The Role of Modeling and Simulation in Coordination of Health Care

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Overview

- To address the role of M&S in Coordination of Health Care we ask
  - Why Does US Health Care need Coordination?
  - Ideas for Fixing The Health Care System – Porter's Value-based Health Care and Pathway-based Coordination
- Then we provide some needed technical background:
  - System Theory and System-of-Systems (SoS)
  - Discrete Event Systems Specification (DEVS) modeling and simulation framework
  - DEVS SoS formalization of Value-based Coordinated Care
- And then present the:
  - Role of the MS4 Modeling and Simulation Environment in implementing and improving Value-based Coordinated Care

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Health Care Reform – A Systems Problem

- US healthcare system, the most expensive in the world,
  - Serves 350 million people with no central control (single payer)
  - an assemblage of **fragmented, loosely coupled, uncoordinated** subsystems embedded in a market economy (Workshop of HC Experts)
  - promotes fee-for-services without reference to the **end-to-end** quality of care and cost delivered to patients.
- President's Council advocates that the U.S. health care industry should adopt **a systems-engineering approach** to improve overall quality and delivery of care
- Improving the health care sector presents a challenge in that the optimization cannot be achieved by sub-optimizing the component systems, but must be directed at the entire system itself.
- An ideal (optimal) health care delivery system will require methods to model **large scale distributed complex systems**.

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US healthcare system consumes 1/3 of Budget. Why?*

- **Medical professionals are smart, work very hard, but are narrowly trained.**
  Example: Clinical trial mindset, control all but variables of interest
  Not trained to cope with complexity of integrating numerous coupled interventions
  Not trained to collaborate in teams

- **System is bad, not the people**
  Doesn't allow them to succeed
  The usual reasons for failure don't apply
  Competition doesn't work: Zero sum - cost shifting

  Value-based health care is the right goal i.e., value not cost
  Positive outcome is more critical than efficiency
  Healthier patients, get them recovered faster, with better functionality
  Positive sum - value everyone benefits

- **Value-based purchasing vs cost-based purchasing**

- **Central driver of value improvement is universal outcome measurement**
  Only 2 examples in US: Organ transplants, in vitriol fertilization

* Michael Porter on Paving the Way for Value-Based Health Care

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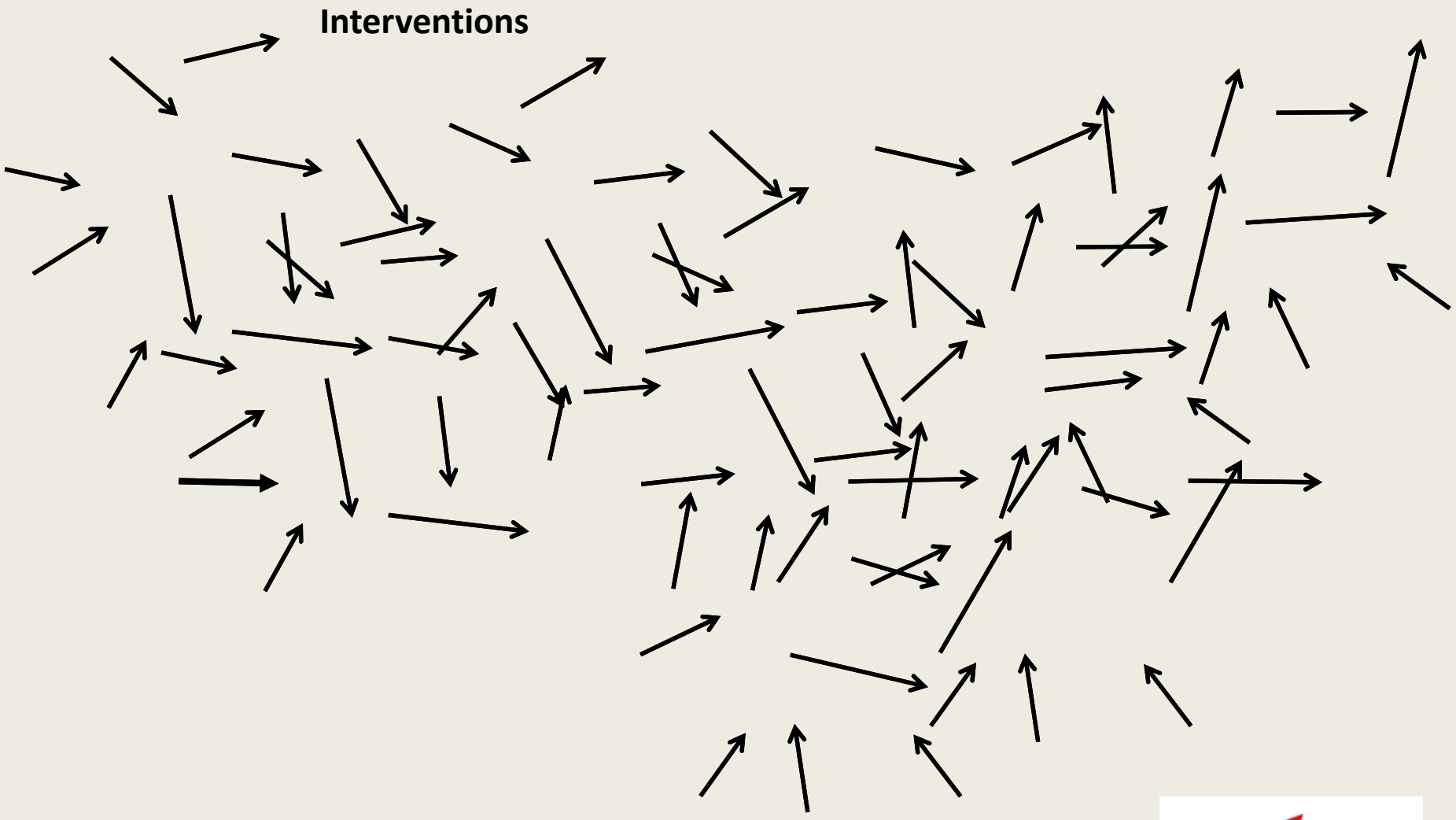
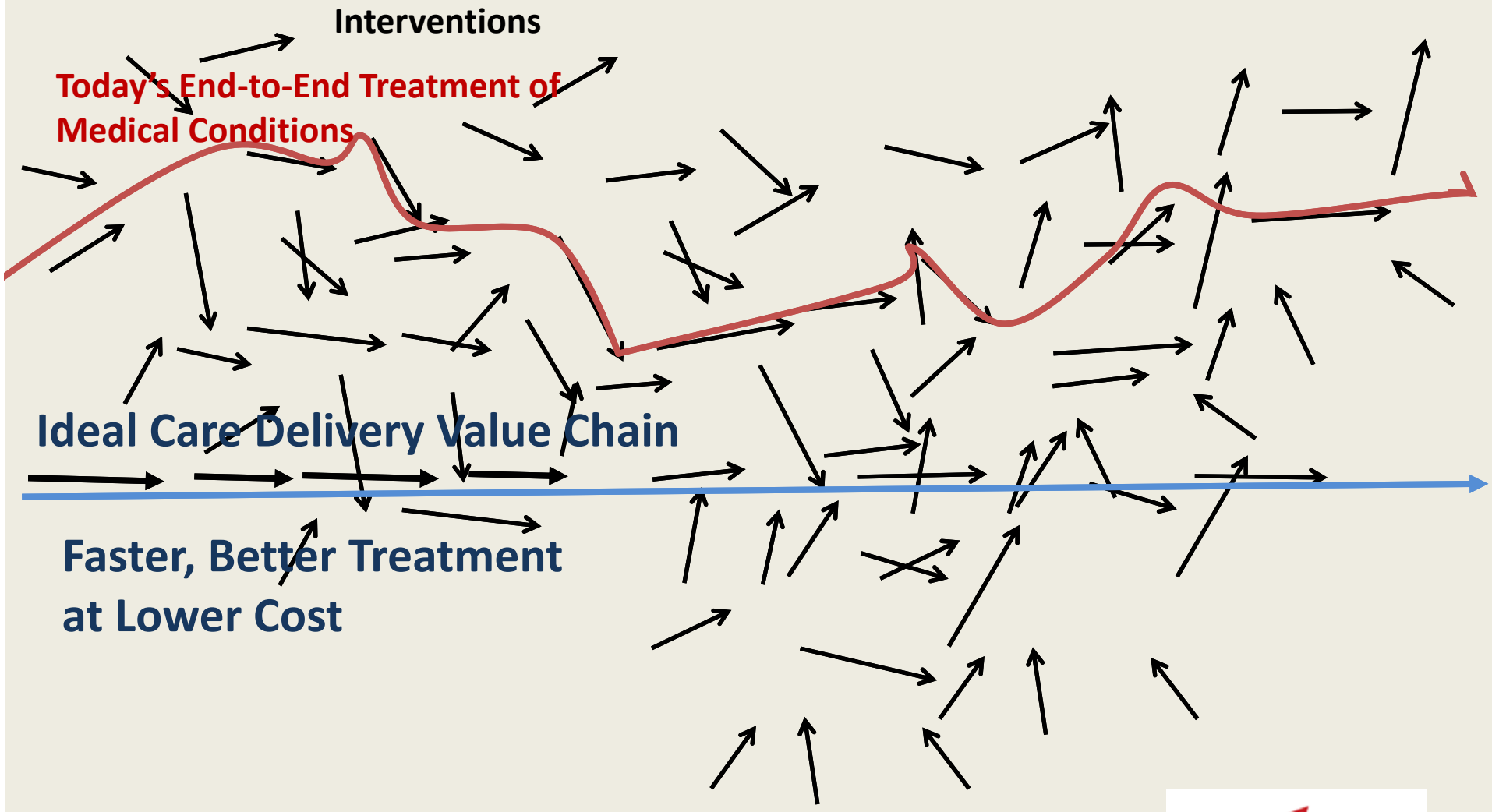
Visualizing the Current State of US Healthcare



