The Application of Black Box Theory to System Development

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Abstract

- The concept of black boxes has been around since the early days of systems theory though some attribute the first use to the field of electrical engineering.
  - It is a simple concept and has a straightforward definition: we know the inputs and subsequent outputs to a system but the internal workings of the system are not visible to us.
- In the realm of systems engineering the application of black boxes facilitates discussing a system at an abstract level with a focus on input and output rather than the details of how inputs are transformed into outputs.
  - Despite this frequent usage in practice, there is little written about black box application beyond usage as an abstraction or simple system representation.
  - It is reasonable to say that it is not well understood that black box theory can be extended beyond the basic definition.
- This presentation is an expanded view of black box theory and how it can be used, especially in model-based systems engineering.
- It addresses the following questions: how extensible and scalable is black box theory? In what domains and under what conditions is black box theory valid? When is it not valid? What are its limitations? How can it be improved and how is it used with other theories in a complementary way?

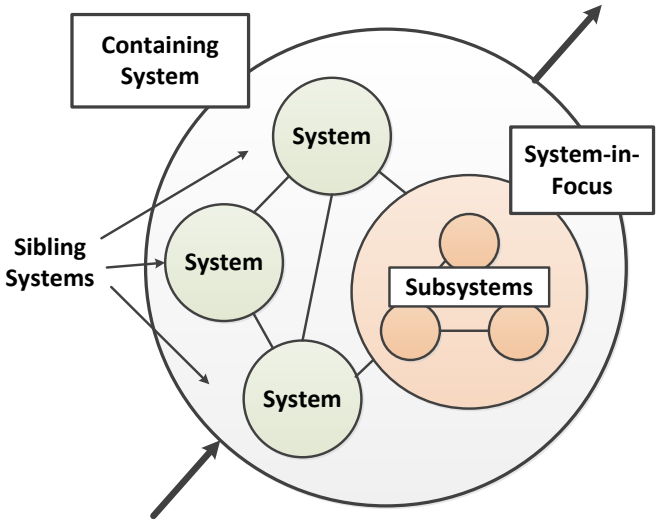
Building The Case For Black Boxes

- The concept of the black box is one of the foundations of systems theory yet black boxes are seldom discussed in the current systems engineering literature.
- The use of black box concepts in systems engineering is generally limited to abstracting out elements of the system design that will be dealt with at a later time.

Key Systems Concepts

- Hierarchy of systems
- Behavior of systems
- System structure
- System boundaries

Hierarchy of Systems



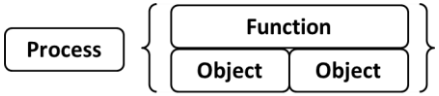
Hitchins' Systems Hierarchy Model (Hitchins 1992)

Behavior Of Systems

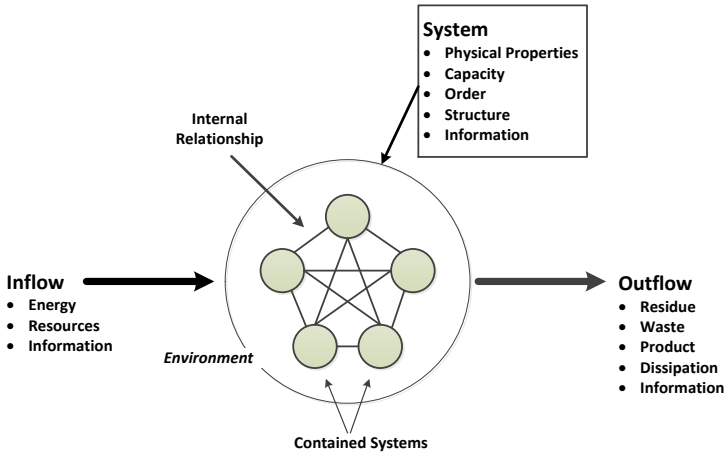
- Checkland notes that an observer can describe system behavior in one of two ways: (1) by focusing solely on inputs and outputs or (2) by describing the system's initial state where the as a black box that contains the requisite transform processes (Checkland 1999).
  - The description of behavior may be either deterministic or stochastic. In addition, the description may reflect the state(s) of the system.
  - This idea plays an important role in the use of black boxes as a tool to describe complex systems and will be discussed further in the section on black box theory.
- Oliver provides two requirements to rigorously describe behavior: (1) the ordering of functions and (2) the inputs and outputs to each function (Oliver 1997).
  - He argues that once the model of desired behavior is developed then it can be mapped to the structural elements.

