Weeks 6 & 7: Cybernetics: the Science of Control & Management

- Sufficiently complex, dynamic systems can use information and knowledge to maintain stability in spite of a volatile environment
- Things can go wrong
  - Inputs are subject to noise and disruption
  - Components wear out and/or act stochastically
  - Systems need to use information to self-correct and possibly adapt to changes in the environment
- Feedback and Feedforward
- The coordination of complex systems
- The adaptation of complex systems
- The hierarchical control subsystem

Motivational Questions

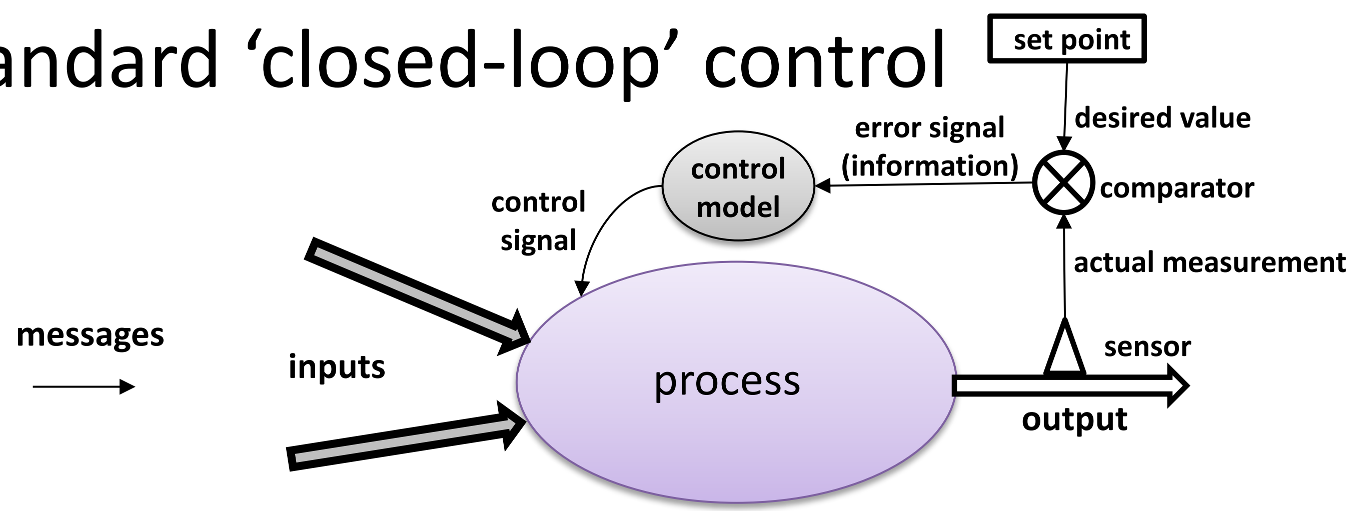
- How do complex, dynamic systems maintain stability and longevity in a "stochastic" world?
  - Stochastic: randomness in aspects of dynamic processes
  - The world is always changing in unpredictable ways
- What are the roles of information and knowledge in maintaining and sustaining complex systems?
  - How are they used to keep systems organized and functioning?

Things Can Go Wrong

- The world is always changing in unpredictable ways
- Uncertainty
  - Random noise
  - Non-stationary stochastic processes
    - Trends away from long-term norms
    - New elements coming into the environment
  - Chaotic processes
  - Example: Climate and Weather
- Entropic Decay – Second Law of Thermodynamics
  - All real physical systems require energy input to maintain form and function
  - All work results in some loss of energy to waste heat, which cannot be used to do more work
- Systems have to be self-maintaining to remain stable over time

Self Regulation - Cybernetics

- Systems can use internal information (messages) and knowledge to self-regulate
- Feedback of information regarding a subsystem's behavior can be used to bring the subsystem into expected performance
- A standard 'closed-loop' control

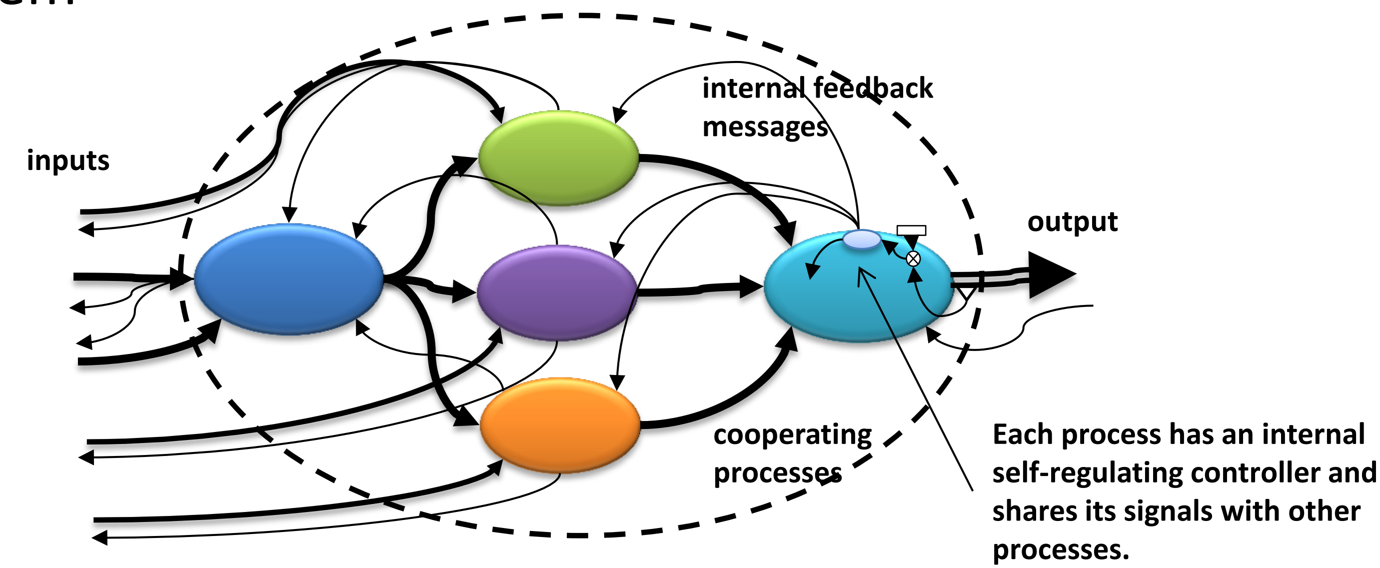


Closed-Loop Control

- A standard, ideal or desired value for the measurement of an output (product) attribute is determined and set
- A sensor measures the actual, real-time value of the attribute
- A comparator device determines how close or far the actual measurement is from the desired set point
- The result is an error signal that can take on zero, positive, or negative error levels
- A ***control model***, and decision processor uses the error to compute a countervailing action (command) that is sent to the main process to cause it to adjust its internal conditions – to reduce the error back to zero

Emergence of Cooperating Processes

- Outputs from some processes are inputs to other processes
- Processes send messages to each other to coordinate inputs and outputs
- The collective of processes emerges as a loosely organized system