Visualizing the Current State of US Healthcare



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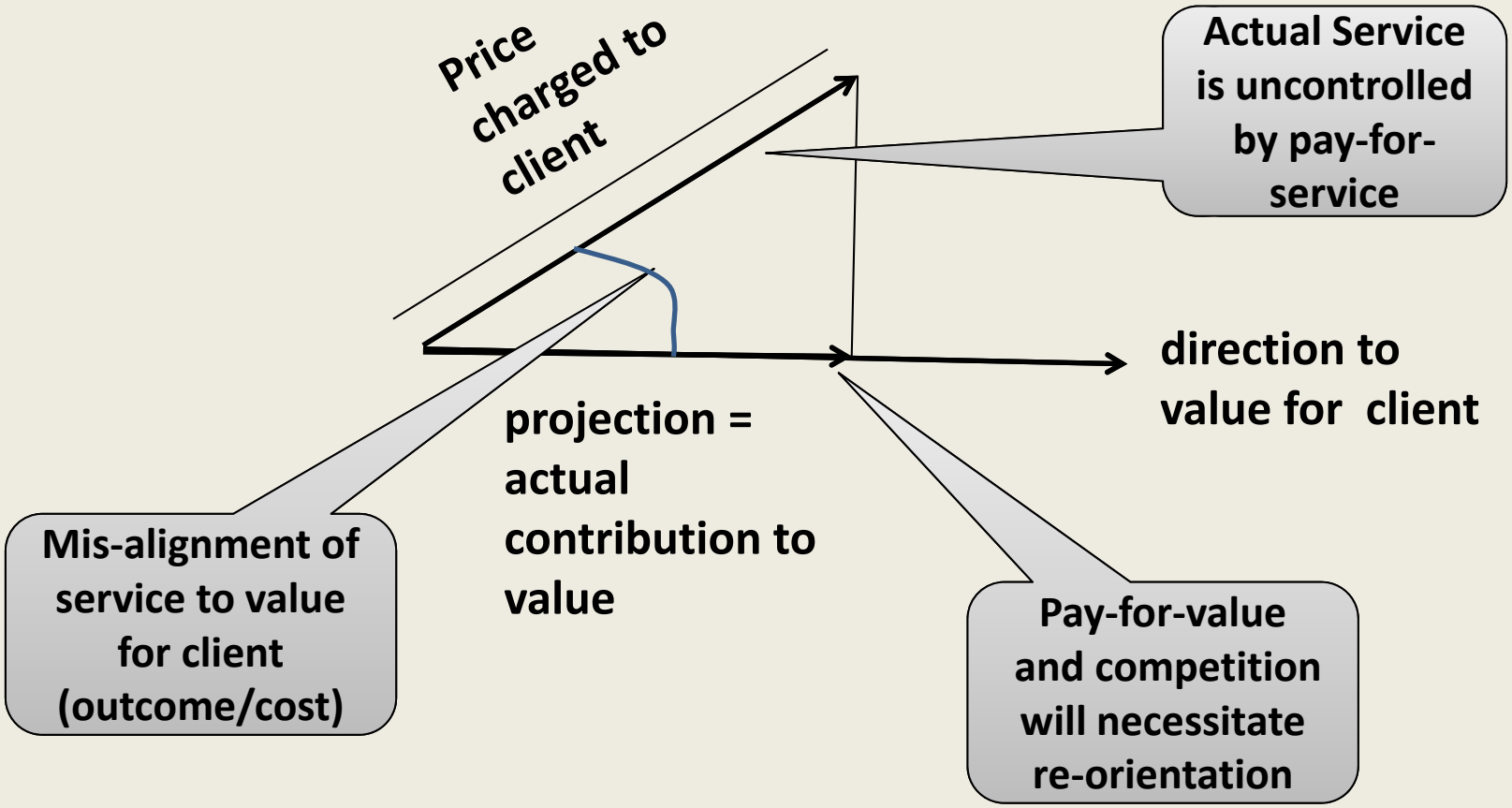
Vector Dot Product Analogy
for Alignment of Service to Value for Client



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Need an Organizing Principle

Two working candidates:

- Porter's Integrated Practice Unit
  - Organization at physicians' practice level
  - Does not scale
  - Requires too much integration
- Pathways Community HUB Model
  - Coordinated care at community level
  - Pathways provide coordination not integration

So combine both into one organizing concept

- Value to consumer = Outcome/Cost
- Care Delivery Value Chain
- Outcome Measurement Hierarchy
- Pathways Coordination Model
- Monitoring, Tracking, Guiding Individuals – Feedback
- Applicable to clinical and extra-clinical care

Ideas From Porter

Implementation By Pathways*

*Zeigler, B.P. et al. Pathways Community HUB: A Model for Coordination of Community Health Care, Population Health Management, V17, 2014

