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# **New Metrics and MOEs for Unmanned, Distributed Forces**

**Jeffrey R. Cares**

**73rd MORSS**



# Introduction

- Existing models focus on attrition and can not adequately represent proposed Information Age combat processes.
- Three views of a Distributed Networked System:
  - Structure
    - What are the links, nodes, boundaries and rules for connection?
  - Dynamics
    - Do actual or potential networked effects exist?
  - Evolution
    - What trajectories do the descriptive characteristics take?
      - Do they converge, diverge or cycle?
- These three perspectives are used to create the Information Age Combat Model



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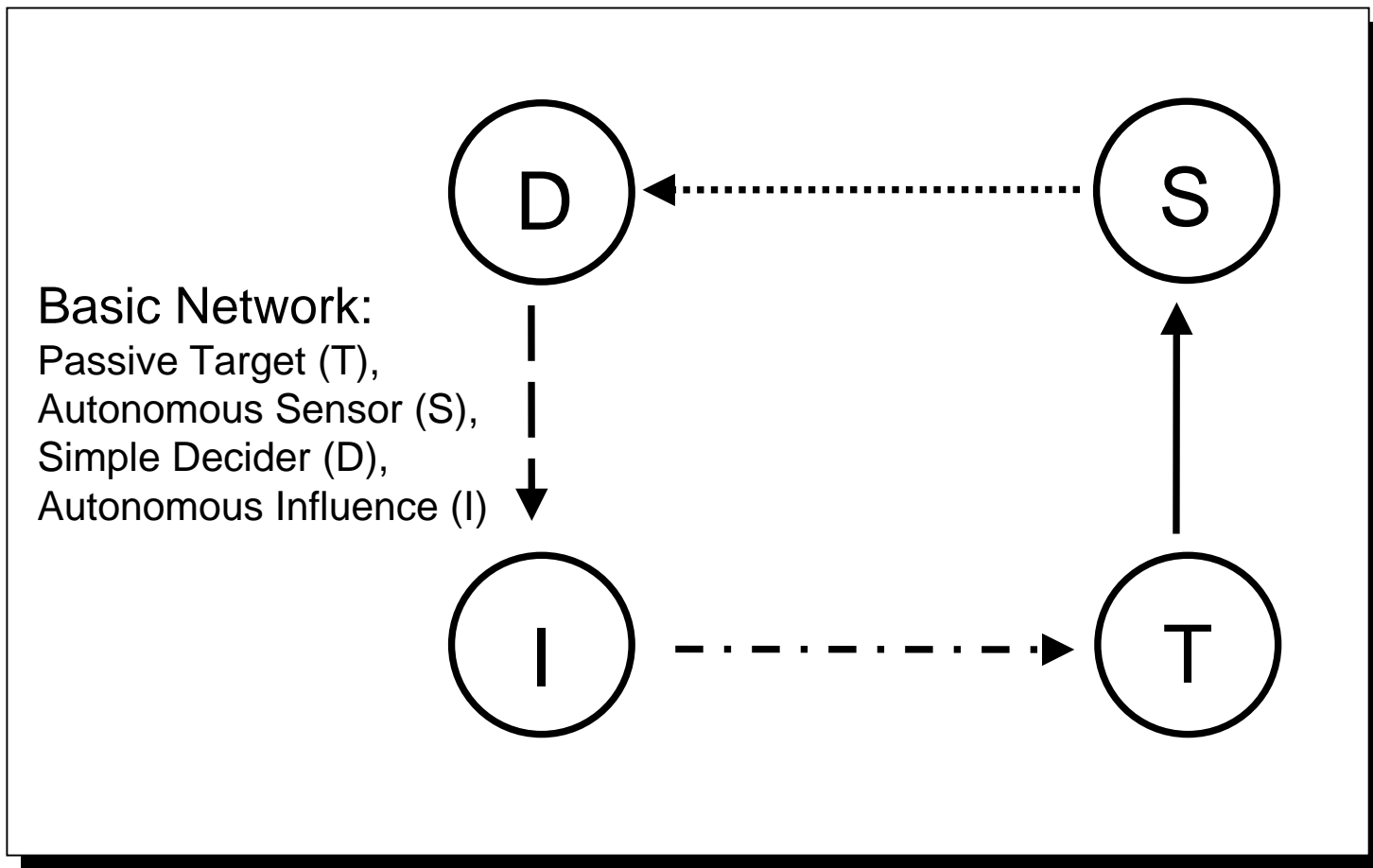
New Metrics  
and MOEs

