# System Dynamics and Modeling

Part 1: Models and Causal Loop Diagrams

# Background for these Sessions

- Token *Engineering* requires *Engineering* principles
- Blending exposure to major concepts (“big ideas”) and effective practice
- This process can benefit from guidance
- Ongoing, iterative process!

# Structure of these Sessions

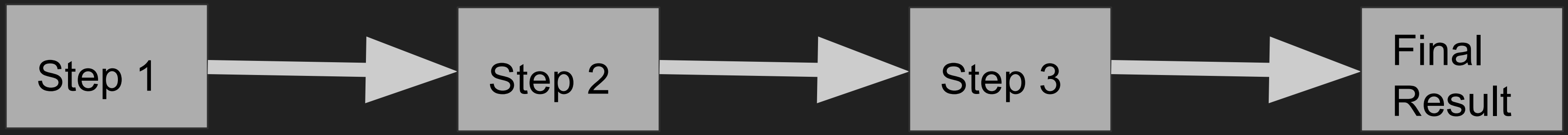
- Community-oriented and discussion-driven (we share expertise)
- *Practical,* playing with concepts through activity.
- Beginning for further exploration (recommended resources)
- *Not a hackathon;* things take time. :)

# Origin of System Dynamics

- Originated in 1950s by **Professor Jay Forrester** at MIT.
- 1947: WHIRLWIND I, first flight simulator, using early digital computers.
- Led to development of new computer memory technology.
- In 1950s, Forrester began to apply science and engineering techniques to industrial management problems.
- Example: the “three-year employment cycle” at General Electric

Source: “Origin of System Dynamics.” System Dynamics Society.
https://systemdynamics.org/origin-of-system-dynamics/

# Open Systems




*Open systems* are characterized by linear step-by-step processes that move from initial state to goal state. Information flow is one-way.

Example: cake recipes, the quadratic formula, anything modeled by basic flowchart

# Closed Systems (feedback systems)

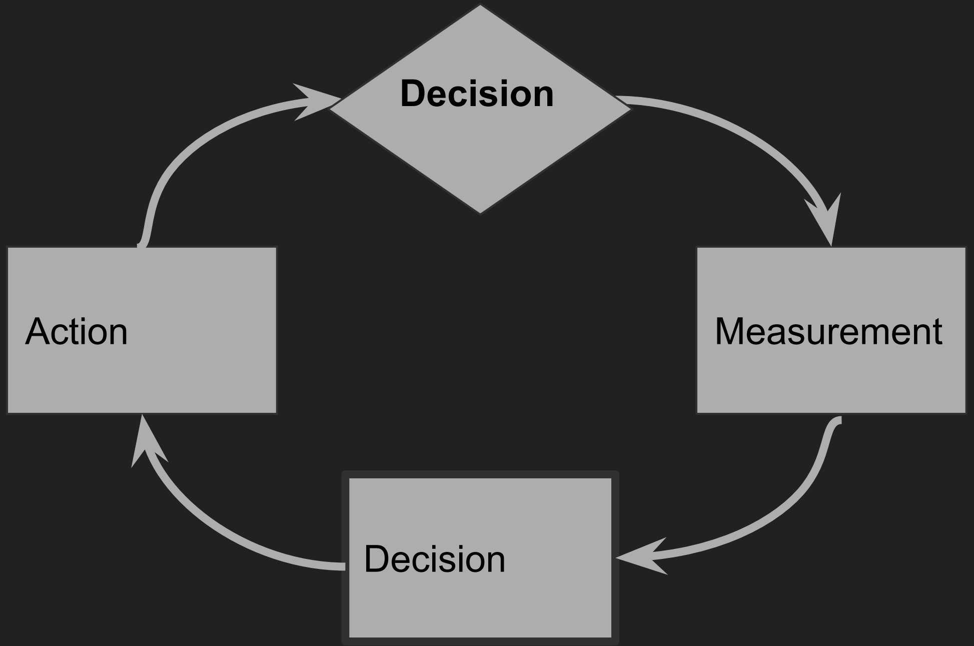



Image based on Figure 4.2a from *Principles of Systems* by Jay W. Forrester. Wright-Allen Press, 1968.

