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Systems Analysis and Nonproliferation

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Presentation to MIIS Fellows



*Exceptional
service
in the
national
interest*



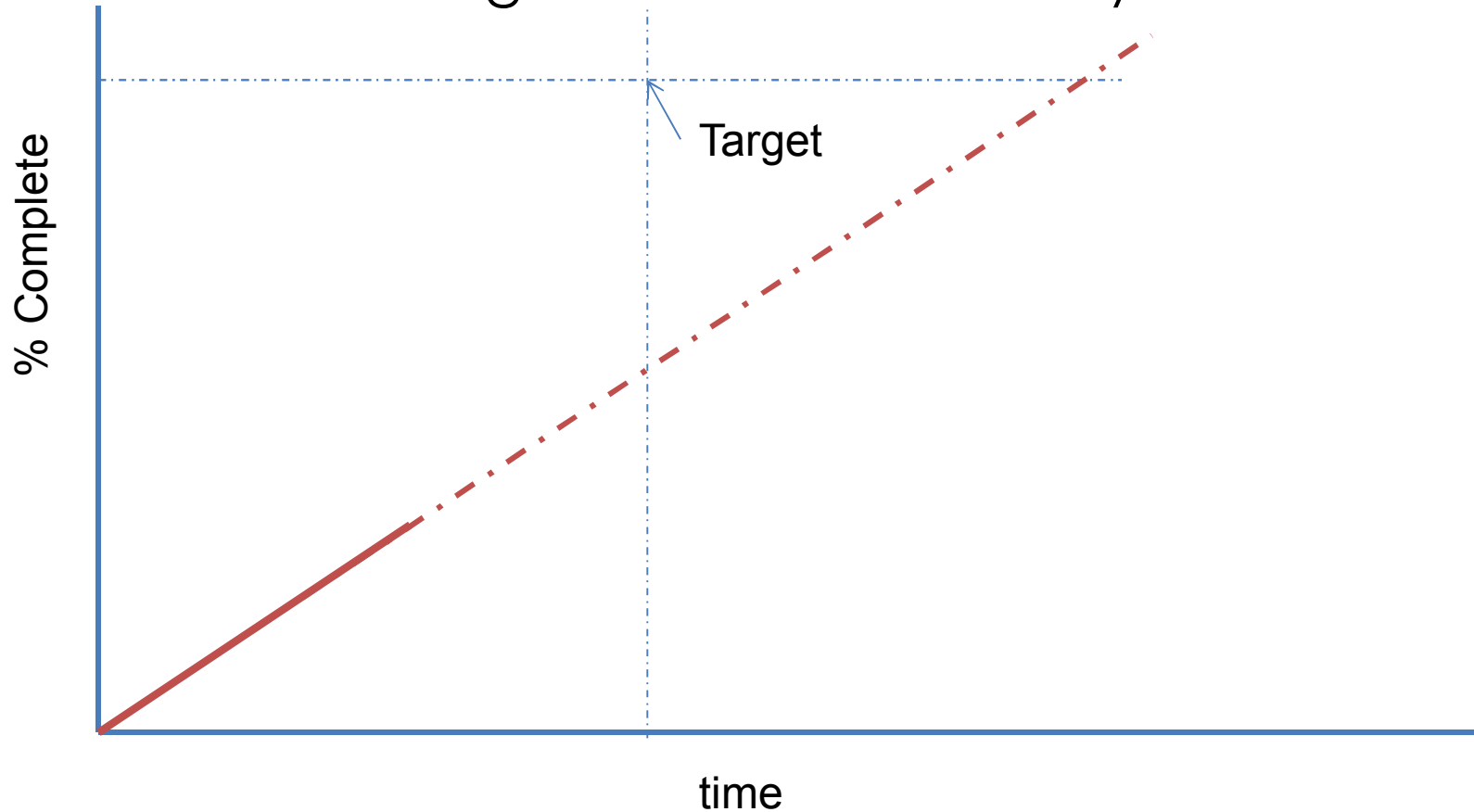
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Lecture Outline

1. Why System Thinking?
2. Definition of a System
3. Objective(s) of a System
4. Types of Systems
5. Systems Thinking and Systems Approach
6. Systems Analysis and System Solution
7. Scientific Method
8. Relationship to Noproliferation

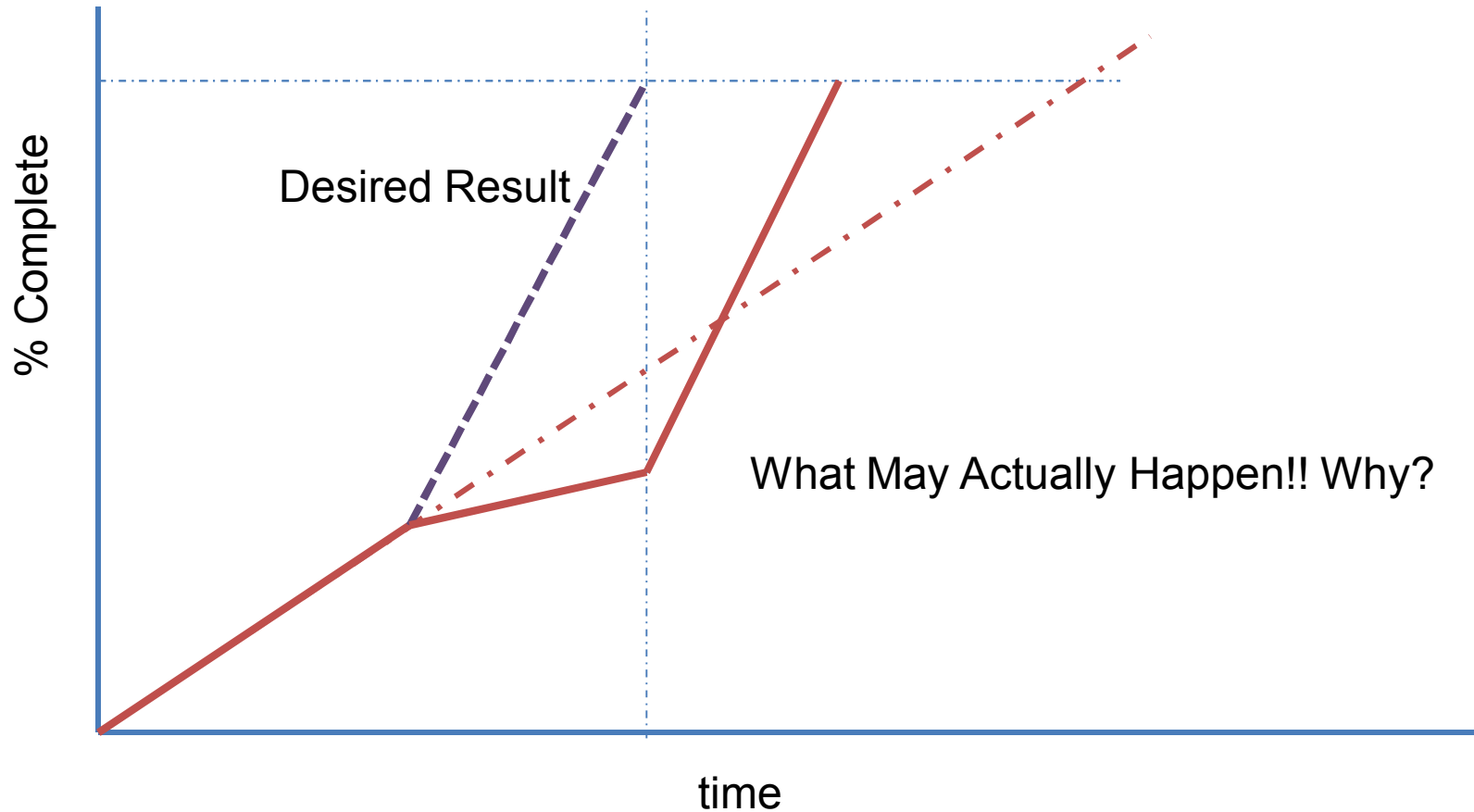
Motivation: Why Systems Thinking?