# Structure



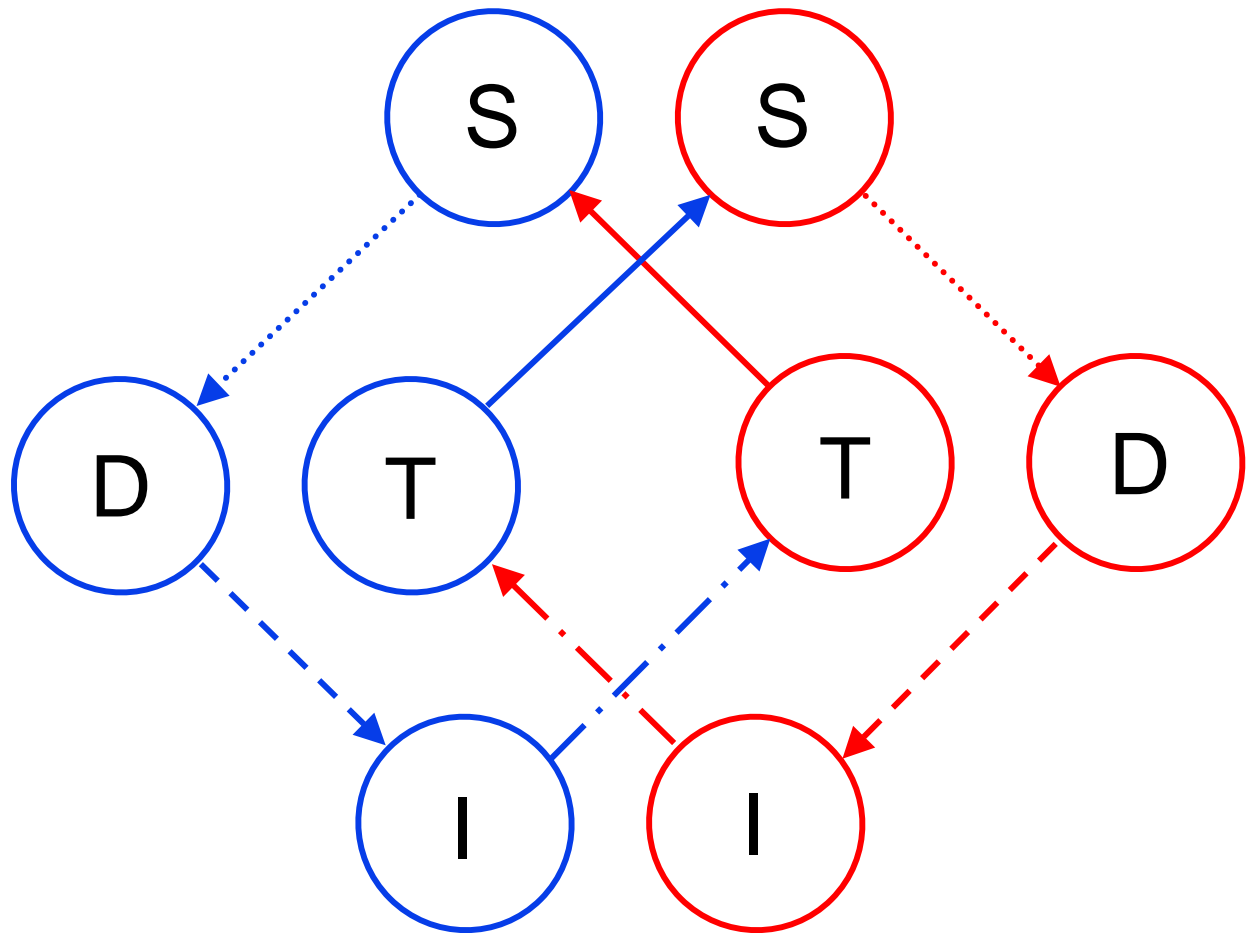
# Combat Network

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and MOEs



# Two-Sided Simple Combat

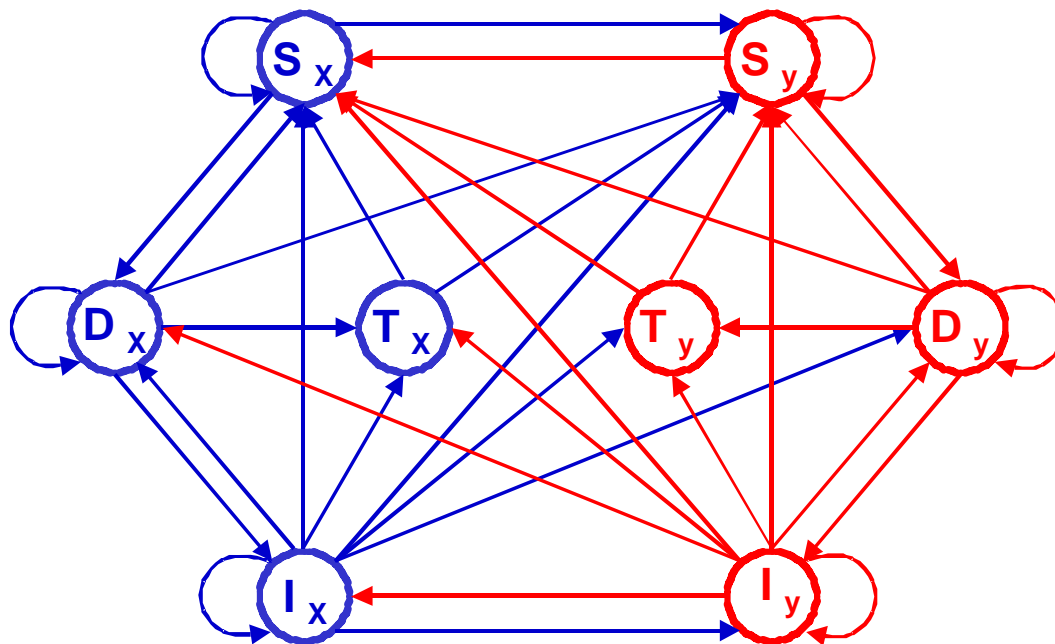
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and MOEs



# Allowable Connections

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and MOEs

Simplest complete combat network



**S: Sensor**  
**D: Decision Maker**

**I: Influencer**  
**T: Target**

# Adjacency Matrix

New Metrics  
and MOEs

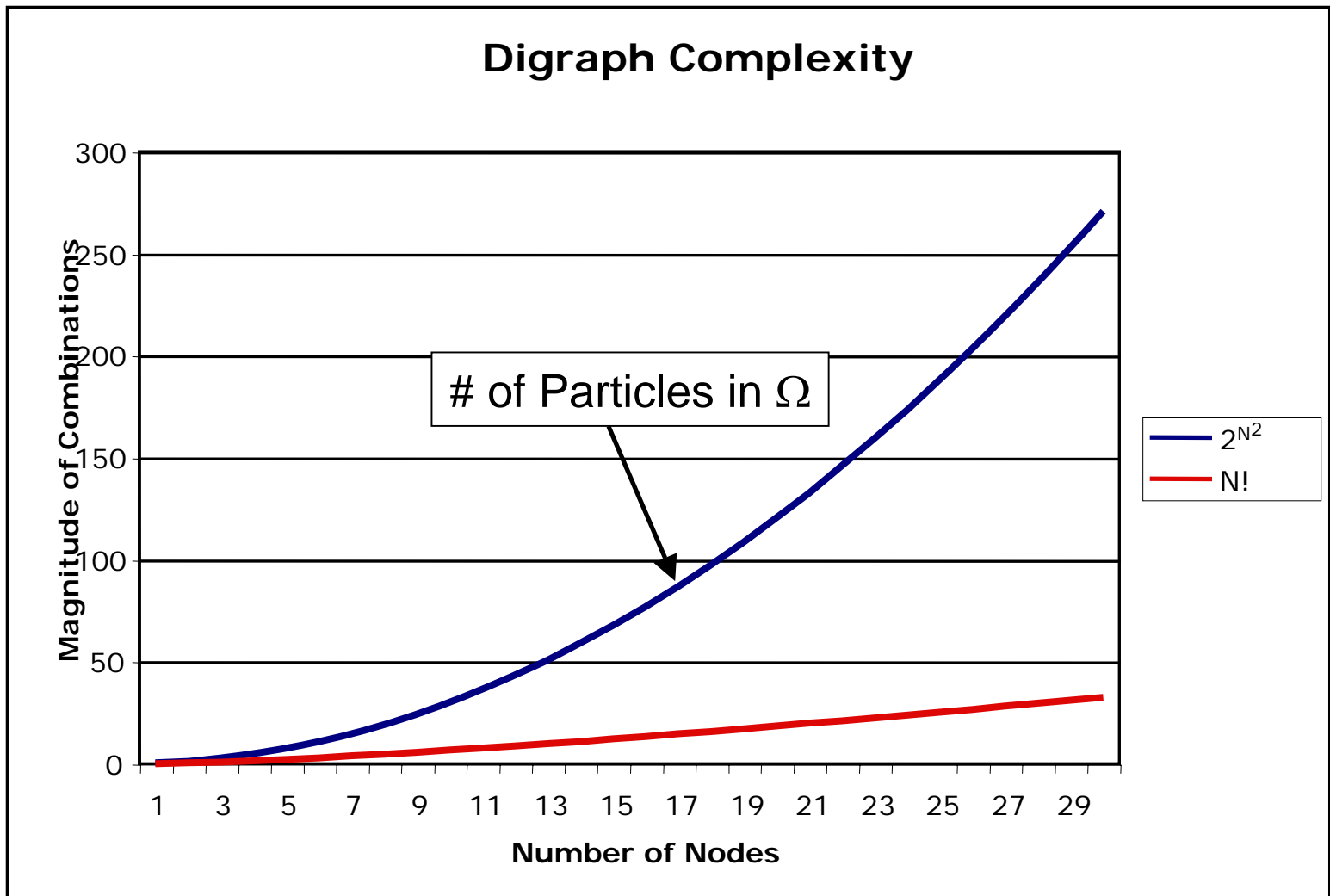
Adjacency Matrix for Simplest, Complete Combat Network