System Structure

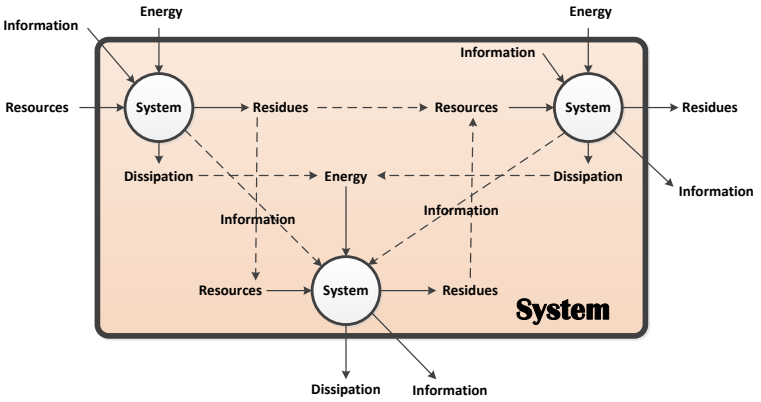
The Process Model



The Relationship between Process, Function and Objects (Langford 2012)

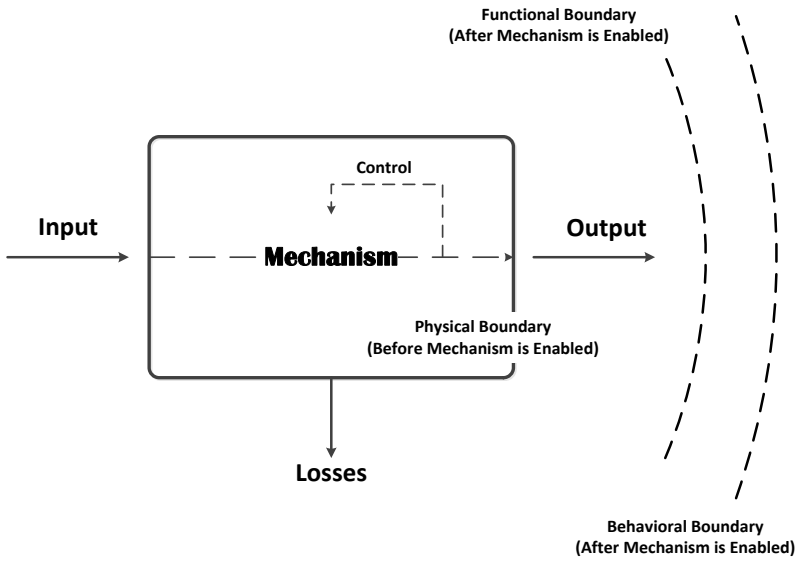


Hitchins' General Systems Model (Hitchins 1992)



. Hitchins' Complementary Set of Systems (Hitchins 1992)

System Boundaries



Langford's Model of Boundaries

Summary of Characteristics

- The four characteristics are what make the black box so useful in analysis and design.
  1. The top level black box is composed of black boxes which in turn are composed of black boxes.
  2. The black box captures behavior through the transformation of inputs into outputs.
  3. This, in turn, gives rise to structure through the allocation of behavior to objects.
  4. Finally, black boxes clearly define system boundaries and, by extension, system interfaces.

Black Boxes And System Design

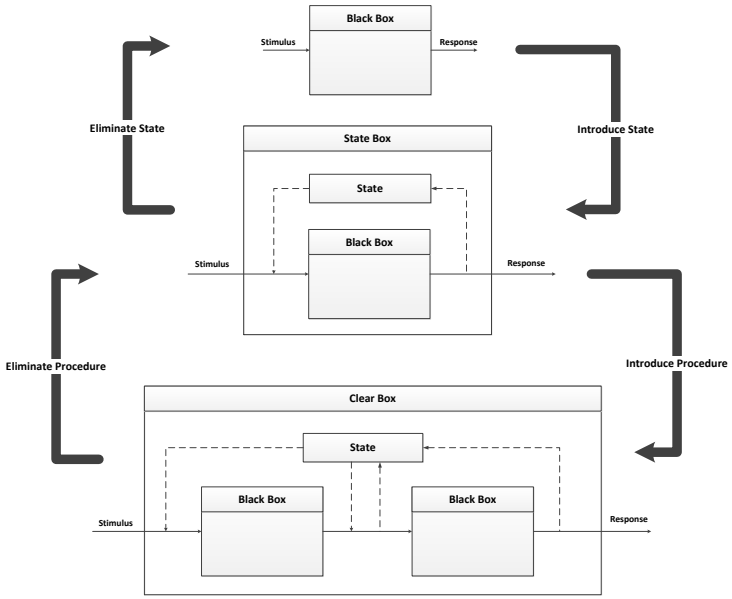
Characteristics of a System	Tools for Analysis
Extreme complexity	Black Box
Probabilism	Information theory
Self-regulation	Feedback principle

