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CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Modeling Systems of Interacting Specialists

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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Outline of Presentation

- Brief Biographical Note
- Where this Section Fits in the Structure of the Complex Systems Course
- Model motivation
- Basic parts and processes
  - Internal dynamics
  - Interaction processes
- Illustrative applications
- Question & Answer Session

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Modeling Systems of Interacting Specialists

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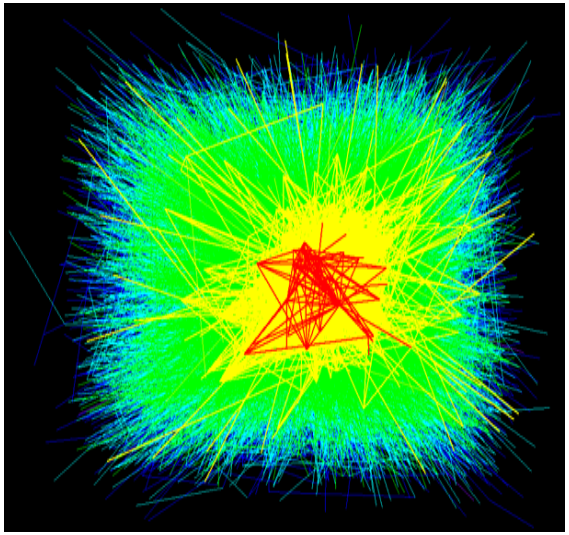
Brief Biographical Note on Walt Beyeler



- Education:
  - BSEE from UNM

- SNL Work Experience
  - 1990s: Subsurface flow and transport modeling for GCD, WIPP; Decision analysis for directing characterization
  - 2001-current: infrastructure modeling and analysis, including
    - Applying complex systems ideas to infrastructures, especially financial systems
    - Using decision support to steer characterization

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Focus of this session

- Fundamentals of Complex Systems ☐
- Methods
  - Modeling Techniques ☑
  - Approaches to Examining Complex Systems ☑
- Applications
  - Examples of the use of complex systems fundamentals to solve problems ☐
  - Learning how to use complex systems **analysis** tools ☐

*Note: These approaches represent a simplified set of complex systems concepts chosen for the CSYS500 systems lectures. Please see the initial two lectures for additional detail and expanded references.

Modeling Approach

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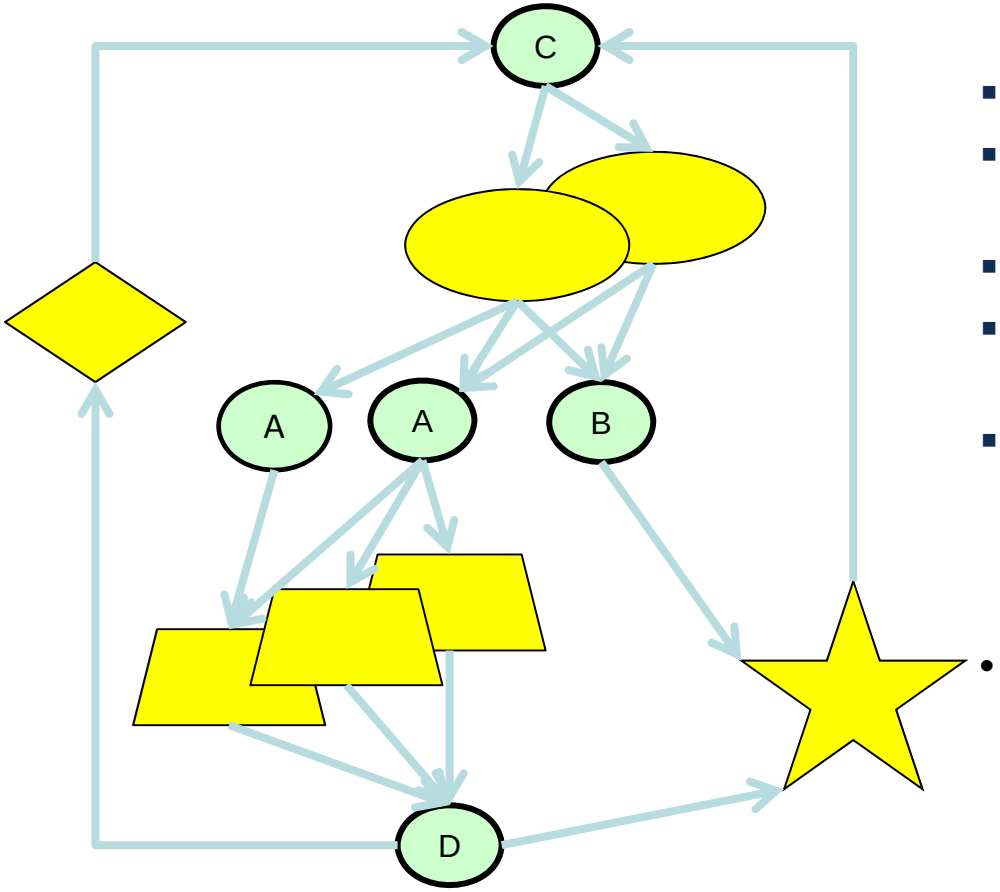
- Consider the diverse problems we confront involving systems composed of adapting interacting components (infrastructures, ecosystems, producers of goods and services…)
- Find the most basic features and processes that are common to all systems, and that dictate their ability to function as individuals and as viable parts of an interacting system
- Build and understand a formal model that captures these features and processes
- Approach the motivating problems through this common formal structure

- Entities that manage resource for their own benefit, and that interact to acquire resources they need.
- Closure: all resources come from somewhere, and that source has its own requirements
- Basic questions:
  - How does the system react to disruptions (loss of resources, producing entities, interconnection)?
  - How do remediations change these reactions?
  - Are there general insights that derive from specific system studies?

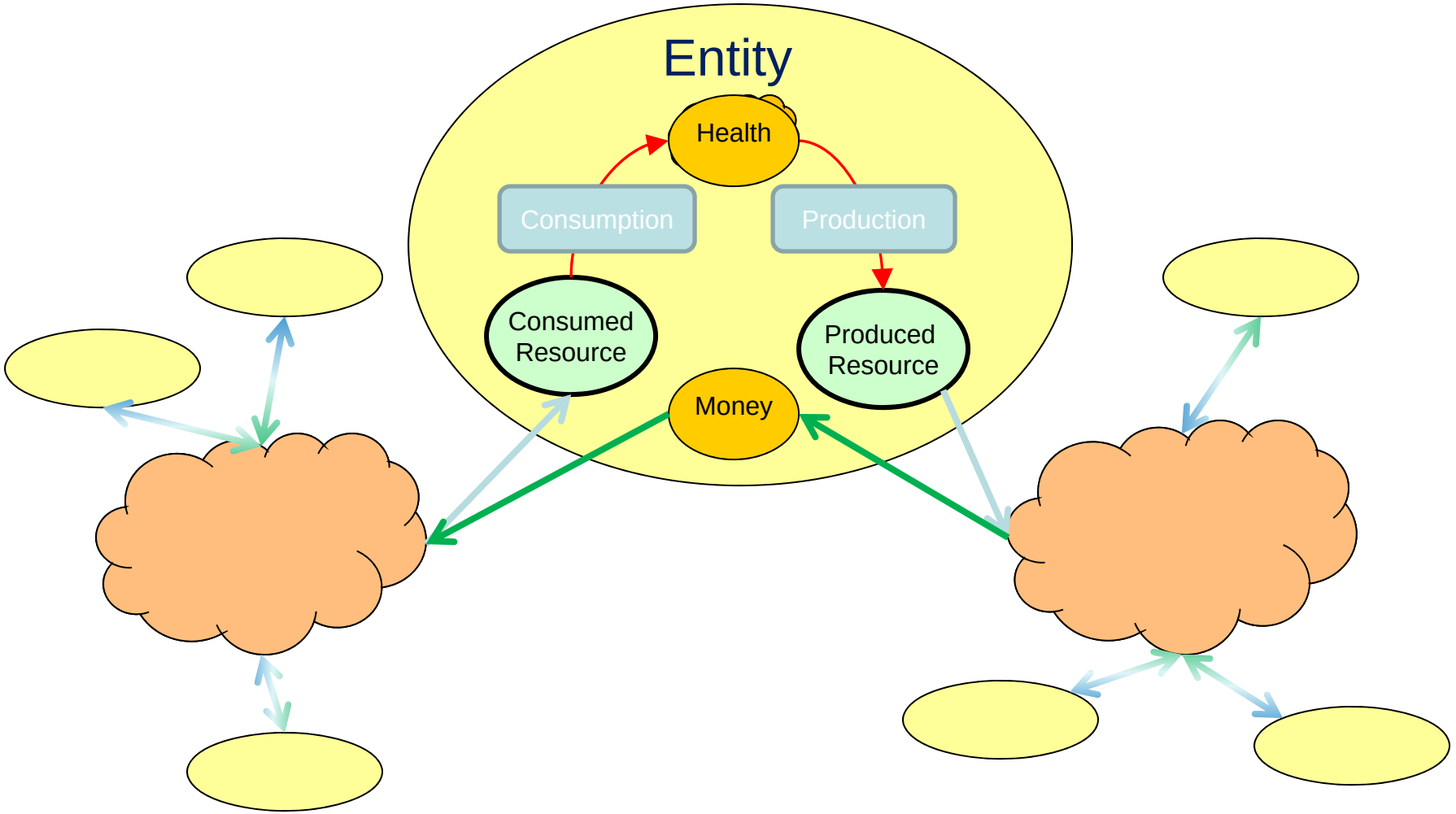
Essential Processes



- Resource consumption and production by entities
- Resource exchange among entities
- Change in entities' state as they respond to resource availability
- Change in entity size or capacity
- Change in connection patterns among entities
- Change in the kinds of entities in the system

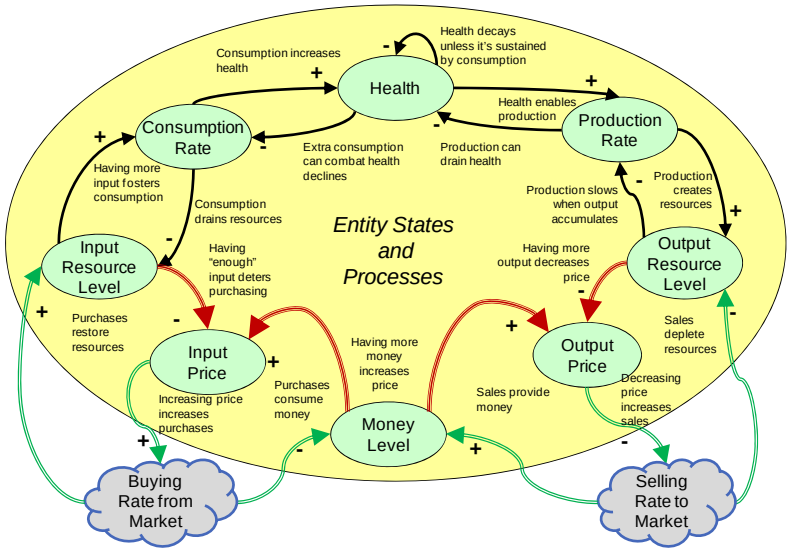
- Only some of these might be relevant for a particular problem. Time constants generally increase from top to bottom, so that slow processes can be considered "frozen".
- The framework allows us to include all of these processes, and to set time constants so that the dynamics interact

Basic Elements



Causal Loop Diagram

- The major reinforcing loop around the outside creates the drive for growth
  - More consumption makes you healthier, leading to more production, more money (energy), more inputs, and more production.
- Growth is *automatically regulated* by flows through the market.
  - When input can't be obtained health and production slides.
  - When output can't be sold inputs can't be acquired.