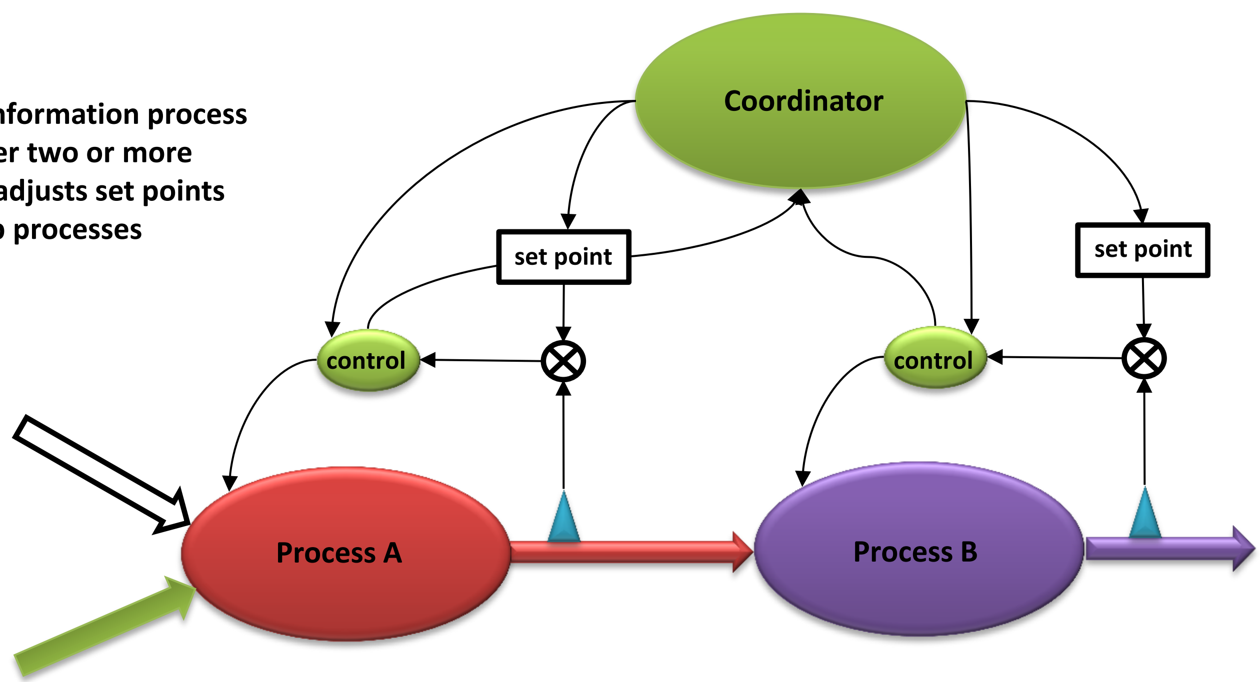


A "Market" of Cooperating Processes

Coordination Above Cooperation

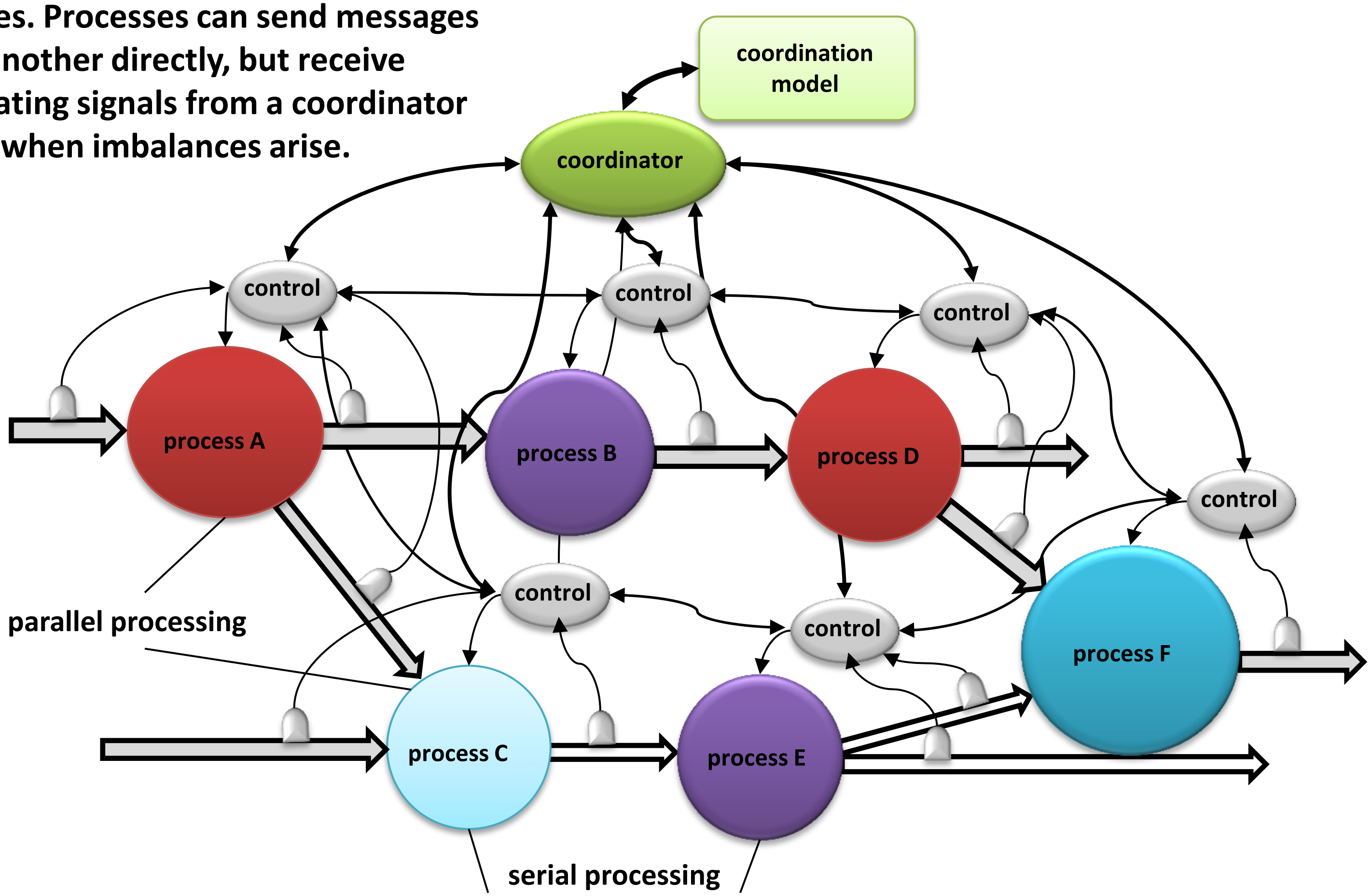
- Cooperating systems can evolve to incorporate a more reliable and dedicated coordinator
- An information processor whose job is to maintain balance between processes
- Logistic control – making sure resources are optimally shared

A coordinator is a special information process that acts as a controller over two or more subsystems (processes). It adjusts set points and control models to keep processes cooperating smoothly.



A More Complex Set of Coordinated Processes

More elaborate coordination models are required to handle complex, cooperating processes. Processes can send messages to one another directly, but receive coordinating signals from a coordinator process when imbalances arise.