Closed systems are iterative processes with *feedback*: actions change the system state, which becomes the input for our next action.

# Example (Supply Chain)

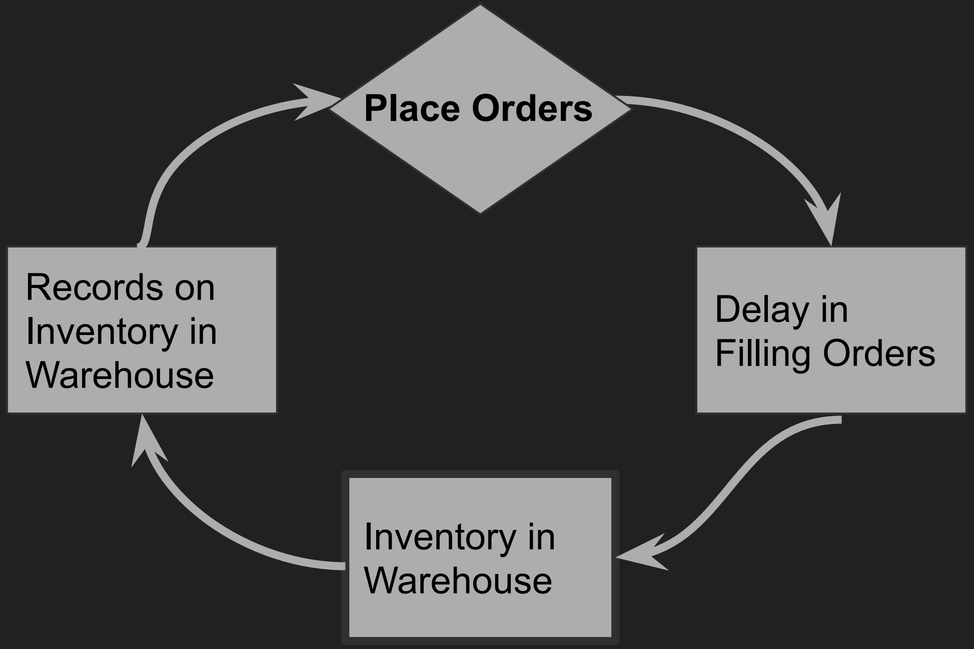



Image based on Figure 1.4b from *Principles of Systems* by Jay W. Forrester. Wright-Allen Press, 1968.

Famous example: [Beer Game]

Another example: driving a car.

# Models of Systems

"A model is a substitute for an object or system."

— Forrester, *System Dynamics*, Section 3.1

There are **many different types of models:**

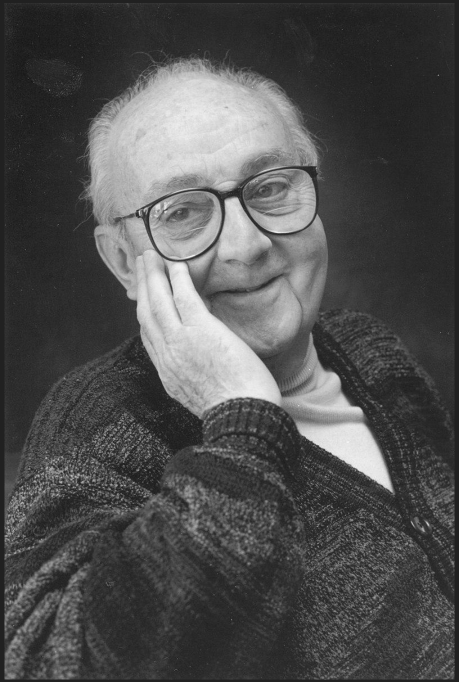
- **Narrative (user stories, hypothetical conversations)**
- **Visual (formal diagrams, rough sketches)**
- **Symbolic (equations)**
- **Numerical (data)**
- **Physical (replicas, wind tunnels, etc.)**
- **Computational (programs, simulators, etc.)**

# Practice

What are some possible models of a house?