	<b>S<sub>x</sub></b>	<b>D<sub>x</sub></b>	<b>I<sub>x</sub></b>	<b>T<sub>x</sub></b>	<b>S<sub>y</sub></b>	<b>D<sub>y</sub></b>	<b>I<sub>y</sub></b>	<b>T<sub>y</sub></b>
<b>S<sub>x</sub></b>	1	1	0	0	1	0	0	0
<b>D<sub>x</sub></b>	1	1	1	1	1	0	0	0
<b>I<sub>x</sub></b>	1	1	1	1	1	1	1	1
<b>T<sub>x</sub></b>	1	0	0	0	1	0	0	0
<b>S<sub>y</sub></b>	1	0	0	0	1	1	0	0
<b>D<sub>y</sub></b>	1	0	0	0	1	1	1	1
<b>I<sub>y</sub></b>	1	1	1	1	1	1	1	1
<b>T<sub>y</sub></b>	1	0	0	0	1	0	0	0

row maps directionally to column = 1, 0 otherwise

# Combat Model Potential Complexity

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and MOEs



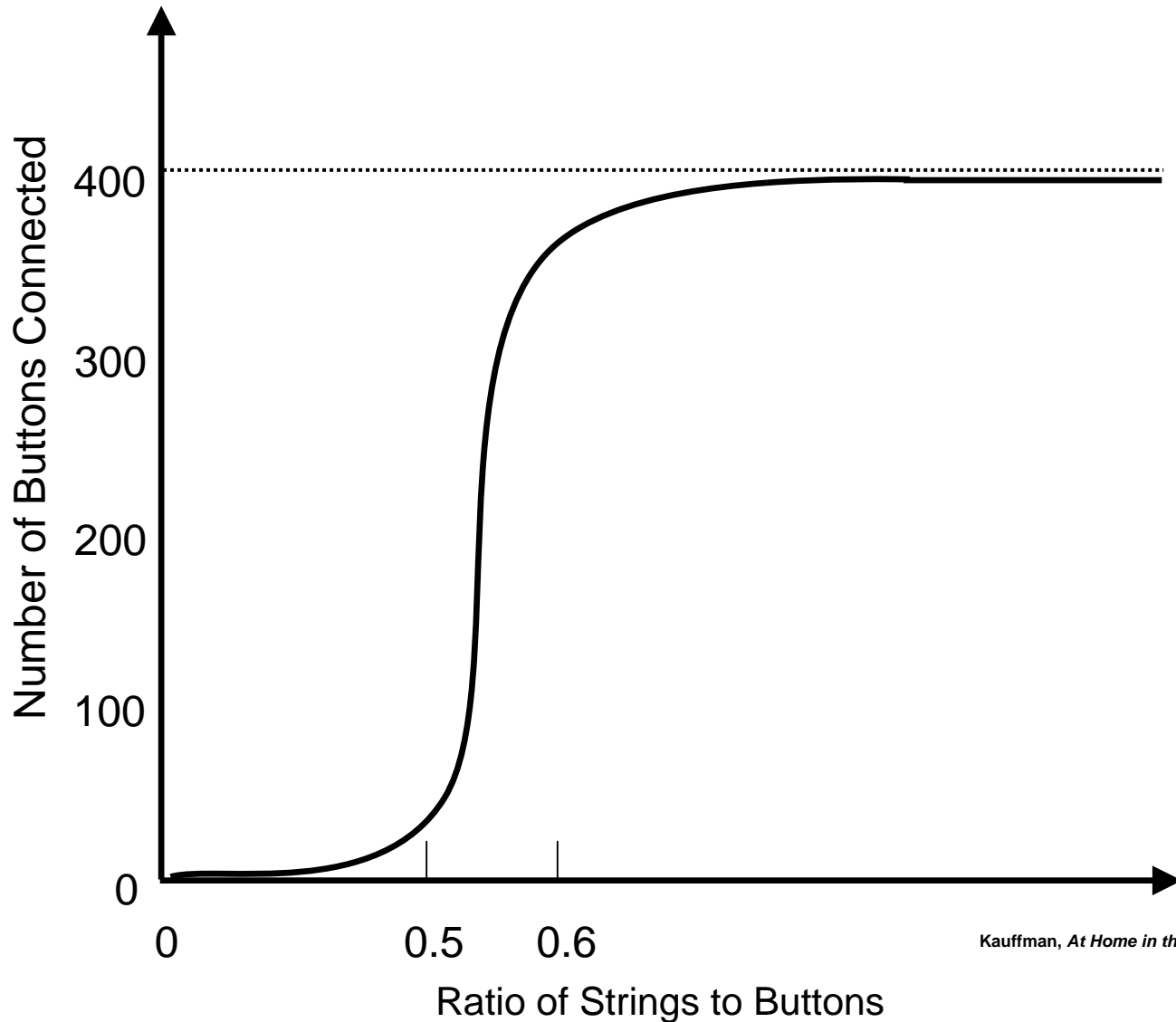


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# Dynamics

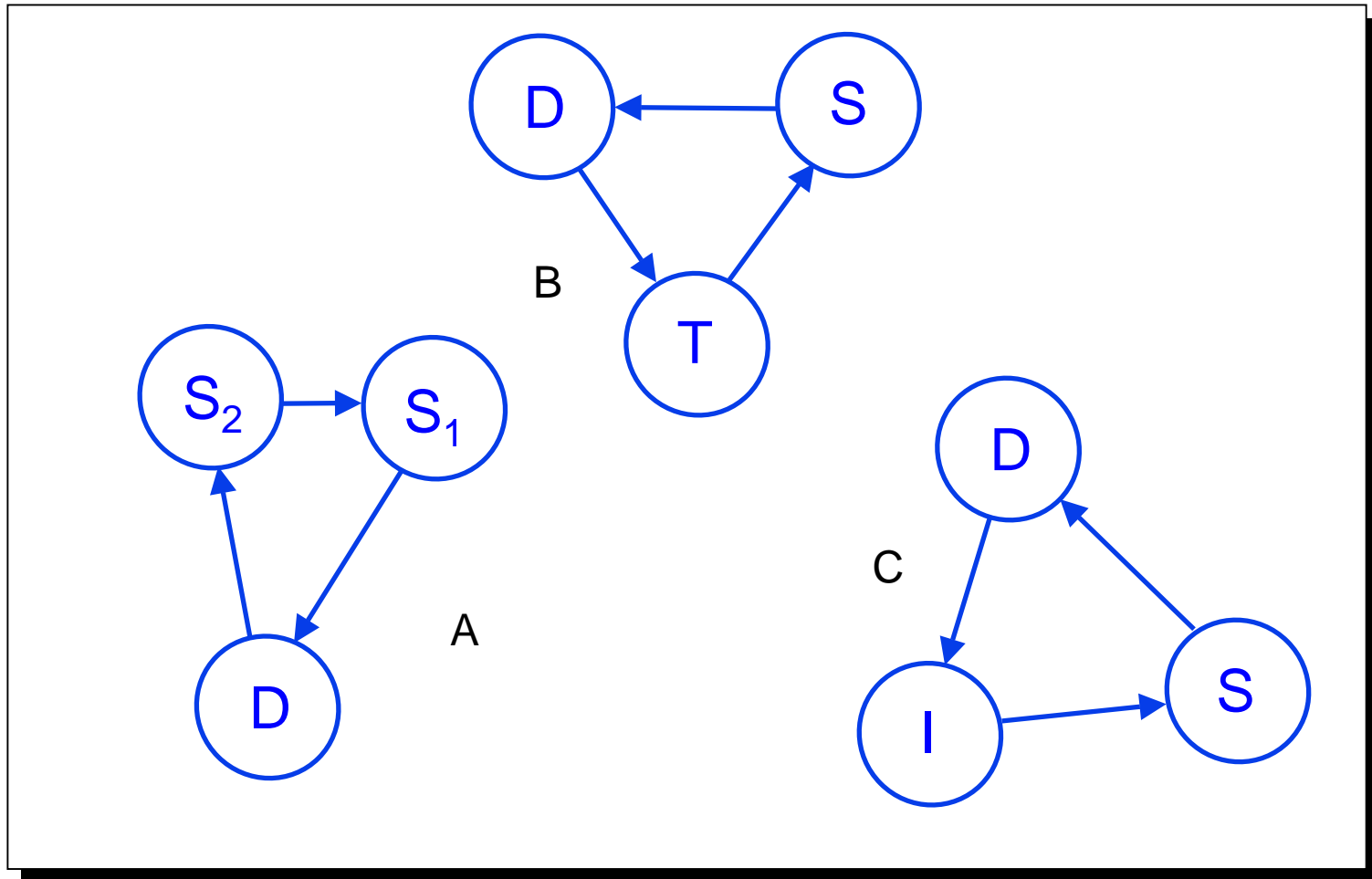
