Basic Concepts is SDM:
Causal Loop Diagram (CLD)



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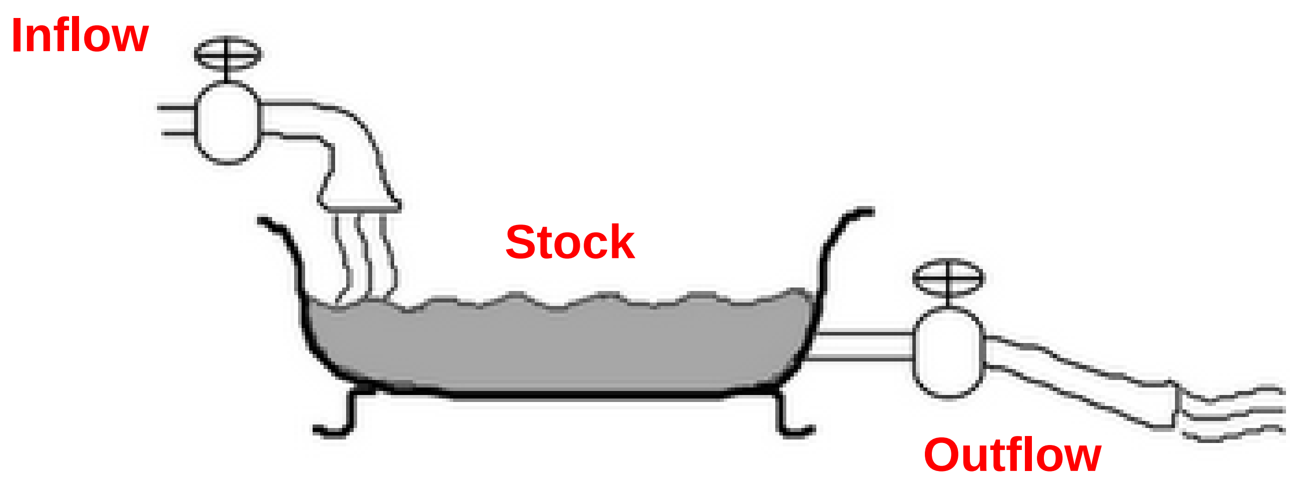
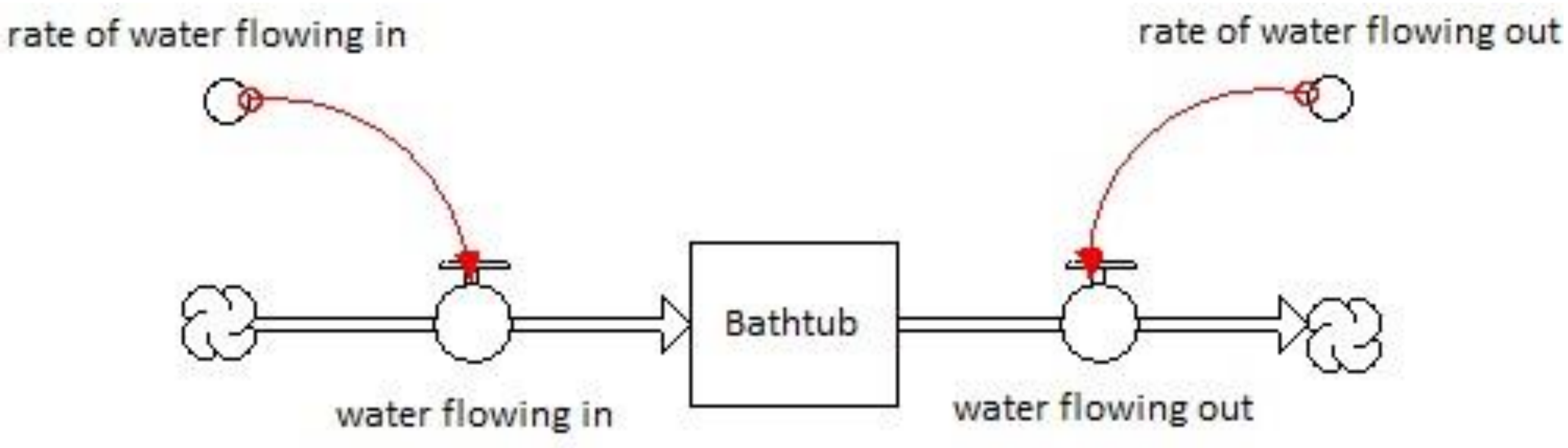
Basic Concepts in SDM: Stocks and Flows

Stock: Accumulation of units, e.g., liters of water in a tub

Flow: Movement of units into, out of, and between stocks



Another Way to Diagram Stocks and Flows



$$\frac{d\,(\text{Stock})}{dt} = \text{Inflow}(t) - \text{Outflow}(t)$$

[Link to demo]