- Suppose you are the head of an organization that is behind on its goal ... What can do you do?



Motivation: Why Systems Thinking?

You decide to add more people. What happens?



Current staff wind up training new staff, reducing productivity!!

Systems Thinking Addresses Complex, Dynamic Problems

- “So many important problems that plague us today are complex, involve multiple actors, and are at least partly the result of past actions that were taken to alleviate them. Dealing with such problems is notoriously difficult One of the key benefits of systems thinking is its ability to deal effectively with just these types of problems and to raise our thinking to the level at which we create the results we want ... even in those difficult situations marked by complexity, great numbers of interactions, and the absence or ineffectiveness of immediately apparent solution.”
- “The approach of systems thinking is fundamentally different from that of traditional forms of analysis. “
- “Traditional analysis focuses on the separating the individual pieces of what is being studied ...”
- “Systems thinking, in contrast, focuses on how the thing being studied interacts with the other constituents of the system—a set of elements that interact to produce behavior—of which it is a part...”
- “... systems thinking works by expanding its view to take into account larger and larger numbers of interactions as an issue is being studied. This results in sometimes strikingly different conclusions than those generated by traditional forms of analysis, especially when what is being studied is dynamically complex or has a great deal of feedback from other sources, internal or external.”

Examining Information or Data

Analysis

an explanation of the whole is derived from explanations of its parts.

Synthesis

something to be explained is viewed as part of a larger system and is explained in terms of its role in that larger system.

Analysis & Synthesis are complementary.

However, synthesis can provide understanding unobtainable through analysis, particularly of collective phenomena.

Basic Definitions

Definitions of a System:

- 1. a regularly interacting or interdependent set of components forming a unified whole (the system) to serve a specific purpose;**
2. An organized set of doctrines, ideas, or principles usually intended to explain the arrangement or working of a systematic whole

Expanded Definition for Our Purposes

A system is a regularly interacting or interdependent set of components forming a unified whole (the system) to serve a specific purpose

A system has the following characteristics:

- **Togetherness/Interconnectivity:** Parts and processes are connected by structural and/or behavioral relationships.
- **Structure:** A description of the elements/components of the system and their relationship to each other
- **Behavior:** A dynamic property that refers to the effect of the system “in operation.”
- **Emergence:** Properties or behavior that are meaningful only when attributed to the system as a whole, not its parts. Also called attributes of the system

Discussion: Examples of Systems (and not!)

**List some examples of systems. What are the components?
What are the behaviors? How are the components related?**

- Air conditioning system
- ...
- ...
- ...

Not every set of items, facts, methods, or procedures is a system

Is a random group of items in a room a system? No!

- *It is a set of items with definite relationships*
- *No unified purpose*
- *Lacks functional relationships.*

System Boundaries and Environment

- In any particular situation, it is important to define the system under consideration by specifying its:
 - limits,
 - boundaries, or scope.
- Everything that remains outside the boundaries of the system is considered to be the environment.
- However, no (real) system is completely isolated from its environment.

Classifying Systems Based on Interaction with the Environment

- A closed system is one that does not interact significantly with its environment; it is not changed by its environment.
 - Exhibits *equilibrium* resulting from internal rigidity that maintains the system in spite of influences from the environment.
- An open system interacts with its environment, taking input and returning output.
 - Exhibits *steady state*, wherein a dynamic interaction of system components adjusts to changes in the environment. Because of this steady state, open systems are self-regulatory and often self-adaptive.

Classifying Systems

There are many other ways to classify systems

- Origin: Natural vs. Man-Made Systems
- Form: Conceptual vs. Physical
- Time Dependence: Static vs. Dynamic

System Analysis Approach

- The System Analysis Approach looks at a system from the top down
 1. Objective of the System
 2. Role of each component or sub-system in supporting the objective of the system
 3. Required attributes of component or sub-system in order to support the objective of the system
 4. Interactions and relationships (synergies and conflicts) between component or sub-system

- By focusing on systems, subsystems, and components in a hierarchy, one is forced to consider all pertinent functional relationships.

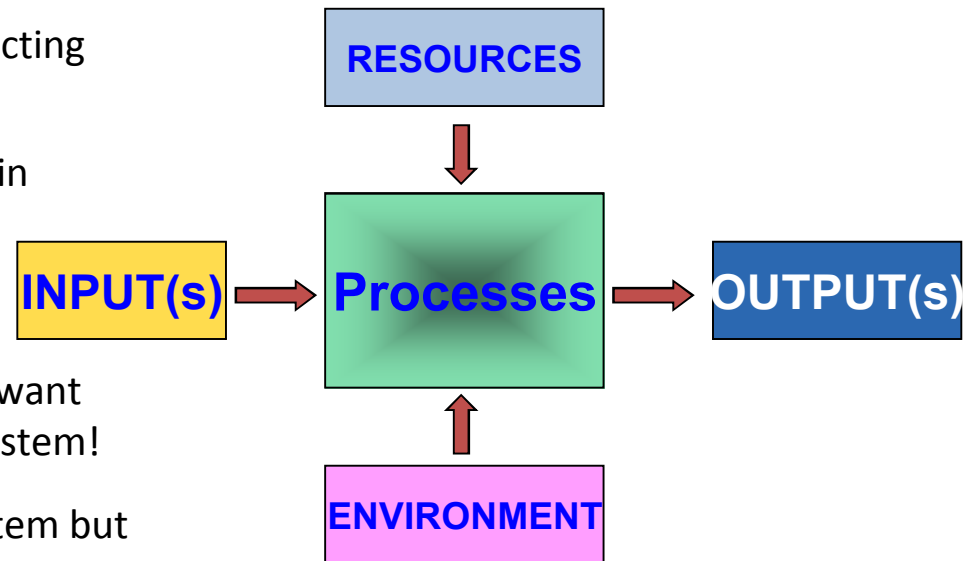
System Objective and Effectiveness

- The objective or purpose of a system must be explicitly defined and understood so that system components may be selected to provide the desired output for each given set of inputs.
- Once defined, the objective or purpose makes it possible to establish one or more given measure of effectiveness indicating how well the system performs.