# Buttons and Strings



Kauffman, *At Home in the Universe*, p.57

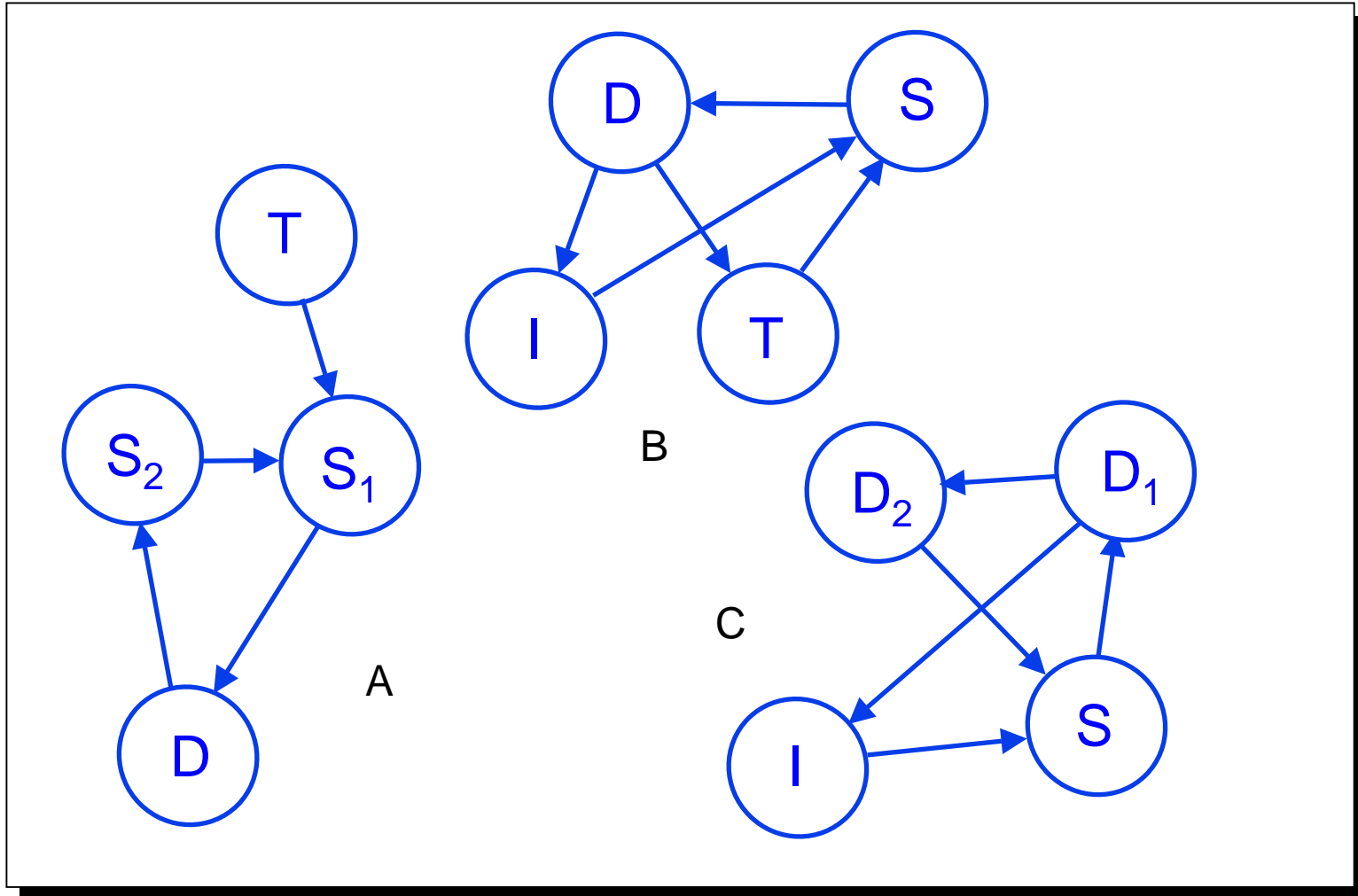
# Control Cycles

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and MOEs



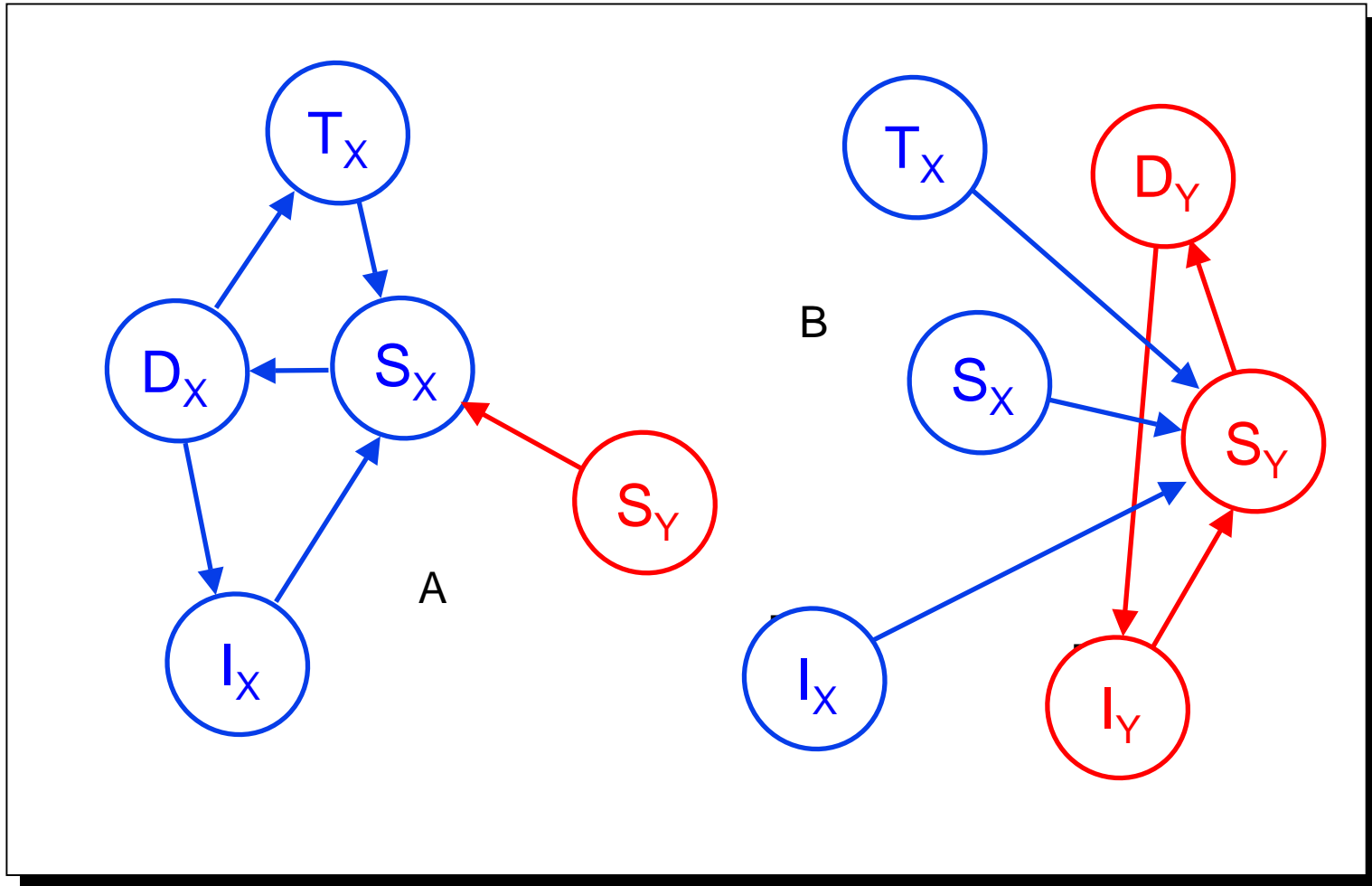
# Catalytic Control Cycles

New Metrics  
and MOEs



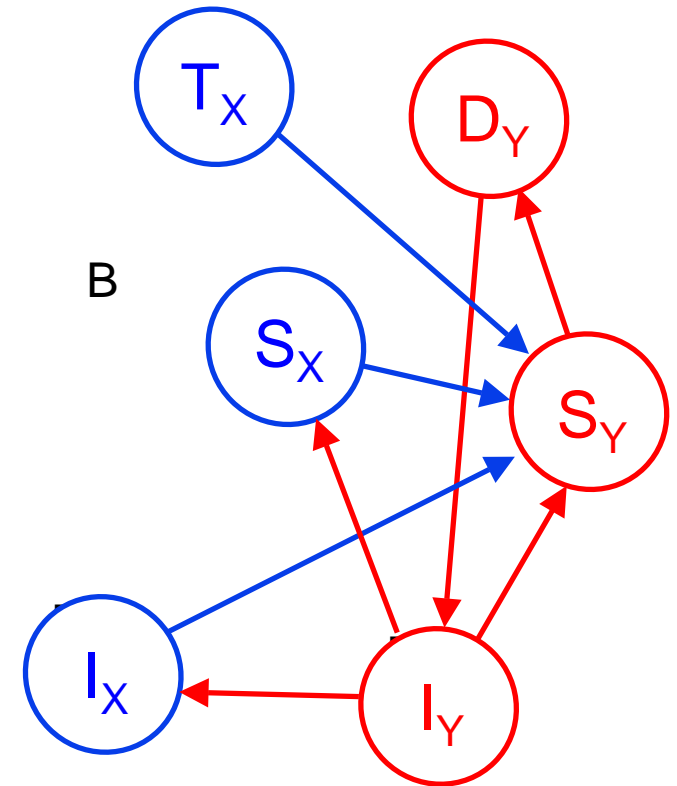
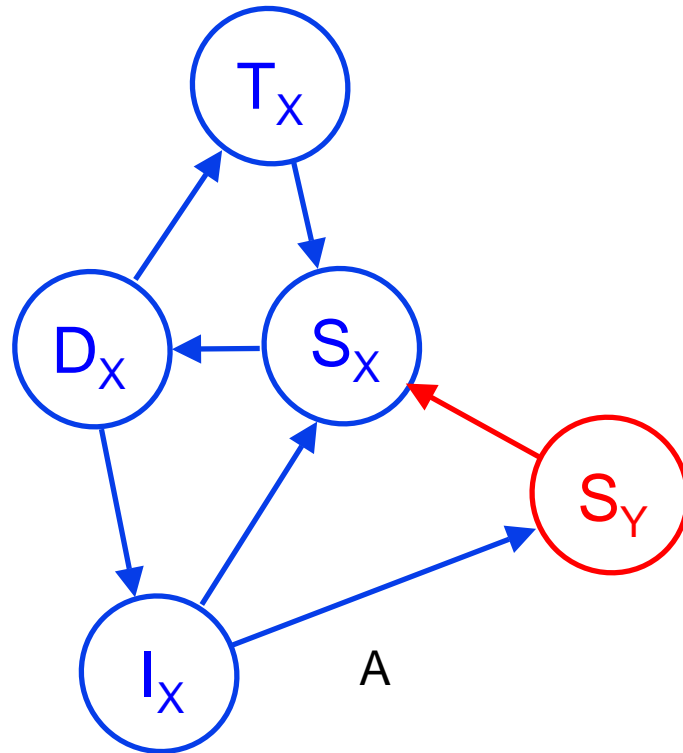
# Catalytic Competitive Cycles