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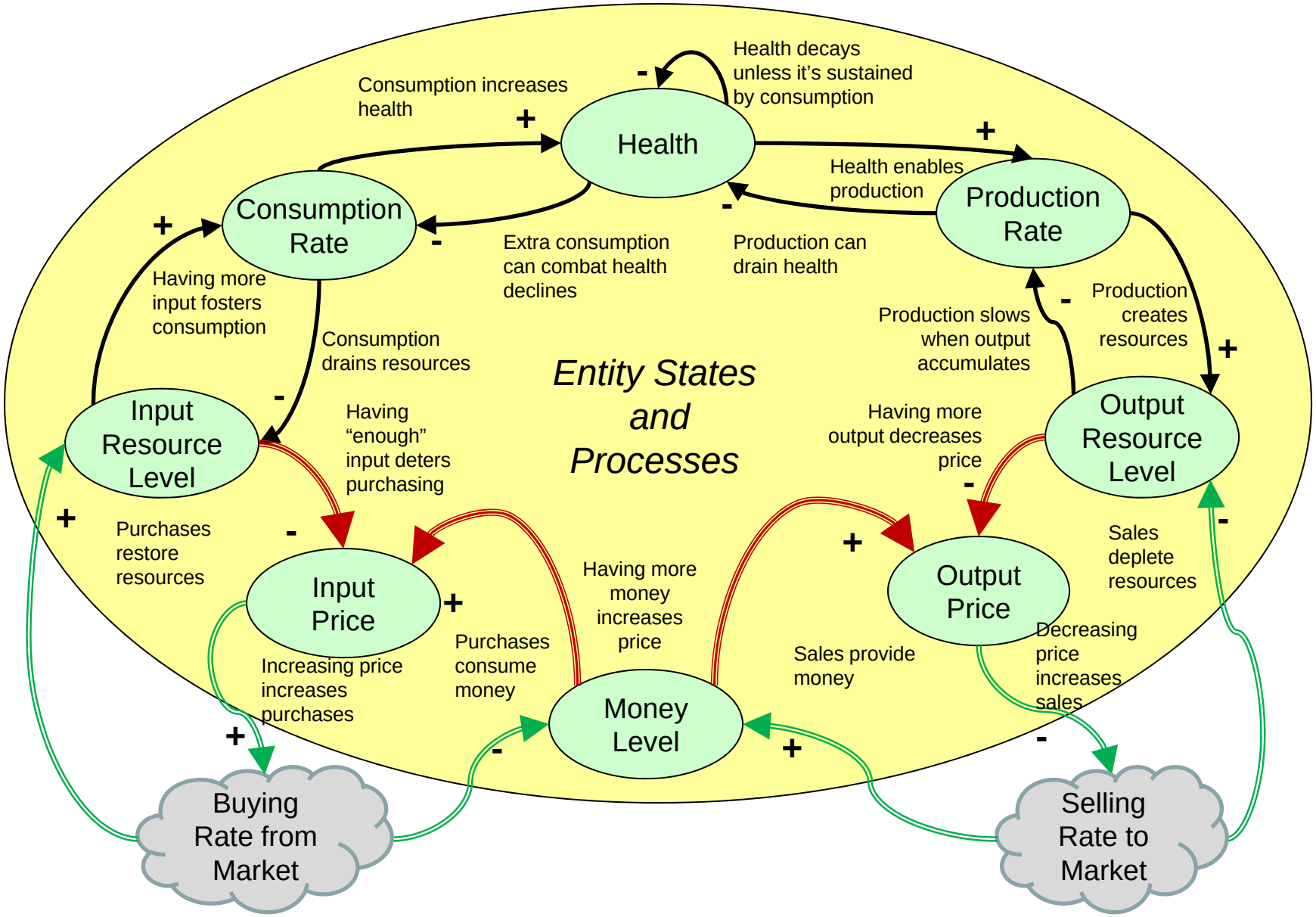
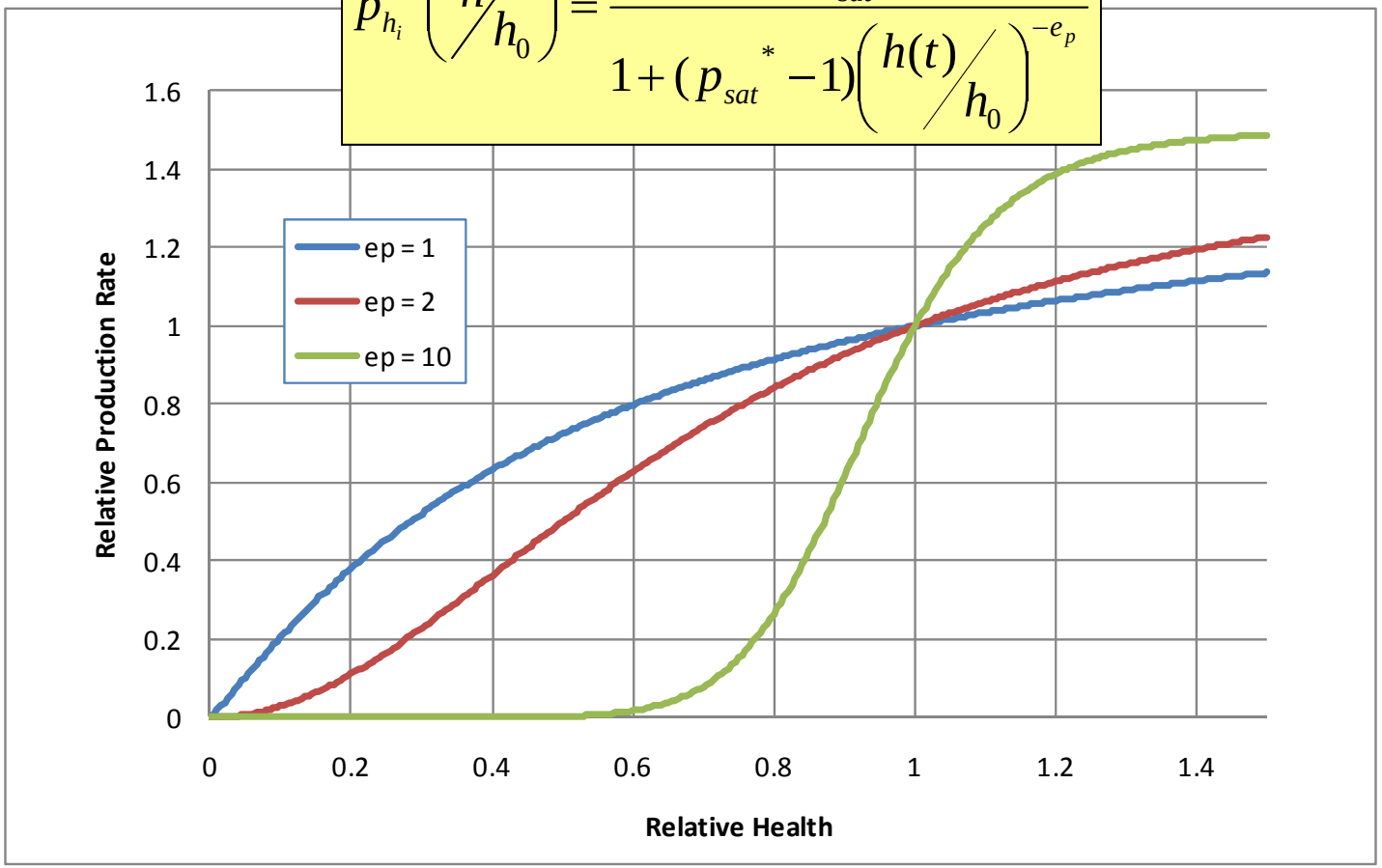
Internal Processes

Causal Loop Diagram



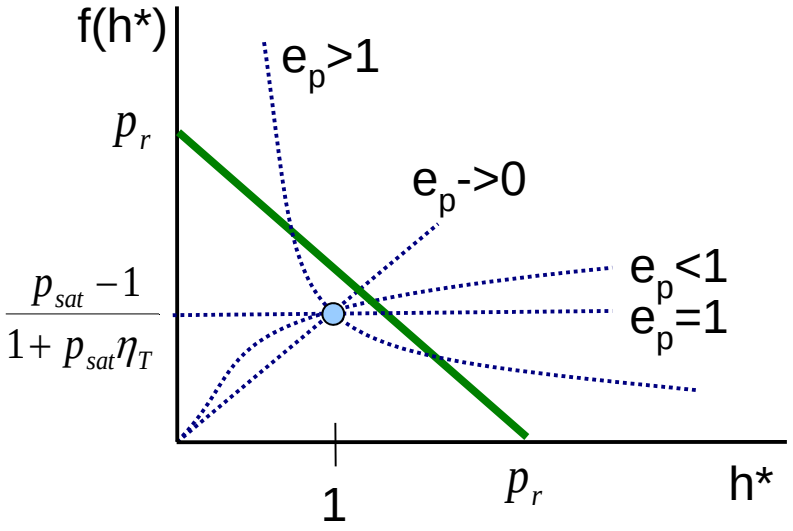
Effect of Health on Potential Production Rate

$$p_{h_i}^{*}\left(h/h_0\right) = \frac{p_{sat}^{*}}{1+(p_{sat}^{*}-1)\left(h(t)/h_0\right)^{-e_p}}$$



Stability Analysis for an Island Entity

$$p_r - h^* = \frac{p_{sat} - 1}{1 + p_{sat}\eta_T} h^{*1-e_p}; \qquad p_r \equiv p_{sat} \frac{p_0}{c_0} \frac{1 + \eta_T}{1 + p_{sat}\eta_T}$$



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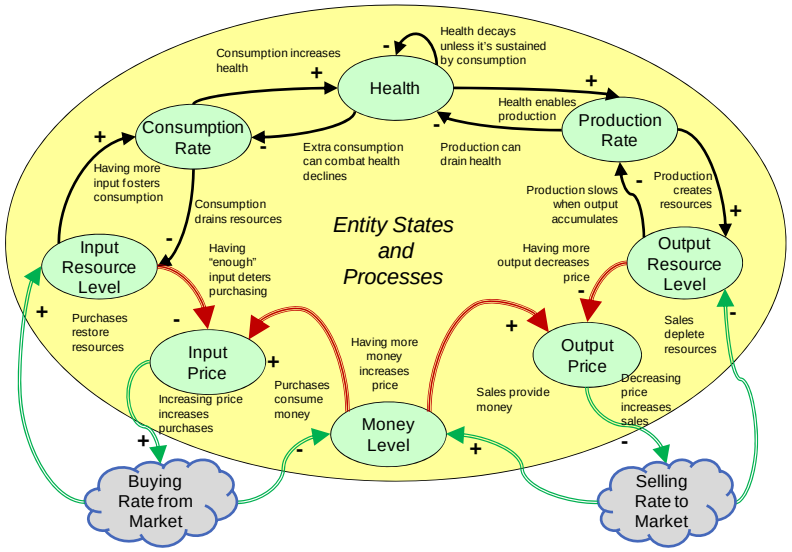
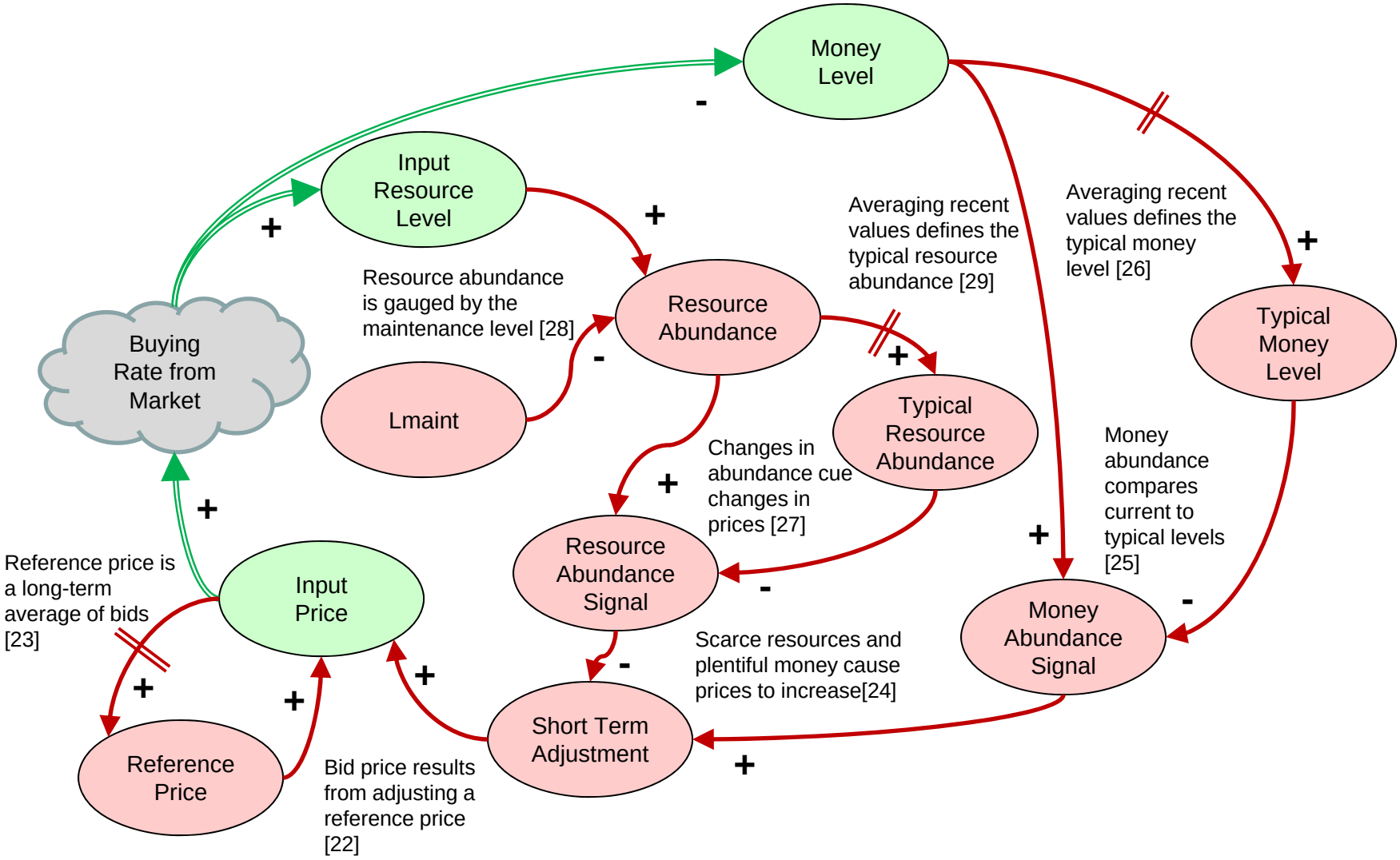
Exchange Processes

Causal Loop Diagram

- The major reinforcing loop around the outside creates the drive for growth
  - More consumption makes you healthier, leading to more production, more money (energy), more inputs, and more production.
- Growth is *automatically regulated* by flows through the market.
  - When input can't be obtained health and production slides.
  - When output can't be sold inputs can't be acquired.