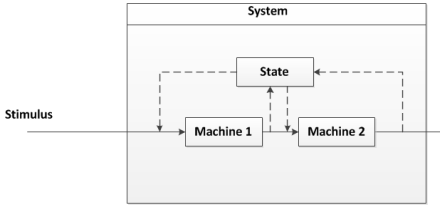
Stafford Beer's System Characteristics versus Analysis Tools.

Black Boxes In Design

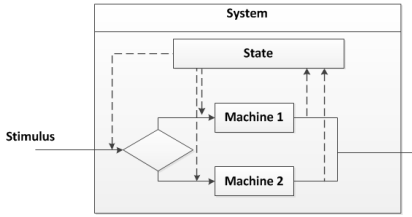
- Page-Jones provided four guidelines as to how black boxes can be used in the system design process.
  1. Each black box should solve one well-defined piece of the problem
  2. Partitioning is done such that each black box is easy to understand; i.e., a function
  3. Partitioning is done only to connect related elements of the problem.
  4. Partitioning should assume that the connections are as simple as possible to ensure the independence of the black box.

Box-structured Methods

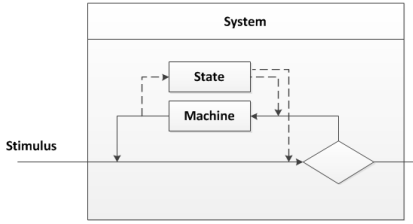




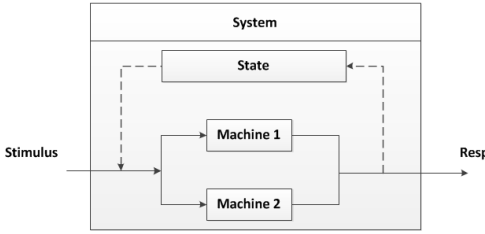
Sequential Control Structure Clear Box



Alternation Control Structure Clear Box



Iteration Control Structure Clear Box



Concurrent Control Structure Clear Box

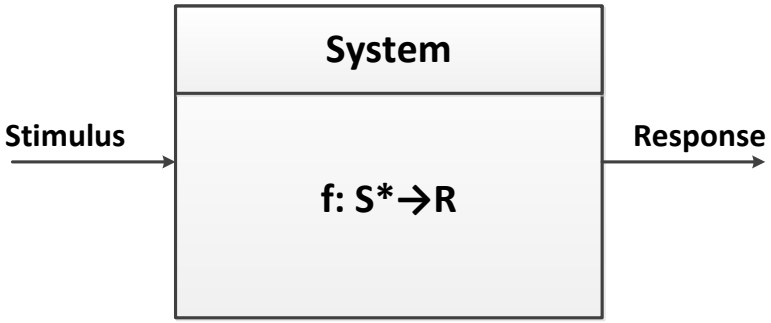
Addressing The Posed Questions

- The preceding slides laid the foundation for accepting black boxes as one of the basic building blocks of systems theory.

- **Therefore black boxes are applicable to all systems.**

How Extensible And Scalable Is Black Box Theory? What Are Its Limitations?