New Metrics  
and MOEs



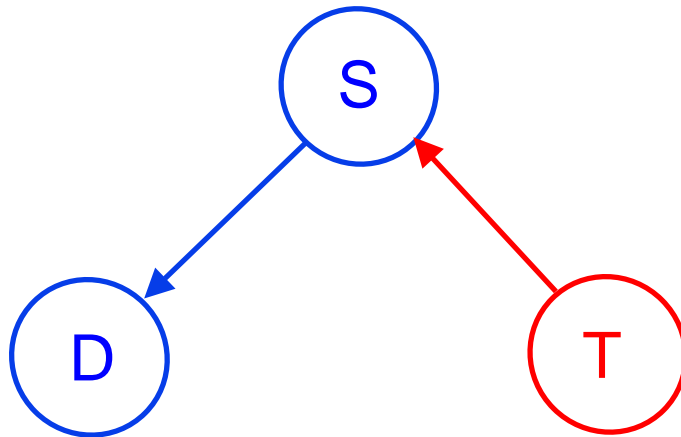
# Combat Cycles

New Metrics  
and MOEs



# No Cycle

New Metrics  
and MOEs



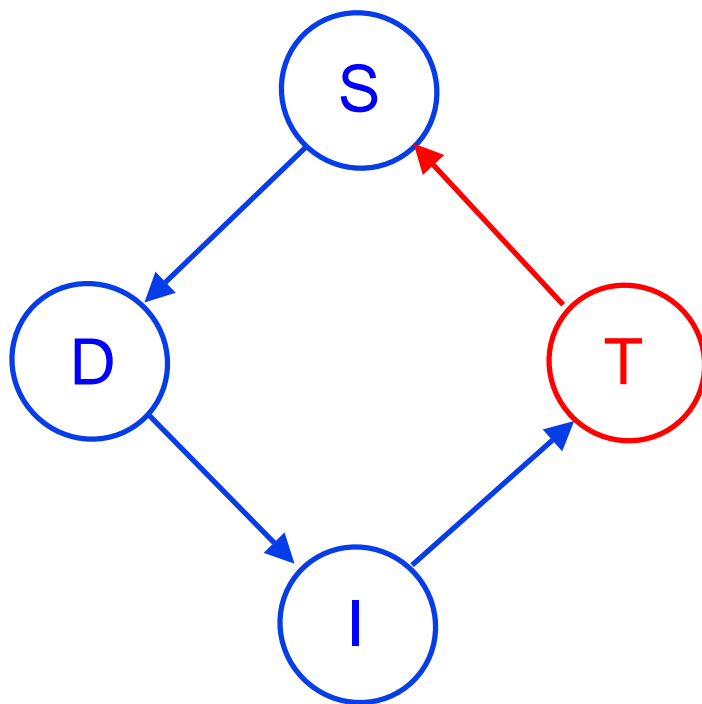
	T	S	D
T	0	0	0
S	1	0	0
D	0	1	0

$$\lambda_{PFE} = 0$$



# Cycle

New Metrics  
and MOEs

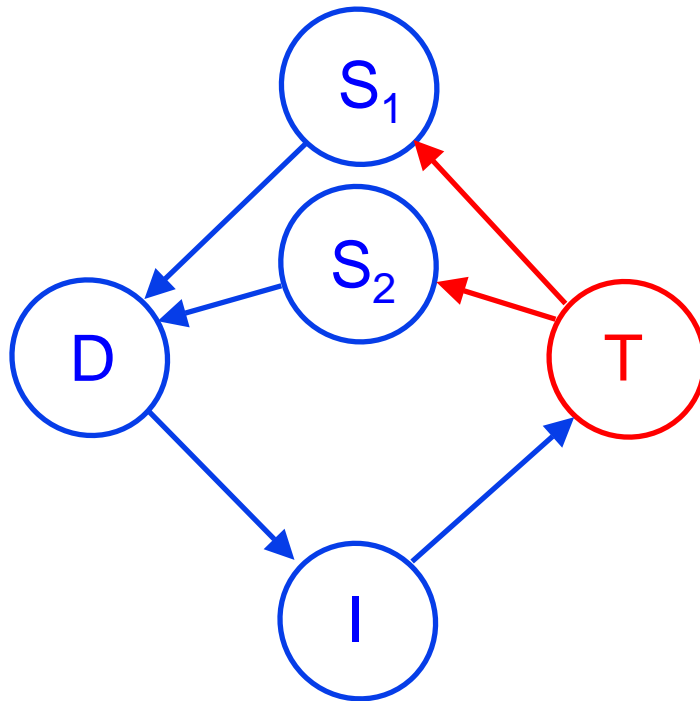


	T	S	D	I
T	0	0	0	1
S	1	0	0	0
D	0	1	0	0
I	0	0	1	0

$$\lambda_{PFE} = 1$$

# Autocatalytic Set

New Metrics  
and MOEs

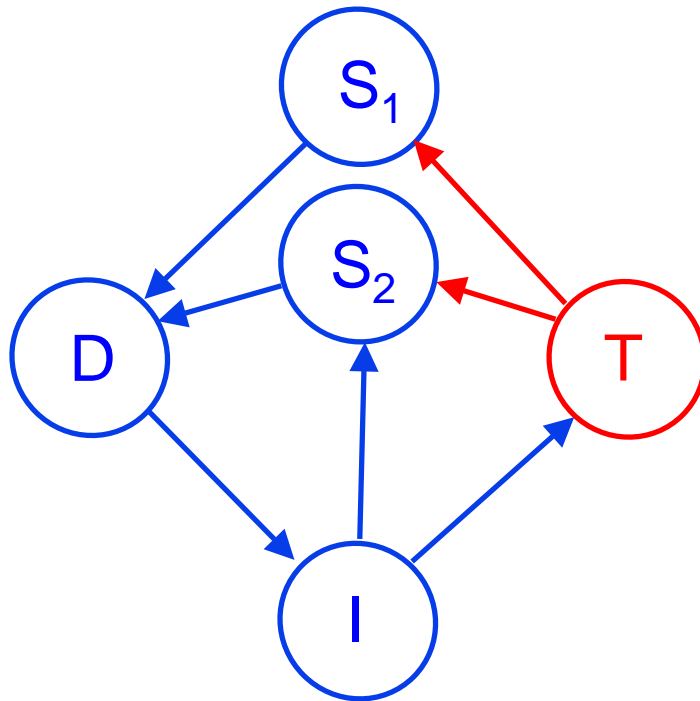


	T	S <sub>1</sub>	S <sub>2</sub>	D	I
T	0	0	0	0	1
S <sub>1</sub>	1	0	0	0	0
S <sub>2</sub>	1	0	0	0	0
D	0	1	1	0	0
I	0	0	0	1	0

$$\lambda_{PFE} = 1.19$$

# Autocatalytic Set

New Metrics  
and MOEs

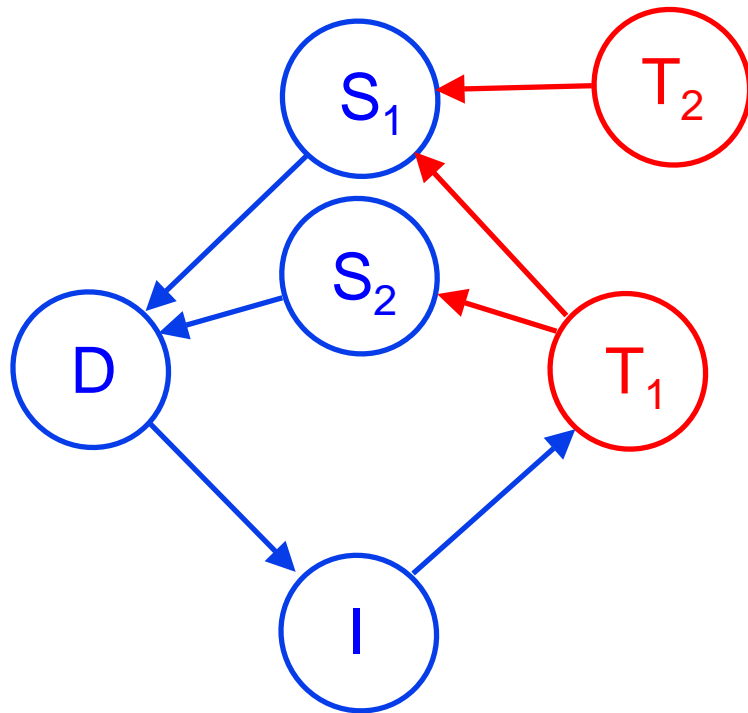


	T	S <sub>1</sub>	S <sub>2</sub>	D	I
T	0	0	0	0	1
S <sub>1</sub>	1	0	0	0	0
S <sub>2</sub>	1	0	0	0	1
D	0	1	1	0	0
I	0	0	0	1	0

$$\lambda_{PFE} = 1.35$$

# Autocatalytic Set

New Metrics  
and MOEs



	$T_1$	$T_2$	$S_1$	$S_2$	$D$	$I$
$T_1$	0	0	0	0	0	1
$T_2$	0	0	0	0	0	0
$S_1$	1	1	0	0	0	0
$S_2$	1	0	0	0	0	0
$D$	0	0	1	1	0	0
$I$	0	0	0	0	1	0

