

# **FUNCTIONAL COMPONENTS AS A BASIS FOR COMPLEX SYSTEM DESCRIPTION: SOME EXAMPLES AND DISCUSSION.**

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## **WHAT I HOPE TO ACCOMPLISH**

- **REVIEW MY PREVIOUS TALK**
- **INTRODUCE NETWORK THERMODYNAMICS AS A UNIQUE FORMALISM FOR SYSTEM MODELING**
- **USE NETWORK THERMODYNAMIC MODELS TO ILLUSTRATE THE DISTINCTION BETWEEN PHYSICAL PARTS OF A SYSTEM AND ITS FUNCTIONAL REALITY**
- **SHOW HOW TOPOLOGICAL ASPECTS OF MODELS CAN PROVIDE INFORMATION NOT OBTAINED FROM MECHANISTIC MODELS**

## **OUR DEFINITION OF COMPLEXITY**

**Complexity is the property of a real world system that is manifest in the inability of any single formalism to be adequate to capture all its properties. It requires that we find distinctly different ways of interacting with systems. Distinctly different in the sense that when we make successful models, the formal systems needed to describe each distinct aspect are NOT derivable from each other**

## **THE MODELING RELATION: A MODEL OF HOW WE MAKE MODELS**

## **WHAT “TRADITIONAL SCIENCE” DID TO THE MODELING RELATION**

## **COMPLEXITY**

- **REQUIRES A CIRCLE OF IDEAS AND METHODS THAT DEPART RADICALLY FROM THOSE TAKEN AS AXIOMATIC FOR THE PAST 300 YEARS**
- **OUR CURRENT SYSTEMS THEORY, *INCLUDING ALL THAT IS TAKEN FROM PHYSICS OR PHYSICAL SCIENCE*, DEALS EXCLUSIVELY WITH**

## ***SIMPLE SYSTEMS OR MECHANISMS***

- **COMPLEX AND SIMPLE SYSTEMS ARE DISJOINT CATEGORIES**

# **COMPLEX SYSTEMS VS SIMPLE MECHANISMS**

- **COMPLEX**
- **NO LARGEST MODEL**
- **WHOLE MORE THAN SUM OF PARTS**
- **CAUSAL RELATIONS RICH AND INTERTWINED**
- **GENERIC**
- **ANALYTIC  $\neq$  SYNTHETIC**
- **NON-FRAGMENTABLE**
- **NON-COMPUTABLE**
- **REAL WORLD**

- **SIMPLE**
- **LARGEST MODEL**
- **WHOLE IS SUM OF PARTS**

- **CAUSAL RELATIONS DISTINCT**
- **NON-GENERIC**
- **ANALYTIC = SYNTHETIC**
- **FRAGMENTABLE**
- **COMPUTABLE**
- **FORMAL SYSTEM**

## **WHY IS ORGANIZATION SPECIAL? BEYOND MERE ATOMS AND MOLECULES**

- **IS THE WHOLE MORE THAN THE SUM OF ITS PARTS?**
- **IF IT IS THERE IS *SOMETHING* THAT IS LOST WHEN WE BREAK IT DOWN TO ATOMS AND MOLECULES**
- **THAT “SOMETHING” MUST EXIST**

EVEN IN THE WORLD OF MECHANISMS THERE ARE THE SEEDS OF COMPLEXITY THEORY

- **THERMODYNAMIC REASONING**
- **OPEN SYSTEMS THERMODYNAMICS**
- **NETWORK THERMODYNAMICS**

## **THE NATURE OF THERMODYNAMIC REASONING**

- **THERMODYNAMICS IS ABOUT THOSE PROPERTIES OF SYSTEMS WHICH ARE TRUE INDEPENDENT OF**

## MECHANISM

- THEREFORE WE CAN NOT LEARN TO DISTINGUISH MECHANISMS BY THERMODYNAMIC REASONING

## FUNCTIONAL COMPONENTS

- MUST POSSESS ENOUGH IDENTITY TO BE CONSIDERED A “THING”
- MUST BE ABLE TO ACQUIRE PROPERTIES FROM LARGER SYSTEMS TO WHICH IT MAY BELONG
- ITS FORMAL IMAGE IS A MAPPING  $f: A \rightarrow B$
- THIS INTRODUCES A NEW KIND OF “DYNAMICS”: RELATIONAL