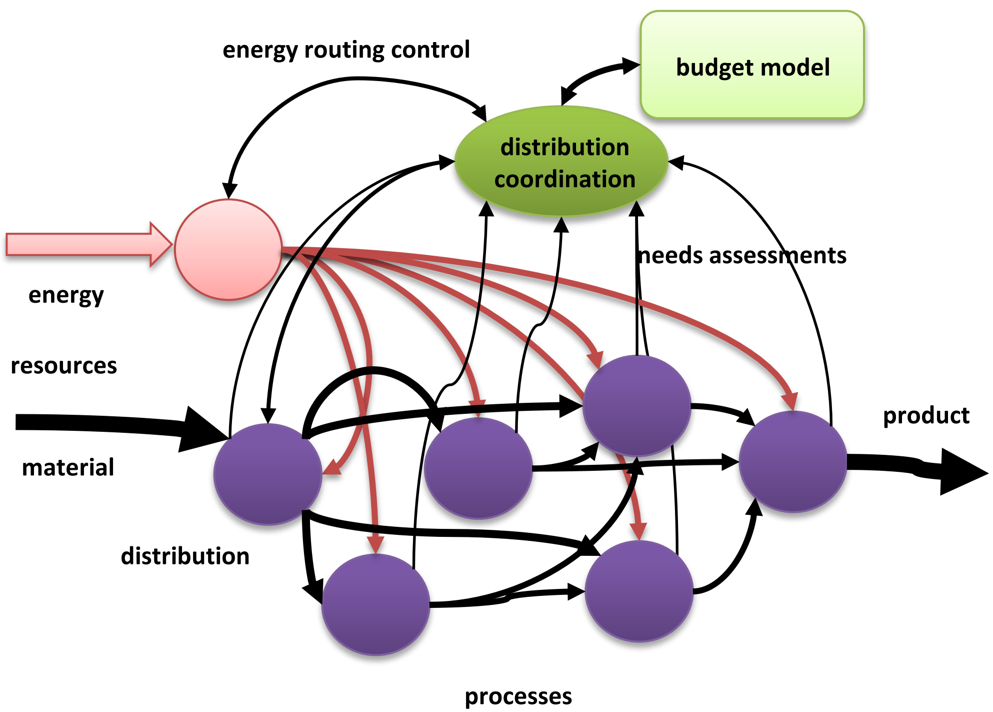


Internal Coordination is Logistical Control

- A ***coordination model*** is used to specify the input/output relations between all of the processes
- Sufficiently complex systems may further divide the coordination task between multiple coordinator processes – this requires a supra-level coordinator to coordinate the inferior-level coordinators
- Coordination hierarchies can be found
  - in living cells – metabolism control
  - whole organisms – central nervous system
  - organizations – management
  - states - government

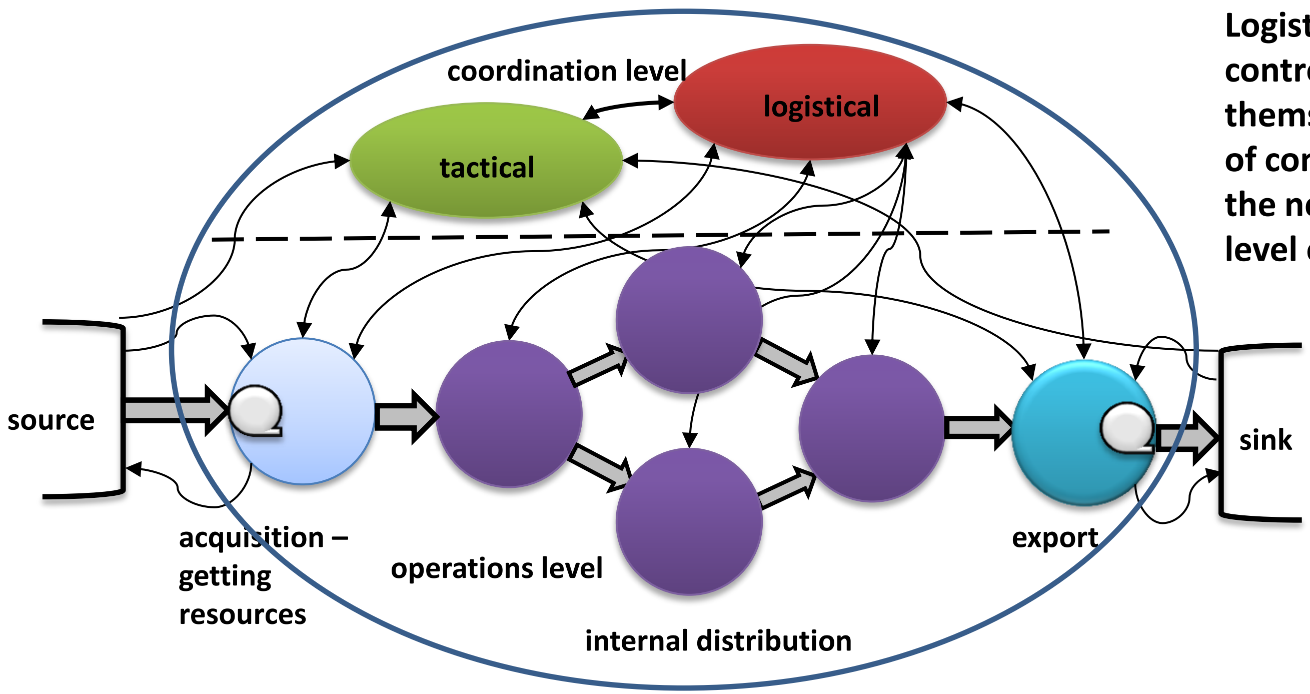
An Example of a Logistical Control – Distribution of Resources

A distribution coordinator uses a budget model to route resources (like energy) to the processes.



Coordinating With the External World – Tactical Control

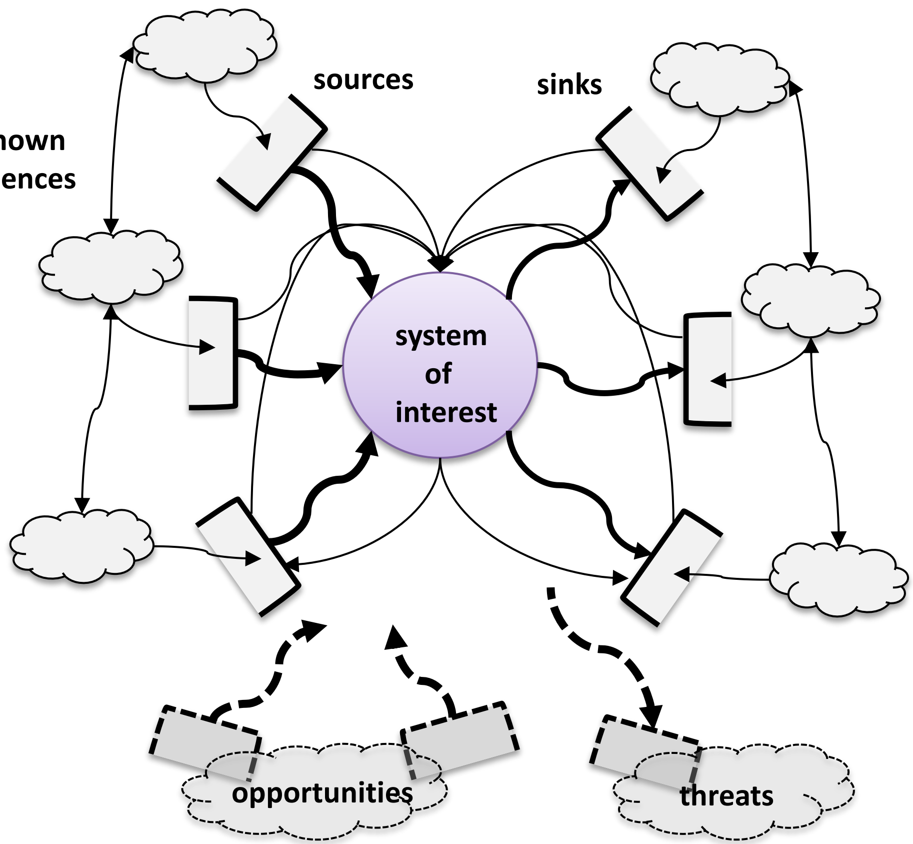
- A tactical controller is similar to a logistical controller but must act to coordinate the system's activities with the environmental entities that are sources and sinks (also threats and opportunities)



Logistical and tactical controllers must cooperate themselves. At some level of complexity this implies the need for an even higher level of control.