$$\lambda_{PFE} = 1.19$$



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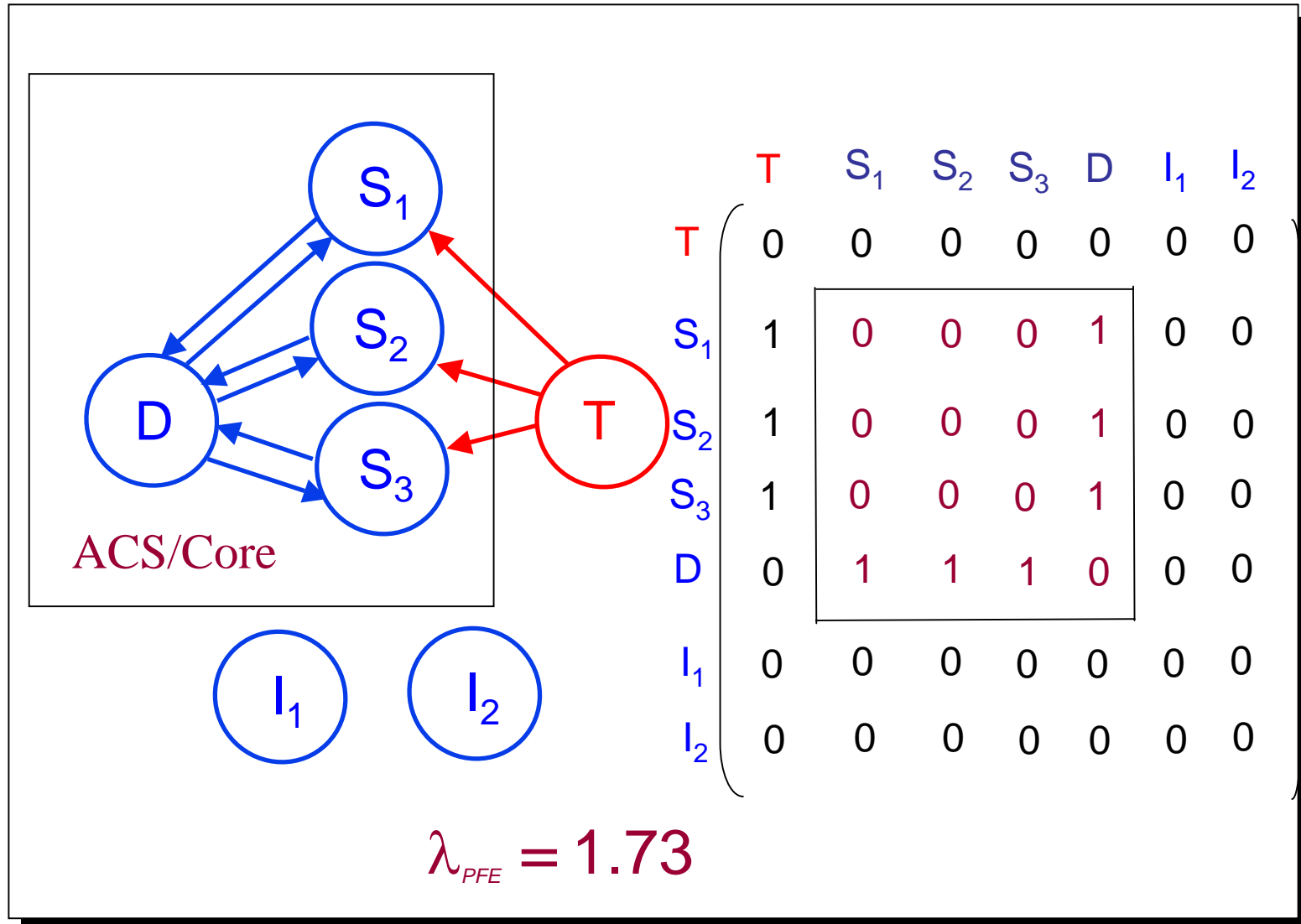
New Metrics  
and MOEs