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Care Delivery Value Chain For Coordinating Interventions

- Integrated/Coordinated interventions oriented around a specific medical condition
- Well-defined sub-segment of Full Cycle of Care
- Care Delivery Value Chain (CDVC)
  - The set and sequence of activities are aligned with value - generally value should increase and cannot decrease, later activities cannot have lesser value than precursors.
  - Taken together, the activities must achieve the desired outcomes
  - The activities have the right scopes to cover the target medical cluster of conditions and to minimally overlap
  - The activities form a coherent whole with seamless handoffs from one to the other – this will ultimately minimize process delays and “dropping the baton”

Knowledge Development						
Informing						
Measuring						
Accessing						
Monitoring						
	Preventing	Diagnosing	Preparing	Intervening	Recovering/ Rehabilitating	Managing

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Fixing Health Care Systems

- Model Health Care as System of System (SoS)
- Develop Coordination Models for SoS
- Apply DEVS-Based Modeling and Simulation Methodology
- Develop Implementations and applications to demonstrate effectiveness
- Expand scope to other areas in need of similar coordination

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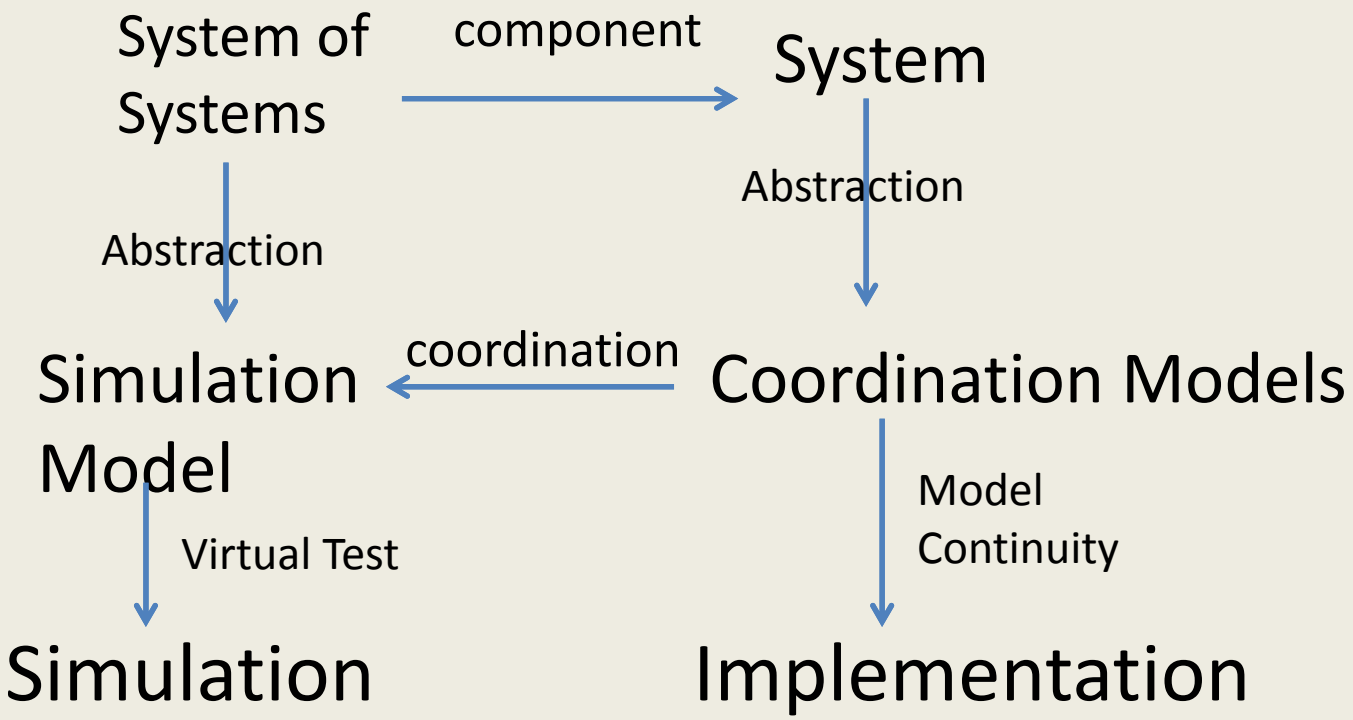
SoS Coordination Development Methodology



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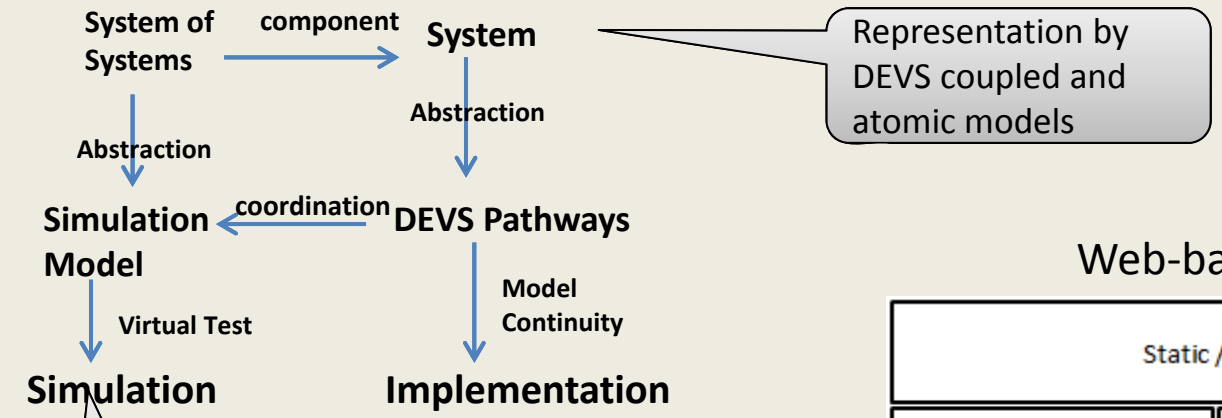
DEVS-Based SoS Coordination Development Methodology

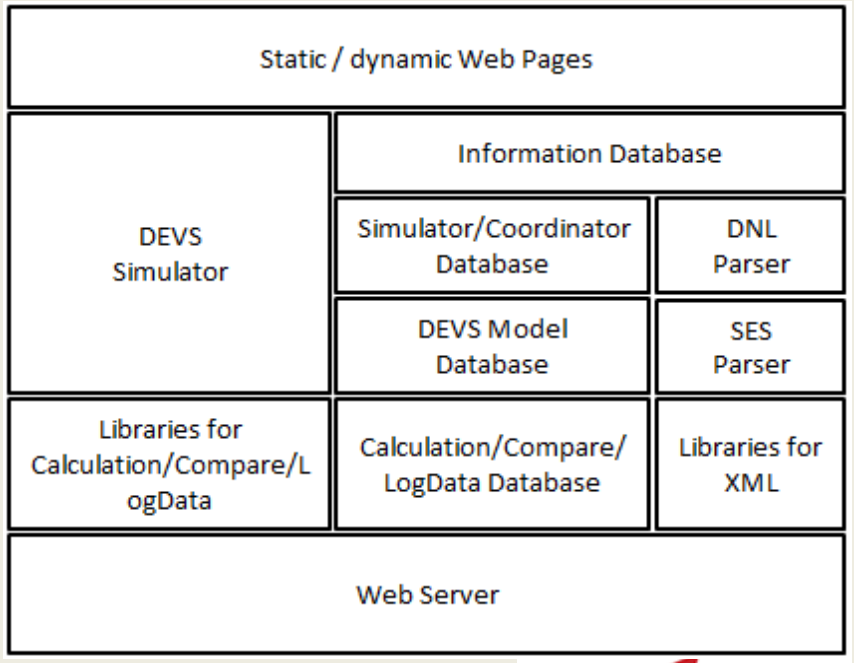


Representation by DEVS coupled and atomic models

DEVS Modeling and Simulation Environments

MS4 Systems provides DEVS-based Integrated Development Environment (IDE) http://ms4systems.com/