Money Level
Input Resource Level
Buying Rate from Market
Resource Abundance
Lmaint
Typical Resource Abundance
Typical Money Level
Resource Abundance Signal
Money Abundance Signal
Input Price
Reference Price
Short Term Adjustment
Resource abundance is gauged by the maintenance level [28]
Averaging recent values defines the typical resource abundance [29]
Averaging recent values defines the typical money level [26]
Changes in abundance cue changes in prices [27]
Money abundance compares current to typical levels [25]
Reference price is a long-term average of bids [23]
Scarce resources and plentiful money cause prices to increase[24]
Bid price results from adjusting a reference price [22]

Making Transactions Through Markets – General Features

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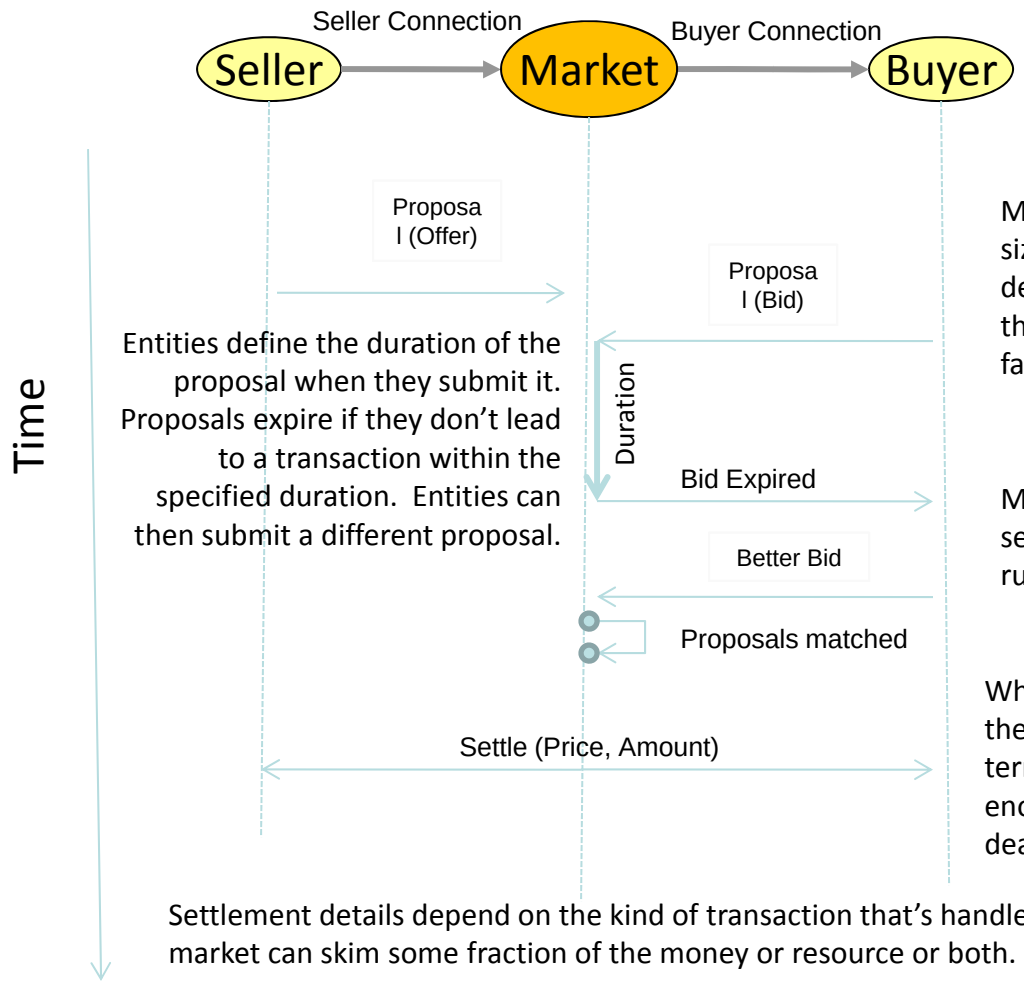
Entities may be connected to a market as a buyer, seller, or both. Entities may be connected to any number of markets. A specific market deals in a specific resource, and in a specific kind of transaction. It uses specific rules for matching prospective buyers and sellers. The general process of interacting through markets does not depend on these details, which are described later.



Entities make transactions by sending proposals to the markets they are connected to. They can do this at any time. Entities use their inventory of resources and money to decide whether and what to propose.

Markets may place limits on proposal (such as minimum size) and will reject non-compliant proposals. Proposals define the terms under which the entity will buy or sell the resource. Any resulting transaction will be at least as favorable to the entity as their proposal.

Entities define the duration of the proposal when they submit it. Proposals expire if they don't lead to a transaction within the specified duration. Entities can then submit a different proposal.

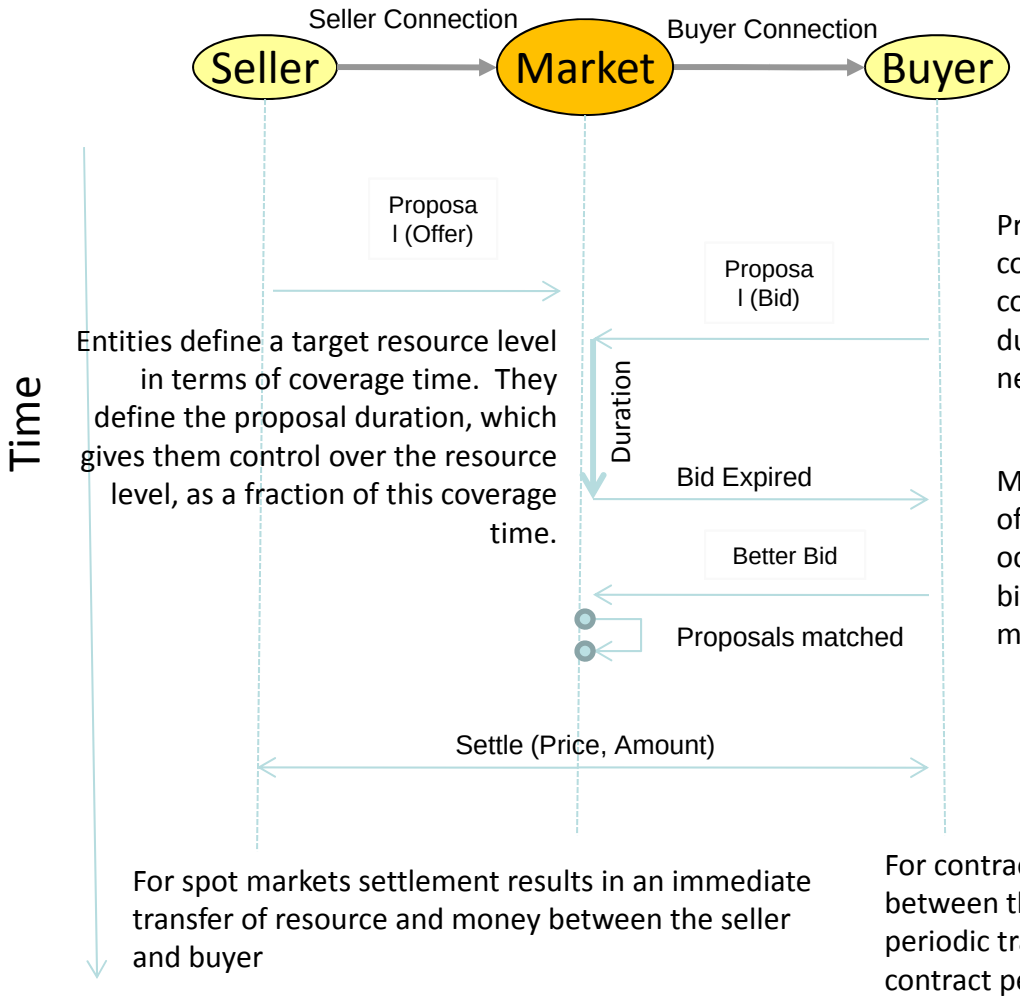
Markets collect proposals from prospective buyers and sellers, and try to pair them off according to some rule.

When a match is made, the buyer and seller are notified of the terms of the deal and are called on to settle on those terms. If they default (for example because they don't have enough money or resource) the other party is notified and the deal is canceled.

Settlement details depend on the kind of transaction that's handled by the market. The market can skim some fraction of the money or resource or both.

Making Transactions Through Markets – Current Implementations

Two basic kinds of transactions can be arranged through markets: spot transactions and contract transactions. The only current kind of contract implemented entails exchange of a set amount of resource at a set price for a specified number of periods. Contracts with different periods and durations can be defined in the model, but each kind of contract trades in its own market.



Entities use their inventory of resources and money to establish a price for the resource. In the current implementation they maintain bids in all markets at that price – they will end up trading more (or only) in the market that tends to give them the best deal.

Entities define a target resource level in terms of coverage time. They define the proposal duration, which gives them control over the resource level, as a fraction of this coverage time.

Proposals are simply defined by an amount and price. In contract markets, the amount is the amount per contracted exchange. Because the contract period and duration are fixed in a given market these aspects are not negotiated.

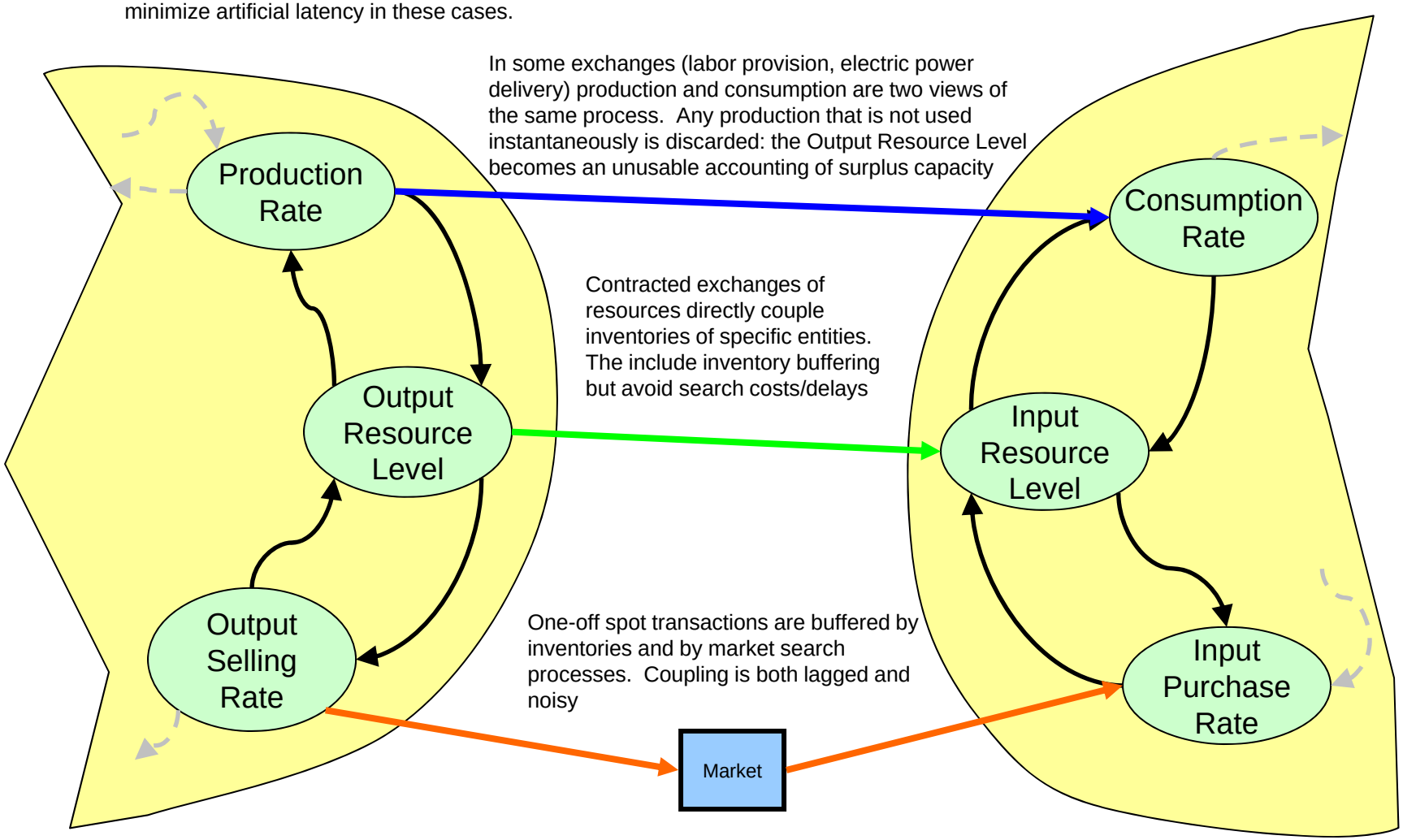
Markets use a continuous double auction to match bids and offers. Only the price is considered, and the transaction occurs for the smaller of the bid and offer amounts. Residual bids or offers can be automatically reposted (if they meet any minimum amount criterion)