NETWORK THERMODYNAMICS COMBINES MECHANISM WITH ORGANIZATION

- **NETWORK ELEMENTS SPECIFY MECHANISM**
- **NETWORK TOPOLOGY SPECIFIES ONE IMPORTANT TYPE OF ORGANIZATION**

NETWORK TOPOLOGY IS THE WAY THINGS ARE CONNECTED TOGETHER

## DO WE USE NETWORK TOPOLOGY IN BIOLOGY?

- **METABOLIC MAPS**
- **FLOW DIAGRAMS**
- **NEURAL NETWORKS**
- **MANY MORE**

## NETWORK ELEMENTS: THE FOURFOLD WAY

NETWORK THERMODYNAMICS APPLIES TO ALL SYSTEMS USING ELECTRICAL SYSTEMS AS ITS ANALOG: EXAMPLE OF MEMBRANE DIFFUSION

- CONDUCTANCE
- VOLTAGE DIFFERENCE
- FLOW OF CURRENT
- AMOUNT OF CHARGE
- OHM'S LAW
- PERMEABILITY
- CONCENTRATION DIFFERENCE
- FLOW OF DIFFUSING MATERIAL
- AMOUNT OF DIFFUSING MATERIAL
- FICK'S LAW OF DIFFUSION

NETWORK THERMODYNAMICS ALLOWS CHEMICAL REACTIONS TO BE MODELED ALONG WITH TRANSPORT, ELECTRICAL EVENTS AND BULK MATERIAL FLOW

- MEMBRANE TRANSPORT
- PHARMACOKINETICS
- MICHAELIS MENTEN REACTION KINETICS (ENZYMATIC)
- BLOOD FLOW AND OTHER FLUID FLOW
- ELECTROPHYSIOLOGY
- ECOSYSTEMS

BIOLOGICAL ORGANIZATION INVOLVES COUPLED SYSTEMS: HOW ORGANIZATION CAN BE ACHIEVED ACCORDING TO THE SECOND LAW OF THERMODYNAMICS: EXAMPLE OF ACTIVE TRANSPORT

WHAT IS THE TOPOLOGICAL REQUIREMENT FOR ACTIVE TRANSPORT?

## BACK TO FUNCTIONAL COMPONENTS

- WE WILL KEEP THE SAME PARTS AND MANIPULATE THEIR ORGANIZATION
- WE CAN PRODUCE DIFFERENT FUNCTIONAL COMPONENTS THIS WAY

THE EXAMPLE OF CHARGED MEMBRANES: EVERYTHING TO BE DISCUSSED IS REALIZABLE IN THE LABORATORY

- MEMBRANE "A" IS A CATION EXCHANGE MEMBRANE
- MEMBRANE "B" IS AN ANION EXCHANGE MEMBRANE

## FIRST CONFIGURATION: A AND B IN SERIES

### SECOND CONFIGURATION: A AND B ARE PLACED IN PARALLEL

#### IN THE PARALLEL CONFIGURATION

- THERE IS NO POTENTIAL DIFFERENCE BETWEEN 1 AND 2
- **NEUTRAL SALT IS MORE PERMEABLE THAN WATER (VERY UNUSUAL-EMERGENT PROPERTY?)**
- **CAN DESALT WATER BY USING PRESSURE AS A DRIVING FORCE**

BACK TO THE FIRST CONFIGURATION: A AND B IN SERIES-  
ADD ENZYME

## IN SUMMARY

- THREE CONFIGURATIONS OF THE SAME PARTS PRODUCED THREE VERY DIFFERENT FUNCTIONAL SYSTEMS
- THIS IS POSSIBLE EVEN IN SIMPLE MECHANISMS
- EVERY ONE IS EXPERIMENTALLY REALIZABLE
- BIOLOGY IS REplete WITH FUNCTIONAL COMPONENTS THAT ARE COMPLEX

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