Web-based Pathways System



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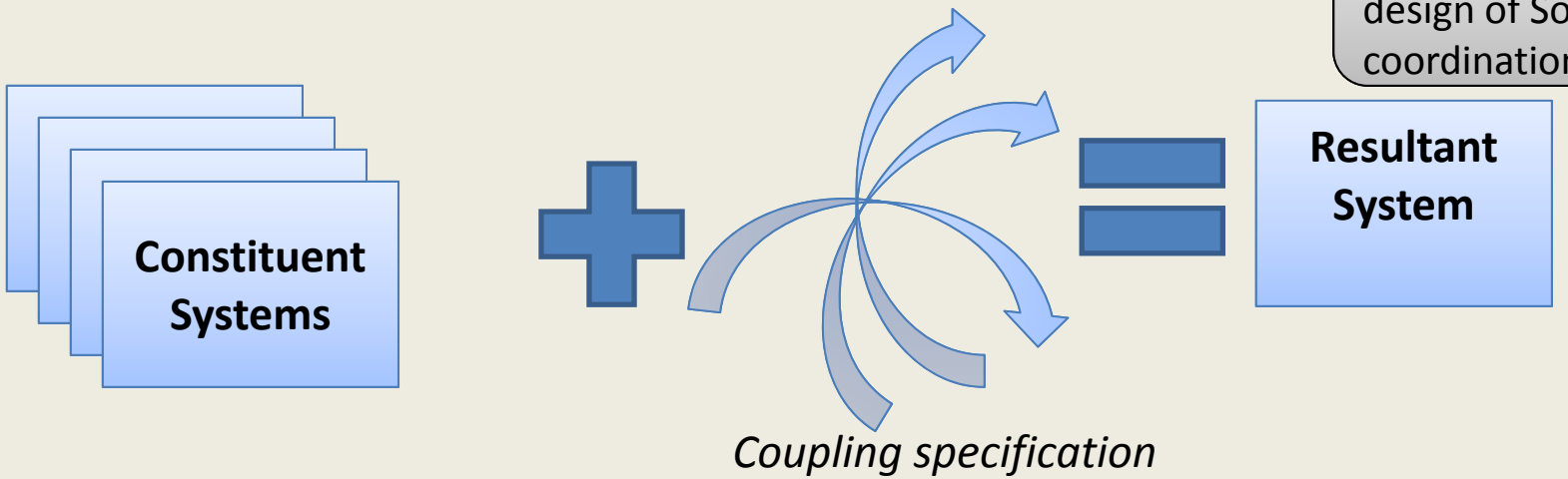
Wymore's Mathematical System Framework*

- **Composition of Systems** – *constituent systems* and *coupling* specification result in a system with structure and behavior emerging from their interaction
- **Closure under coupling** – resultant is a well-defined system just like the original components

Will show how this can help in design of SoS coordination



*Tuncer I. Ören and B. P. Zeigler, "System Theoretic Foundations of Modeling and Simulation: A Historical Perspective and the Legacy of A. Wayne Wymore", SIMULATION September 2012 vol. 88 no. 9 1033-1046

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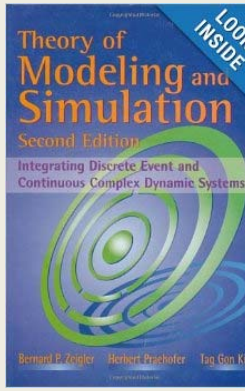
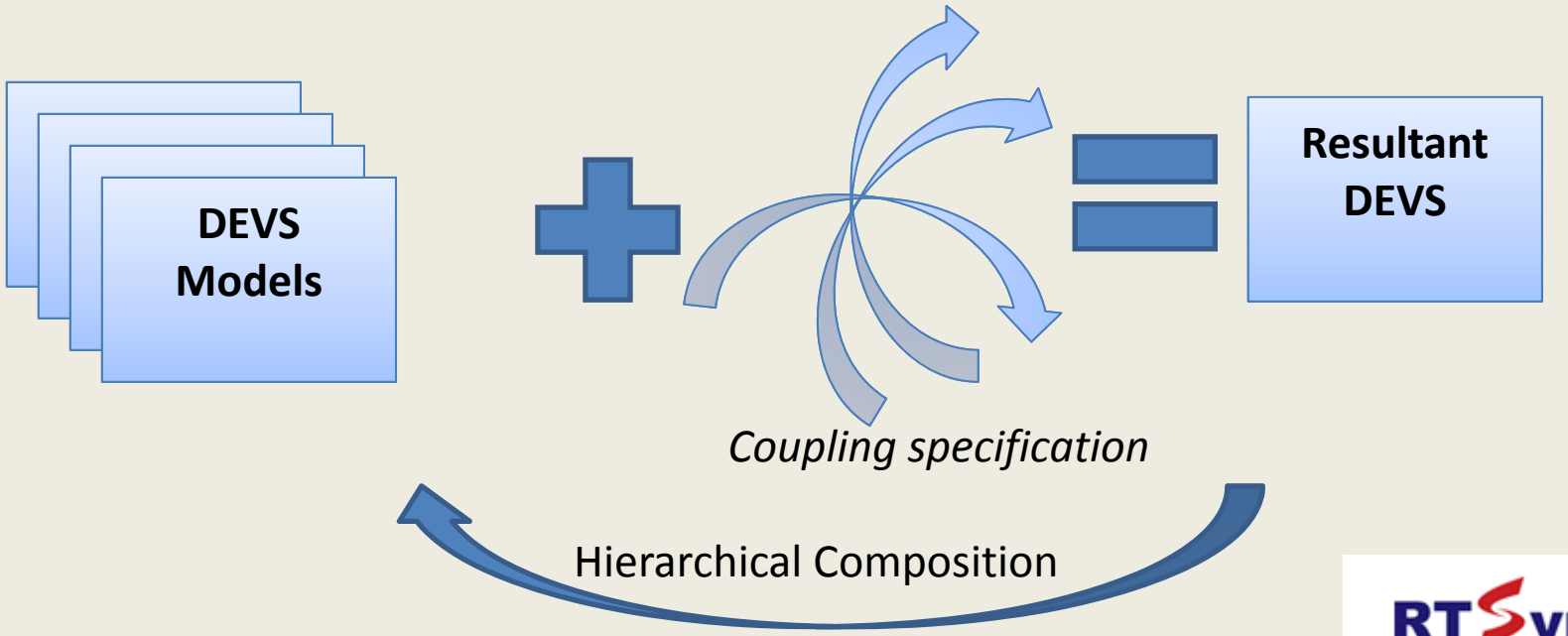
Discrete Event System Specification (DEVS) Formalism



