Biological Functional Modeling

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Biological Functional Modeling Method

* Gain an understanding of biological system:
  1) Find a good reference (e.g., biology text book)
  2) Read about the biological system; take notes
* Scope functional model; define boundaries:
  3) Define a research question to answer
  4) Define a mimicry category
  5) Define a mimicry scale
* Create functional model:
  6) Model the biological system within the bounds set by Steps 3-5 using the Functional Basis and engineering-to-biology thesaurus
  7) Validate model against scope or have a biologist review the model

Biological Categories for step 4

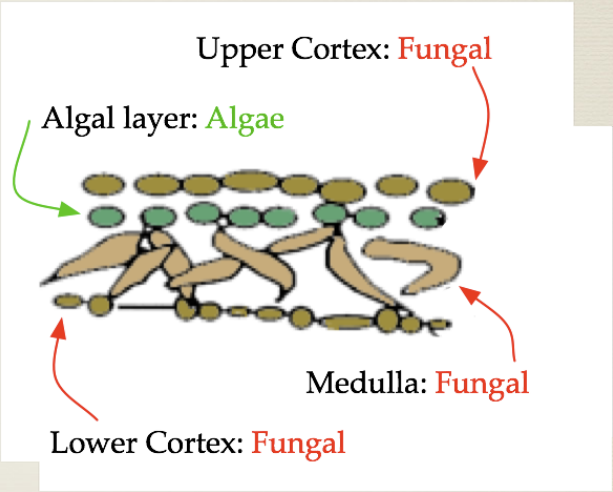
Physiology
Morphology
Behavior
Strategy

Biological Scale for step 5

Ecosystem
Population
Organism
Multi-organ Systems
Organ
Tissue
Multi-cell Systems
Cellular
Sub-cellular
Molecular complexes
Molecular
Atomic

Biological Functional Model of Lichen

Lichen is a symbiotic organism–mycobiont (fungus) and a photobiont (algae)



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Brodo, I. M., S. D. Sharnoff, et al. (2001). Lichens of North America. New Haven, Yale University Press.

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http://biology.arizona.edu/sciconn/lessons2/Murray/Id_sheet.htm

Biological Functional Model of Lichen

* Lichen is a symbiotic organism– comprised of a mycobiont (fungus)and a photobiont (algae)
* The mycobiont completely surrounds and protects the photobiont
* The photobiont performs photosynthesis to create carbohydrate sugars that feed both organisms
* Communication occurs to control the amount of water, nutrients and sunlight that are needed for photosynthesis

Biological Functional Model of Lichen

Translations using the engineering-to-biology thesaurus:

* The mycobiont (fungus) and photobiont (algae) are *solid/liquid/mixture materials*
* The mycobiont is *secured* to and *prevents* the photobiont from harm
* The photobiont *converts liquid, solids and EM energy into chemical energy* that feed both organisms
  * *Measurement* and *control signals regulate* the amount of water, nutrients and sunlight that are passed to the photobiont

Biological Functional Model of Lichen

What is the design question?

- How do the mycobiont (fungus) and photobiont (algae) interact to survive as the symbiotic organism, lichen?

Biological Functional Model of Lichen

Which category?

* Understanding the symbiosis requires knowledge of functionalities of the two organisms that comprise the lichen. The symbiosis of the two organisms involves resource sharing to allow the lichen to exist.
* One could argue that the symbiosis is the category of behavior because the question considers survival. However, the functional model would also need to include states for harsh climates or areas of limited resources, and demonstrate the change in carbohydrate production and dormancy, respectively.
* Physiology is chosen

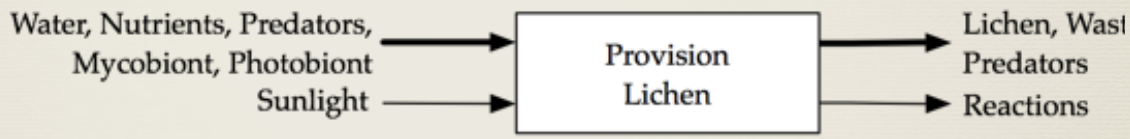
Biological Functional Model of Lichen

Which scale?