For what purposes might these different models be useful?

# Important Principles in Modeling (1)

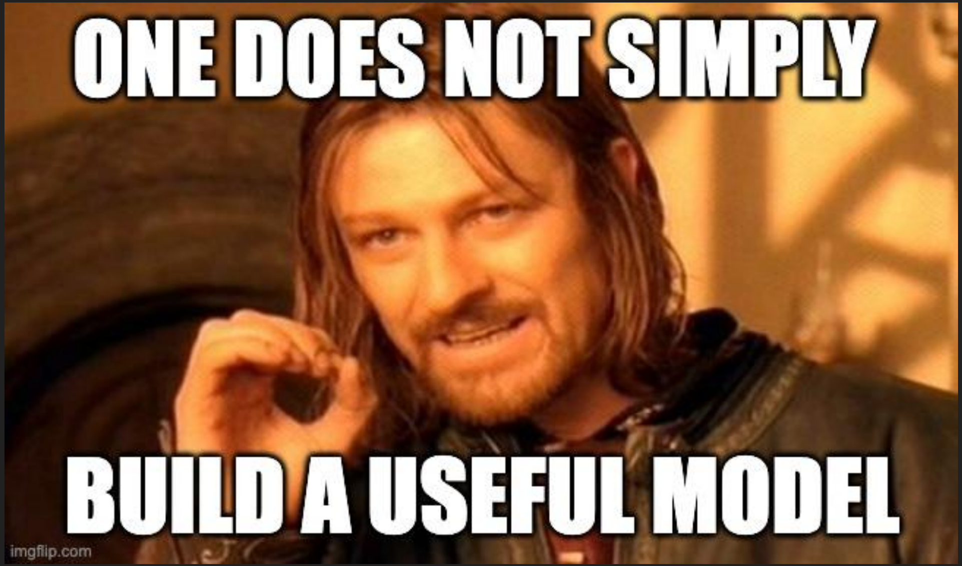


“All models are wrong, but some are useful.” – George Box

# Important Principles in Modeling (2)

"Every gambler knows that the secret to survival is knowing what to throw away and knowing what to keep."

– [Kenny Rogers, "The Gambler"]



# Exercise

Suppose you are modeling an automobile race.

What variables would you track in this system?

What are some variables that exist in the system, that you might choose to leave out of your model?

# Purpose of the Model?

“A model should be built for a purpose.”