FLOW: Rate of change (derivative)

STOCK: Accumulation over time (integral)

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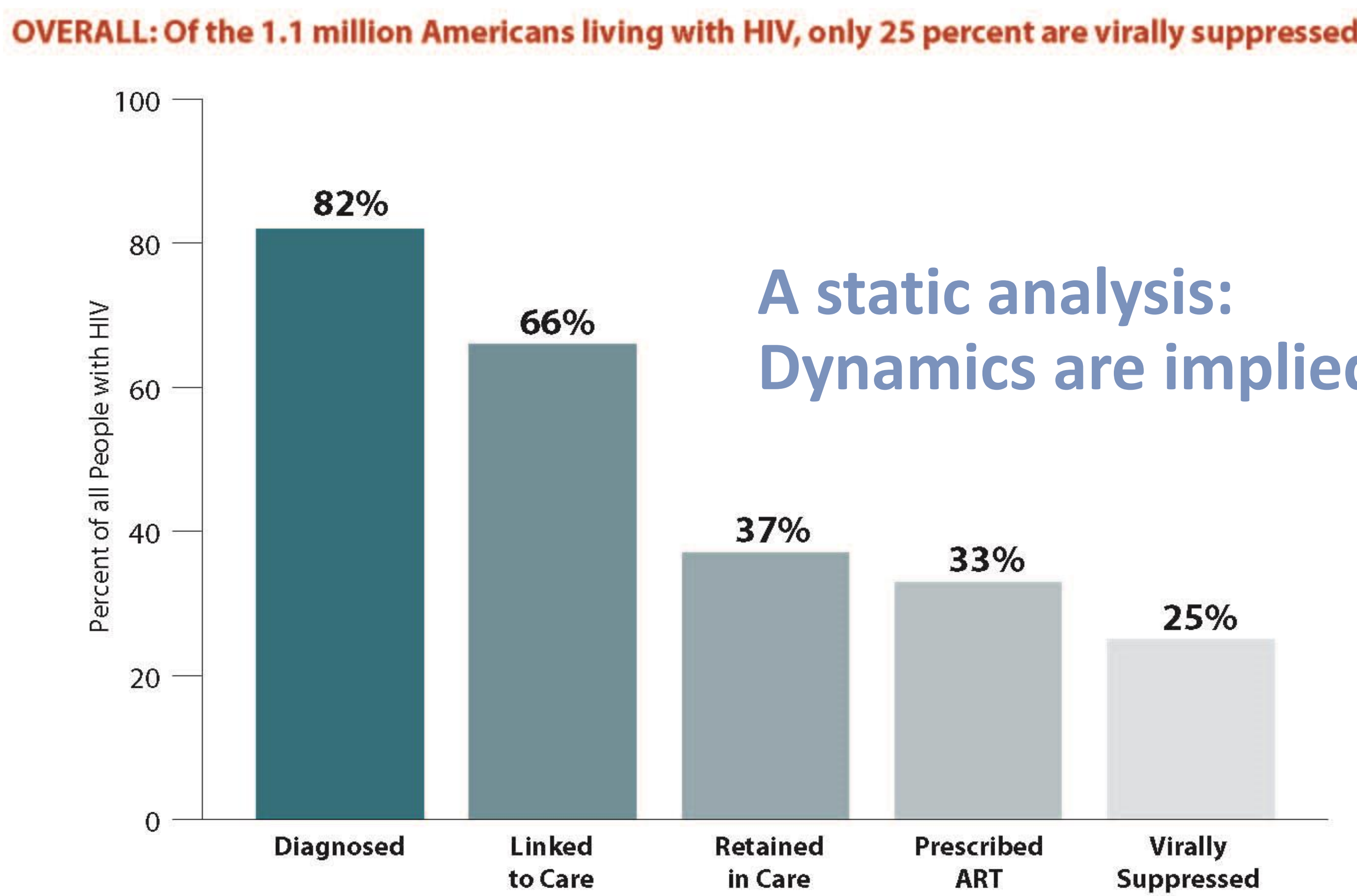
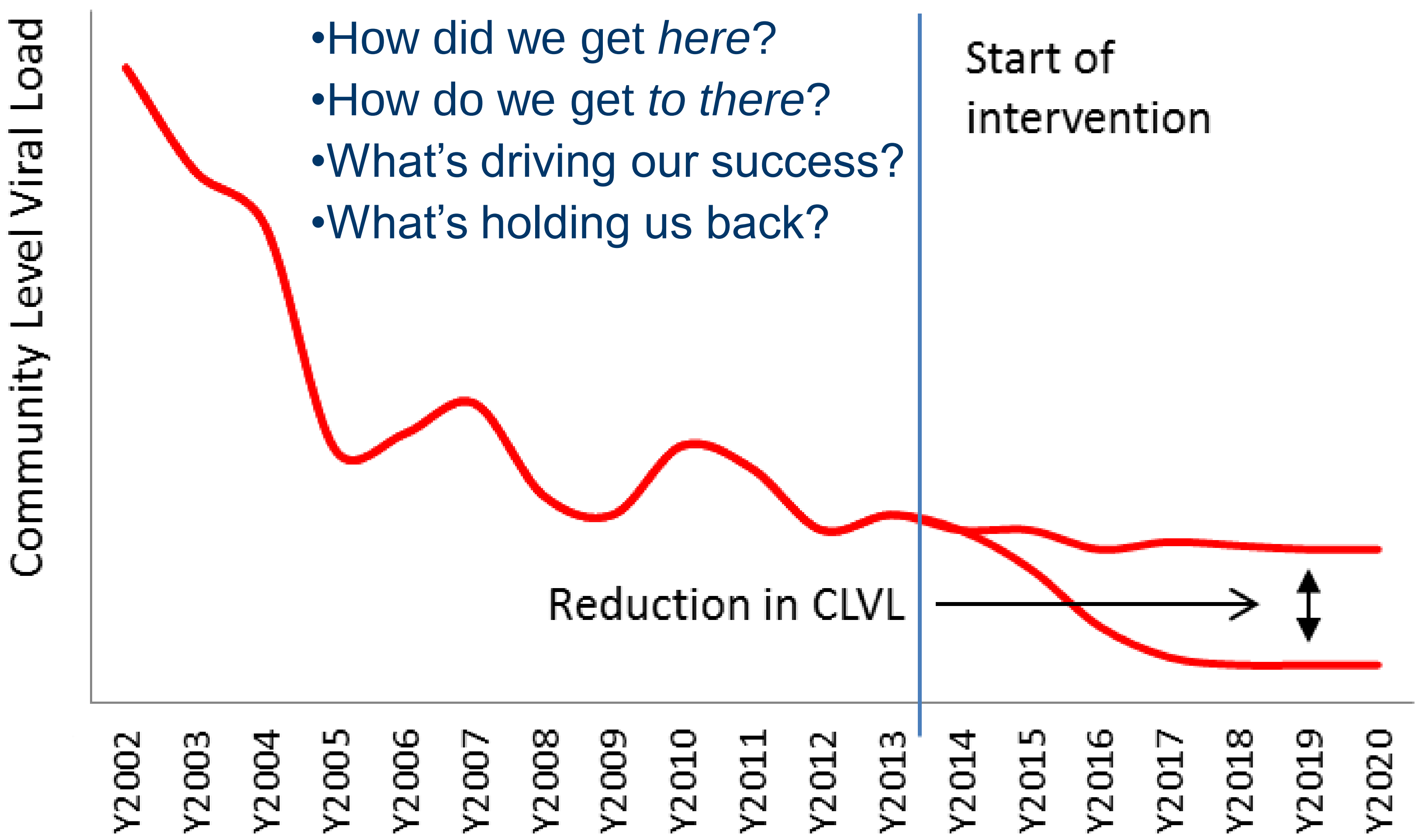
CDC Stages of Care and the "Treatment Cascade" – US Population **(July 2012)**