For spot markets settlement results in an immediate transfer of resource and money between the seller and buyer

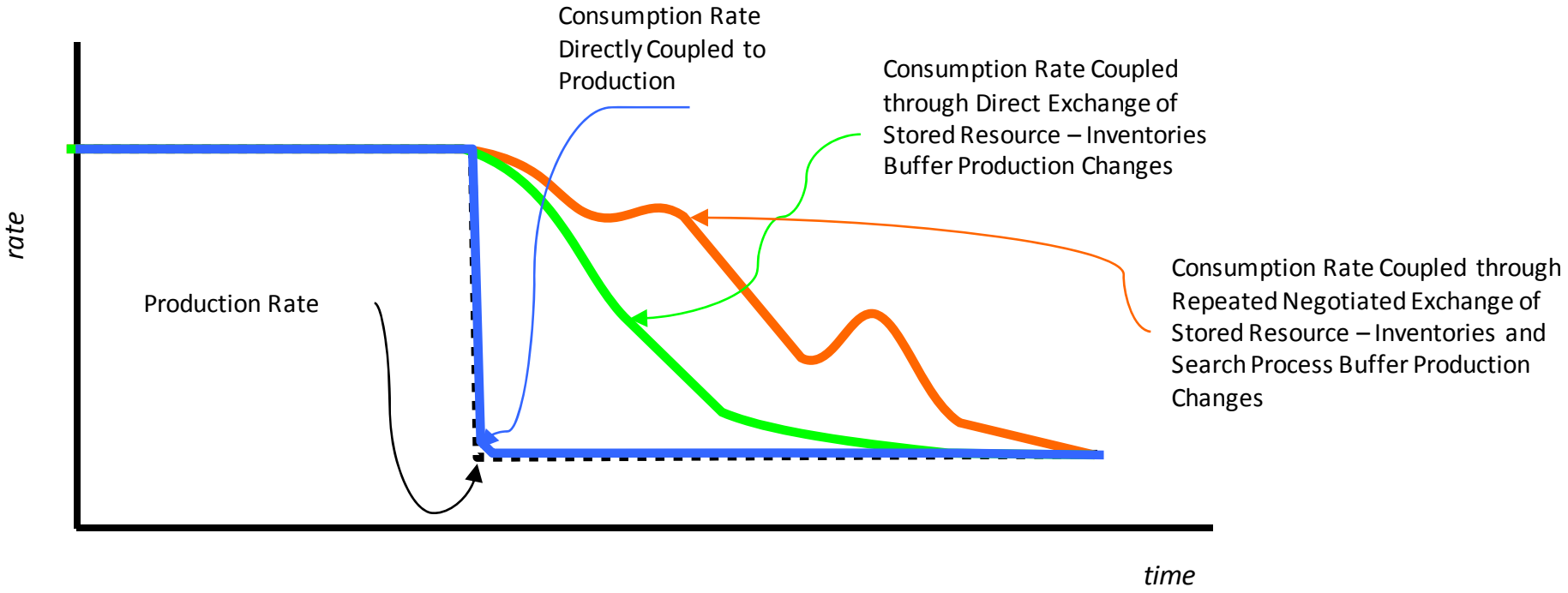
For contract markets settlement creates a new contract link between the seller and the buyer. This contract tries to make periodic transfers of money and resource at the scheduled contract periods.

Hierarchy of Entity-to-Entity Interconnection

We can define three general patterns of interconnection between entities. These patterns can be thought of as creating increasingly close coordination between the production process and consumption process. Our initial implementation will be limited to the "loosest" pattern involving spot exchanges of lumps of stuff. This is a good pattern for many resources but a poor pattern for some services (such as labor or electric power) in which the resource is consumed as it is produced. We can reduce inventory times to minimize artificial latency in these cases.



Latency of Different Coupling Mechanisms



Exploring Simple Patterns of Interaction

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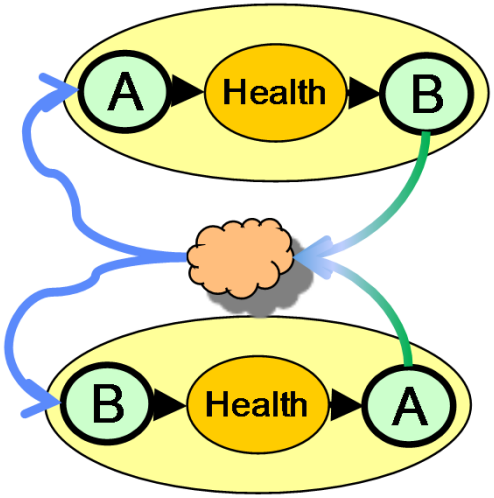
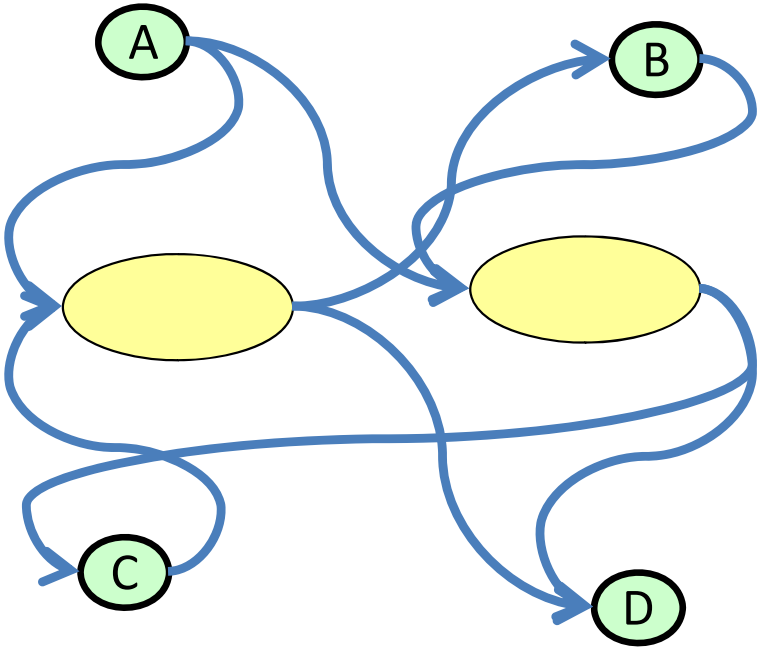
Complete Interdependency



Some equilibrium results can be derived; Sensitivity to exchange process can be studied…

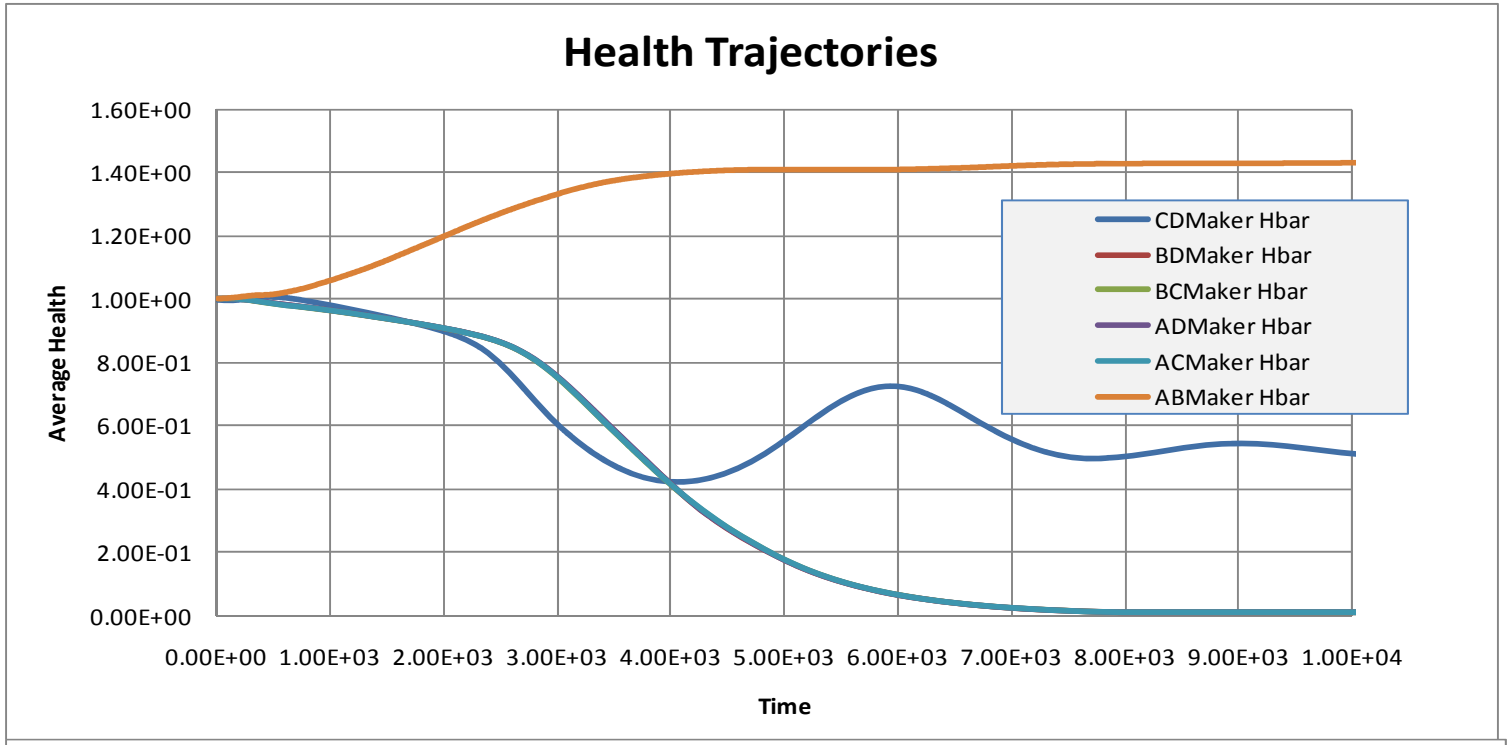
Using four resources minimally allows for input substitution and output specialization



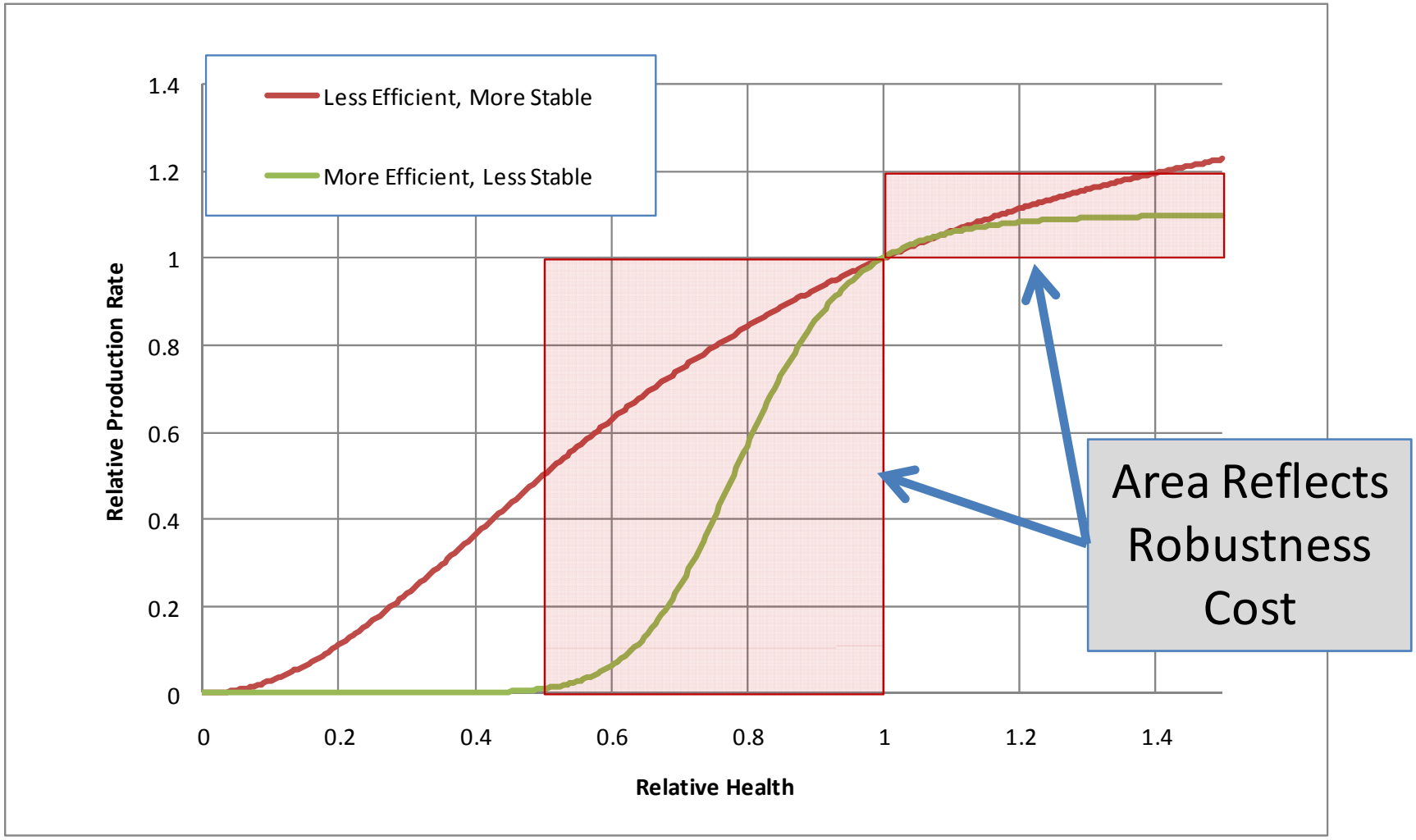
Six distinct input/output patterns are possible

What happens when one type is especially productive?