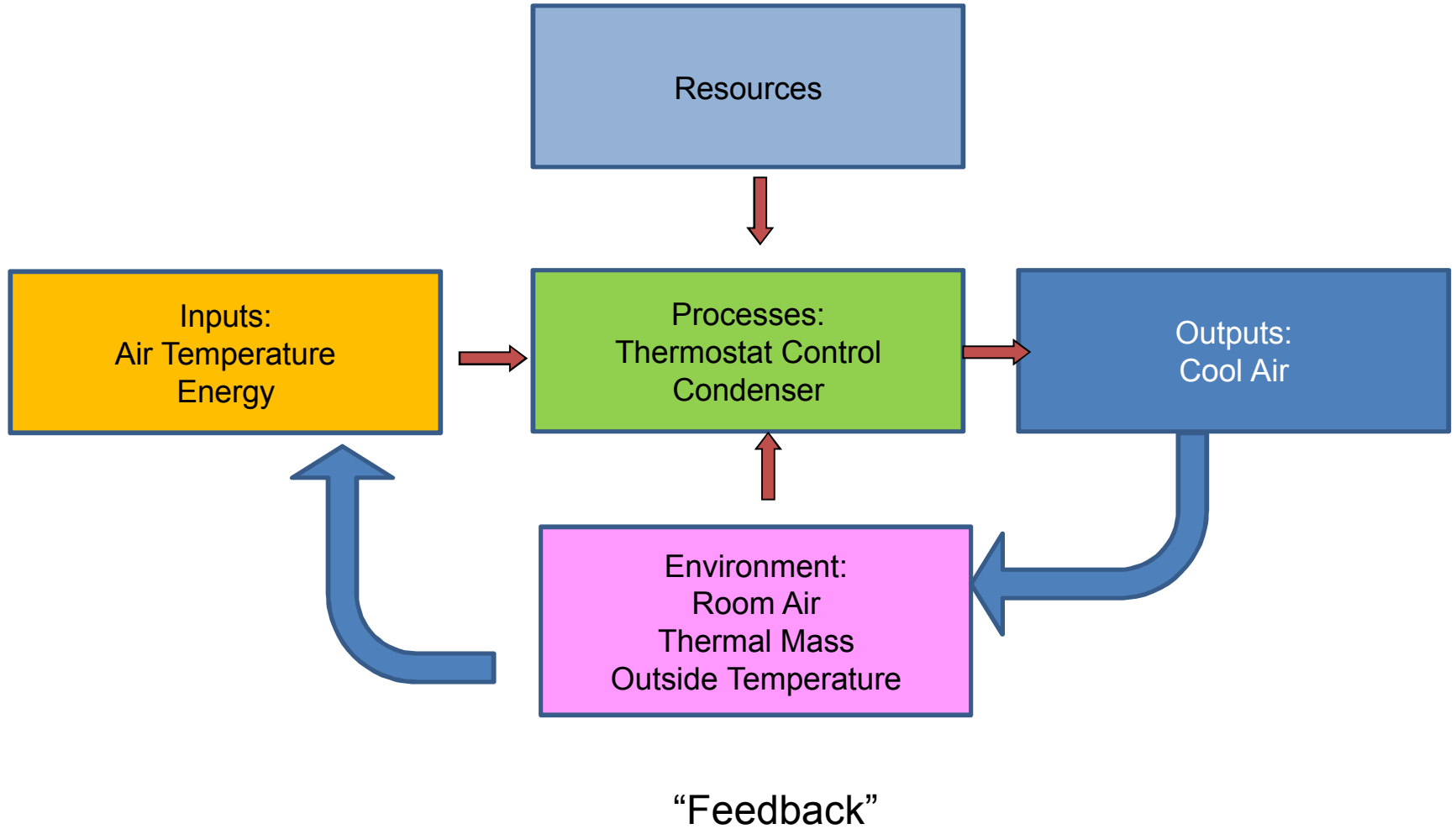
A Universal Model For Describing a System

We can describe a system and its environment with the following elements

- **Processes:** A set of behaviors or processes that transform the inputs into the outputs
 - Can be a combination of many interacting processes
 - Interaction among processes results in feedbacks
- **Input(s):** Instructions to the system
- **Output(s):** The effect of the system -- we want these to match the “objective(s)” of the system!
- **Resources:** Materials or ... used by the system but not consumed or transformed
- **Environment:** Natural or Human-Made Systems with which the system interacts

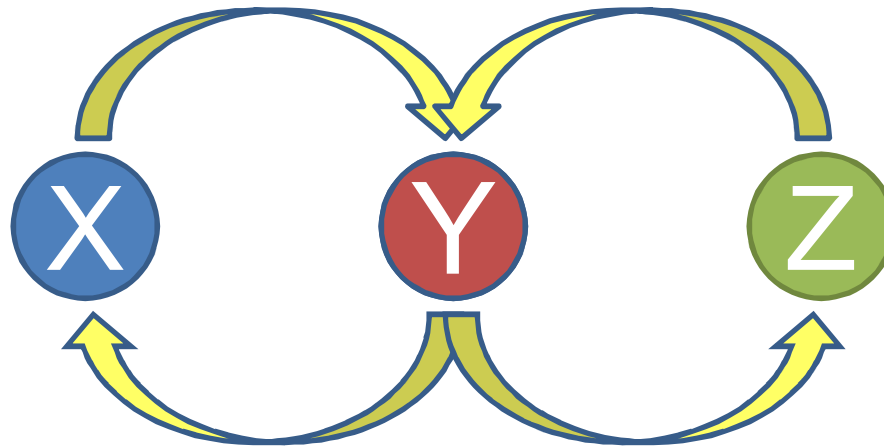


Example: Cooling System



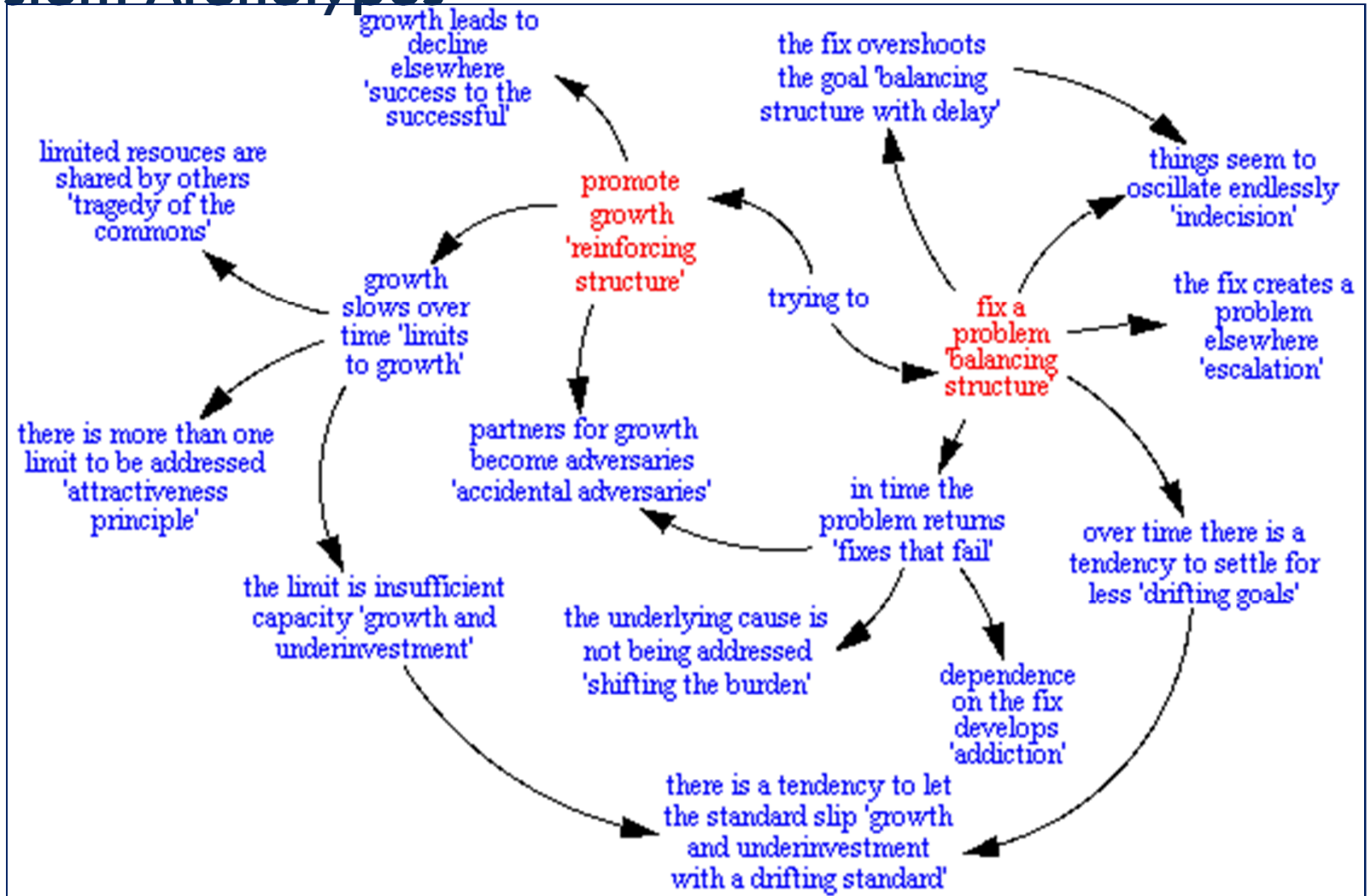
Feedbacks Create “Behaviors”