# Evolution

# Core Shift

## Time Step 1

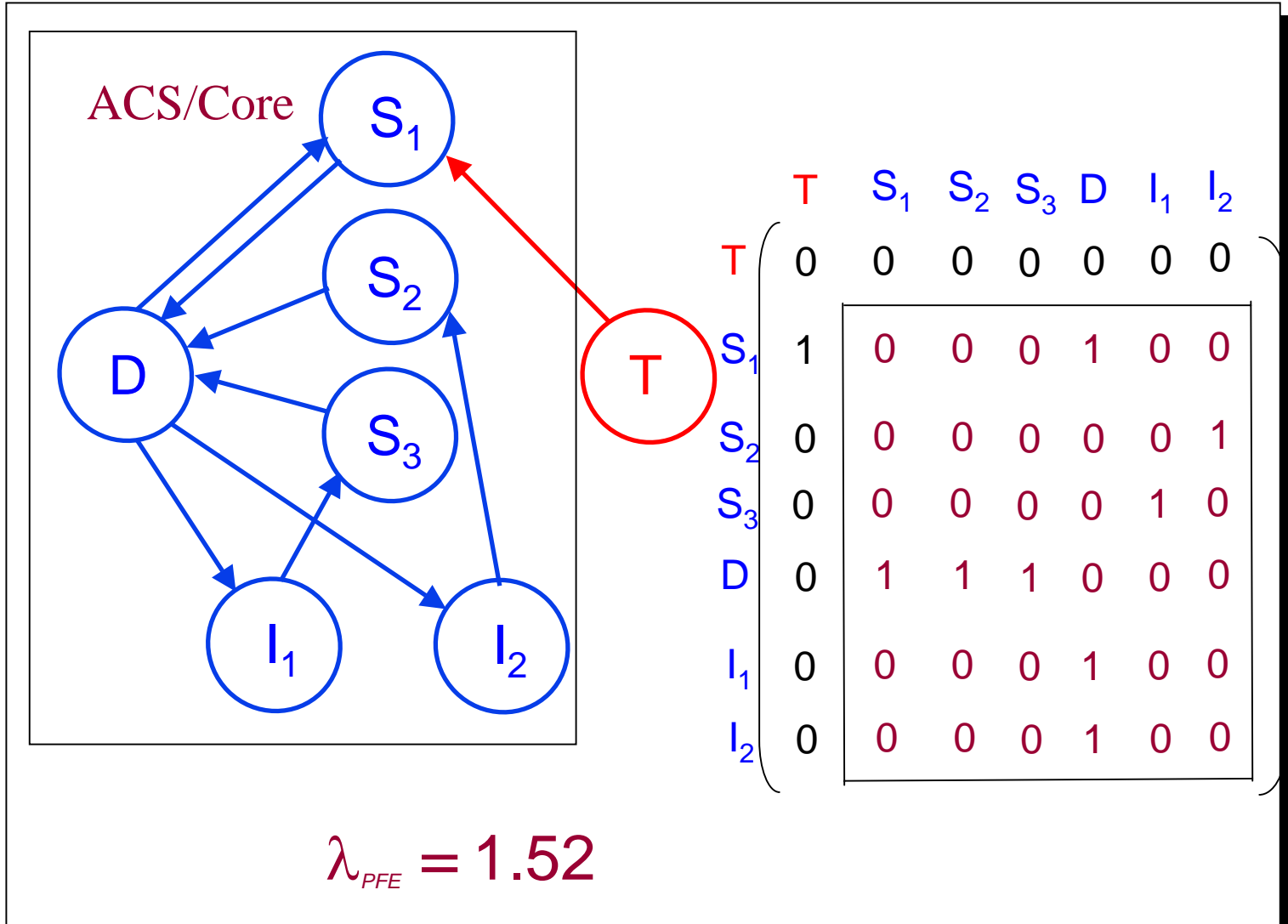
New Metrics  
and MOEs



# Core Shift

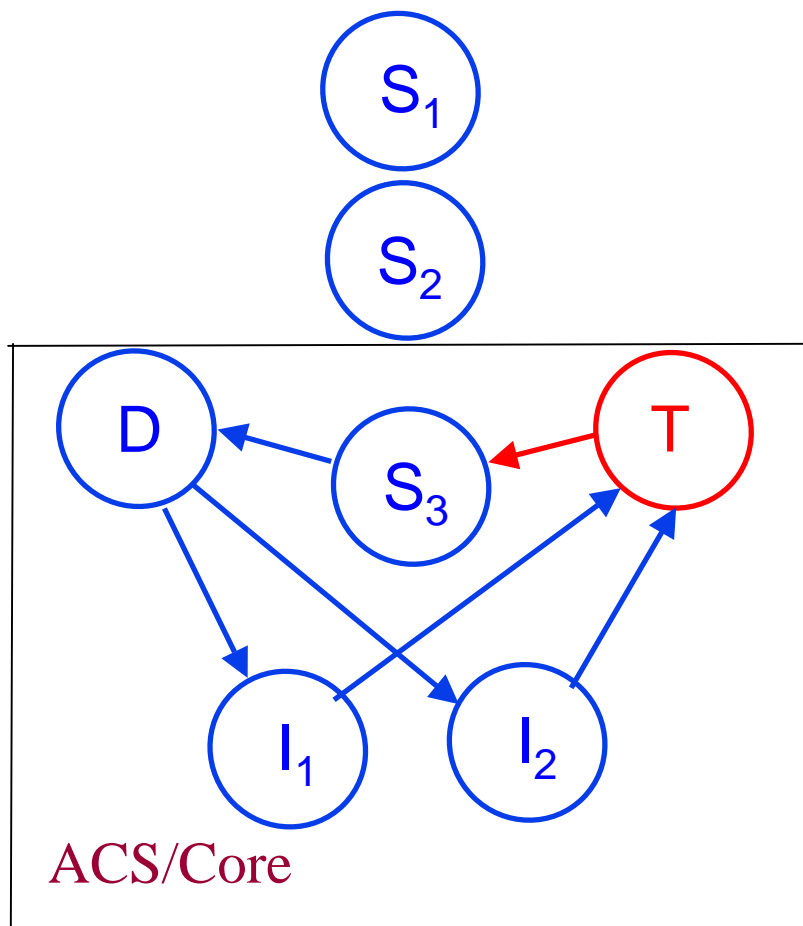
## Time Step 2

New Metrics  
and MOEs



# Core Shift

## Time Step 3

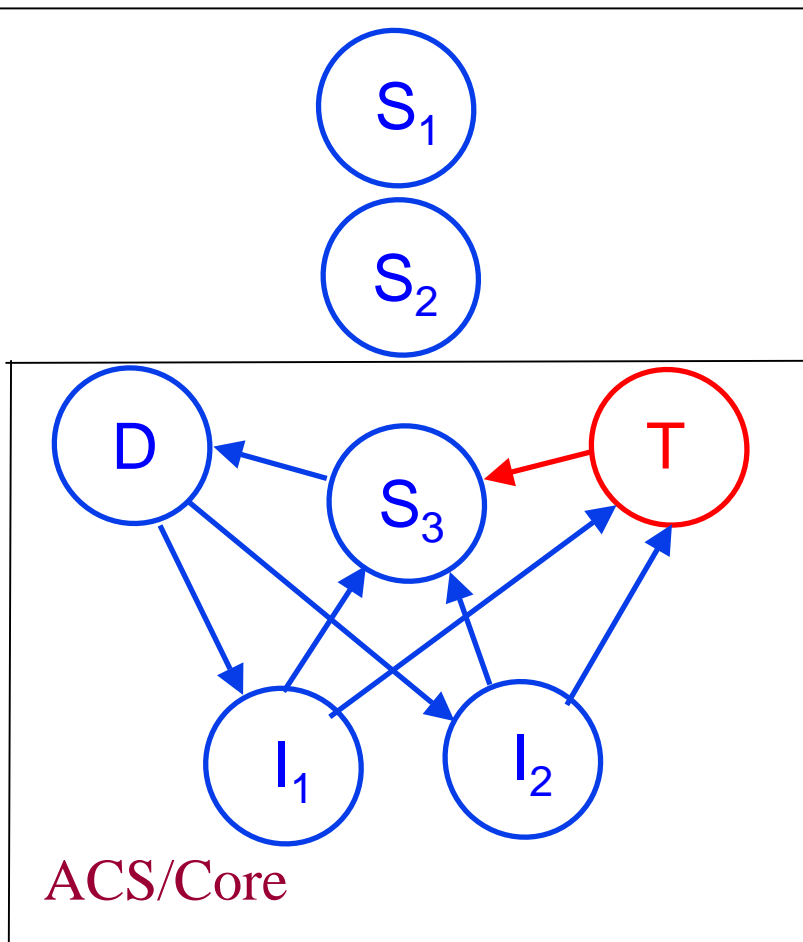


	T	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	D	I <sub>1</sub>	I <sub>2</sub>
T	0	0	0	0	0	1	1
S <sub>1</sub>	0	0	0	0	0	0	0
S <sub>2</sub>	0	0	0	0	0	0	0
S <sub>3</sub>	1	0	0	0	0	0	0
D	0	0	0	1	0	0	0
I <sub>1</sub>	0	0	0	0	1	0	0
I <sub>2</sub>	0	0	0	0	1	0	0

$$\lambda_{PFE} = 1.19$$

# Core Shift

## Time Step 4



	T	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	D	I <sub>1</sub>	I <sub>2</sub>
T	0	0	0	0	0	1	1
S <sub>1</sub>	0	0	0	0	0	0	0
S <sub>2</sub>	0	0	0	0	0	0	0
S <sub>3</sub>	1	0	0	0	0	1	1
D	0	0	0	1	0	0	0
I <sub>1</sub>	0	0	0	0	1	0	0
I <sub>2</sub>	0	0	0	0	1	0	0

$$\lambda_{PFE} = 1.50$$

# Network Metric Thumb Rules

## Experimentation and Analysis

New Metrics  
and MOEs

Metric	Range	Operational Significance
Number of nodes, $n$	$n > \sim 100$	Network effects unlikely to occur with $n < 50$
Number of links, $l$	$l < \sim 2n$	$l \ll 2n$ , too brittle $l \gg 2n$ , too much overhead
Degree distribution	Skewed	Adaptivity, modularity
Largest hub	$< 100$ links	Hub appears, recedes by reconnection 5% of links
Average path length	$\log(n)$	Short distances even for large networks (e.g., $10^4$ nodes $\rightarrow$ Average path length = $\sim 4$ )
Clustering	Skewed	Hierarchy, organization
Betweenness	Skewed	Cascade control
Path horizon	$\log(n)$	Self-synchronization
Susceptibility/ Robustness	Low (random removal) High (focused removal)	Hubs should be kept obscure until needed, damage abatement/repair schemes
Neutrality Rating	$(0, 1)$	Increased network effects, decreased susceptibility, tipping points
Coefficient of Networked Effects	$(0, 1)$	Network effects $PFE/n$



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