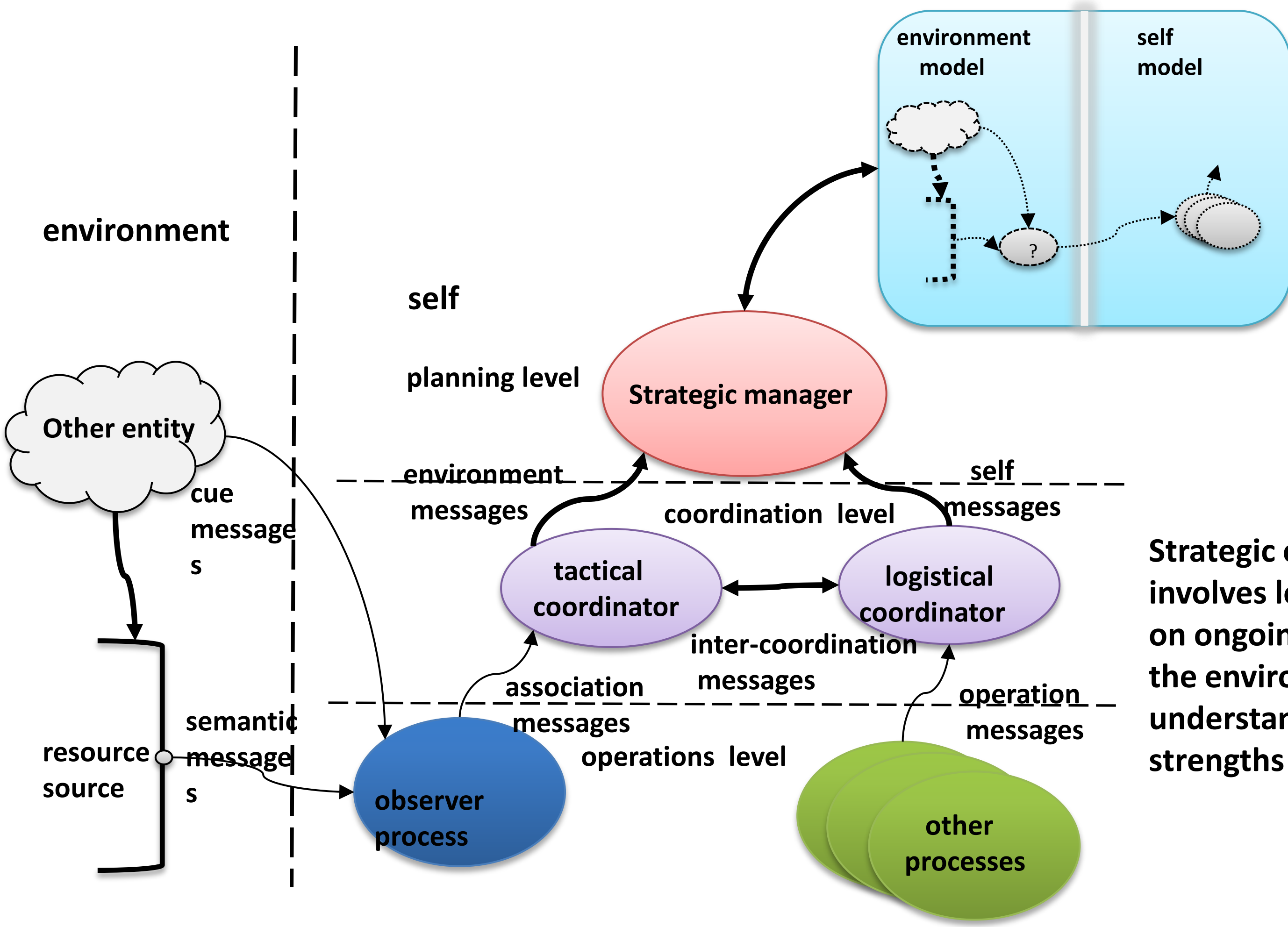
Complex Systems in Complex, Changing Environments

- Combining the stochastic, possibly chaotic, and hidden nature of real environments



Systems that deal with multiple sources and sinks, including unknown possibilities, e.g. opportunities and threats, are subject to high degrees of uncertainty. Influences on sources and sinks that are not known to or observed by the system add even more uncertainty to stability.

Strategic Control for Planning and Long-term Coordination



Strategic control (management) involves longer-term planning based on ongoing behaviors of entities in the environment and an understanding of the self (e.g. strengths and weaknesses).

The Hierarchical Control Model

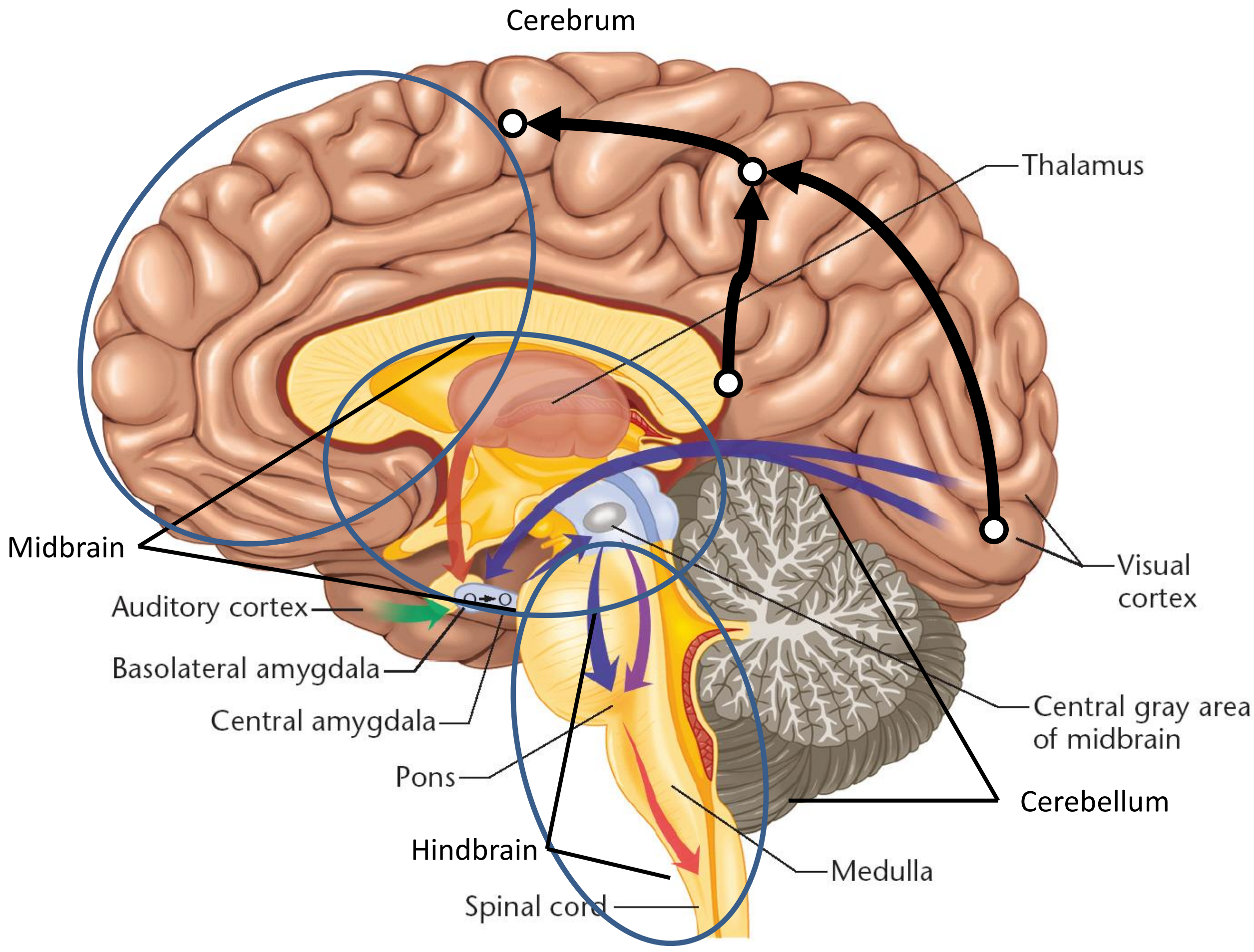
- This model is ubiquitous in many kinds of systems
- Complex systems in complex environments
- Uncertain and ambiguous dynamical processes
- Natural systems, including human societies, have evolved toward this structure
- Information and Knowledge are used to obtain stability in the face of an unstable world
- The human brain is possibly the most successful examples of a hierarchical control system in action

