

SYSTEMS OF SYSTEMS

In "The Art of Systems Architecting" by Mark Maier and Eberhardt Rechtin, a system of systems is defined as one in which the constituent systems -

1. Fulfill valid purposes in their own right, and continue to operate to fulfill those purposes if disassembled from the overall system.*
2. Are managed (at least in part) for their own purposes rather than the purposes of the whole; the components systems are separately acquired and integrated but maintain a continuing operational existence independent of the collaborative system.*

Two key characteristics which derive from this definition are:

Emergence: Properties which do not belong to any of the constituent parts will emerge from the combined system of systems.

Evolution: The system of systems will change over time as constituent systems are added, retired, or replaced.

Due to advances in system automation, systems of systems are an ever increasing reality of our world. Left unmanaged, a system of system will slowly evolve into an extremely complex, and often very fragile, entity. The support costs surrounding these entities are huge and can become serious burdens to an operation.

CASE EXAMPLE: MANUFACTURING

Generation	Description	Physical Appearance	Software Infrastructure
Generation I	Manual Production		
Generation II	Computerized Test		
Generation III	Test Executive		
Generation IV	Process Center		
Generation V	Enterprise		

Production lines begin as manual operations. The introduction of a computer to automate various tasks hallmarks the second generation. The third generation is marked by the introduction of an application, the test executive, to manage the automated tasks. The test executive is both powerful and expensive which drives a desire to reuse it for different products and product generations. This moves into the fourth era - the process center. The production line is now a system of systems with an life independent of the products it is producing. It is now economically feasible to invest in advanced features, such as robotic automation. On the flip side, critical components, such as the operating system and programming language, age and become obsolete. This is a critical stage in the life of a manufacturing operation. The desire is to move to the

enterprise generation where a full collage of systems brings a rich production ability spanning multiple geographies. However, the inability of the process center to smoothly evolve over time may become a crippling hobble to the business.

CASE EXAMPLE: THE INTERNET

The Internet is the classic example of a system of system done well. It is in a constant state of growth and flux as computers and web sites come and go, yet it continues to provide the richest source of information on the planet. For this research, the solutions being developed by the Internet community and key both approach and application.

AN EVOLUTIONARY ARCHITECTURE

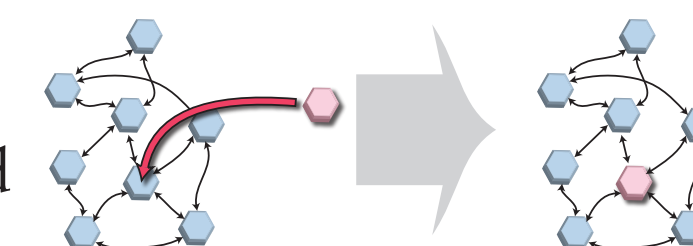
An evolutionary system of systems architecture will be defined as one which conforms to the following two principals:

1. The complexity of the system of systems framework does not grow as constituent systems are added, removed, or replaced.
2. The constituent systems do not need to be re-engineered as other constituent systems are added, removed, or replaced.

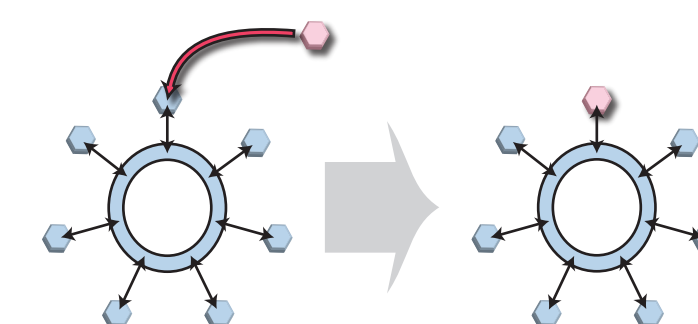
An evolutionary architecture will have three components: standards, interfaces, and automated verification/validation abilities.

STANDARDS

An unmanaged system of systems will develop a wide variety of interfaces between each of the constituent systems. This makes replacement extremely difficult as it requires updating all of the connected systems as well as the replaced system. It is therefore critical to select or design common standards.