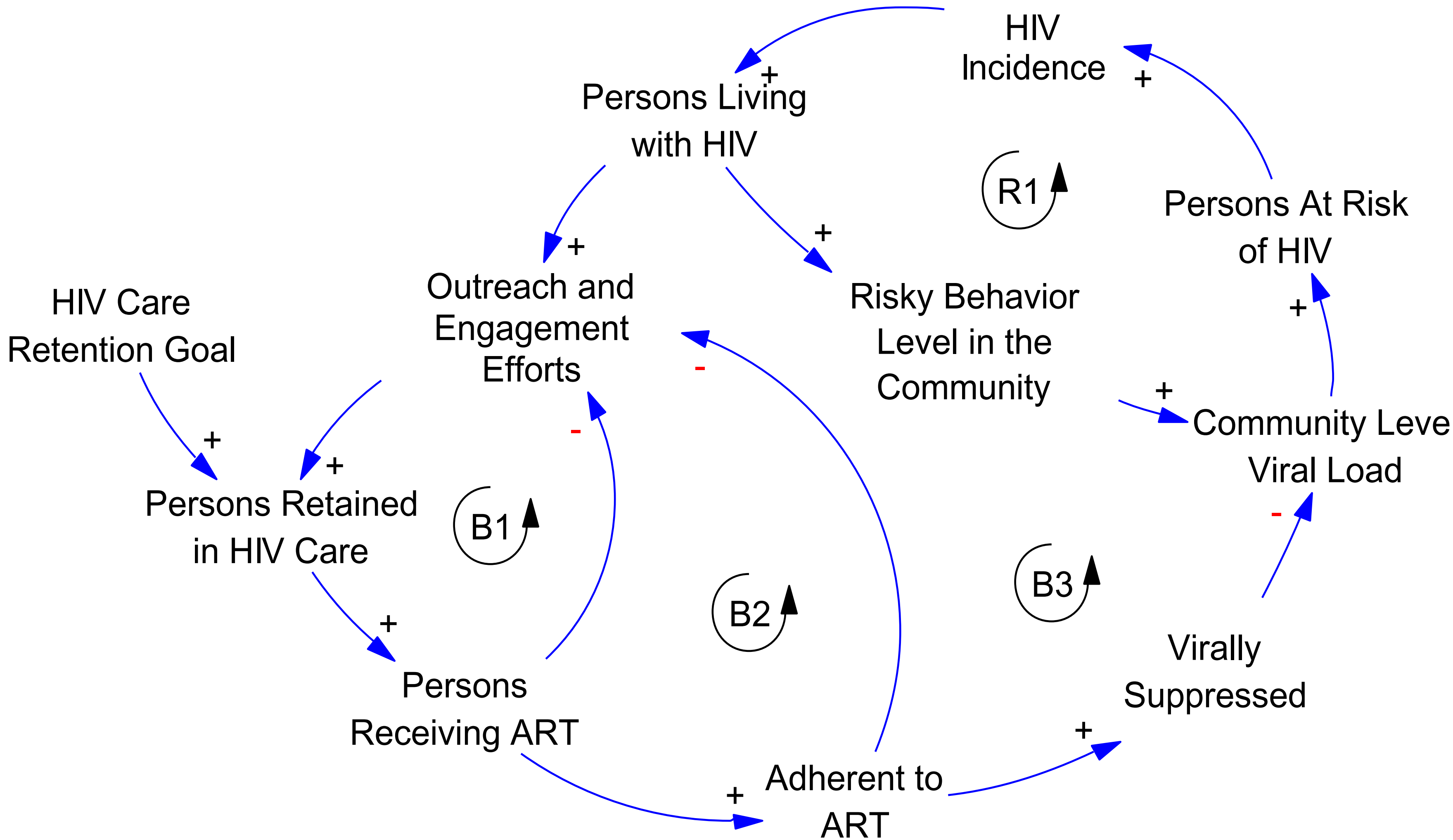


A static analysis: Dynamics are implied.

A Hypothetical Reference Mode: Community Level Viral Load (CLVL) Over Time (2002 – 2020)



A *Causal Loop Diagram* Depicting the Dynamics of Community Viral Load



A systems thinking approach to conceptualizing women’s empowerment

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Need help with GitHub download or installing *Stella Architect*?

BREAK & TECHNICAL ASSISTANCE CHECK

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Systems Science Methodologies

- A broad class of intellectual methods for understanding part-and-whole interactions (Trochim, 2006)
  - Social Network Analysis
  - Micro-simulation Modeling
  - Agent-based Modeling
  - **System Dynamics Modeling**
- What is System Dynamics Modeling (SDM)?
  - A computer-aided approach to policy analysis and design characterized by information feedback (i.e., circular causality) (Richardson, 1996)
  - [mathematically] A set of differential equations representing hypothesized time-dependent inter-dependencies among specified variables
  - [philosophically] A methodology intended to foster in-depth understanding about the 'structure' and 'behavior' of complex problems

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System Dynamics Modeling (SDM) is *Participatory Research*

- In SDM, *group model building* engages *key stakeholders* in all phases of modeling
  - Patients and caregivers, frontline health workers, payors, and policy-makers, researchers, others
  - Introduction to group model building: https://en.wikibooks.org/wiki/Scriptapedia
- SDM has the potential to:
  - Promote deep understanding about complex problems
  - Identify robust policies and implementation strategies
  - Inform novel research questions, hypotheses, and/or study designs
  - Build models that build community: Establish task forces, coalitions and other collaborative partnerships