- **DEVS Atomic and Coupled Models** specify Wymore Systems
- **Composition of DEVS Models** –*component D*EVS and *coupling* result in a DEVS with structure and behavior emerging from their interaction
- **Closure under coupling** – resultant is a well-defined DEVS just like the original components



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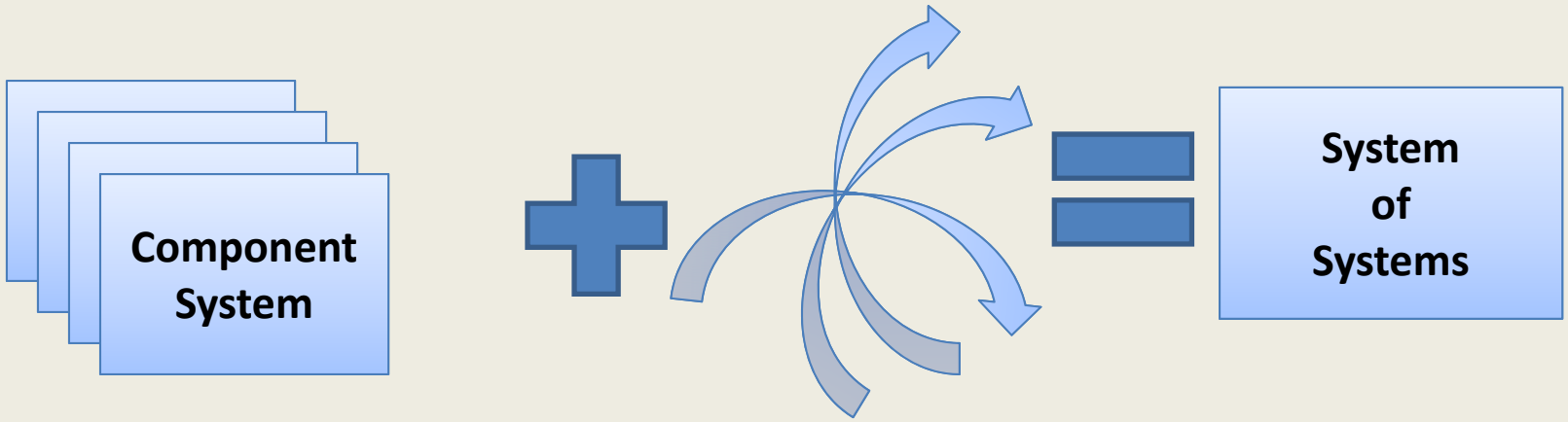
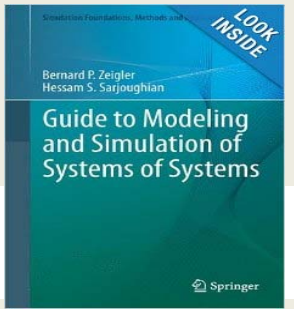
MS4 Systems DEVS IDE Support of Systems of Systems*



Coupling specification

- **System of Systems (SoS)** – composition of systems - *component systems* have legacy properties e.g., autonomy, belonging, diversity
- **Coupling** has properties e.g., connectivity, coordination
- **Structural and behavioral properties** characterize resulting SoS with properties such as fragmented, competitive, collaborative, coordinated, etc.



* Guide to Modeling and Simulation of Systems of Systems, Bernard P. Zeigler and Hessam S. Sarjoughian, Springer; 2013 edition (December 28, 2012)

DEVS Pathways

- Pathways are event-based control mechanisms that can orchestrate services of disparate providers to achieve a client's goal.
- A Pathway is a sequence of steps that can check for sub-goal achievement in real-time and progress from step to step only upon confirming such achievement.
- Pathways coordinate actions among multiple users that interact with the client
- Pathways measure, track and monitor individual progress
- Pathways collect and aggregate data to provide analytics for overall supervision and management
- Pathways are dynamic processes and can be combined to accomplish more complex client goals
  - The Pathways Monitor can start up/spawn additional pathways based on
    - time-scheduled actions – active calendar
    - contingent on actions taken or not taken
    - passage of time
    - as a result of data collected during pathway execution

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Expression of Pathway as DEVS Atomic Model: Instance of Formalization and Implementation

An *Atomic Pathways model is a* DEVS

AtomicPathway = $(X, Y, S, \delta ext, \delta int, \lambda, ta)$

where

X is the set of inputs;

Y is the set of outputs;

S is the set of *sequential* states;

$\delta ext : Q' X \rightarrow S$ is the *external state transition function*;

$\delta int : S \rightarrow S$ is the *internal state transition function*;

$\lambda : S \rightarrow Y$ is the output function;

$ta : S \rightarrow \Re 0+ \cup \infty$ is the *time advance function*;

with $Q = \{ (s, e) \mid s \in S , 0 \leq e \leq ta(s) \}$

is the set of *total states*.

Formalize

Definition of Set and Functions

$X = Answers \cup \{ Activate \}$, $Y = Queries \cup \{ Activate \}$

$S = \{s_0, s_1, s_2, s_3, \ldots s_N\} \cup \{Success, Failure, Incomplete, End\}$

$ta(s_0) = \infty$

$\delta ext\ (s0\ ,,e,\ Activate) = s_1$

$\delta int(s_i) = s_{i+1}$ $ta(s_i) = 0$ $\lambda(s_i) \in Queries$

$\delta ext(s_{i+1},,e,ans) = s_{i+2}$ *for ans* $) \in Answers$

$ta(s_{i+1}) = T_{i+1}$ $\delta int(s_{i+1}) = Incomplete$

$\delta ext(s_N,,e,ans) \in \{ Success, Failure \}$

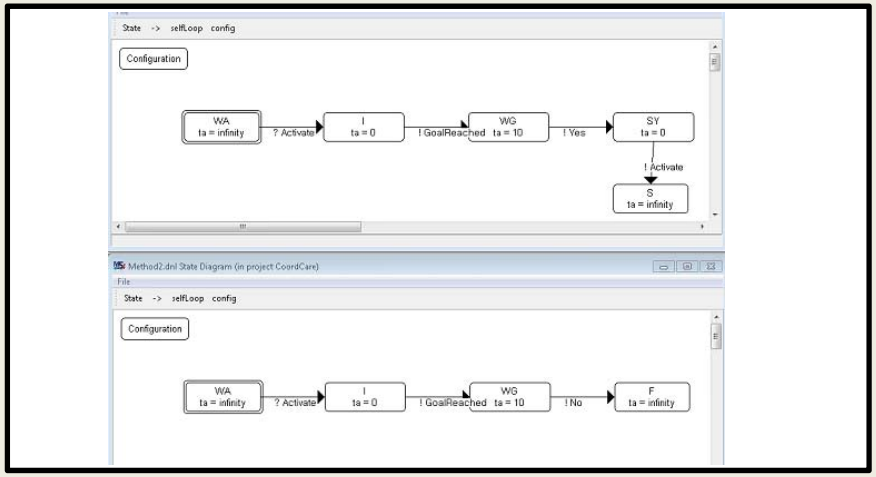
$ta(s_N) = T_N$ $\delta int(s_N) = Incomplete$