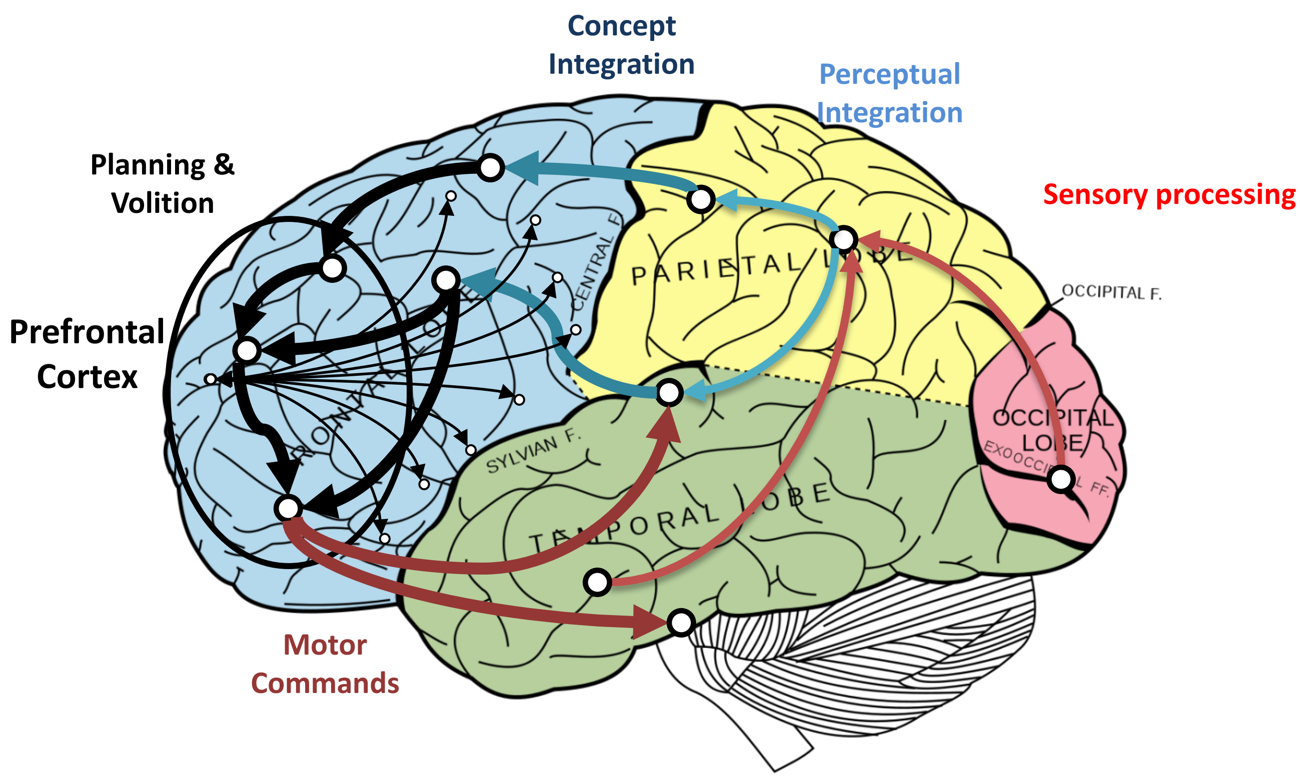
Seminar Questions

- Why is internal control necessary for maintenance of function?
- Why is adaptivity a requirement for internal control?
- What role do models play in the levels of the cybernetic hierarchy?
- Are hierarchies good or bad or...?
- What is it about the world that makes it necessary to have a hierarchical cybernetic subsystem?

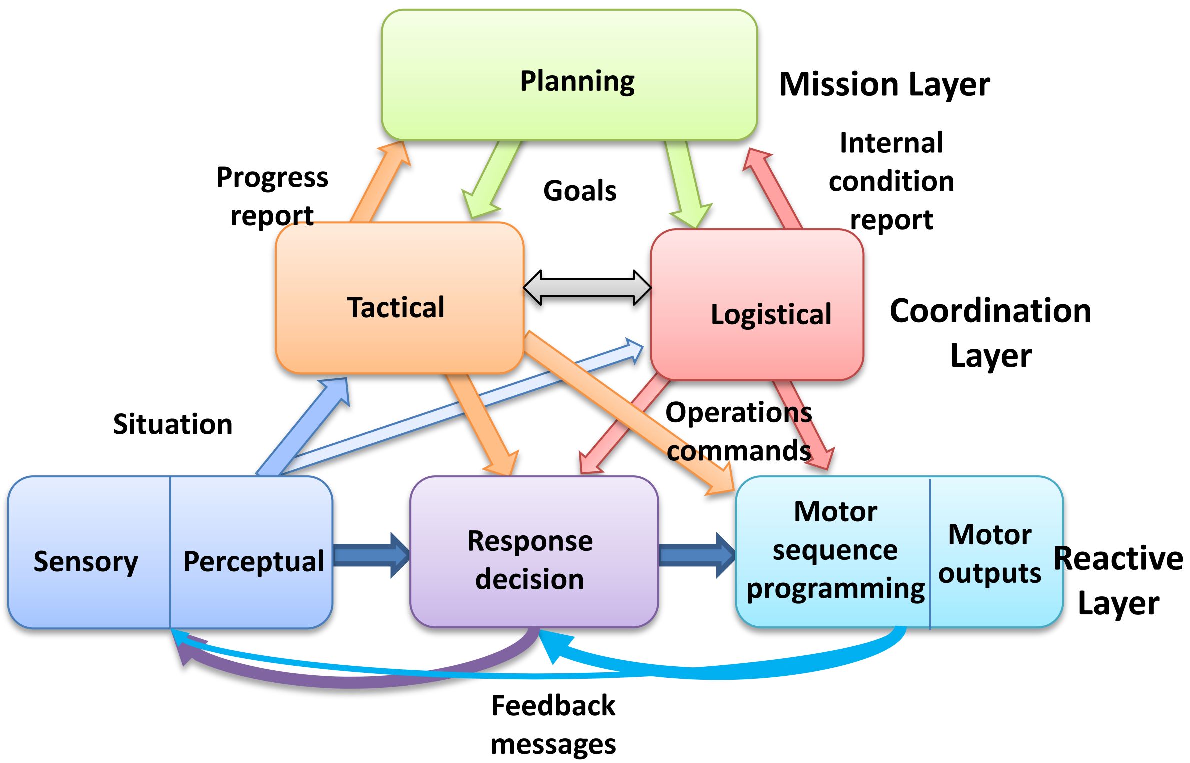
The Brain as a Hierarchical Control System

- Operational level – “hind brain”
  - Getting sensory data from the body
  - Controlling glands, muscles, and viscera
- Coordination level
  - Logistical level – “mid brain”
    - Hormone balances
    - Circulatory, breathing, digestion control
  - Tactical level – “fore brain”
    - Limbic system – fear, hunger, sex
    - Expanded sensory system in neocortex
- Strategic level – “prefrontal cortex”


Cerebrum
Thalamus
Midbrain
Auditory cortex
Basolateral amygdala
Central amygdala
Pons
Hindbrain
Spinal cord
Visual cortex
Central gray area of midbrain
Cerebellum
Medulla