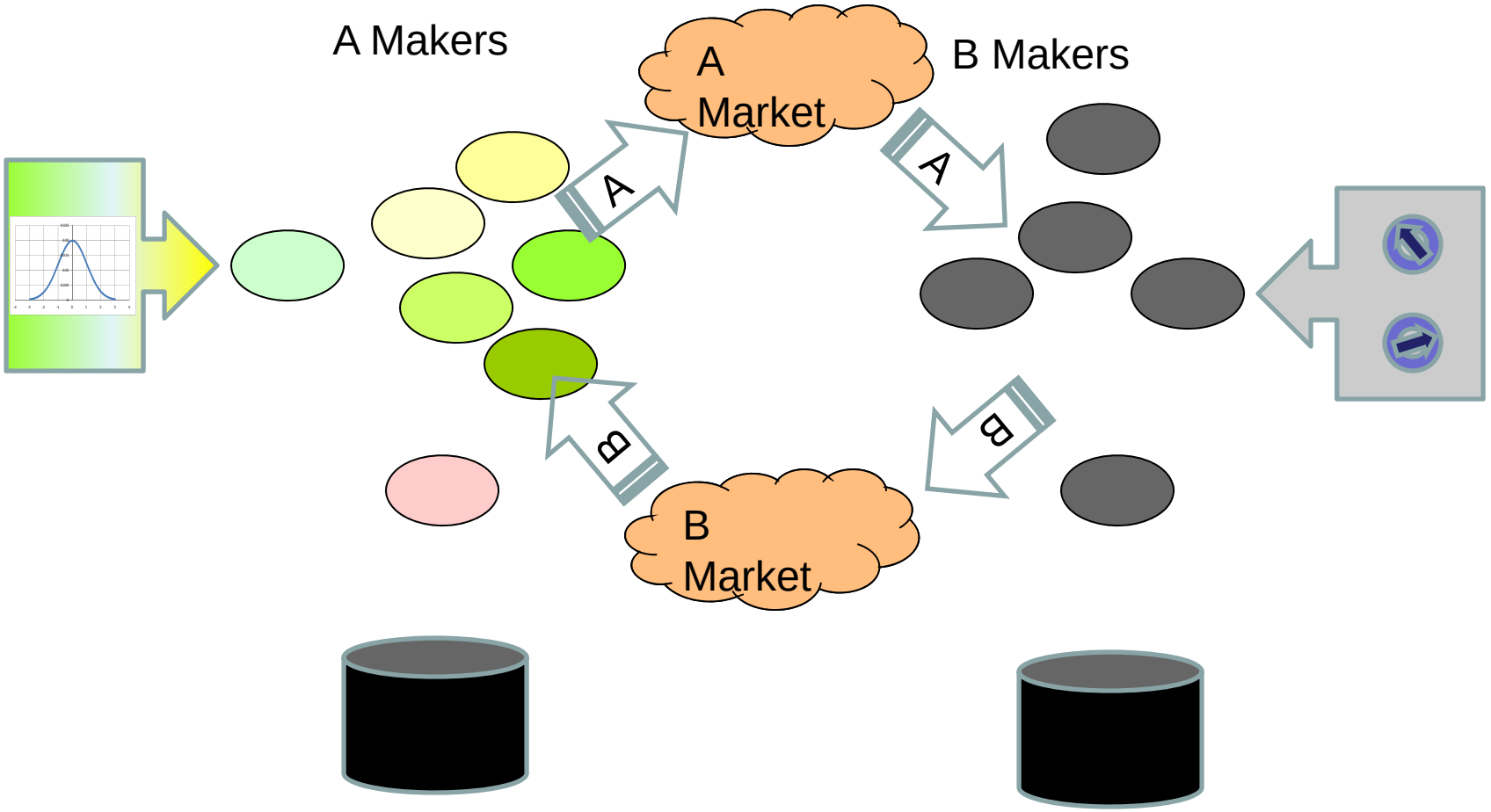
Competitive Exclusion



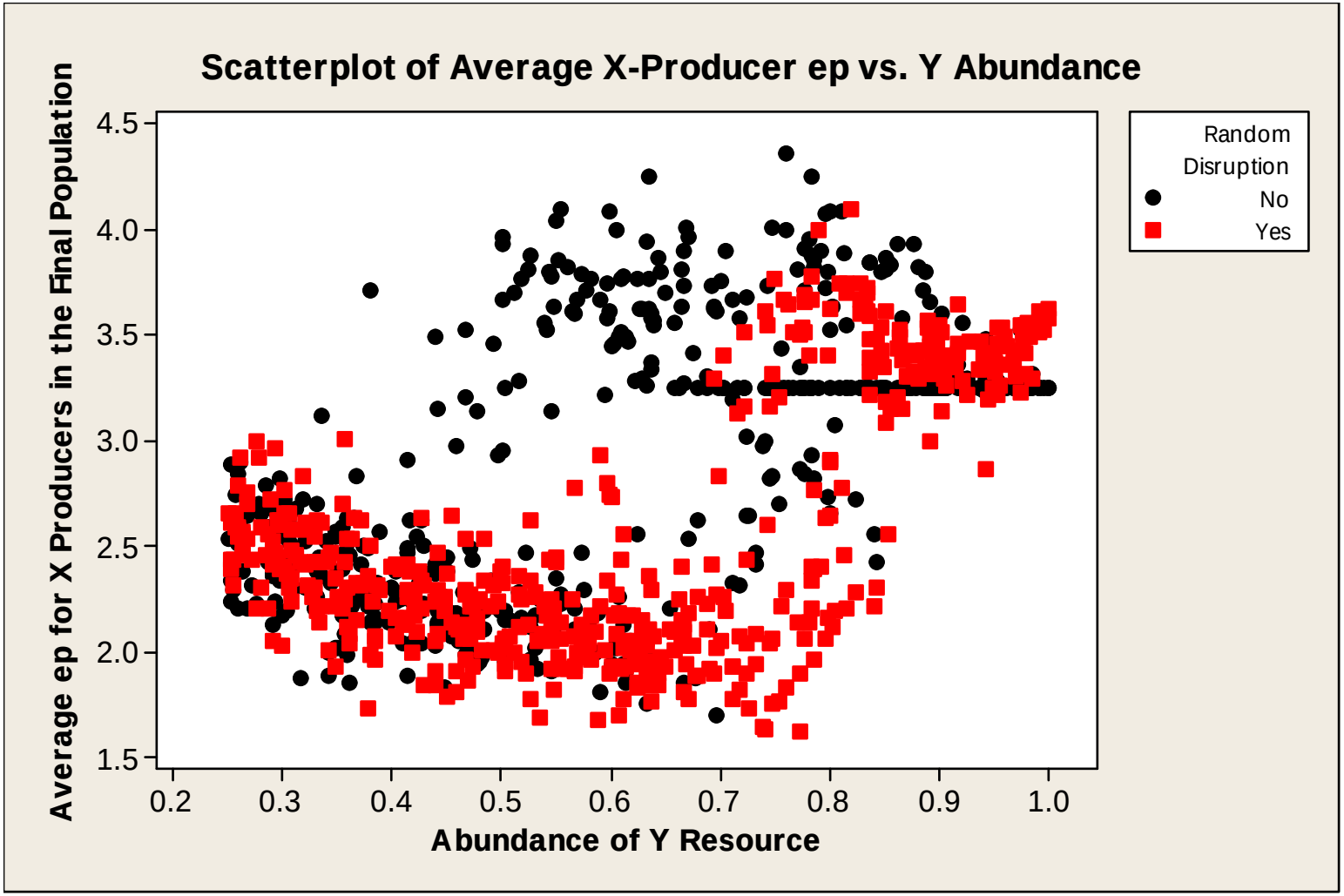
Robustness/Efficiency Tradeoff



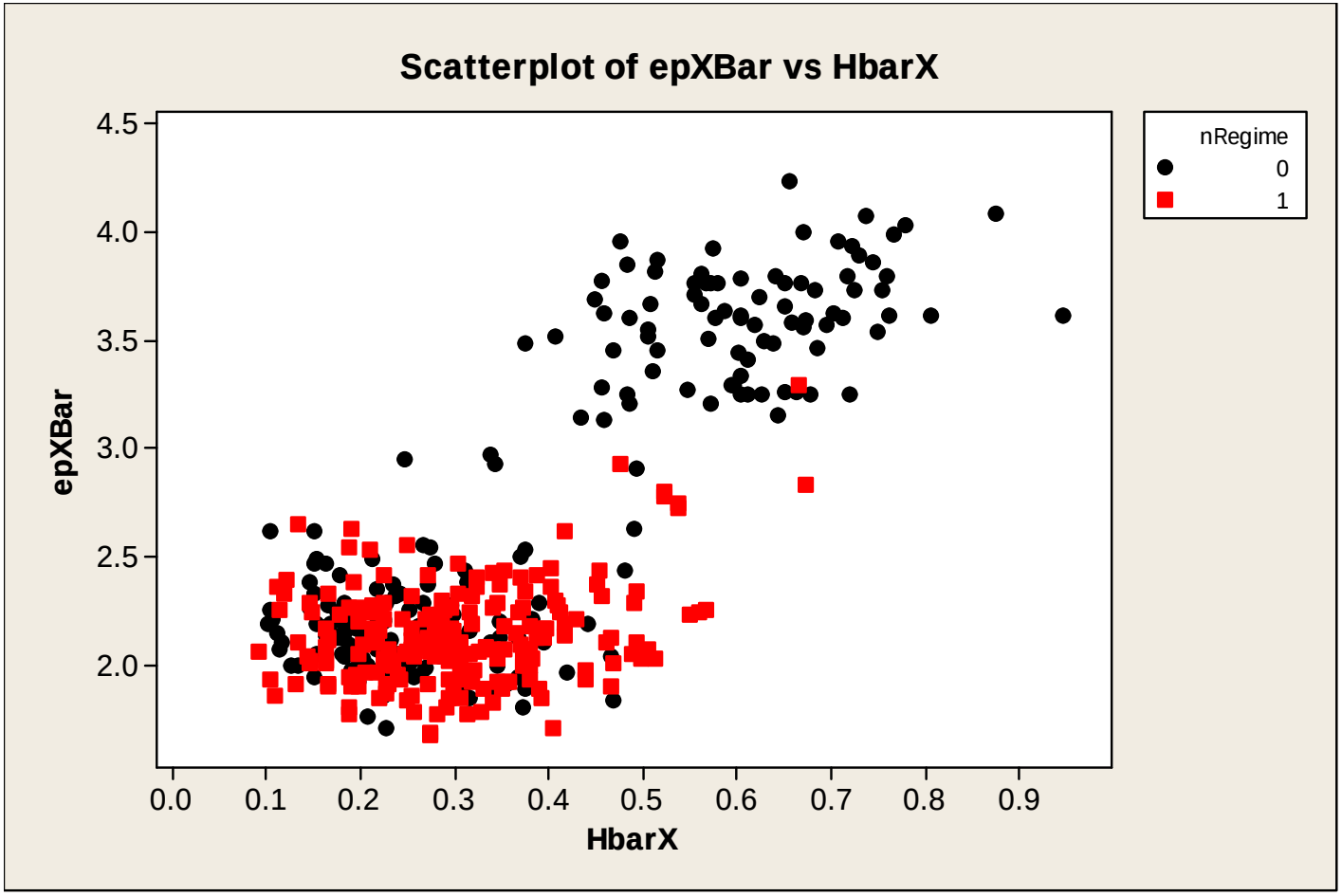
Robustness/Efficiency Configuration



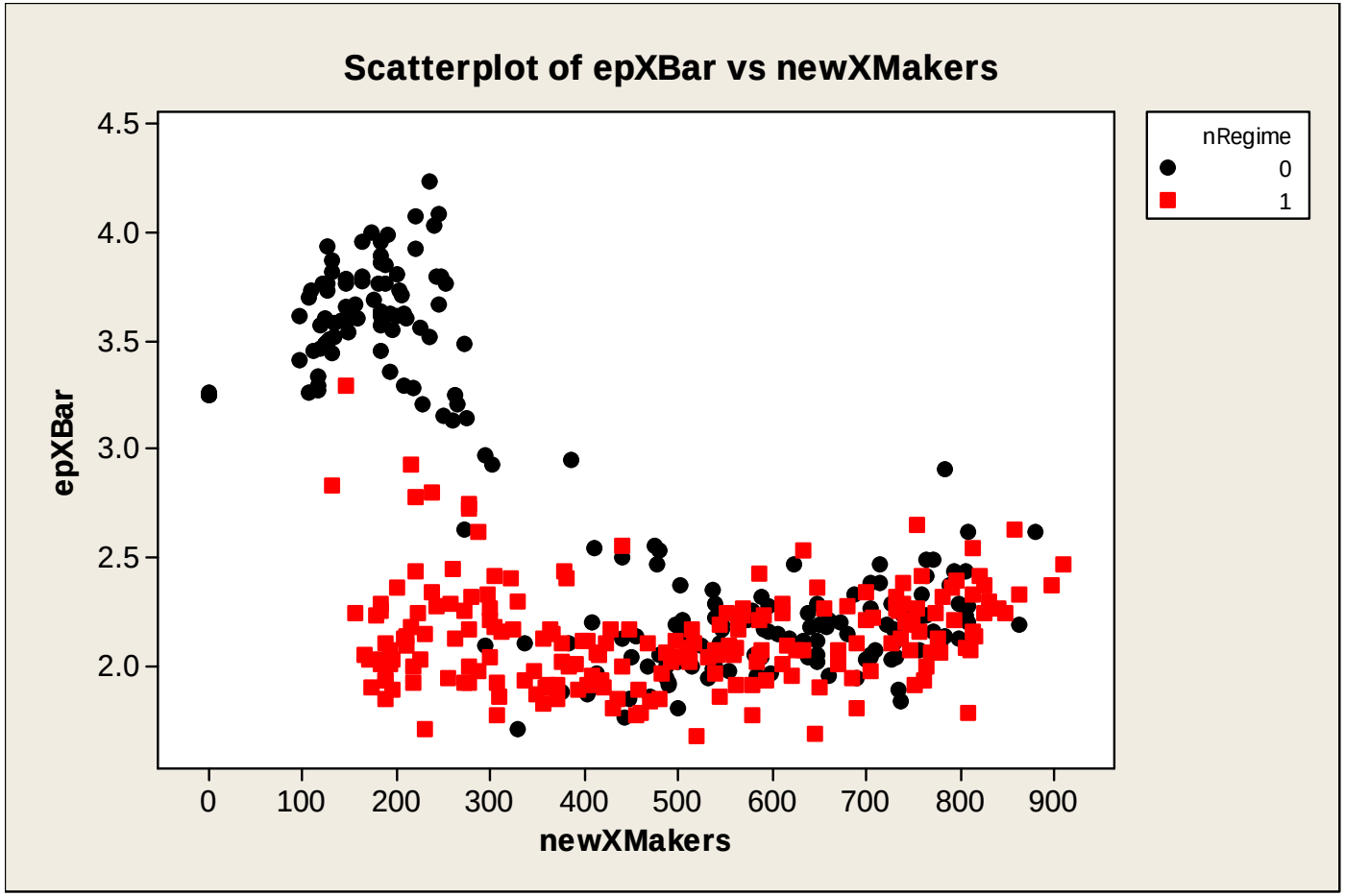
Robustness/Efficiency Tradeoff



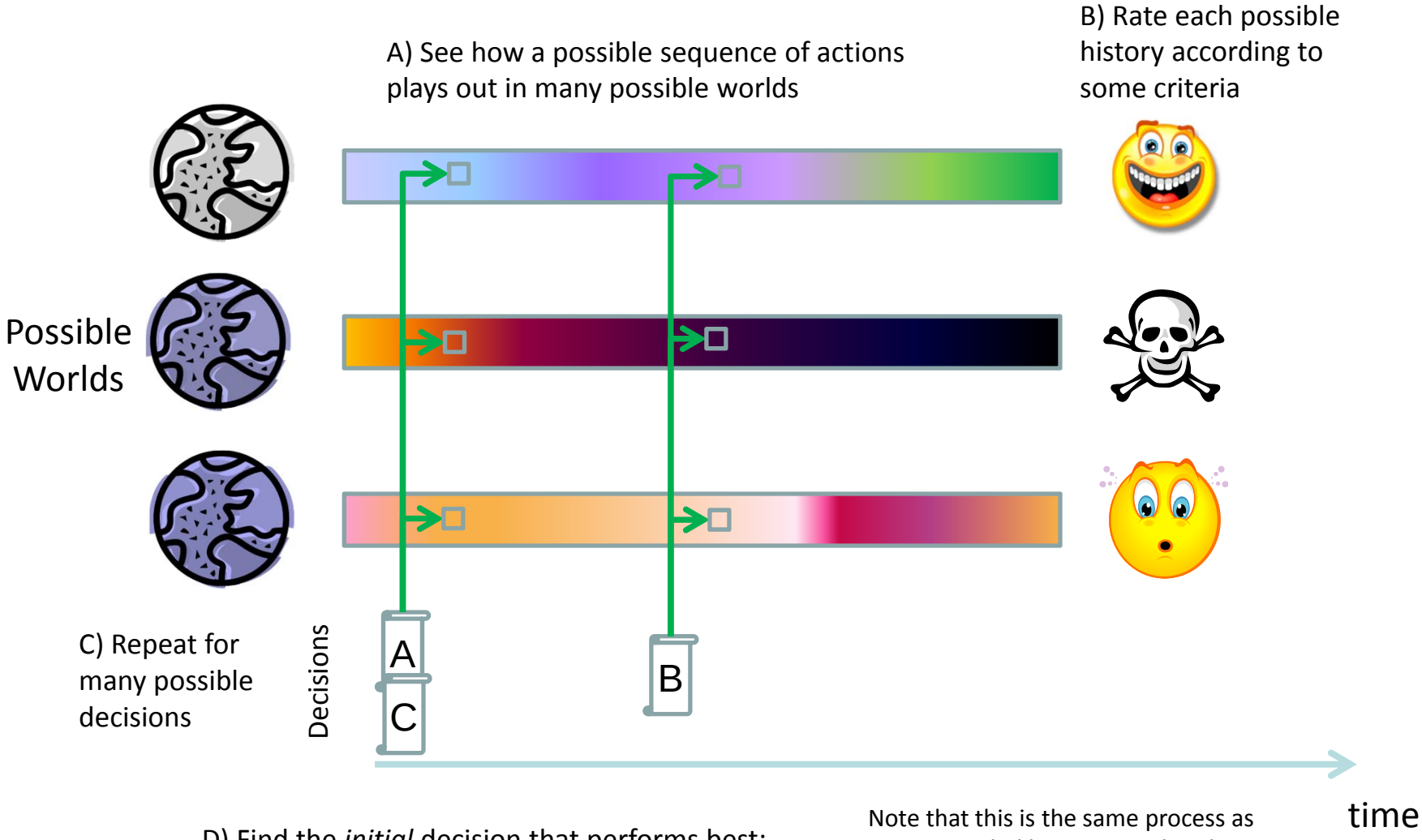
Robustness/Efficiency Tradeoff



Robustness/Efficiency Tradeoff



3) How are decisions evaluated?



D) Find the *initial* decision that performs best:

- Depends on how criteria, worlds are weighted

Note that this is the same process as recommended by RAND in their long-term decision-making methods