Sometimes called “mutual interaction” or “interrelationships”



Increasing complexity
X affecting Y affecting Z affecting Y affecting X

System Archetypes



- Studying and understanding the feedback is crucial in system analysis
- System dynamics is a methodology for studying and managing systems

When to Use System Analysis Approach?

Some indicators that we are dealing with a system:

- Multiple interdependent parameters affect behavior of the system;
- Multiple perspectives on just what the situation is, and how to deal with it;
- Troublesome/Problematic Behaviors
 - Endless oscillation;
 - Previously applied fixes have created new problems
 - Performance goals are declining
 - Partners have become adversaries – competing interests
 - Growth in one area leads to decline elsewhere

Exercise: What makes a company successful?

- Contrast two kinds of answers:
 - A list
 - A simple dynamic model – success to the successful or some simple growth model

System Analysis and System Solution

- Up to now we have provided the foundations on which we will build the system solution approach
- First we need to analyze the problem – as a system
- Next we will discuss the major steps in developing a solution – as a system
- Notice the role of critical thinking in these processes

- Determine if problem represents a system
 - Components/Structure
 - Behavior
 - Emergence

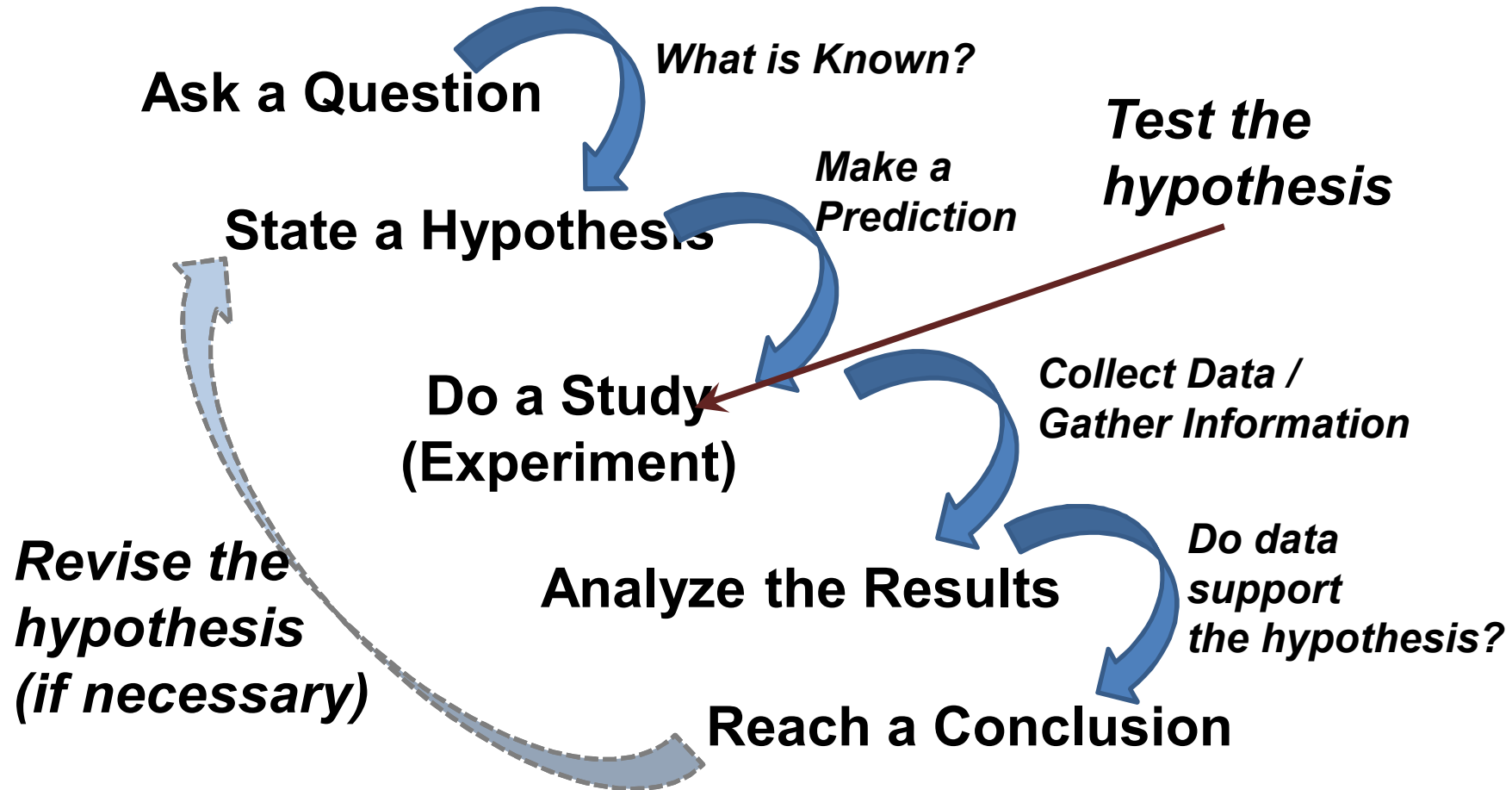
- Additional indicators
 - multiple perspectives about the situation
 - How to deal with the situation
 - Problematic behaviors
 -

System Analysis / Solution Approach

- Determine the system
 - Type
 - Objective(s) / Goals / Scope
 - Components and their attributes
 - Role of each component
 - Relationships among components
 - Feedbacks
 - Environment
 - Boundaries

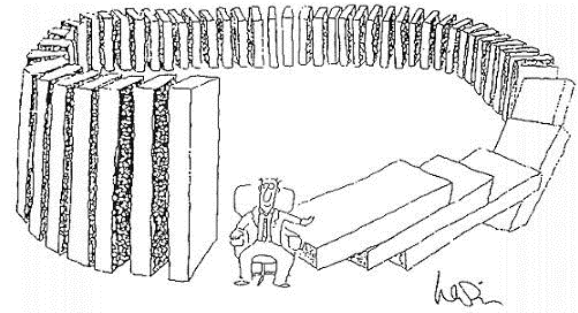
- Use Scientific Method to Test your Hypothesis
 - Evaluate a solution

The Scientific Method



System Approach to Problem Solving

- Define the System's Purpose, Goals or Objectives
- Gather Information
 - Data
- Analyze the System
- Examine System Dynamics
 - Feedback
- Evaluate Risk & Consider Unintended Consequences
- Develop Plans to Mitigate Risk
- Develop Solutions
 - Consider multiple possibilities
 - Rank Solutions
- Make Recommendations
 - Decision



Concluding Remarks

- System thinking is one of the most important analytical capabilities available to us
- Systems Analysis provides a holistic approach to deciding what we need or want
 - Achieving our goals within our resource constraints
- Decision Analysis and Risk Analysis are useful in that context
- When facing sequential decisions, consider future effects
 - Think forward, then back to the initial decision



KEEP IN MIND THE BIG PICTURE



How can we apply a system approach to understand and manage nuclear proliferation?