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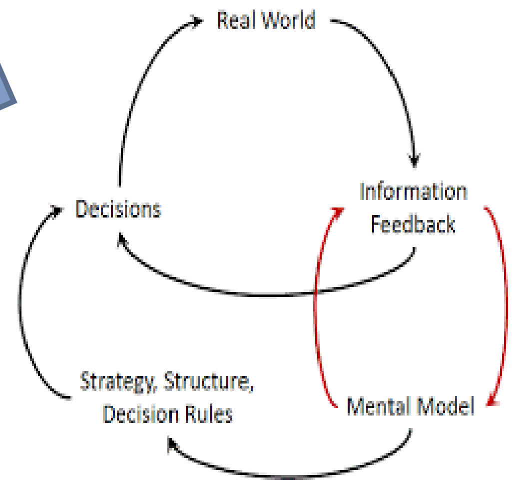
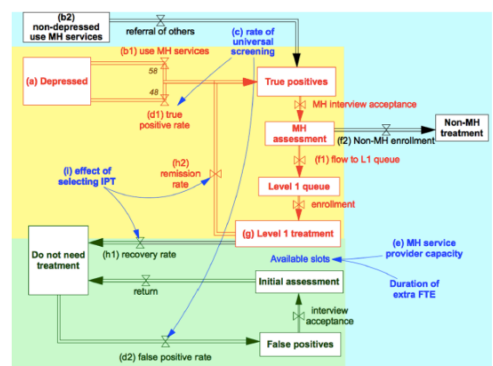
System Dynamics Modeling is Participatory

Stakeholder engagement

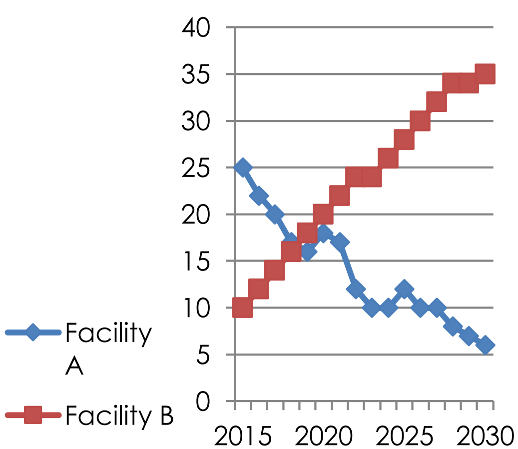


Mental models made explicit

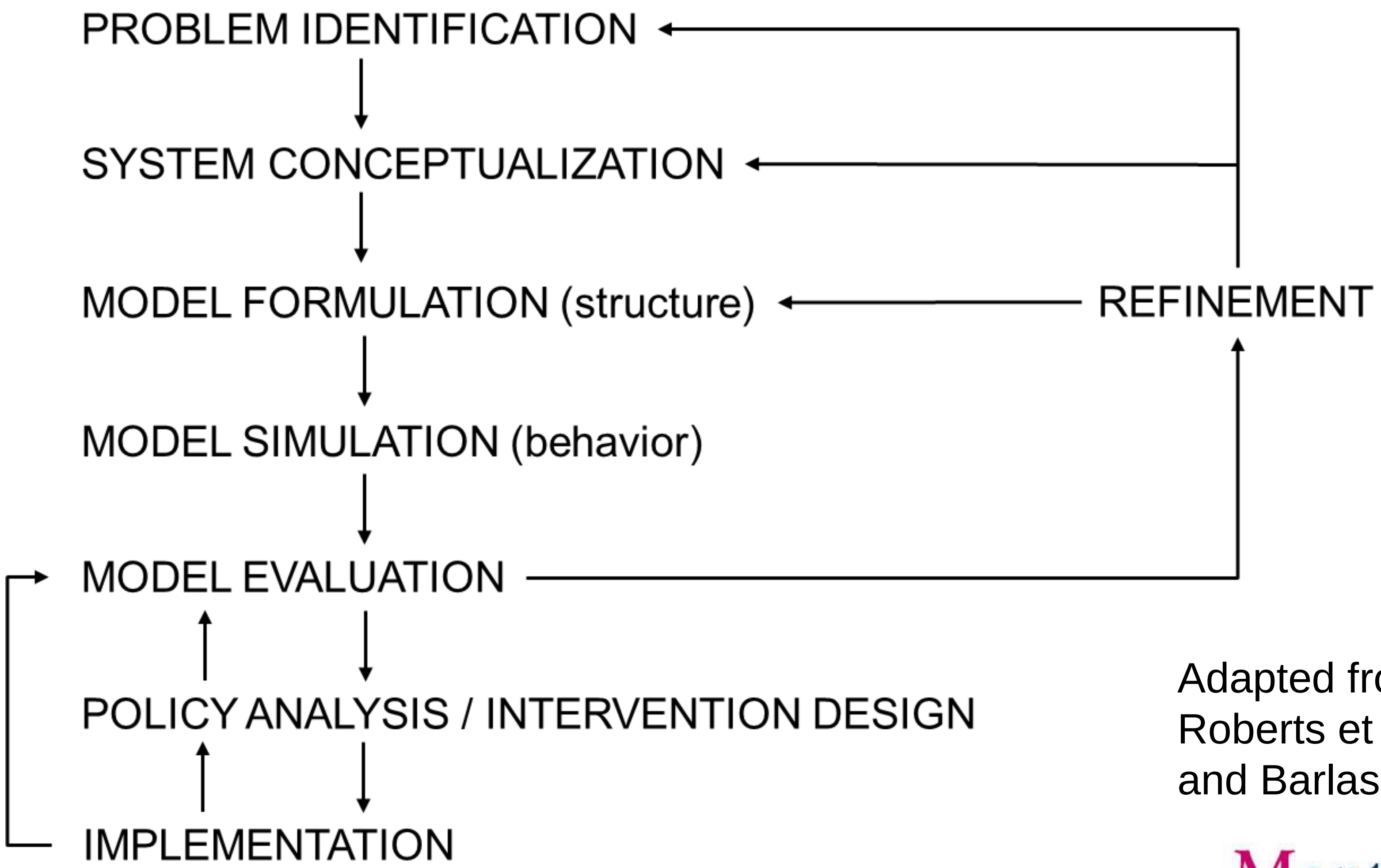
System ‘structure’ formulated and calibrated