* Examining lichen at the organism scale reveals that two materials are secured together and energy is absorbed to sustain and protect life.
* Examining lichen at the organ scale reveals that the photobiont produces carbohydrates through photosynthesis for consumption by both organisms and the mycobiont provides protection for both.
* At the tissue scale, the lichen exhibits many fungal filament networks to sustain life that branch and then fuse together when they meet to form a mesh of hair-like threads. The top surface is normally a layer of tightly packed hyphae called a 'cortex'. The body is known as the thallus.
* A mixed scale of organism and organ is chosen

Biological Functional Model of Lichen

* Design Question: How does the symbiosis contribute to survival?
* Category: Physiology
* Scales: Organism and Organ



Material
Energy
Signal

Biological Functional Model of Lichen

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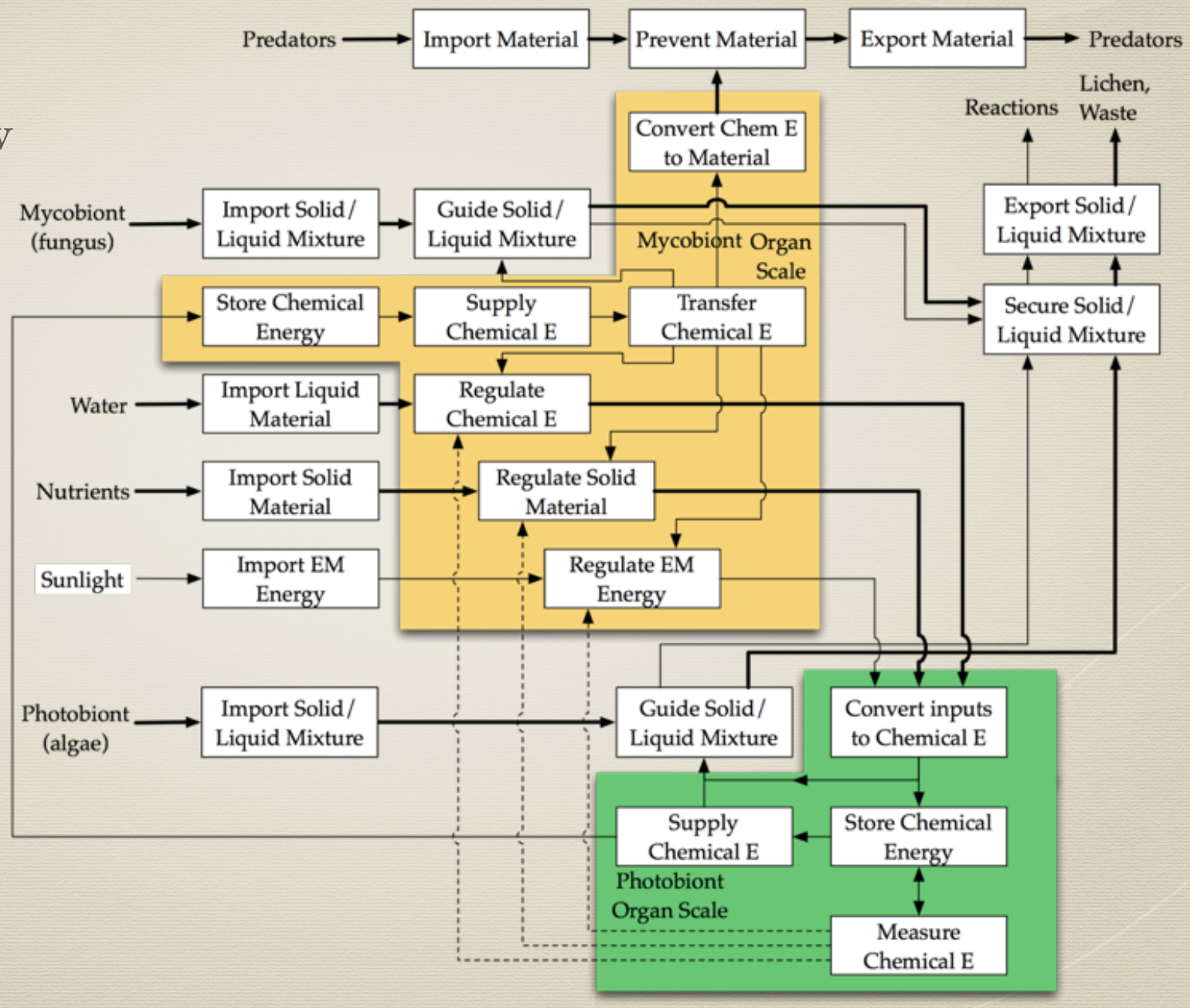