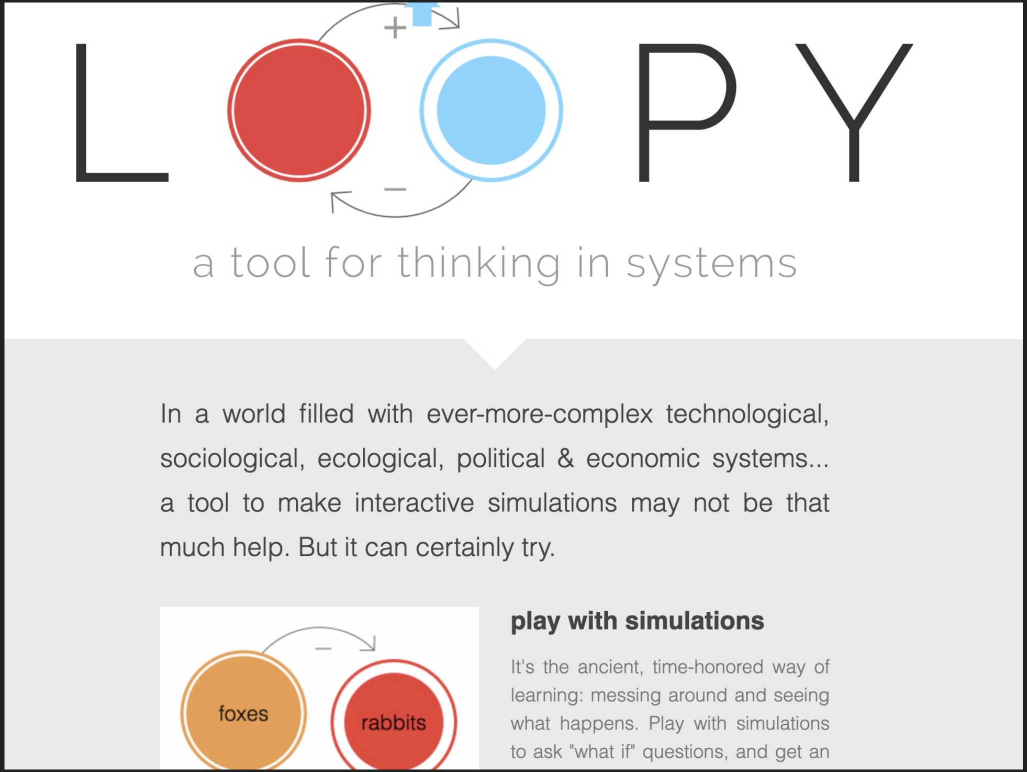
– Jay Forrester

# Causal Loop Diagrams

- Causal Loop Diagrams were *not* part of Forrester's original work on Systems Dynamics.
- The first Systems Thinkers focused on *quantitative tools:* equations and stock-and-flow diagrams.
- Causal Loop Diagrams are a *quantitative* tool: this is both their main benefit and their main drawback.

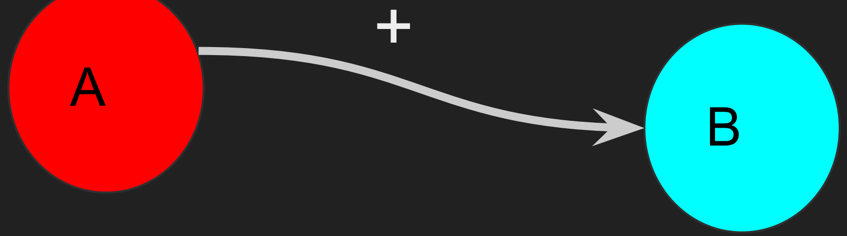
# Loopy: A Basic Tool for Causal Loop Diagrams

https://ncase.me/loopy/



# Structure of Causal Loop Diagrams

Variables in the system are represented by nodes.




There is an arrow from A to B if A influences B.

"+" (or "S") : change in A leads to similar change in B (increase A -> increase B)

"-" (or "O") : change in A leads to opposite change in B (increase A -> decrease B)

# Feedback Loops

***Feedback loops*** are the fundamental building blocks of closed systems.

One of the main points of causal loop diagrams is to recognize the feedback loops in the system and how they interact.

A feedback loop can be recognized in a Causal Loop Diagram by arrows that follow in the same direction to and from the same node.

# Reinforcing and Balancing Feedback Loops

Reinforcing - the effect of the initial variable tends to be amplified

Balancing - the effect of A leads to changes that tend to lead to a counterbalancing effect in A (often driven by a *goal state*).

# Example: Educational System

https://www.researchgate.net/publication/6414923_Using_system_dynamics_modeling_to_understand_the_impact_of_social_change_initiatives

# Looking at Some Examples

https://ncase.me/loopy/v1/pages/examples/

# Exercise 1 *(adapted from Principles of Systems, Forrester, 1968)*

A student wishes to maintain a B average in the course.

They must decide how much time to allocate to studying each week.

Draw a feedback loop that illustrates this situation.

# Exercise 2 *(adapted from Principles of Systems, Forrester, 1968)*

A teacher wants to pace instruction so that student understanding and retention is maximized.

Draw a basic feedback loop that shows how the teacher makes this decision based on understanding.