Model ‘behavior’ evaluated



The Iterative Nature of SDM Development and Validation



Adapted from Roberts et al. (1983) and Barlas (1996)

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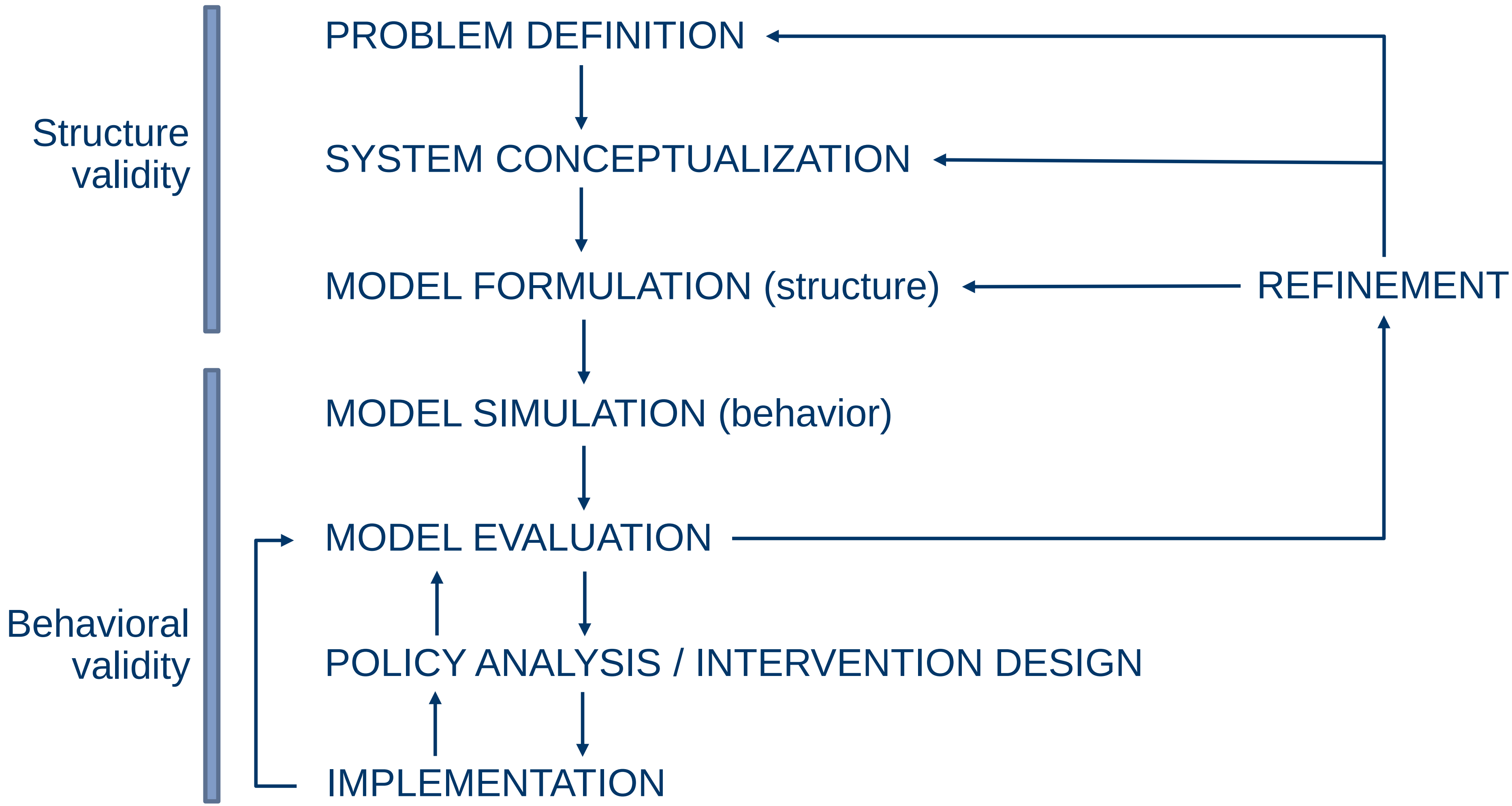
The Iterative Nature of SD Model Development and Validation