Biological Functional Model of Lichen

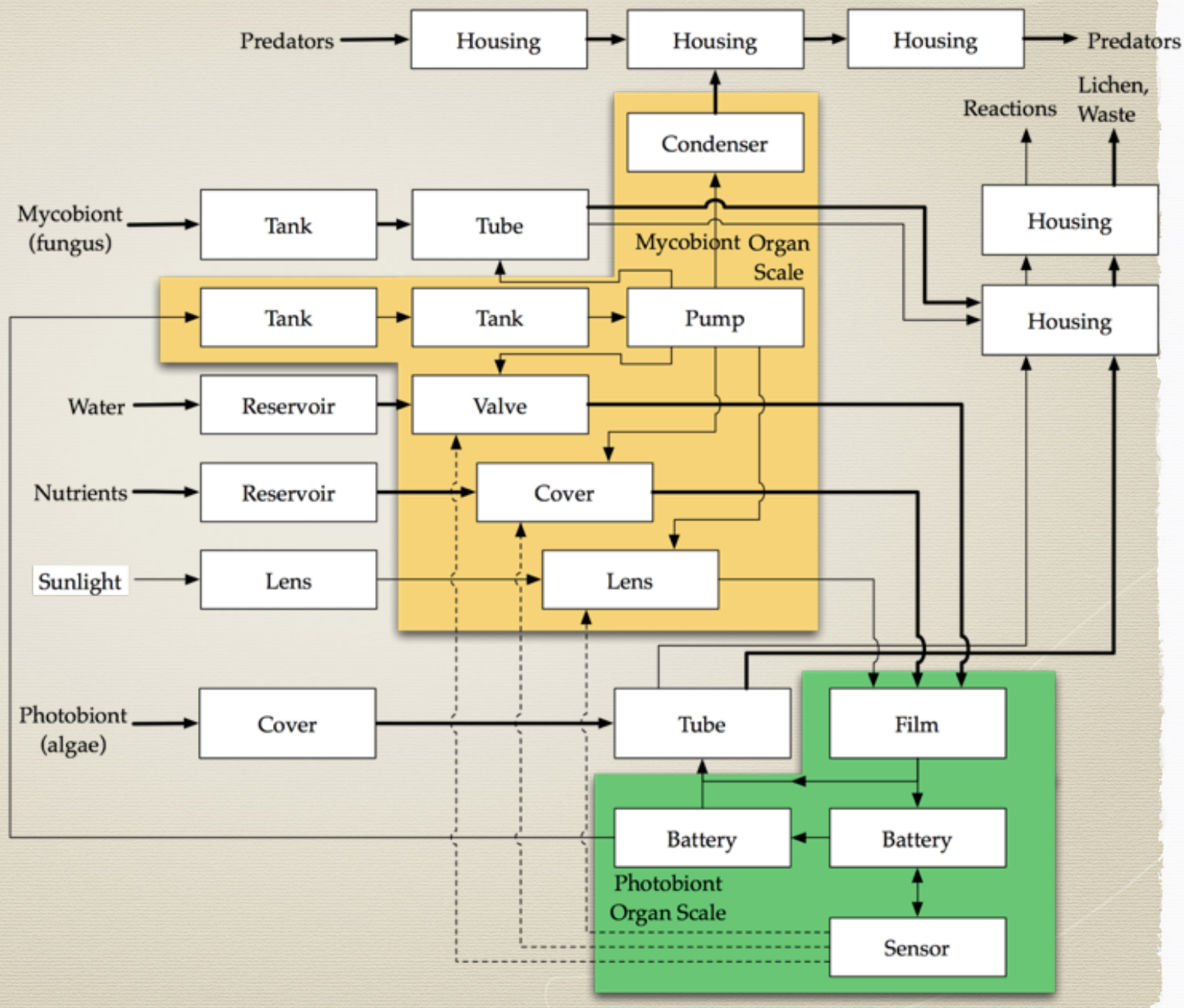
* The biological functional model was validated through two meetings with a lichenologist of the Oregon State University Plant Pathology and Botany Department
    * The first meeting consisted of both the researchers and the biologist arriving at common understanding of the nomenclature required to (1) describe a biological system as an engineered system and (2) describe a biological system to an engineer
    * The first meeting also explained how our initial representation fails to capture the most recent advances and understanding in the field
    * The model changes were reviewed and approved during the second meeting

Once you have a biological functional model, it can be used to generate concepts and identify analogies.