# Exercise 3 (simple population growth)

The growth of a population (rabbits, bacteria) can be modeled by considering:

- Mature individuals
- New births

What type of feedback loop would these two variables form?

What type of growth would we predict based on this loop?

# Extension

What variables is the previous system lacking?

What other feedback loops interact with the population growth feedback loop?

# Flywheels and Virtuous Cycles

“X creates more X”

[The Amazon Flywheel]()

# System Archetypes

Over time, systems thinkers have developed a common visual dictionary of patterns that recur in systems.

https://thesystemsthinker.com/wp-content/uploads/2016/03/Systems-Archetypes-I-TRSA01_pk.pdf

# Ongoing Practice

For each system archetype presented in the document, find an example system from a book, article, or from the Loopy examples library.

As you consider Causal Loop Diagrams of (cryptoeconomic) systems, look for the common archetypes and see how they occur.

# Example 4 (Bitcoin Mining)

Build a causal loop diagram that considers the following variables:

- The number of Bitcoin miners
- Likelihood of winning the next Bitcoin block
- Profitability of Bitcoin mining

# Balancing Loops: Algorithmic Stablecoins

Many algorithmic stablecoins operate on the principle of balancing loops to return the price to a particular peg.

Example: **FRAX v1**

- **FRAX - actual stablecoin, intended to be pegged to $1**
- **CR - collateral ratio; % of USDC needed to mint a FRAX share (FXS)**
- **FXS - FRAX Share**

Consider the following variables:

- FRAX price
- Collateral Ratio
- Supply of FXS
- Price of FXS

# Practice Exercise (estimated 30 minutes)

Consider a temperature regulation system, which produces heat when a room is too cold.

1. Identify variables needed for model of system.
2. Build Causal Loop Diagram

# Practice Exercise (approximately 30 minutes - 1 hour)

Imagine that you own an artist’s market, where artists rent booth space to sell art.

You take applications from artists, then charge a commission for what each artist sells.

Identify the relevant variables for this system, then build a Causal Loop Diagram model for the system.

# Mini-Project Idea: UST-LUNA ecosystem

The collapse of the price of UST could be viewed as arising from a  reinforcing feedback loop related to the tokenomics of UST and LUNA.

**Exercise for Future Discussion:** Build a Causal Loop Diagram that relates the relevant variables of the UST-LUNA ecosystem and identifies the feedback loops that led to this price collapse.

# Weaknesses of Causal Loop Diagrams

- Physical Information vs. Conserved Quantities
- Misleading relationships

[https://www.systems-thinking.org/intst/d-3312.pdf](https://www.systems-thinking.org/intst/d-3312.pdf)

**ARCHIVES**
(D-3312)

Founded in the mid-1950s, the field of system dynamics has intellectual roots reaching much further into the past. The Archives section of the Review seeks to publish material from that past which can contribute to current theory and practice. The section welcomes previously unpublished but deserving system dynamics work, classics from past system dynamics literature that should receive renewed attention, and previously published articles from other disciplines of particular significance to current system dynamicists. Contri-