Adapted from Roberts et al. (1983) and Barlas (1996)

A Topology of Validation Tests

(Forrester & Senge, 1980; Barlas 1996; Martis, 2006)

Validity Type	Tests of suitability	Tests of consistency	Tests of utility
Structure	• Structure-Verification • Dimensional-Consistency • Extreme-Conditions • Boundary-Adequacy	• Face Validity • Parameter-Verification	• Appropriateness for Target Audience
Behavior	• Parameter Sensitivity • Structural Sensitivity • [Policy Sensitivity and Robustness]	• Behavior-Reproduction • Behavior-Prediction • Behavior-Anomaly • Family Member • Surprising Behavior • Extreme-Policy • Boundary Adequacy • Behavior-Sensitivity • Statistical • [Changed Behavior Prediction]	• Counter Intuitive Behavior • [Implementable Policy]

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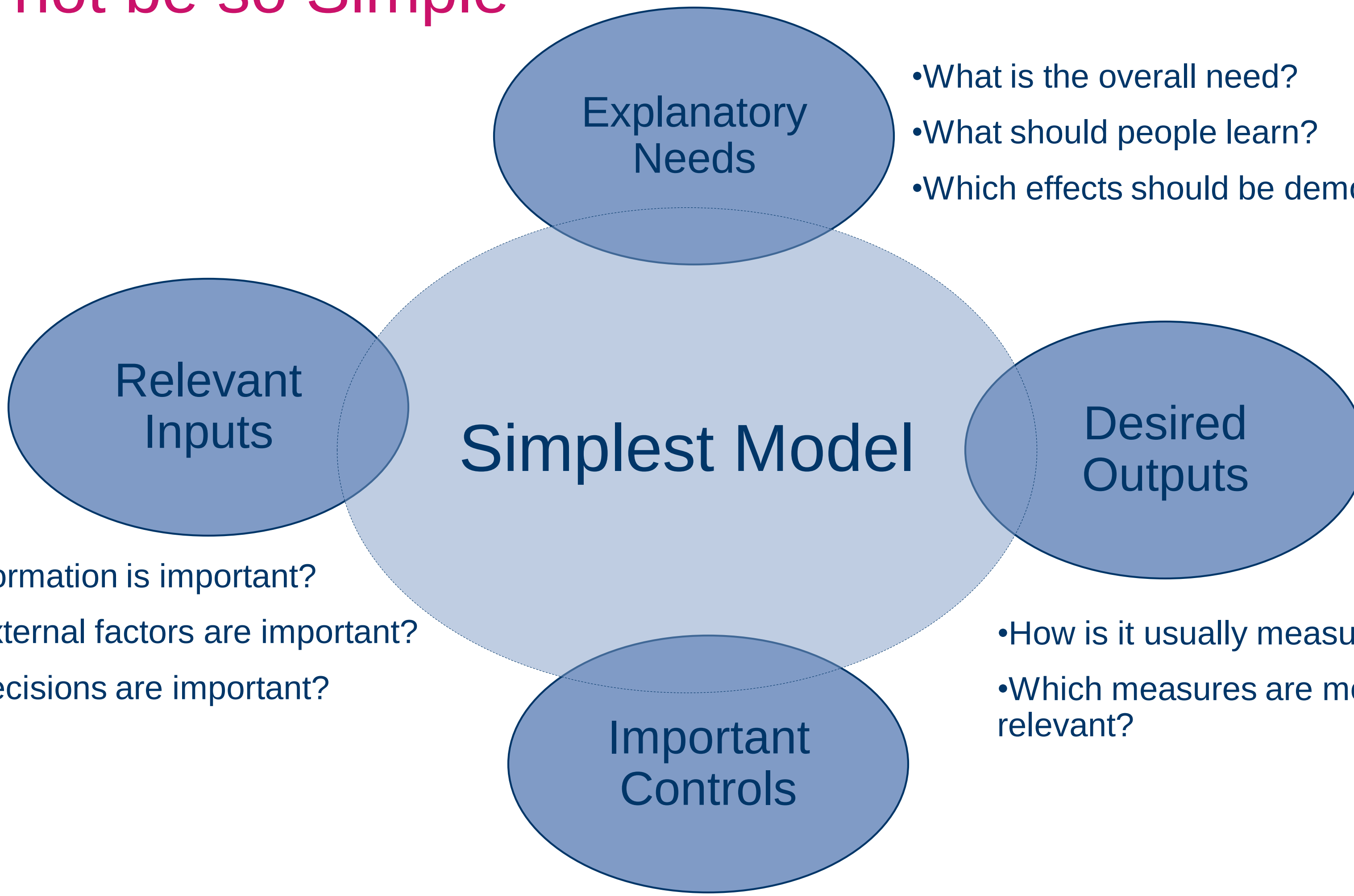
Modeling Challenge

The "Simplest Model" may not be so Simple

Models sometimes need to be complex, making them hard to understand and trust. To be useful, such models must be well calibrated and tested.