$ta(Success) = 0$ $\lambda(\ Success\ ) = Activate$

$\delta int(Success) = End$ $ta(End) = \infty$

$ta(Failure) = \infty$ $ta(Incomplete) = \infty$

Implement



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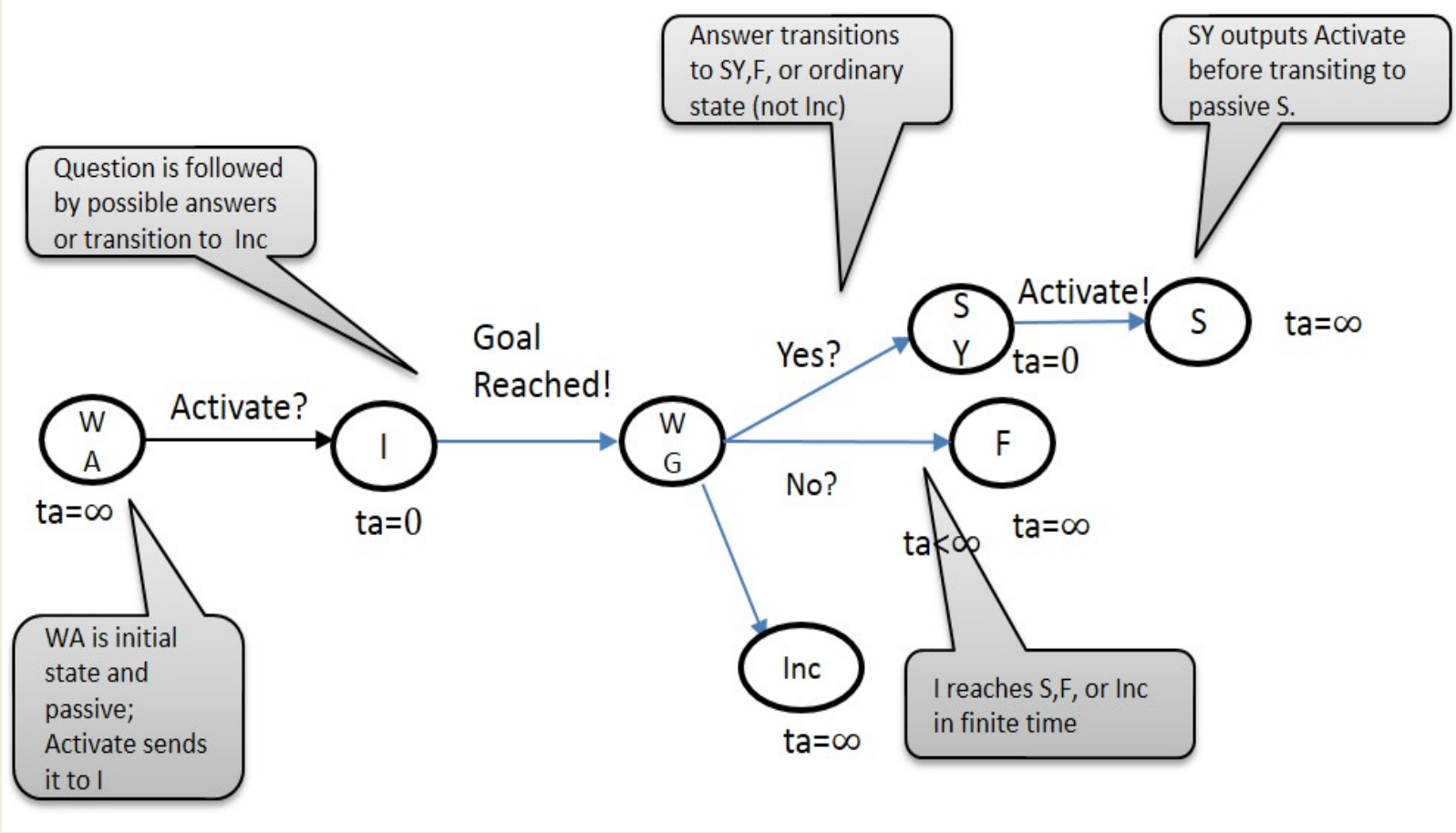
Example: Single Q&A Pathway Model



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Pathways for Coordination

- Can design pathways to represent coordination processes.
- Coupling atomic pathway models can coordinate the behavior of multiple concurrent pathways.
- DEVS closure under coupling will assure that the resultant is a DEVS model.
- More than that, the resultant is also expressible as an atomic pathway model, establishing **closure of pathway models under coupling**.
- The following property is proved for such **closure**:
- **Finite Termination Property**: For any pathway model, there is a finite time *T*, such that the model or all its components reach, and passivate, in any one the three types of states: Success, Failed, or Incomplete within time *T* after initialization.

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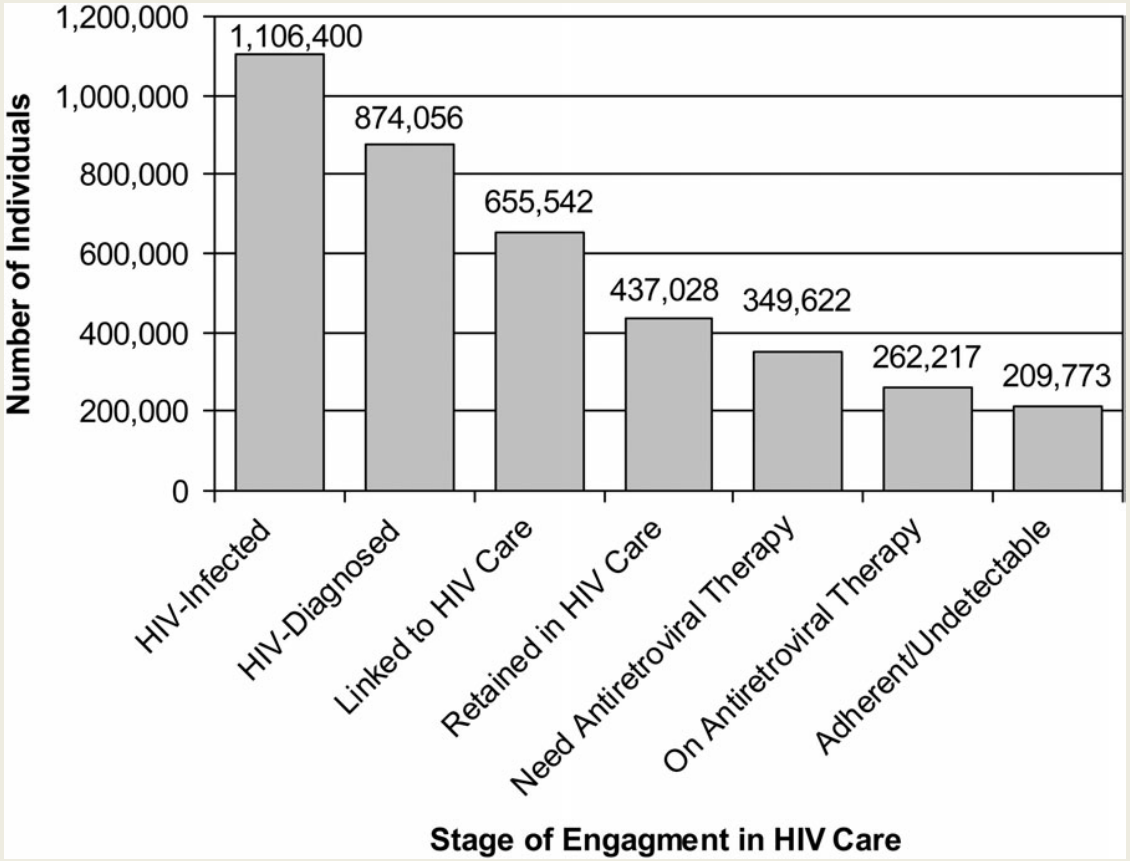
Pathway Coordination Example Application:

Drop-off of Untreated Patients at Stages of Engagement in HIV Care



The Spectrum of Engagement in HIV Care and its Relevance to Test-and-Treat Strategies for Prevention of HIV Infection . Edward M. Gardner,et al., Oxford Journals Medicine Clinical Infectious Diseases Volume 52, Issue 6 Pp. 793-800

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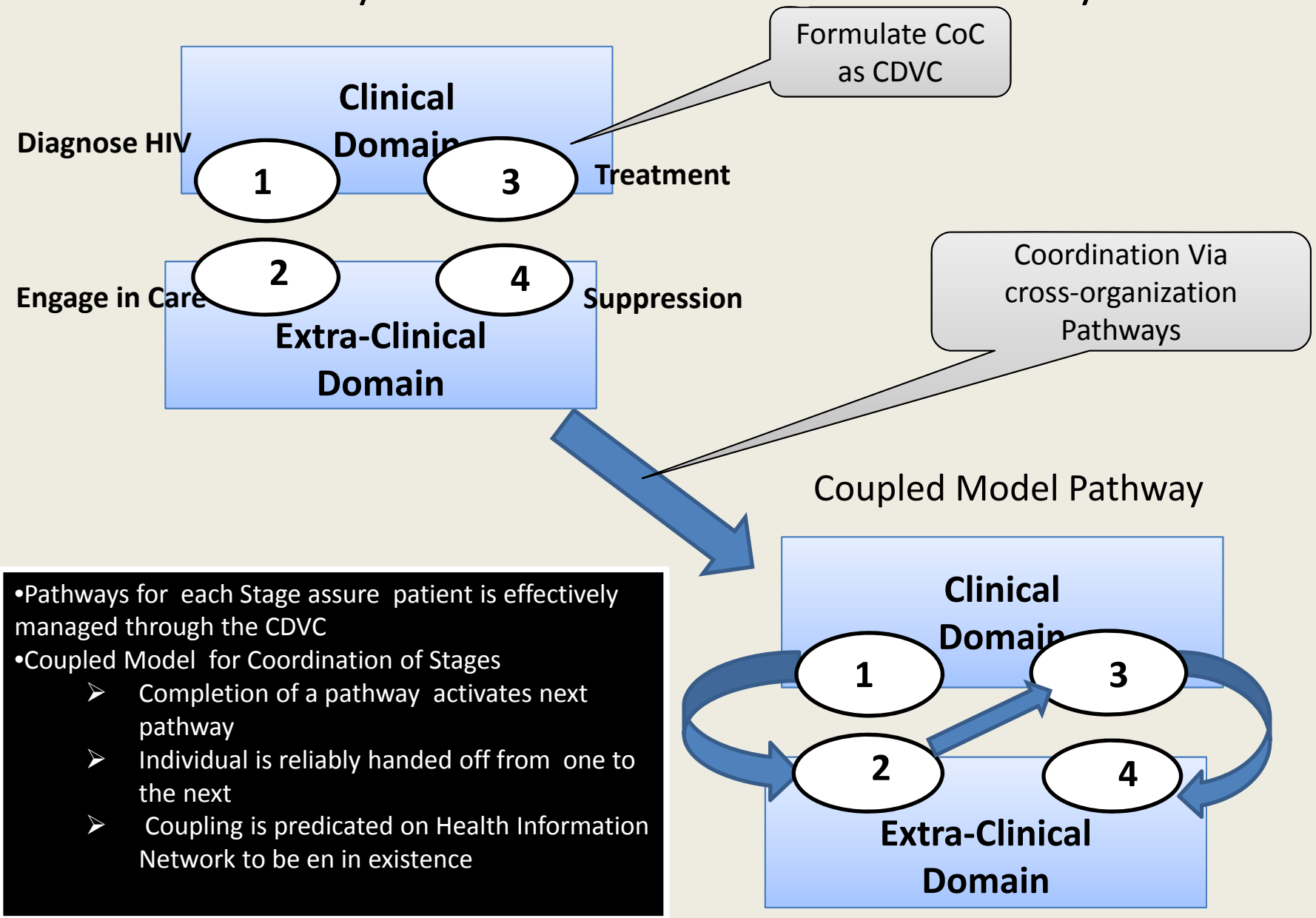
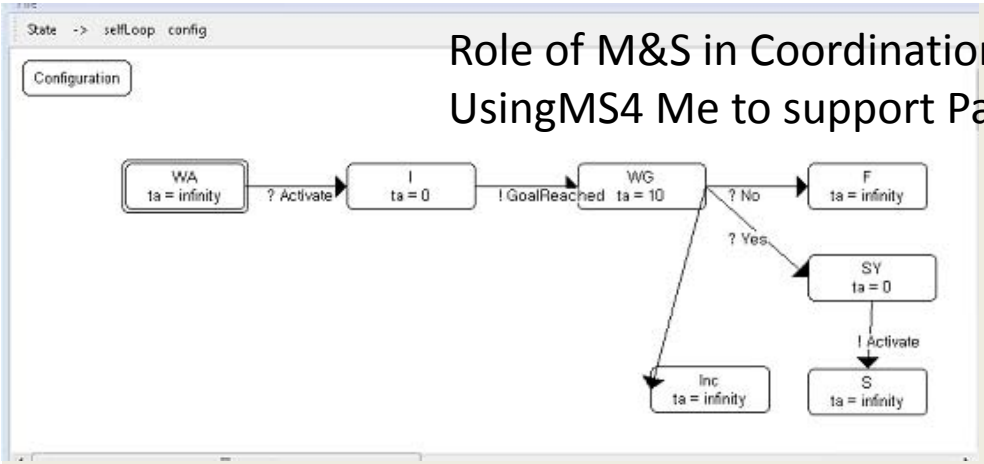
Pathways Coordination of HIV-AIDS Continuity of Care



- Pathways for each Stage assure patient is effectively managed through the CDVC
- Coupled Model for Coordination of Stages
  - Completion of a pathway activates next pathway
  - Individual is reliably handed off from one to the next
  - Coupling is predicated on Health Information Network to be en in existence

Role of M&S in Coordination of Health Care:
UsingMS4 Me to support Pathways Design and Implementation