- Formal Methods



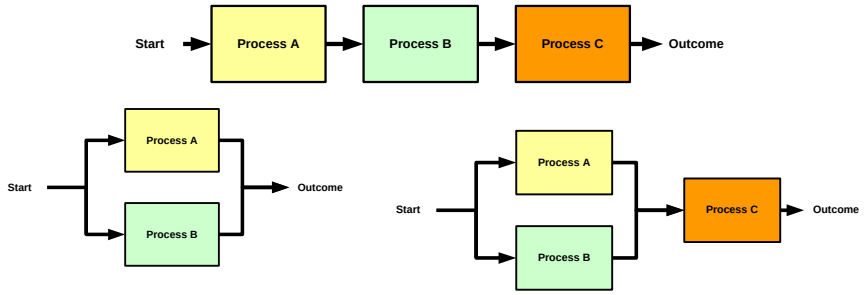
A Mathematical Definition of a Black Box

- Object-Oriented Paradigm

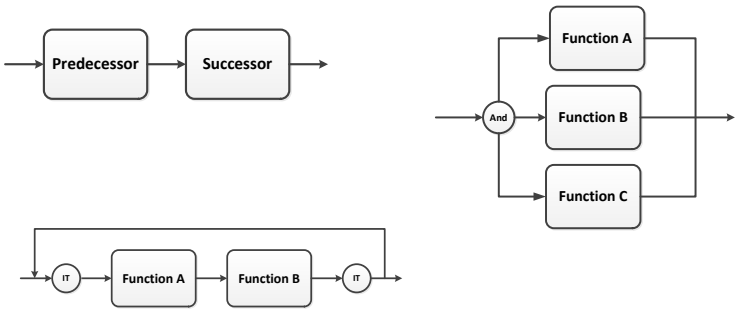
Because the black box abstracts out the "how" it can be used at the highest level to represent the system as well as at the lowest level to represent the smallest object contained in the system.

In What Domains And Under What Conditions Is Black Box Theory Valid? When Is It Not Valid?

- Performance Analysis



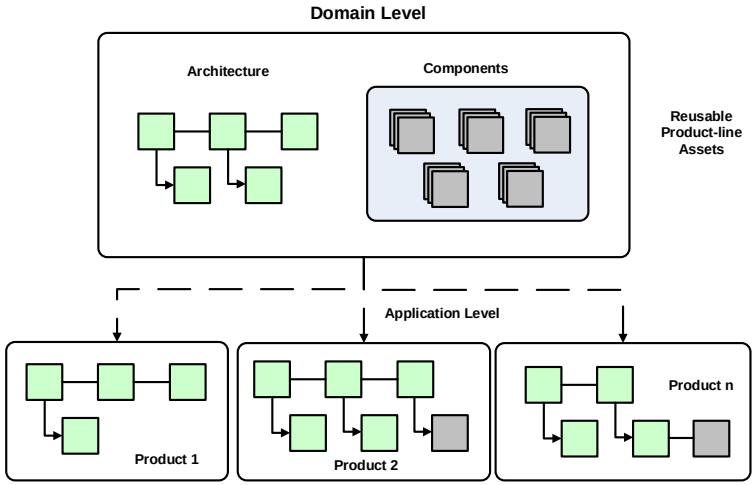
- Functional Analysis (FFBD)



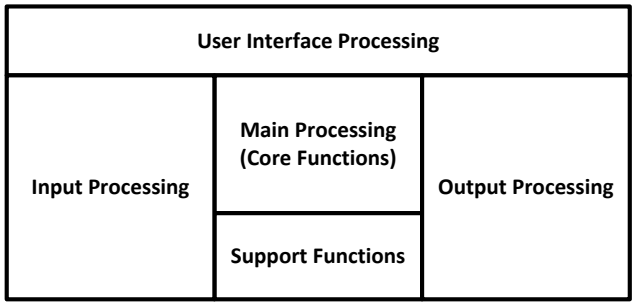
Always Valid!

How Can It Be Improved And How Is It Used With Other Theories In A Complementary Way?

- Integration
- Product Lines



- Hatley - Pirbhai



The Architecture Template

Summary

- It is clear that black box theory is extensible and scalable and is valid in all domains and under all conditions.
- If there are limitations, it is because black boxes are viewed too simplistically.
- Examples were given that illustrate how black box theory fits with other important concepts in systems theory.
- How can it be improved? Through application. The more black-box methods are used, the better the nuances will be understood. Which, in turn, will help to realize the potential of a simple, but powerful paradigm.

Future work

- Two opportunities for future work are the development of a formal systems specification language based on the work of Mills and Hevner and the development of computer-based, black-box tools.
- Mill's and Hevner's papers and book focused on the application of the BDL to information systems.
  - It is a simple but formal language that may well have great value in specifying systems.
- The area of black-box tools is of interest because black boxes are an excellent way to communicate concepts.