Concept Integration
Perceptual Integration
Sensory processing
Planning & Volition
Prefrontal Cortex
Motor Commands
PARIETAL LOBE
CENTRAL F.
OCCIPITAL F.
OCCIPITAL LOBE
EXOOCCIPITAL FF.
SYLVIAN F.
TEMPORAL LOBE
FRONTAL LOBE

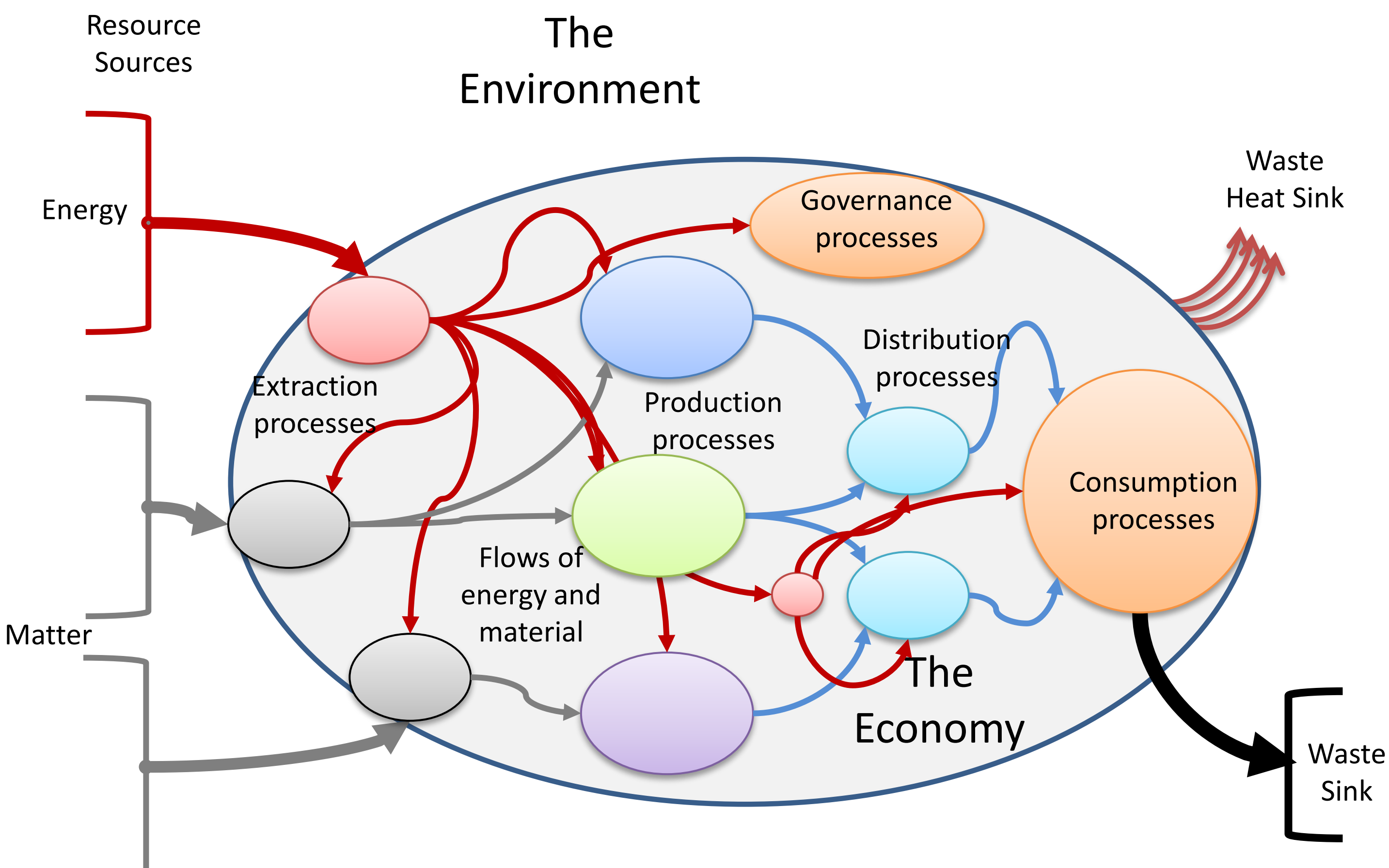
Schematic


Planning
Mission Layer
Progress report
Goals
Internal condition report
Tactical
Logistical
Coordination Layer
Situation
Operations commands
Sensory
Perceptual
Response decision
Motor sequence programming
Motor outputs
Reactive Layer
Feedback messages

The Political Economy as a Hierarchical Control System

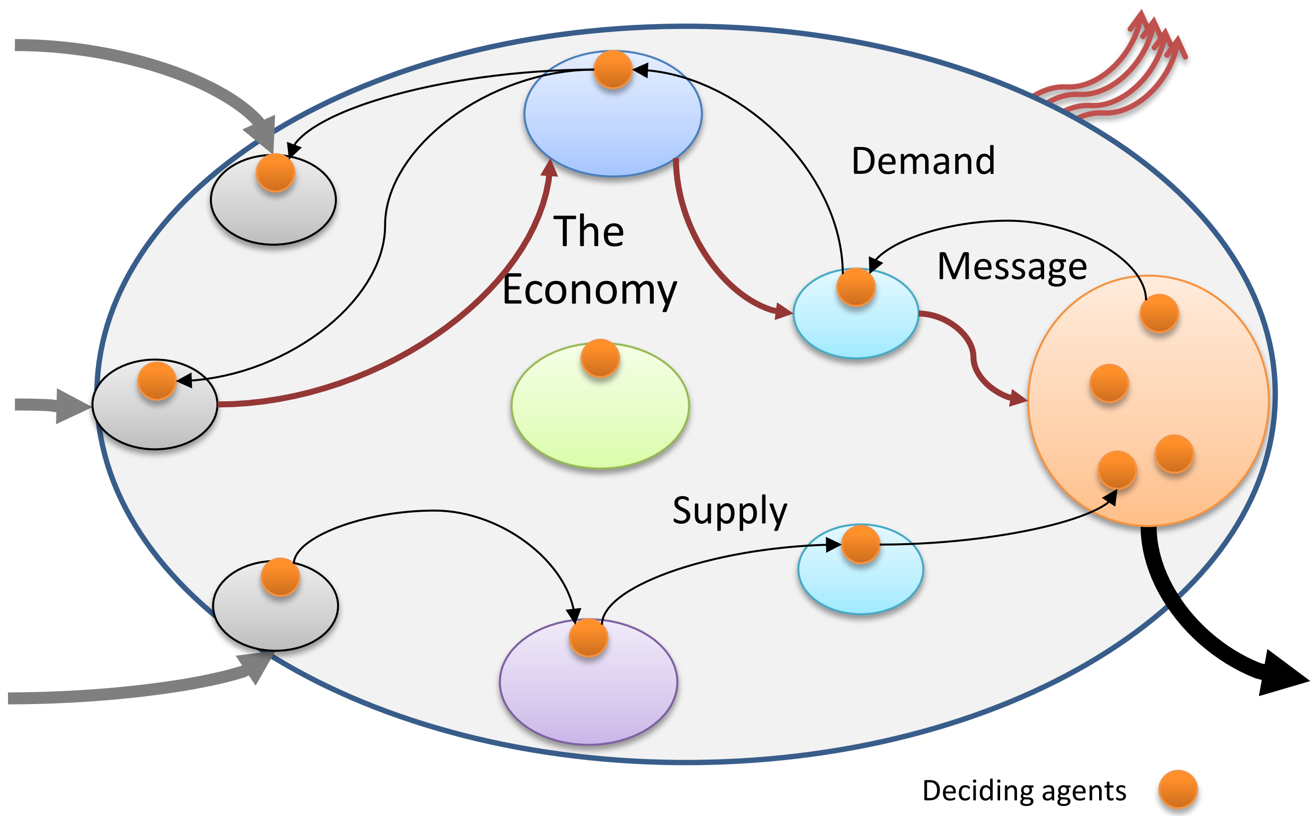
- The fundamental economy is based on the flow of materials and energy from environmental sources, through work and distribution process, to consumption, which produces wastes.
- Energy is required to do work and obeys the laws of thermodynamics – especially the 2nd
- Materials can be recycled but that takes work and thus energy. Energy cannot be recycled.