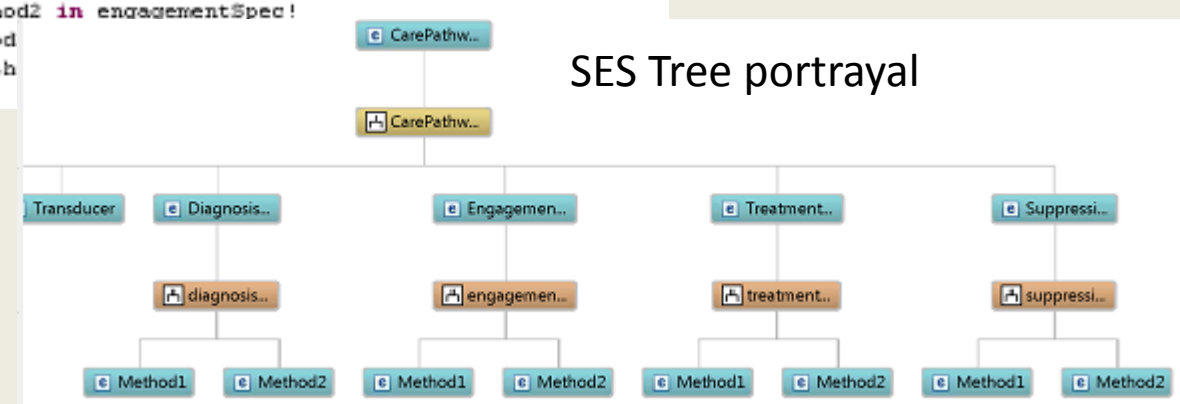


State Designer of Pathways

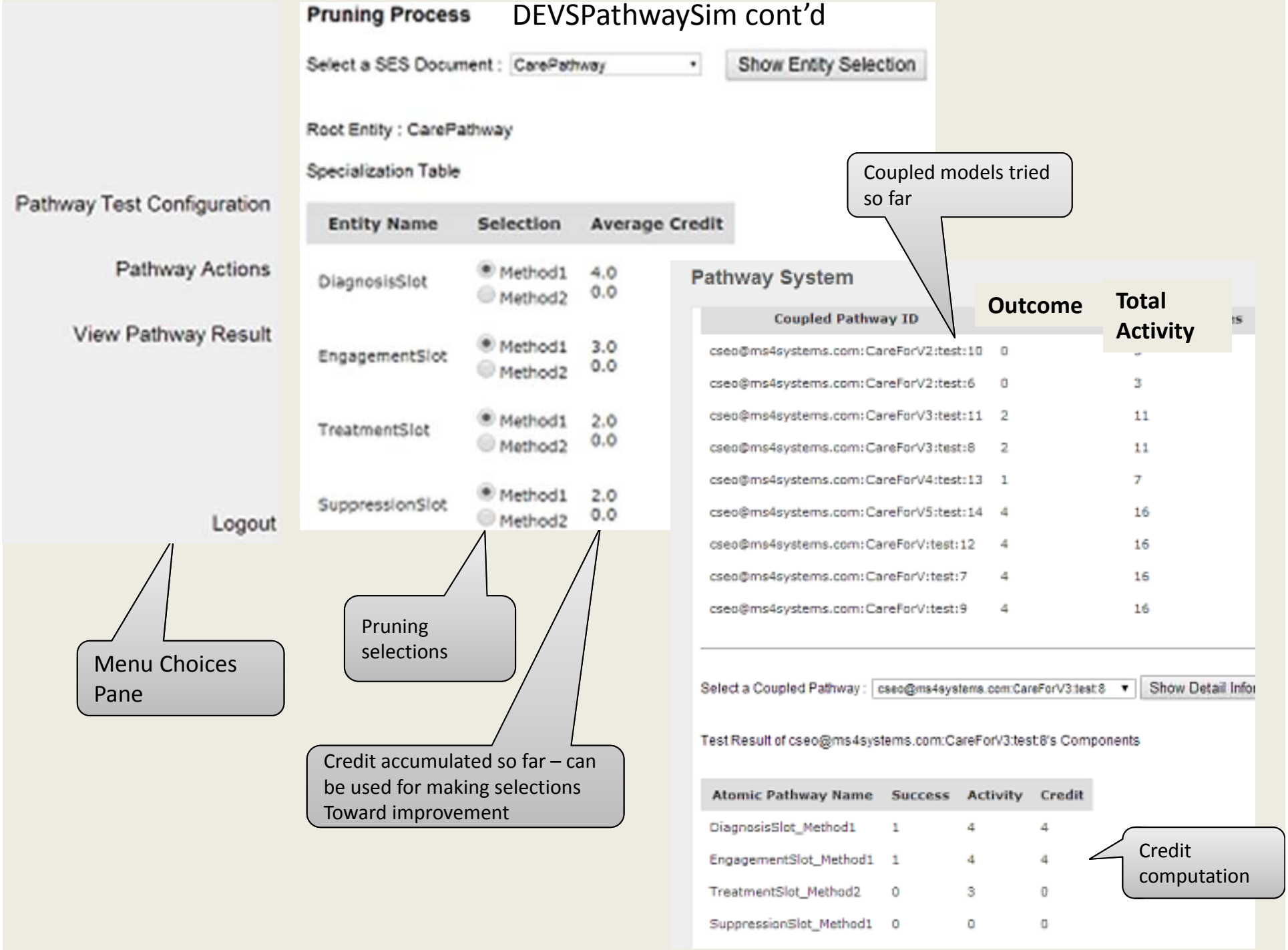
```
From the CarePathwaysys perspective, CarePathway is made of  Generator, Transducer,
DiagnosisSlot, EngagementSlot, TreatmentSlot, and SuppressionSlot!
From the CarePathwaysys perspective, CarePathway sends start to Generator!
From the CarePathwaysys perspective, Generator sends Activate to DiagnosisSlot!
From the CarePathwaysys perspective, DiagnosisSlot sends Activate to EngagementSlot!
From the CarePathwaysys perspective, EngagementSlot sends Activate to TreatmentSlot!
From the CarePathwaysys perspective, TreatmentSlot sends Activate to SuppressionSlot!

From the CarePathwaysys perspective,DiagnosisSlot sends Yes to Transducer!
From the CarePathwaysys perspective,EngagementSlot sends Yes to Transducer!
From the CarePathwaysys perspective,TreatmentSlot sends Yes to Transducer!
From the CarePathwaysys perspective,SuppressionSlot sends Yes to Transducer!

From the CarePathwaysys perspective,DiagnosisSlot sends No to Transducer!
From the CarePathwaysys perspective,EngagementSlot sends No to Transducer!
From the CarePathwaysys perspective,TreatmentSlot sends No to Transducer!
From the CarePathwaysys perspective,SuppressionSlot sends No to Transducer!

DiagnosisSlot can be Method1 or Method2 in diagnosisSpec!
EngagementSlot can be Method1 or Method2 in engagementSpec!
TreatmentSlot can be Method1 or Method
SuppressionSlot can be Method1 or Meth
```

System Entity Structure (SES)
specification of
HIV-AIDS Continuity of Care

SES Tree portrayal



DEVSPathwaySim cont'd



The Unique Features of DEVSPathwaySim

DEVSPathwaySim is built on the MS4Me Modeling and Simulation Platform and offers unique features based on this layering:

- Concurrent pathways can operate in series, parallel or combinations
- Pathways measure outcome events of SoS simultaneously with activity in the system components
  - This information is correlated to provide *ratings of component value*, i.e., ability to participate in creating outcome value
  - *component ratings can inform combinatorial selection to improve system outcome value*

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Summary

- Health Care Reform is usefully viewed as a Systems Problem
- Porter's Value-based Health care and CDVC within a more inclusive Pathways Coordinated Care framework provides needed coordination
- Formalized this framework using System-of-Systems (SoS) theory expressed in the DEVS Modeling and Simulation methodology
- MS4 Modeling and Simulation Environment based on DEVS supports design and implementation in a systems engineering approach

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Take-aways

- In complex SoSs, what's measured **can** be improved:

  In a competitive environment it **will be** improved.

  - DEVS pathways coordinate and measure value at SoS level .
  - Activity-based credit assignment (ACA) enables ratings of component system for contribution to value.
- SES with ACA support searching through combinatorial spaces for incrementally improved SoSs.
- **Future research challenge: how to use M&S to enable Health care SoS (and others) to become true self-learning systems**!

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