- Is the nonproliferation regime a system?
- What are its objectives?
- What are its components?
- Does it interact with other systems

Dr. Mohagheghi will examine this question
after lunch

Backups

Properties of System Components

As they work together toward some common objective or purpose (**System Objectives**), a set of interrelated **components** has the following properties:

- The properties and behavior of each component of the set depends on the properties and behavior of at least one other component in the set [**Interaction, Relationships**].
- The properties and behavior of each component of the set has an effect on the properties and behavior of the set as a whole [**Emergence**].
- Each possible subset of components has the two properties listed previously; the components cannot be divided into independent subsets [**Interdependent**].

Classifying Systems Based on Origin

- Natural Systems are those that came into being by natural processes – without human beings
 - Exhibit a high degree of order and equilibrium: seasons, food chain, water cycle
 - Adapt themselves to maintain an equilibrium with the environment: Organisms and plant life
 - Material flows are cyclic, no dead ends, no waste
- Human-Made Systems are those in which human beings have intervened through components, attributes, and / or relationships
 - Are embedded in the natural world and interface with natural systems
 - Are embedded in human activity systems (e.g., culture, society)
 - Have human-machine interfaces
 - Human decision-making affects performance

The impact of human-made systems on natural systems must be examined carefully; impacts could be positive or negative

Classifying Systems Based on Form

Conceptual Systems are those represented by symbols that describe the attributes of their components; for example:

- Ideas, plans, concepts, and hypotheses
- Mathematical models

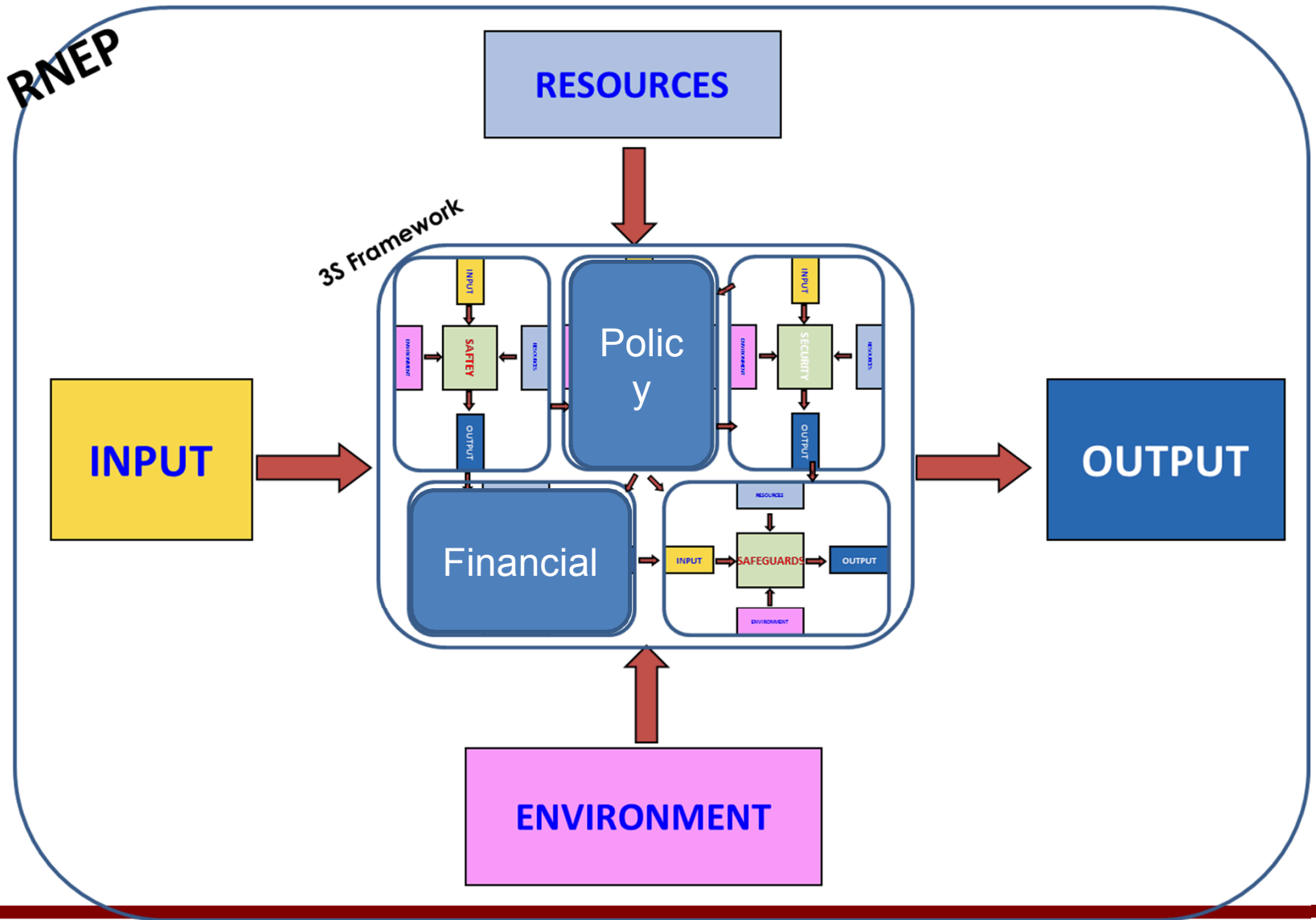
Physical Systems manifest themselves in physical form. They are composed of real components