The Economy and the Environment



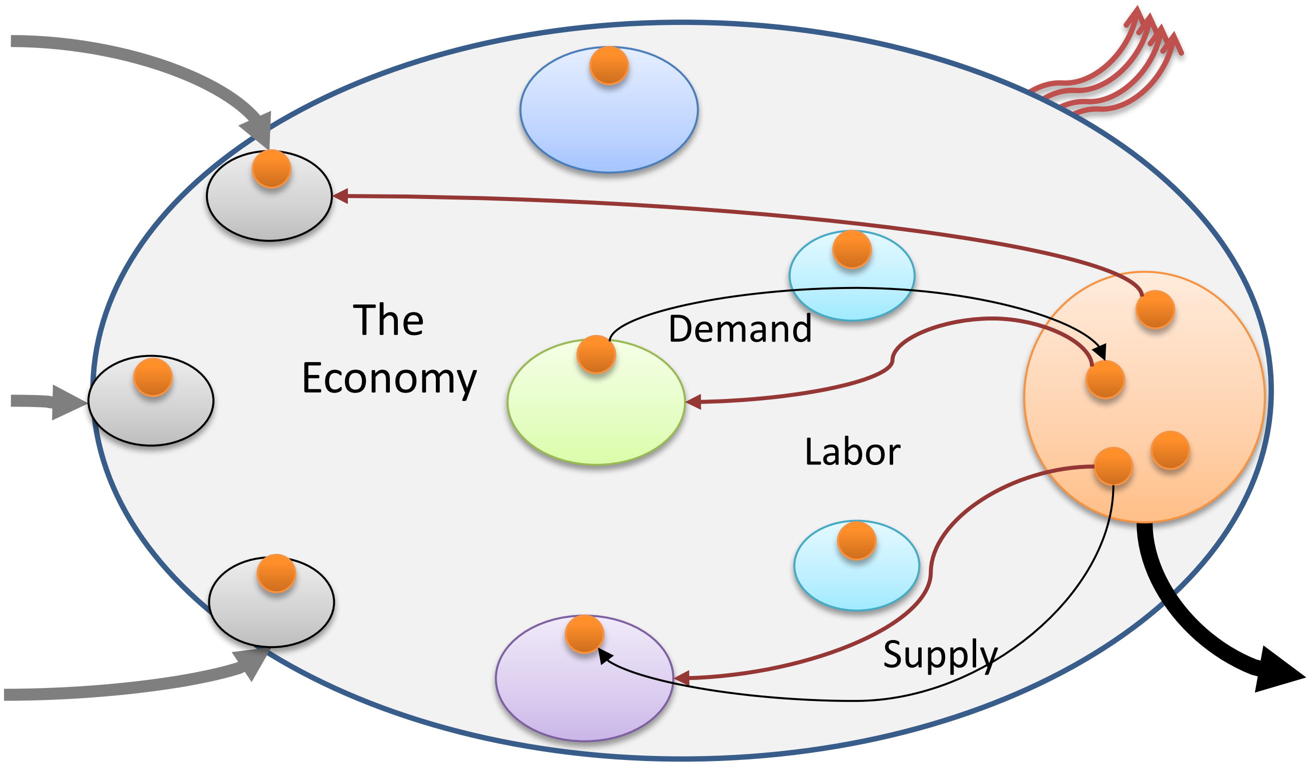
Energy flows from sources (extraction) through work and distribution processes to consumers, eventually flowing out as wastes.

Adaptive (deciding) Agents and Information Flow Controlling Trade



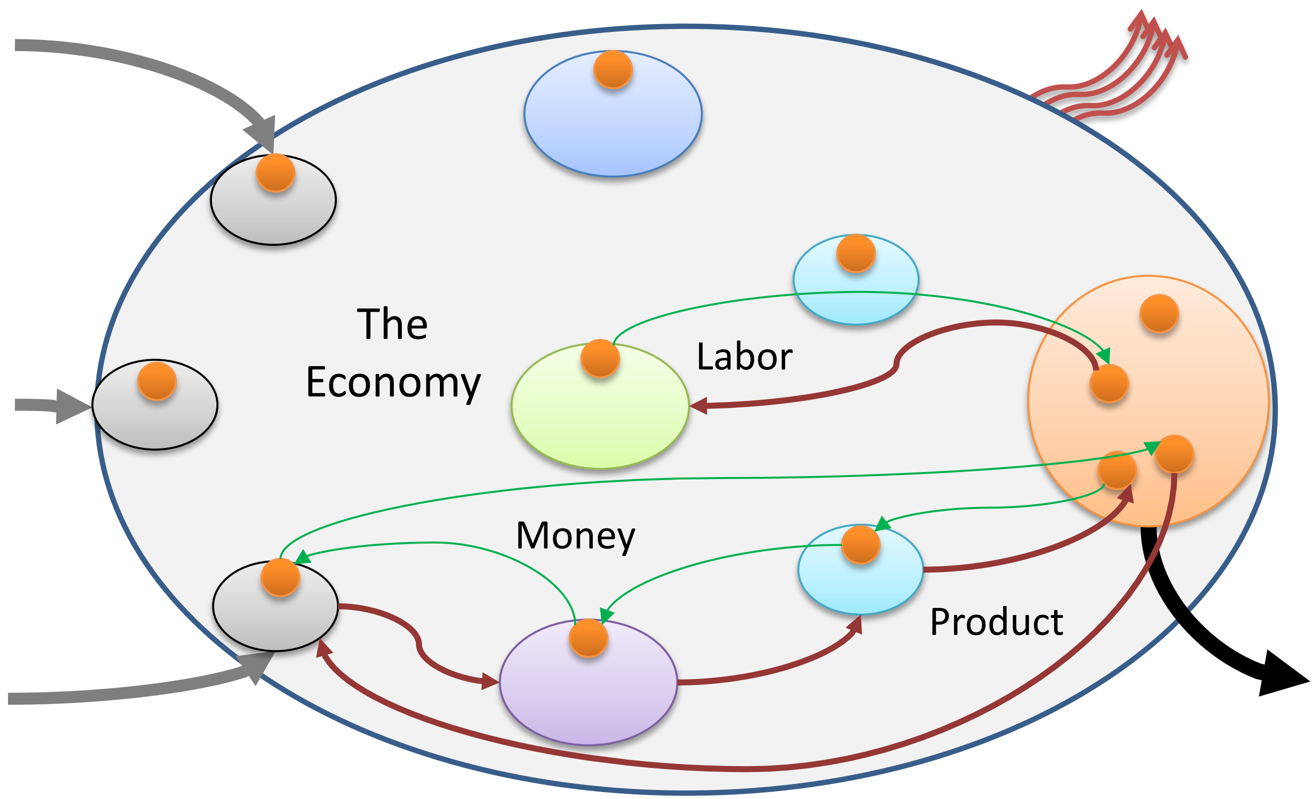
Agents use information to decide how much work to do, and when to do it.