4) How is a possible history evaluated?

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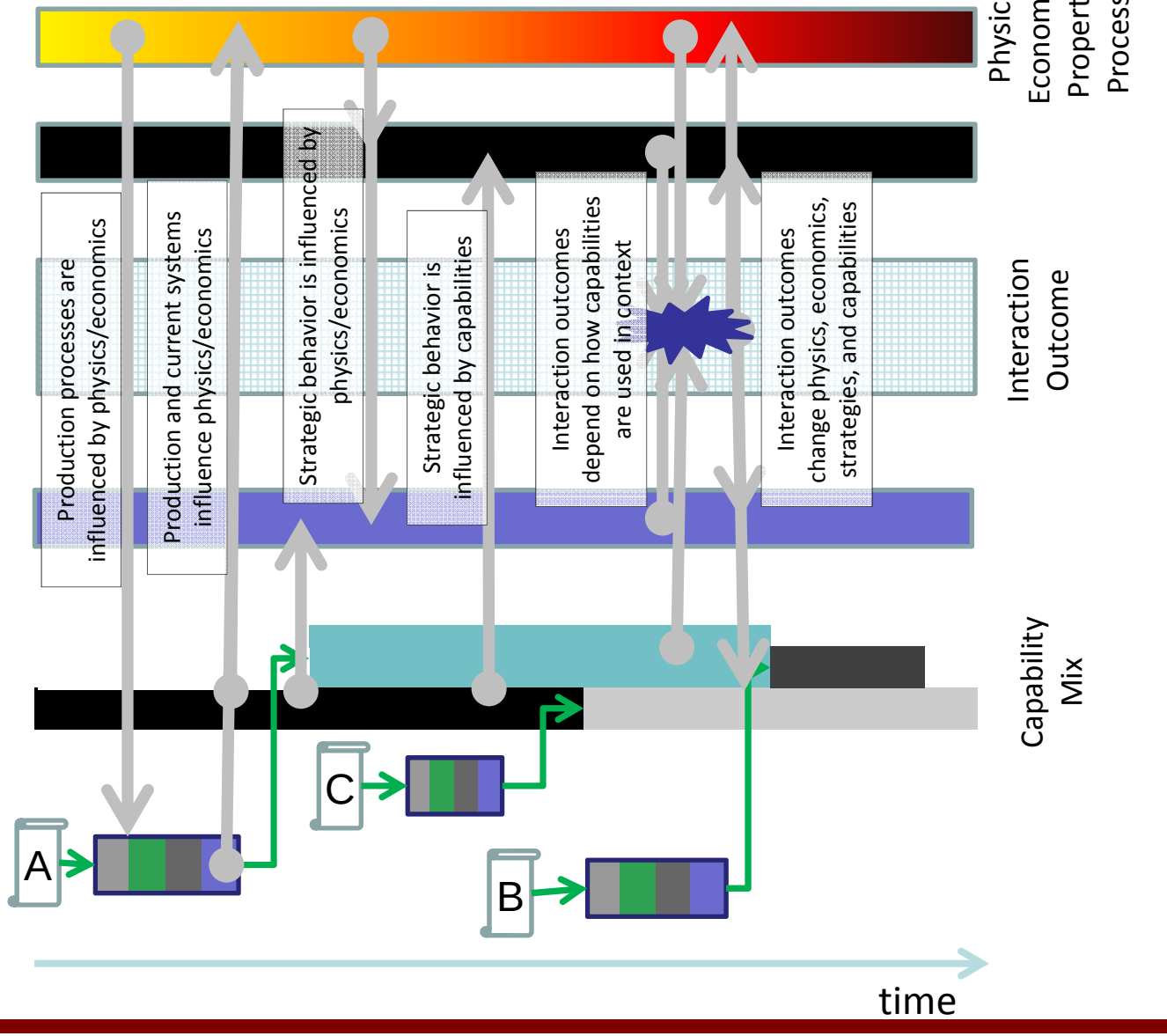
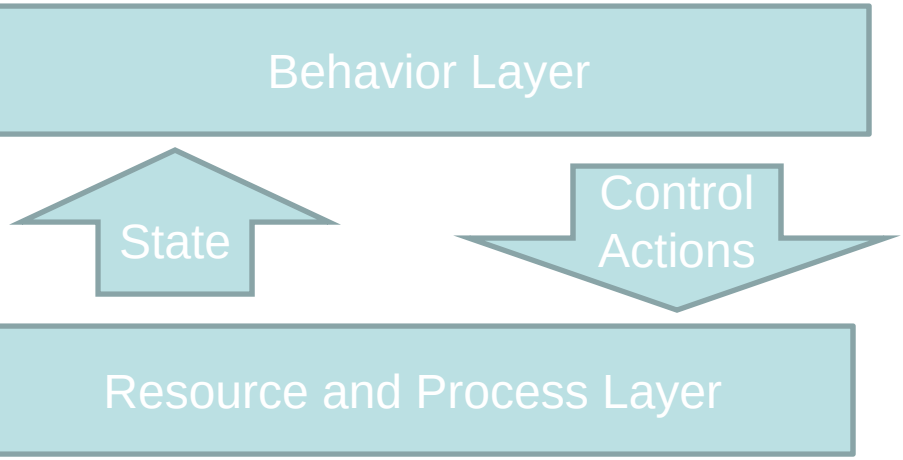
World model may have components, which makes it easier to generate alternatives. Three are shown here: physics/economics, strategic behavior of US, and strategic behavior of all other actors

Possible World



Decisions initiate production of systems at specified times

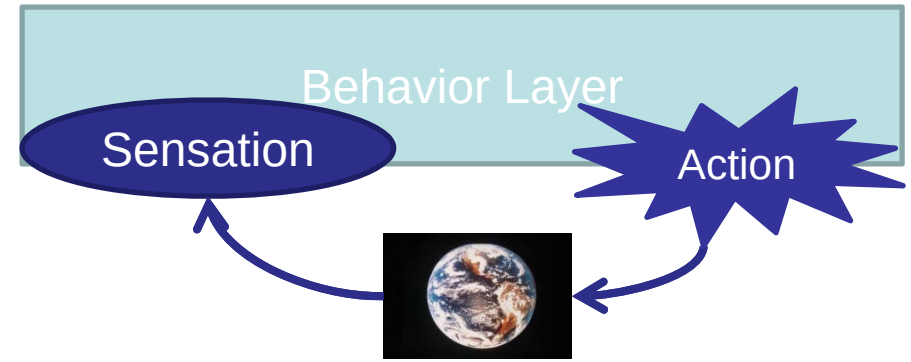
State – Resource (including Entity) levels and relationships. Visibility varies across entities, and state information is mediated by a Sensing object