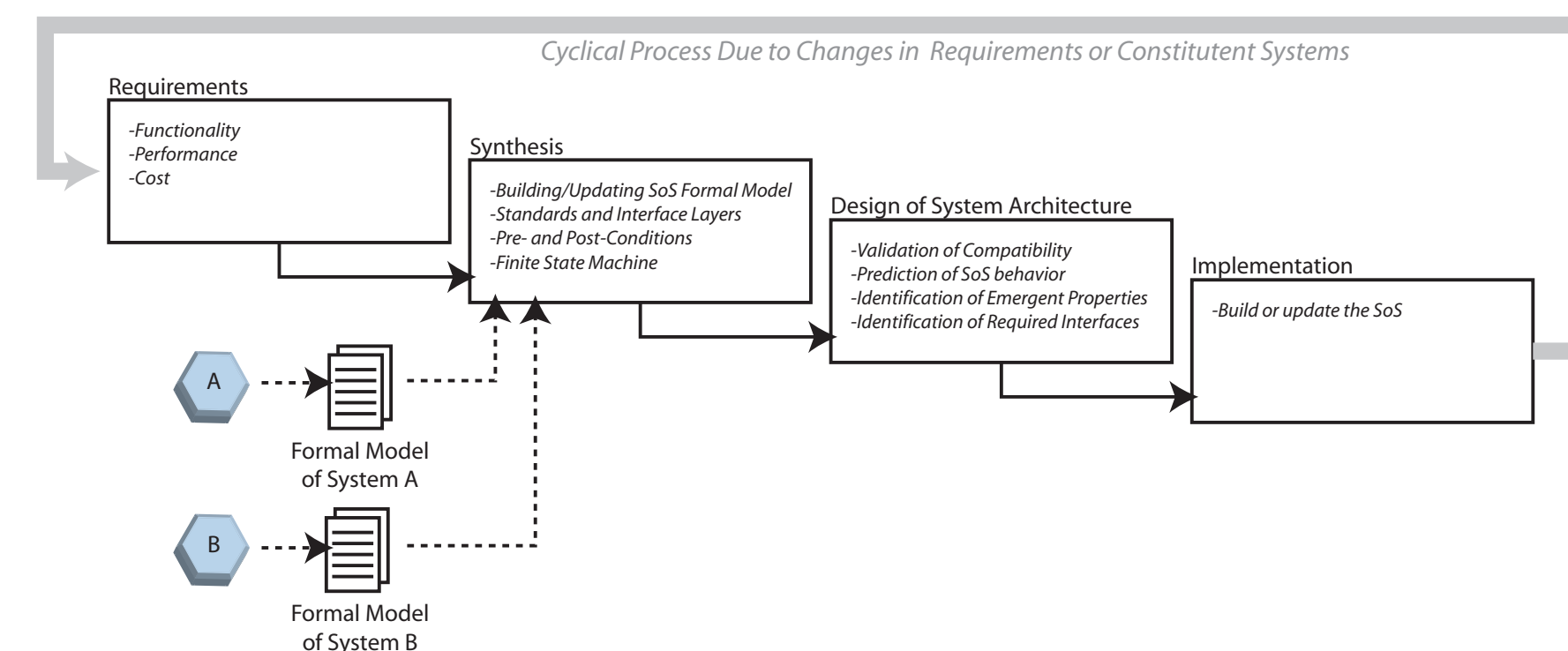
INTERFACES



While insisting on a single standard interface is huge advantage, in practice it is neither a complete solution nor realistic. For example, the old systems may be compatible with the new, but they need to be told of the new. Secondly, standards change over time. Thus, some sort of interface layer or system is required.

AUTOMATED VERIFICATION AND VALIDATION

Good long-term support strategies for systems of systems need to employ a "continual system verification and validation process" as an integral part of ensuring design correctness, preventing the managed system evolution straying from its intended pathway, and containing recurring costs both in money and time. Ad-hoc approaches to system of systems analysis are limited by the size and complexity of problems that are tractable. Since this is not always the case, formal approaches are needed.



The verification and validation is a cyclical process which will start with the formal representations of requirements, goals, and the constituent systems. It will then need to synthesize the model for the system of systems. The design of the systems of systems will then need to be tested for correctness. Then the design can be implemented with a high degree of confidence.