Labor Agents and Trade



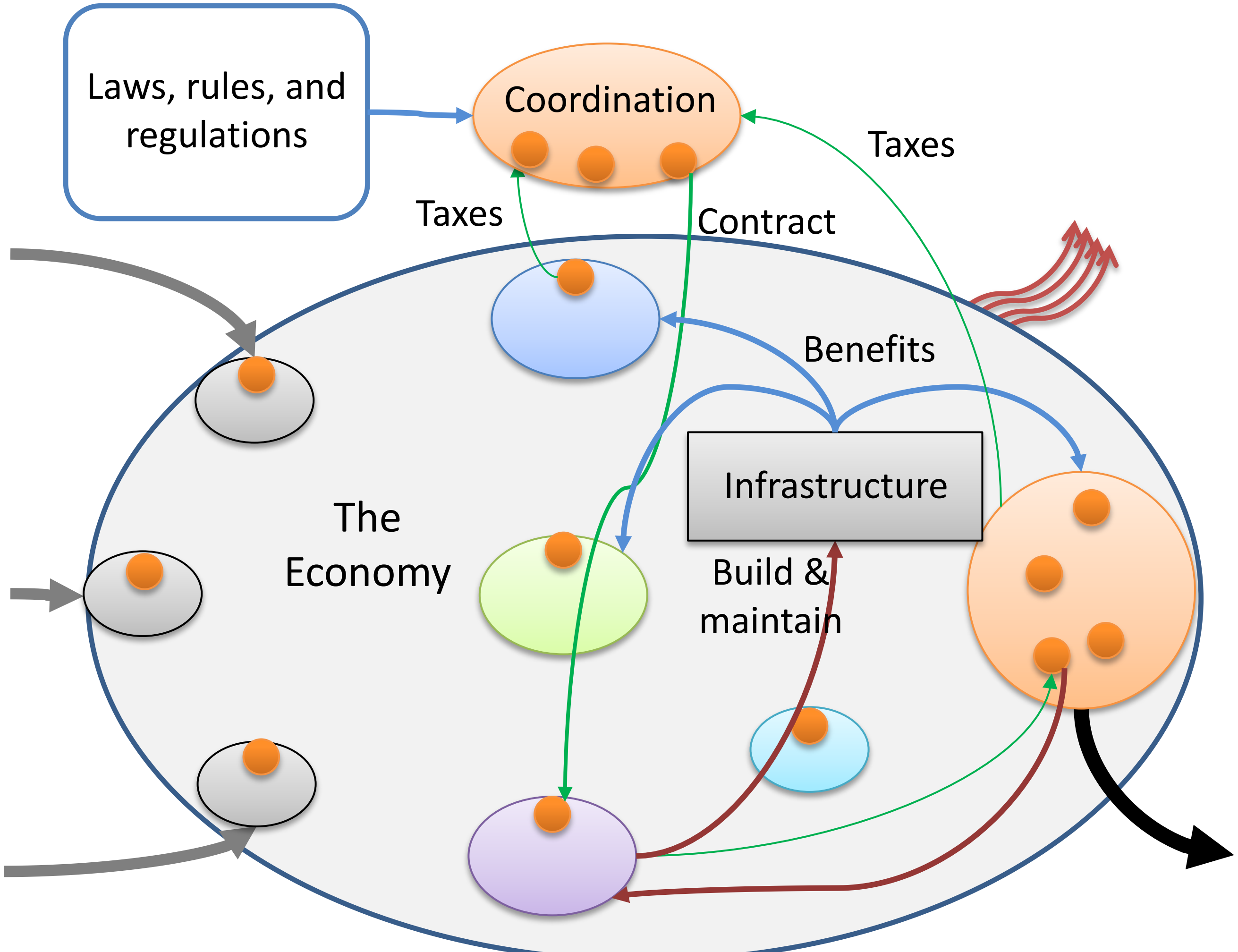
Agents supply labor to work processes in exchange for an ability to control the output of other work processes (for consumption).

Money Conveys Information to All Agents via Price

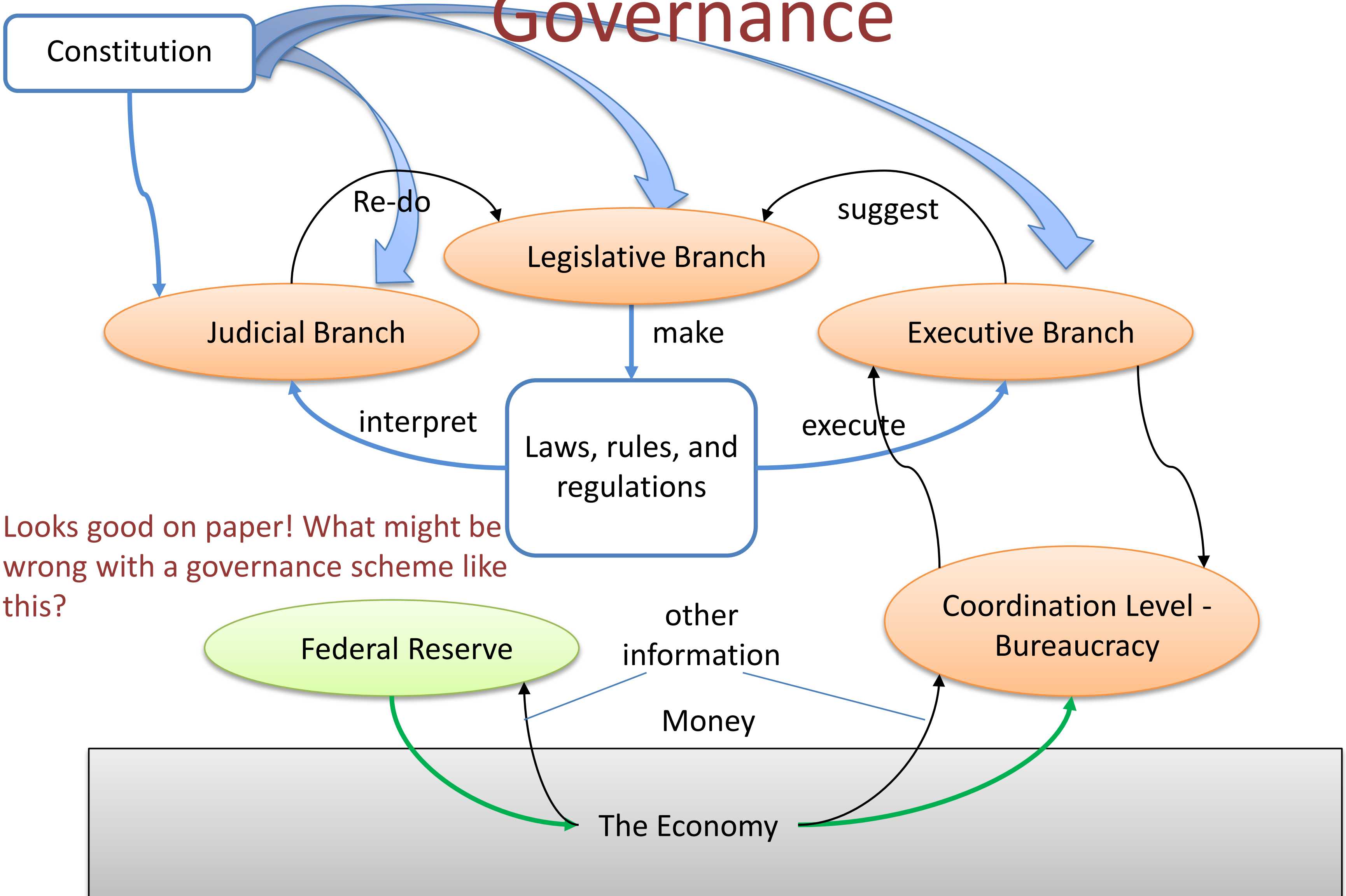


Money flows in the opposite direction of energy (embedded in products or as labor).

Governance Coordination



Strategic/Planning Level of Governance



Looks good on paper! What might be wrong with a governance scheme like this?