One knowledge base to use with functional models is the design repository:
http://ftest.mime.oregonstate.edu/repo/browse/

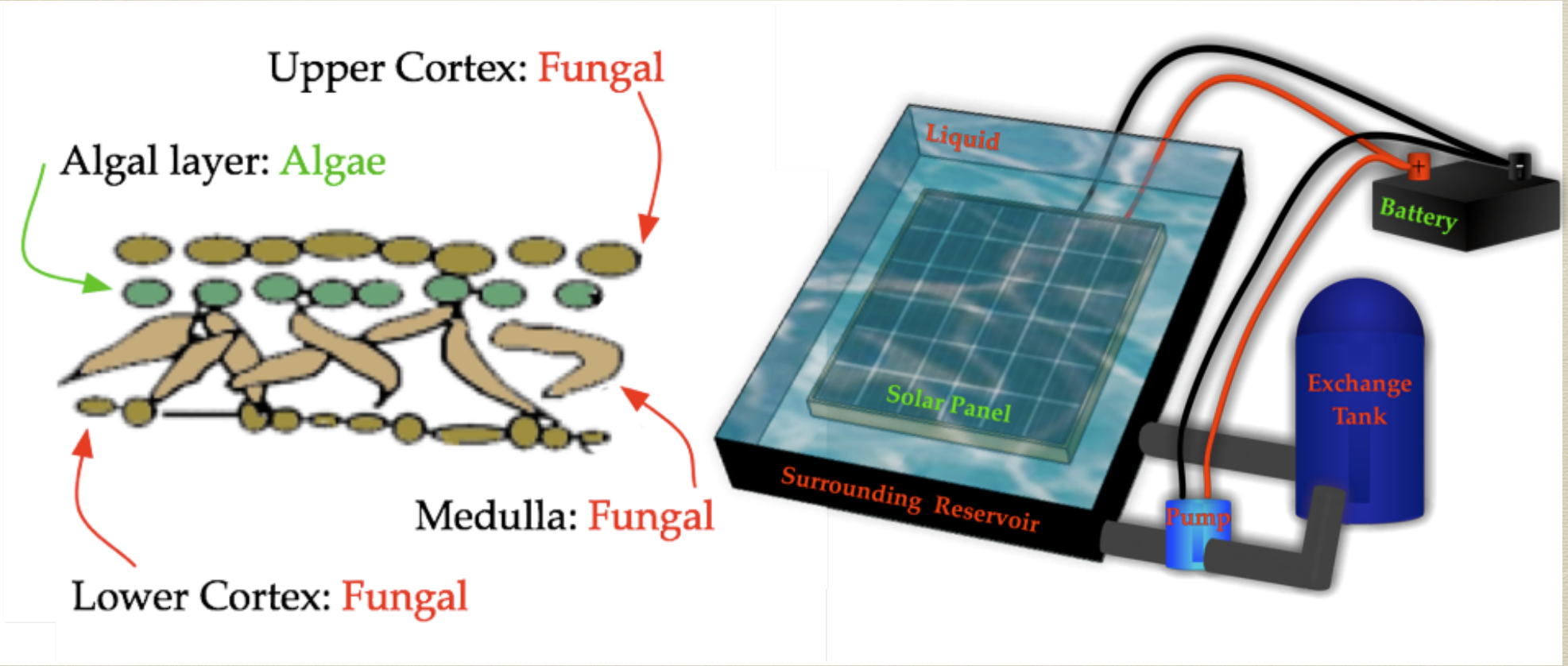
Lichen inspired adaptable solar energy system

To complete the design, the biological functional model is used to identify analogous engineering components by looking for components in the design repository.



Lichen inspired adaptable solar energy system

The liquid surrounding the solar panel provides thermal regulation and concentrates light to allow the system to adapt to changing conditions



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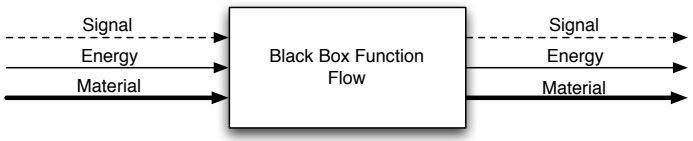
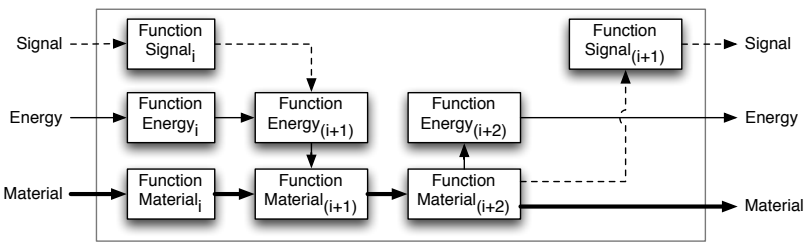
* Stroble, J.K., McAdams, D.A., Stone, R.B., Shu, L.H., Watkins, S.E. (2008) "Modeling the Cellular Level of Natural Sensing Solutions with the Functional Basis for the Design of Biomimetic Sensor Technology." IEEE Region 5 Technical Conference, Kansas City, MO, USA.