- Occupy or consume physical space
- Examples: Cars, a Nuclear Power Plant

Classifying Systems Based on Time Dependence

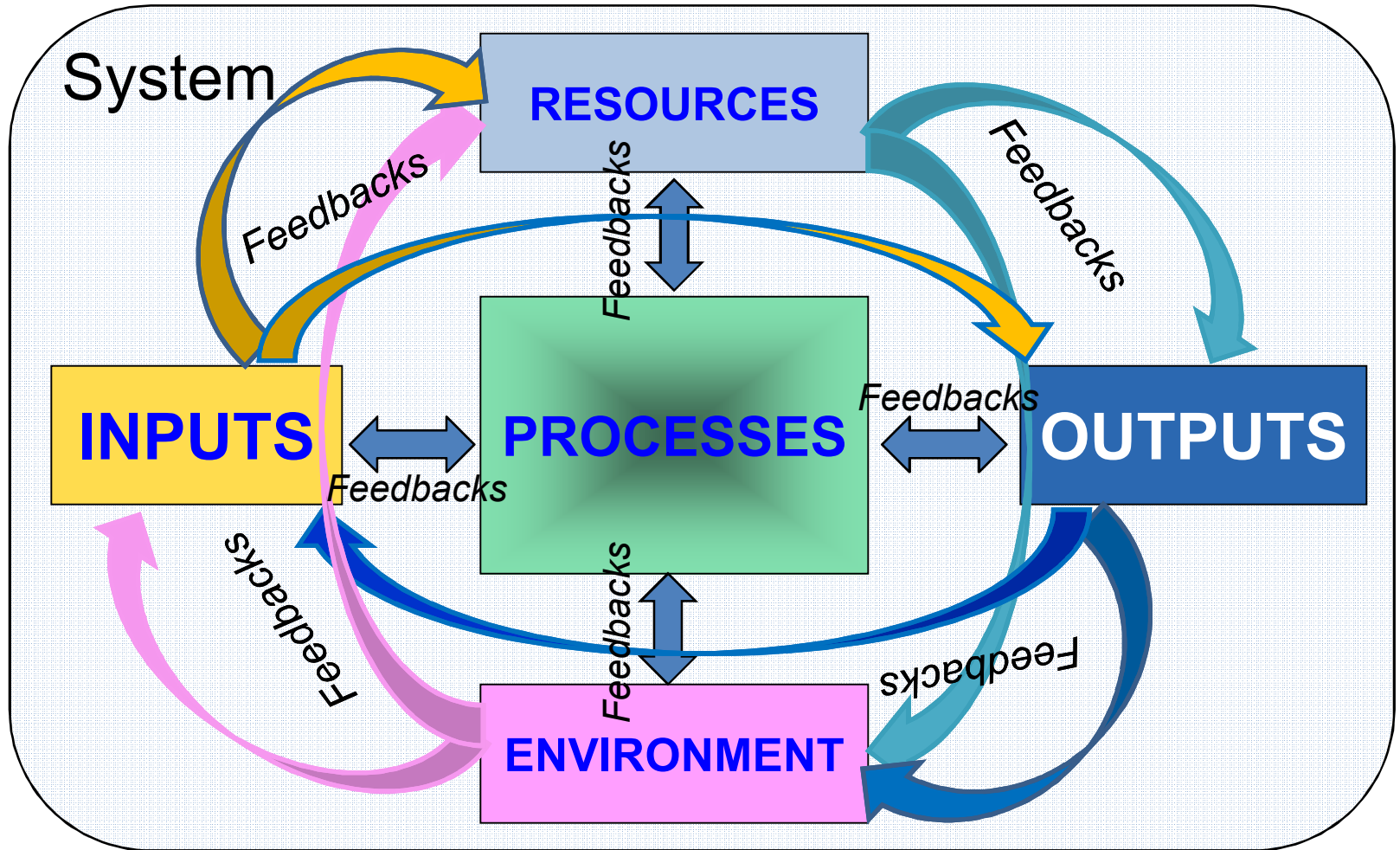
- A static system is one having structure without activity, as exemplified by a bridge
 - Does not rise its height when the water level rises
 - Does not warm itself when ice forms on its surface
- A dynamic system combines structural components with activity. An example is a school: combining a building with Fellows, teachers, books, and curricula.
- [would like to get in the idea of change over time more explicitly]