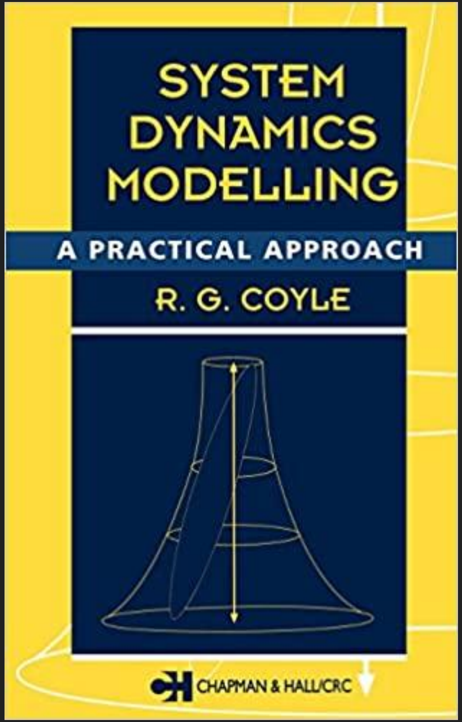
## Problems with causal-loop diagrams

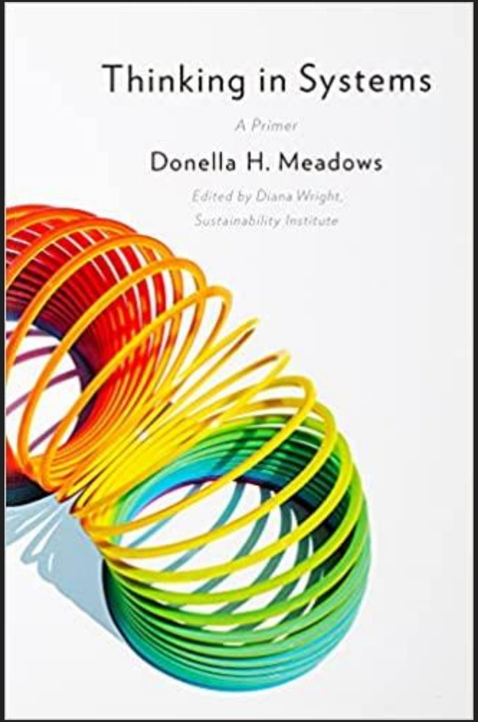
George P. Richardson

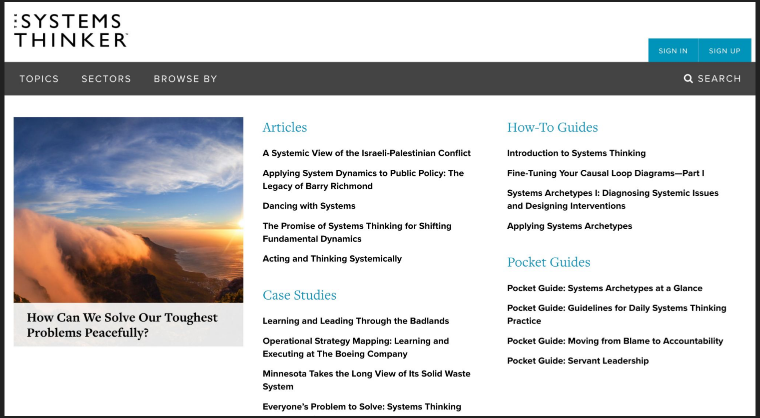
*The first system dynamics work did not include the use of causal-loop diagrams. Feedback structure was portrayed by equations or stock-and-flow diagrams. Such representations were natural for engineers. In an attempt to make system dynamics accessible to a wider range of people, causal-loop diagrams have become increasingly popular. In many texts and courses they are the first tool described. Indeed, recently several analysts have proposed that system dynamics studies can be carried out without the development of formal models at all (Morecroft 1985; Wolstenholme and Coyle 1983; Wolstenholme 1985). Causal-loop diagrams often figure prominently in such analyses. Yet even those who advocate the use of qualitative system dynamics are careful to point out that in all the successful applications of such qualitative methods the analysts have had extensive experience with formal model building. Nevertheless, it seems inevitable that people at all experience levels will continue to rely on causal-loop diagrams.*

*In the following paper dating from 1976, George Richardson describes a variety of problems which often arise in causal-loop diagramming, both in the development of the diagrams and the explication of behavior from them. The main difficulties arise because causal-loop diagrams obscure the stock and flow structure of systems. We sometimes emphasize so heavily the role of feedback structure in generating behavior that the crucial role of accumulation processes is lost. Even experienced modelers are easily misled by causal-loop diagrams. I suggest the following experiment: take the causal-loop diagram for the family feud described in Richardson's paper and ask a random sample of system dynamics modelers or students how it will behave. In my experience, one will not only receive a wide range of answers but most of these will be incorrect. Then repeat the*

# Recommended Resources

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