- What is the overall need?
- What should people learn?
- Which effects should be demonstrated?

- What information is important?
- Which external factors are important?
- Which decisions are important?

- How is it usually measured?
- Which measures are most relevant?

- What can people control?
- Which decisions are important?

Walker and Wakeland, 2014

Balancing Breadth and Depth in System Dynamics Model Building and Calibration

1. Parsimony: Continually look to simplify the model as much as possible, given its intended purpose and targeted audience
2. Allow for redesign along the way, but know when to stop
3. Carefully document choices made throughout process to stay organized and minimize ‘cycling’
4. Define *rubrics* | *tools* that facilitate model testing and foster stakeholder confidence

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Types of Data for Model Formulation

- Quantitative Data (numerical)
  - <u>Cross sectional data</u>: Charting the nonlinearities
  - <u>Time Series Data</u>: Defining the problem (i.e., defining key ‘reference modes’)
- Qualitative Data (written, mental)
  - Elicit the concept of the ‘reference mode’ from published findings or participant stakeholders (operators)
  - Methods
    - Observational approaches
    - Key informants interviews
    - Group interviews or Focus groups

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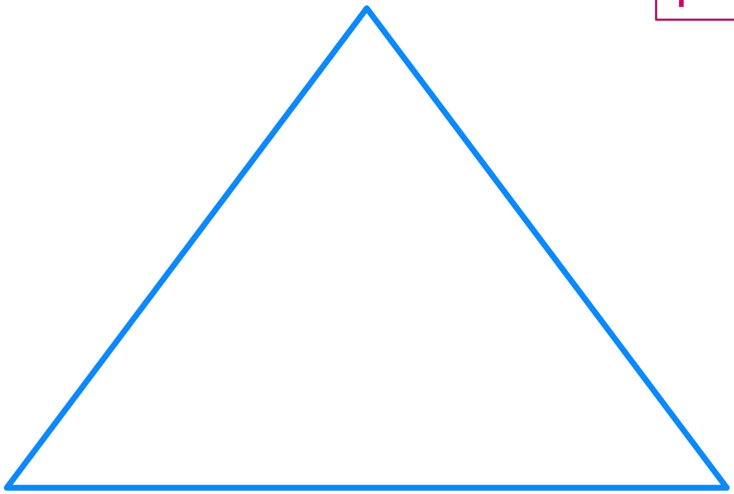
Triangulating Sources of Information in System Dynamics Modeling Projects

Stakeholders’ Expertise and Lived Experience

Validity threat: Selection and/or participation bias



Validity threat: Error of omission

Scientific Reviews and Published Empirical Evidence

Validity threat: Date quality/ fallibility

Primary & Secondary Data Analyses (Qualitative and Quantitative)

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Understanding structure and behavior: First order delays and smooths

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Simulating characteristics of populations: Co-flow structures

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Simulating patterns of disease in populations: Aging chain structures (S-I-R)

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Tradeoffs in Modeling

1. Generality: Applicability of model to phenomena other than that for which it was developed
2. Realism: Degree to which the model reflects reality as viewed by experts in the field
3. Fit: Degree to which the model output matches historical data and has predictive accuracy
4. Precision: Fineness of model and level of details specified

Levins, R. (1966); Ip et al. (2013)

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Three Levels of System Dynamics Modeling

Costanza and Ruth (1997)

1. Scoping and consensus-building models (limited information | high generality)
2. Research models (incorporates detailed historical or other empirical data sources)
3. Management or surveillance models (builds upon the first two stages; used to over an extended period to examine the implications of management actions)

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Concluding Caveats

- EVERY model-building project is unique
  - The model and the modeling process both contribute value
  - Participatory process will help shape effective engagement and will inform modeling tradeoffs
- Need to consider
  - Time to build, test, and apply the model(s)
  - Modelers' skill/training and stakeholders' expert knowledge
  - Access to and quality of key data
  - Capacity to facilitate participatory modeling and to create practicable user interfaces for models
- Need to build effective rapport with target audience
  - Build trust; Achieve 'small wins' in model development
  - Appreciate differing philosophies of science

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