We may have a system of systems

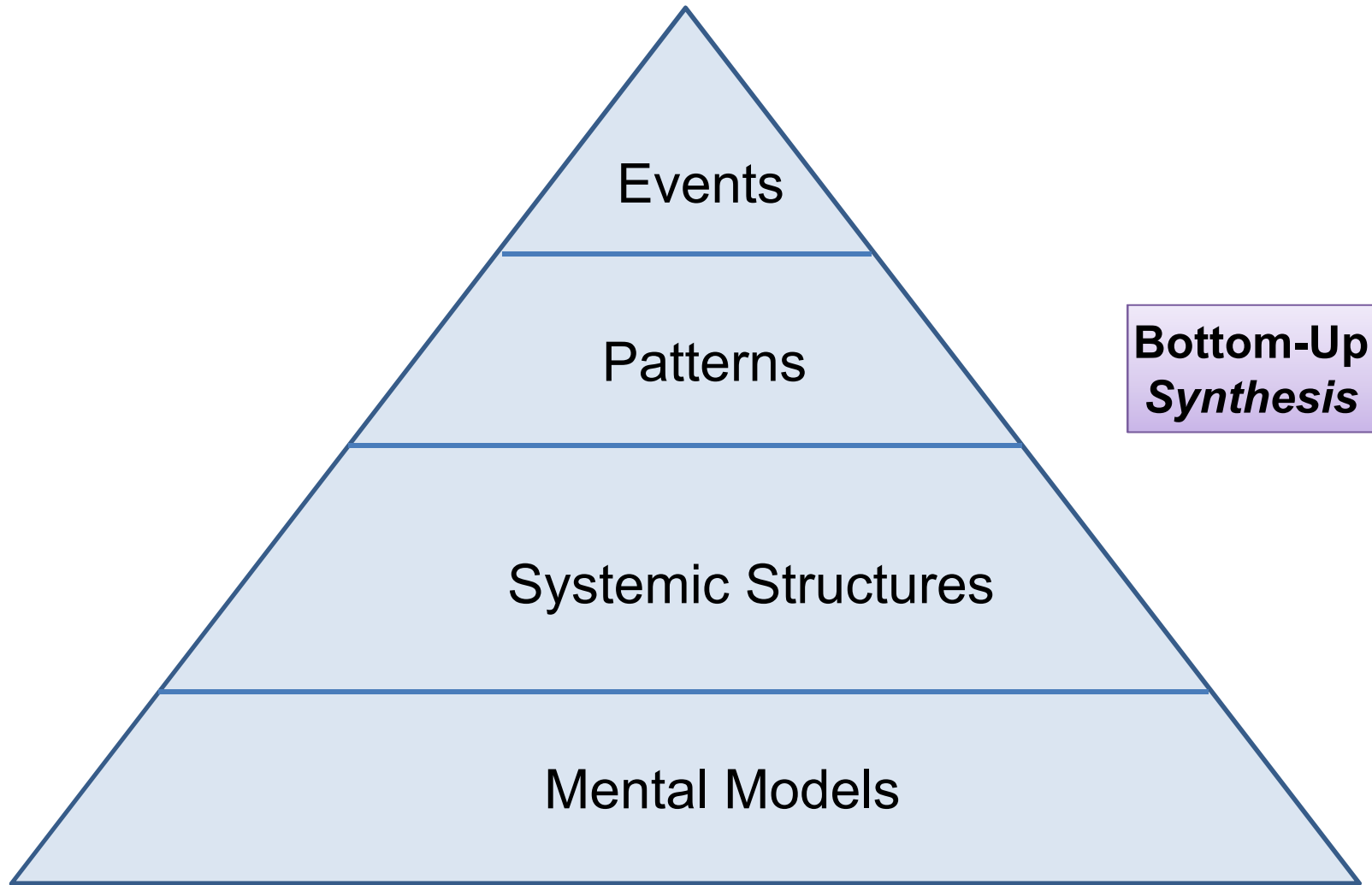


Complex Component / Sub-system Feedbacks

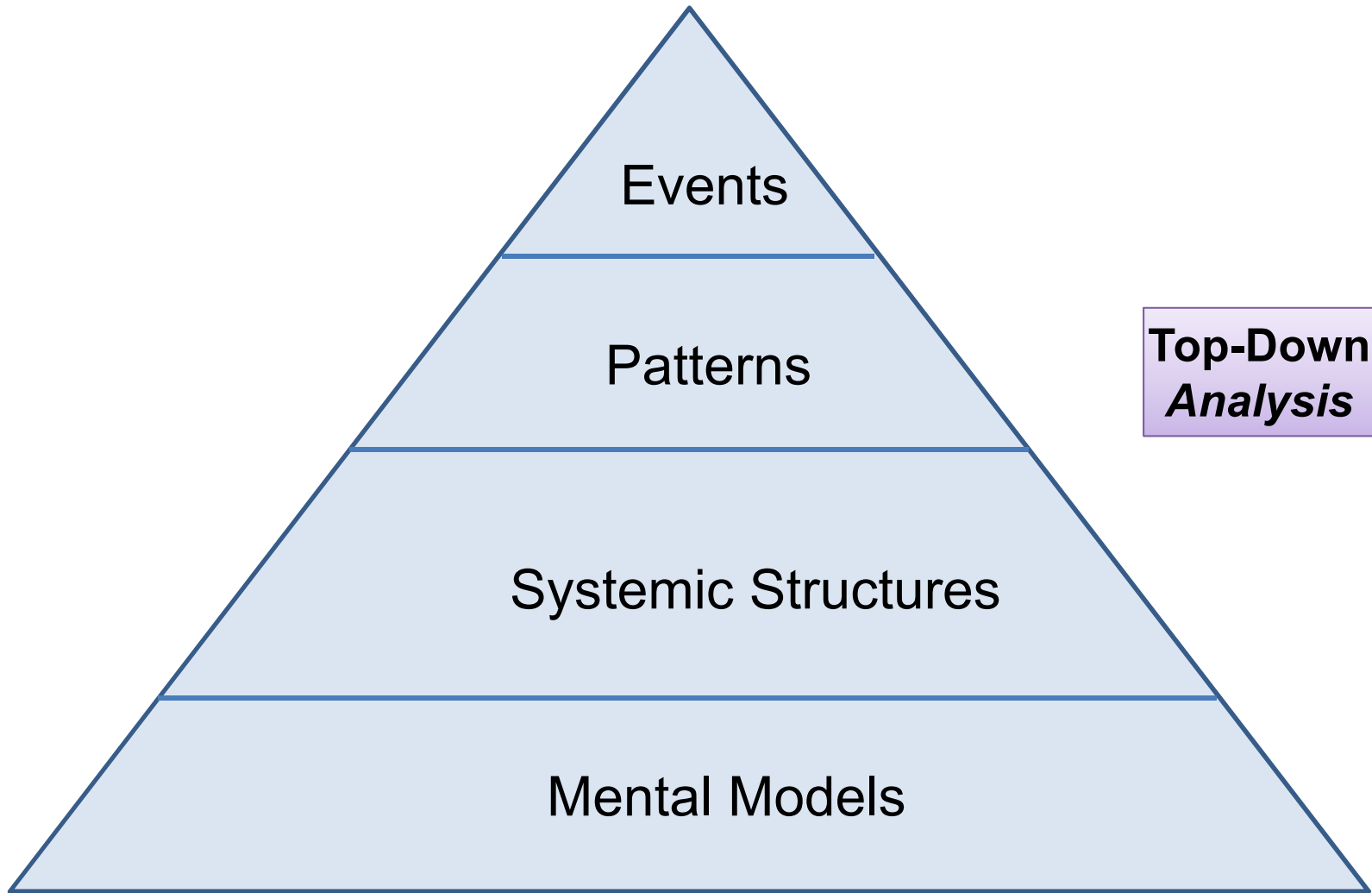
Interactions/Interplays



Another Perspective: Four Levels of Thinking



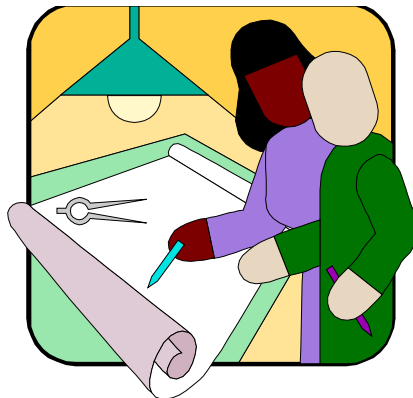
Another Perspective: Four Levels of Thinking



What is The Scientific Method?

The *Scientific Method* is a body of techniques for

- Investigating phenomena
- Acquiring new knowledge, or
- Revisiting previous knowledge



The Scientific Method

The Scientific Method relies on Evidence

Empirical & Measurable

- Systematic observation, measurement, experiment
and
- Formulation, testing, & modification of *hypotheses*
- ✓ Subject to principles of *reasoning*

Apply Critical Thinking Skills

The Scientific Method

How to Start?

- Clearly state the problem
 - Clarity
 - Is this an important or critical problem?
 - Significance
- Can the problem be solved?
- Is the issue focused enough to allow a manageable approach?
 - Precision
- Are interactions with other issues being considered?
 - Breadth

"The greatest challenge to any thinker is stating the problem in a way that will allow a solution."

-- Bertrand Russell

Hypothesis

- A testable explanation for observations and questions about the physical universe.
 - A hypothesis makes a prediction that can be *tested*
 - *Experiment, observation or measurement*

The ability to test a hypothesis is fundamental to The Scientific Method

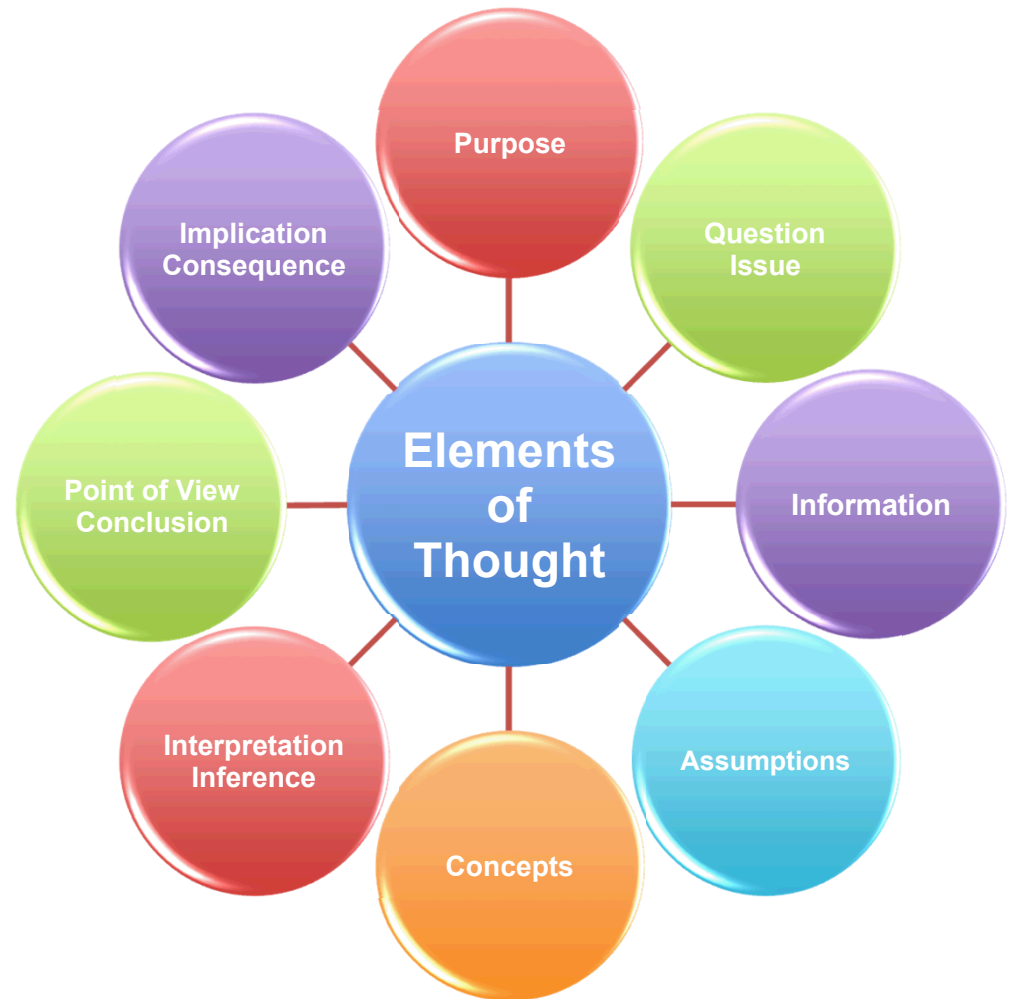
How to Develop a Hypothesis?