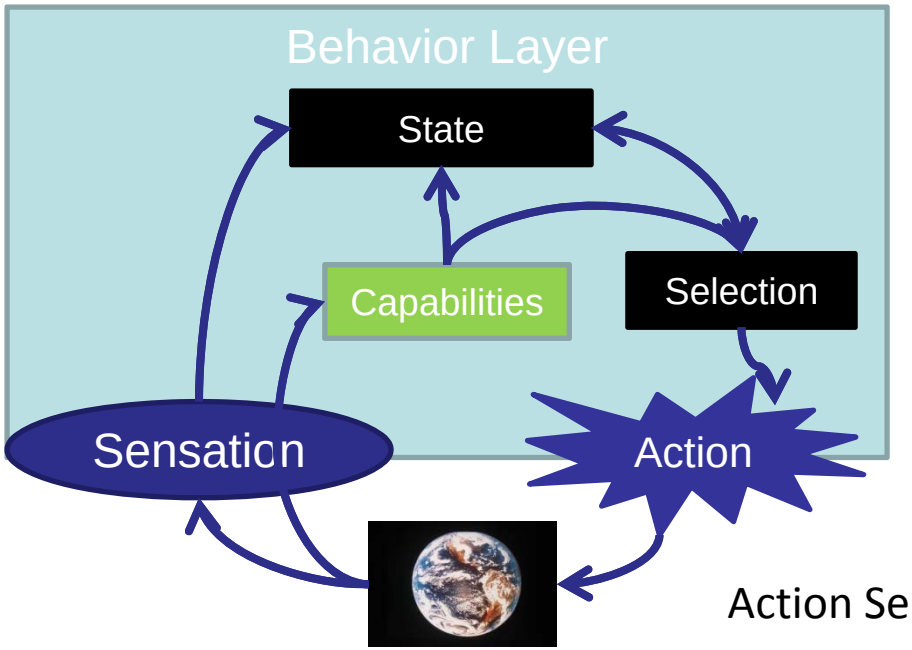


Control Actions are undertaken by a specific Entity. They may fail or succeed probabilistically

Kinds of Control Actions	
Concrete Description	*Abstract Description*
Instantiate a new process	
Connect to/Disconnect from a Market	Add/Delete a relationship between an Entity and a Market Entity
Instantiate Entities	Trigger a specific kind of production process
Adjust parameters on processes	
Join/Leave a compound Entity	Add/Delete a relationship
Set defense policy	Change boundary rules

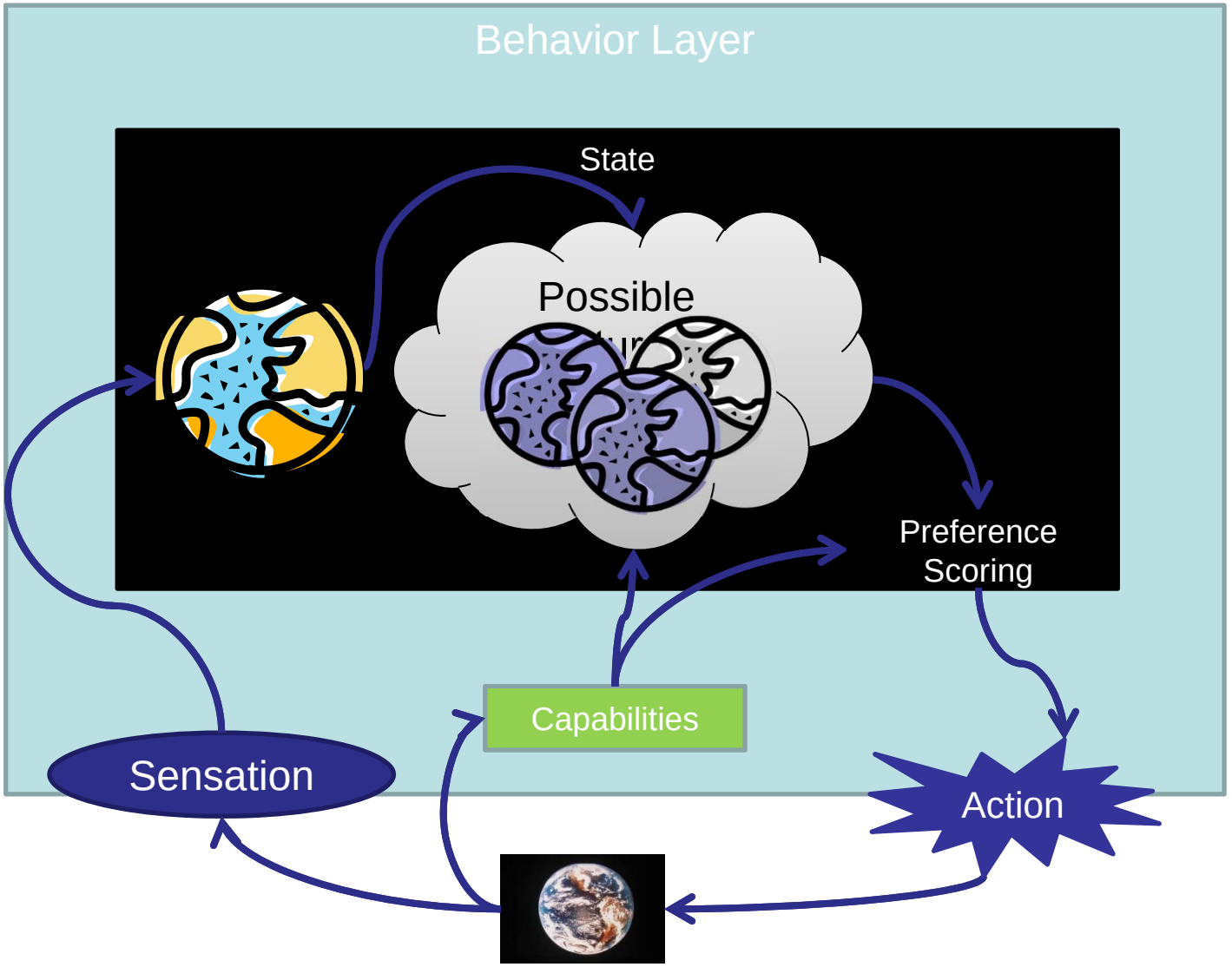
Formulations of Decision-making



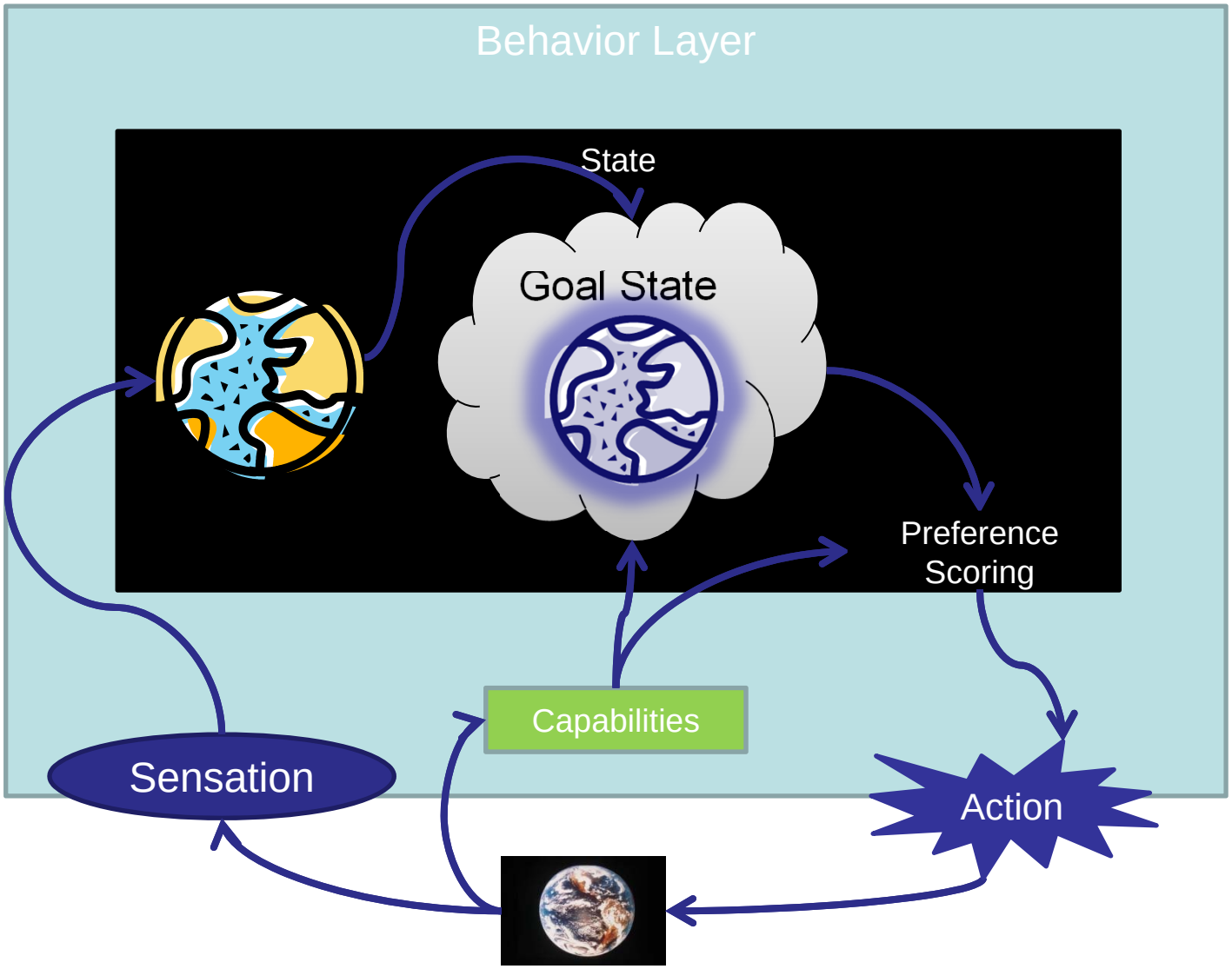


Action Selection

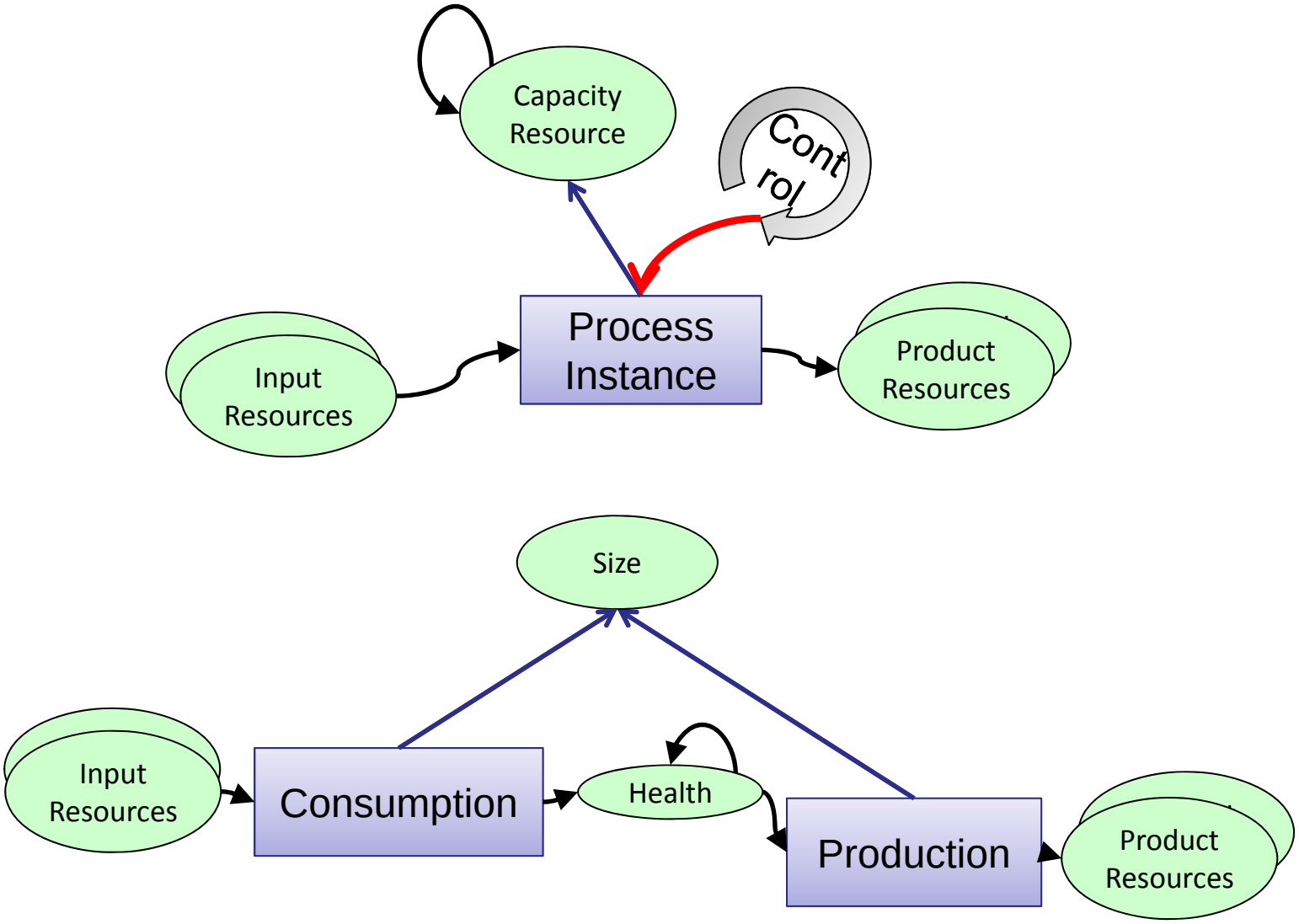
Formulations of Decision-making (cont.)



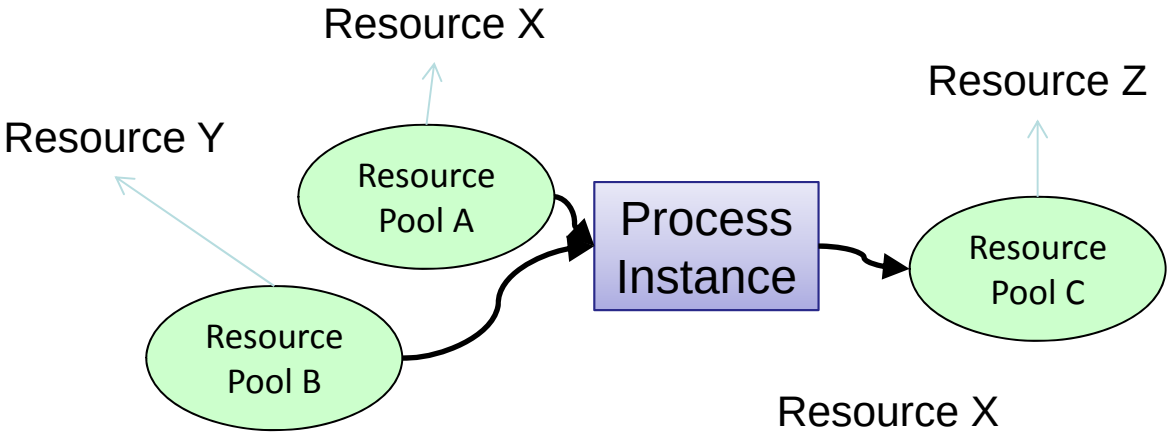
Formulations of Decision-making



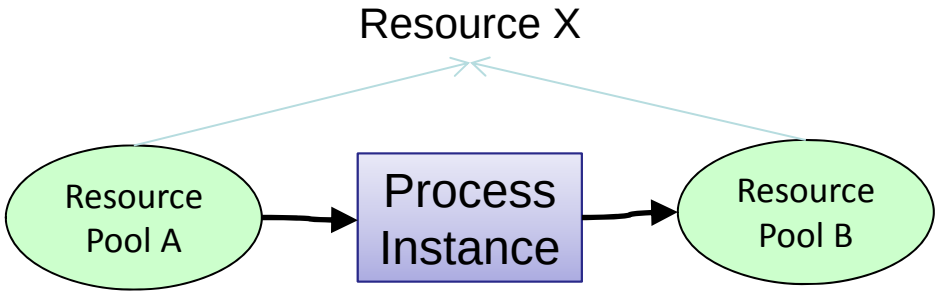
Process Patterns



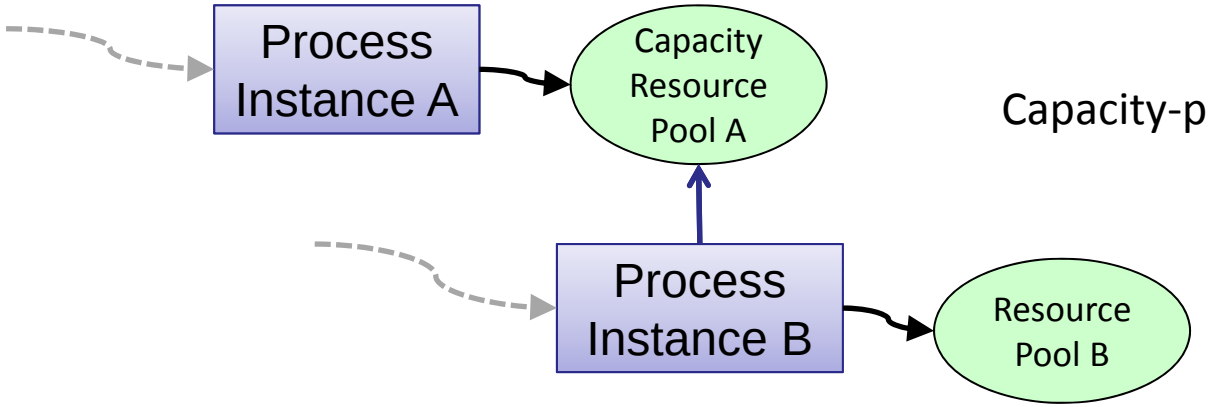
Process Patterns (cont.)



Producing Process
- includes making new Entities



Transporting Process
- includes theft and
(with loss) destruction



Capacity-producing Process

Simple Structure of an Economy

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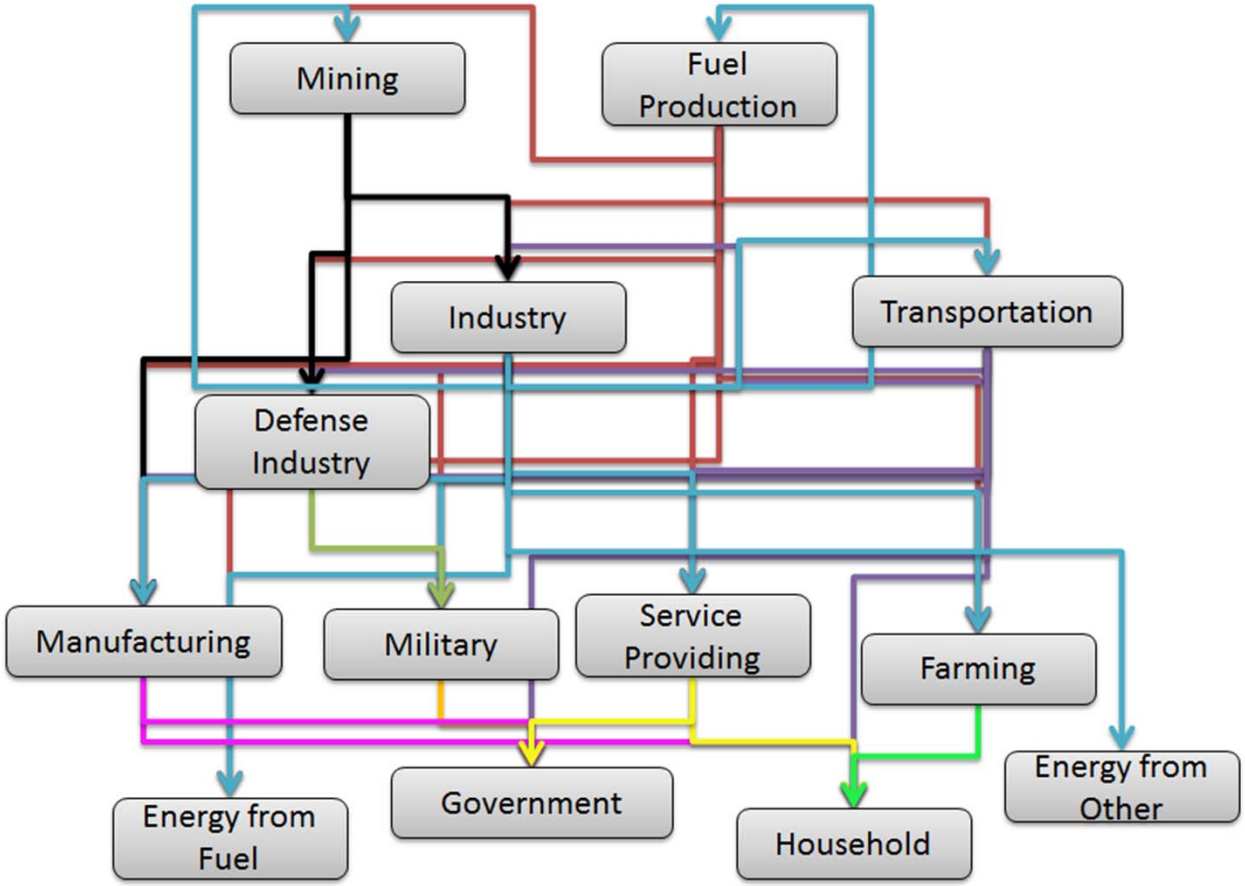

Production Chain Dynamics

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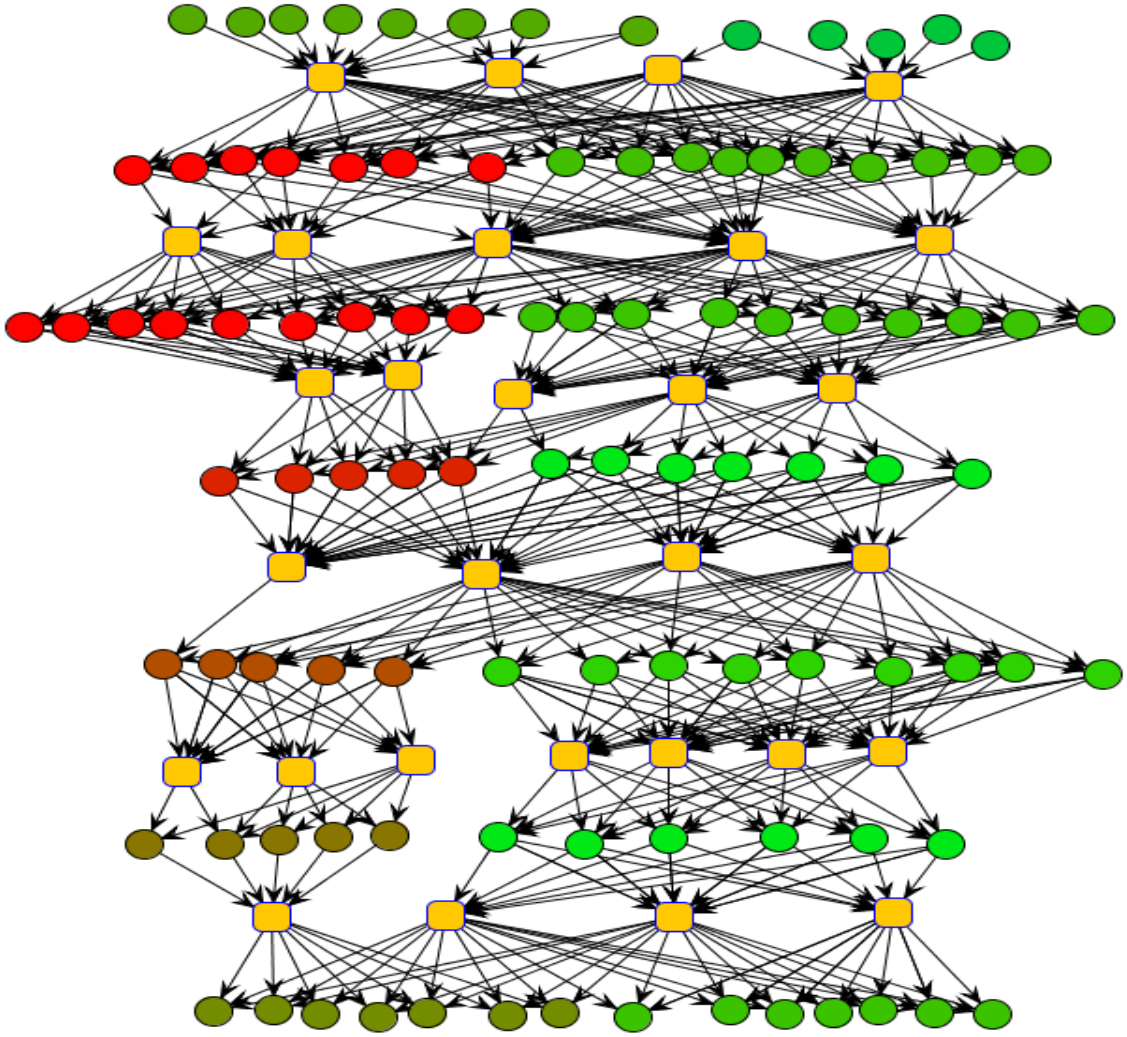

Summary

- Many interesting systems are composed of specialized users and producers of resources
- The essential processes that operate in such systems can be modeled using a few simple elements, which can be configured and interpreted to study particular problems

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QUESTIONS & ANSWERS

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