- A hypothesis is developed after researching the subject
 - “Educated Guess”
- Develop an understanding of the underlying issues
 - Educate yourself by learning about existing information on the topic
 - Background research
- Hypothesis is a proposal
 - ... that answers the question
 - ... for a solution to the problem
 - That can be tested
 - It makes a prediction
 - Observation, measurement, or experiment *tests* the hypothesis

The key is to
educate oneself
first.

Remember: The Elements of Thought

1. Purpose
2. Question or Issue
3. Information
4. Assumptions
5. Concepts
6. Interpretations *or* Inferences
7. Point of View *or* Conclusion
8. Implication *or* Consequence



The Scientific Method & Critical Thinking

1. Ask a question or state the problem
 2. State a Hypothesis
 - Propose an explanation
 - Testable!
 3. Gather information or data
 - Experiment or Study
 4. Analyze the information
 5. Reach a Conclusion
 6. Re-examine the Hypothesis
 - Revise if necessary
- Purpose
 - Question or Issue
 - Information
 - Assumptions
 - Concepts
 - Interpretations *or* Inferences
 - Point of View *or* Conclusion
 - Implication *or* Consequence

Examining Information or Data

Analysis

an explanation of the whole is derived from explanations of its parts.

Synthesis

something to be explained is viewed as part of a larger system and is explained in terms of its role in that larger system.

Analysis & Synthesis are complementary.

However, synthesis can provide understanding unobtainable through analysis, particularly of collective phenomena.

We will return to these concepts when we examine Systems

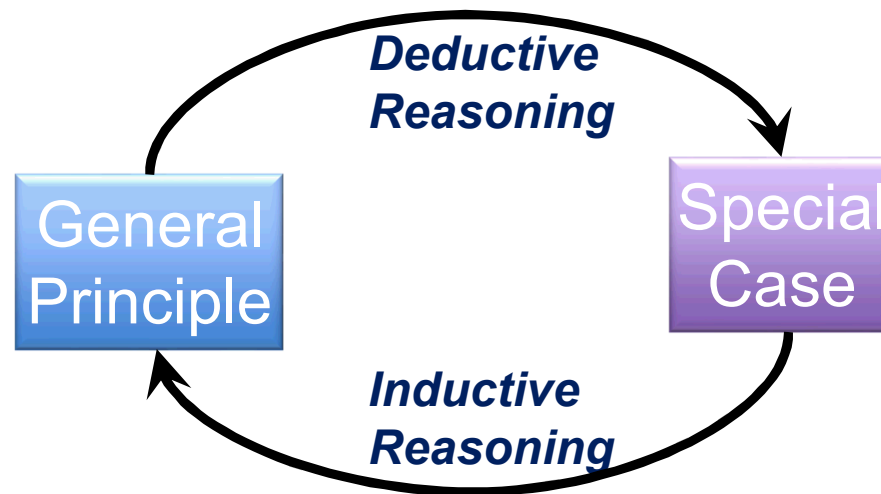
The Scientific Method

Deductive Reasoning

- Draw a specific (narrow) conclusion from a broad concept
 - Categorical
 - Hypothetical
 - Disjunctive

Inductive Reasoning

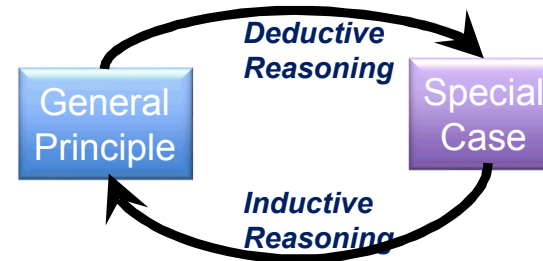
- Use specific instances to infer a broader principle
 - Analogy
 - Causation
 - Generalization
 - Hypothesis



Deductive and Inductive Reasoning

Deductive Reasoning

- Categorical
 - Based on a universal claim
- Hypothetical
 - If/Then
 - if “A” is true, then “B” must follow
- Disjunctive
 - Either/Or
 - Either “A” is true or “B” is true, but not both



Inductive Reasoning

- Analogy
 - Draw (tentative) conclusions based on similarities
 - “A” is like “B” and “B” is like “C”; therefore “A” is (potentially) like “C”
- Causation
 - Determining cause & effect
 - Distinguishing from correlation
- Generalization
 - Inferring from a small sample to a larger population
 - Representativeness & sample size
- Hypothesis
 - Consistency
 - Plausibility
 - Comprehensiveness
 - Simplicity
 - Predictability
 - Testability

The Scientific Method & Critical Thinking

- Important:
We are not trying to prove (or disprove) the hypothesis
 - Be objective: seek the real answer to the hypothesis (based on data)
 - Accuracy
- Gather information that is *relevant* to the problem or question
- Identify cause and effect
 - Independent Variables
 - Dependent Variables
- A valid experiment must be repeatable
 - Precision

Scientific Method: Analyze the Test Results

- Interpret, evaluate, and assess your information
- Show the results of the research
 - Organize and display the results
 - Use Tables, Charts, and Graphs
 - Use all relevant observations.
- Explain discrepancies if possible.
 - Results commonly raise additional questions
 - Might lead to additional research.

The Scientific Method & Critical Thinking

Reporting your Findings

1. Problem Statement

- State the reason for the study
- What question is being asked and why?

2. State Hypothesis

3. Describe your study or experiment

4. Report the data or information

5. Summarize your analyses

- Consider potential challenges & alternative interpretations

6. State your conclusions

- Provide arguments supporting your conclusions
- Review evidence both in favor *AND* against
- If appropriate, provide arguments against opposing views
 - Why do you disagree? Why don't they work?

Synthetic Thinking / Analysis

- **The synthetic mode of thought, when applied to systems problems is called the *systems (analysis) approach*.**
- This way of thinking is based on the observation that, when each part of a system performs as well as possible, the system as a whole may not perform as well as possible.

[Q: Why is that? What is missing here?]

- **This follows from the fact that the sum of the functioning of the parts is seldom equal to the functioning of the whole.**
- **Accordingly, the synthetic mode seeks to overcome the often observed predisposition to perfect details and ignore system outcomes.**

For an Open and Dynamic RNEP (System) we need to “clearly understand the synergy between its components.”

System Analysis - Tools

- Many tools have been developed to help analyze system feedbacks and system optimizations.
 - Mathematical modeling & simulations
 - Sensitivity analysis