Some background info on creating (non-biological) functional models

Functional Models





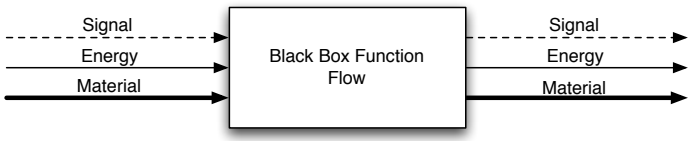
- Define overall system function
- Identify system boundaries
- Identify flows of Energy (E), Material (M), and Signal (S)
- Identify interfacing objects that exchange E, M, or S
- Conserve E and M

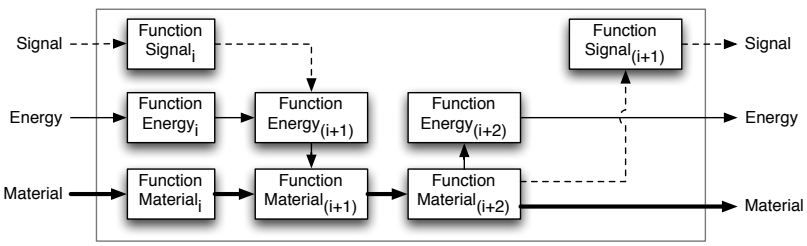
Class (Primary)	*Secondary*	*Tertiary*
Branch	Separate	
		Divide
		Extract
		Remove
	Distribute	
Channel	Import	
	Export	
	Transfer	
		Transport
		Transmit
	Guide	
		Translate
Connect		

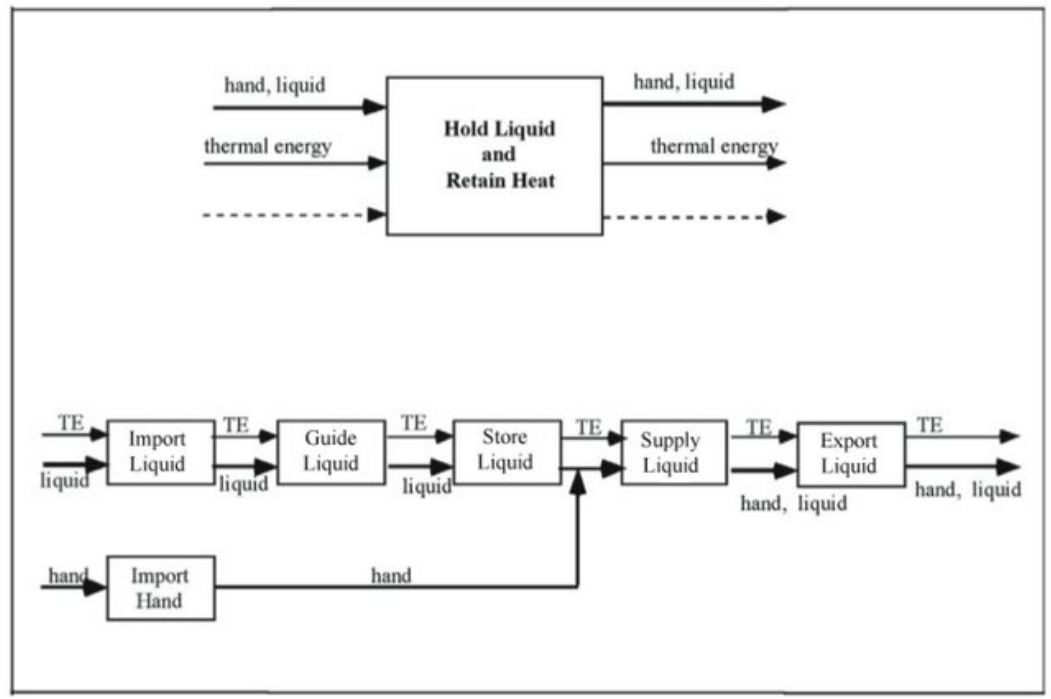
Class (Primary)	*Secondary*	*Tertiary*
Material	Human	
	Gas	
	Liquid	
	Solid	Object
		Particulate
		Composite
	Plasma	
	Mixture	Gas-gas
		Liquid-liquid
		Solid-solid
		Solid-Liquid
		Liquid-Gas
		Solid-Gas
		Solid-Liquid-Gas
		Colloidal

(Hirtz et al. 2002)

Functional Model Example







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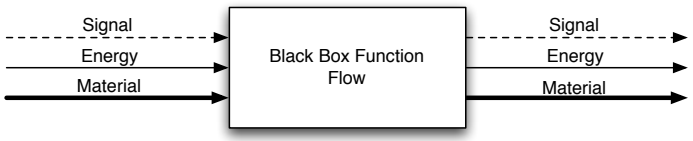

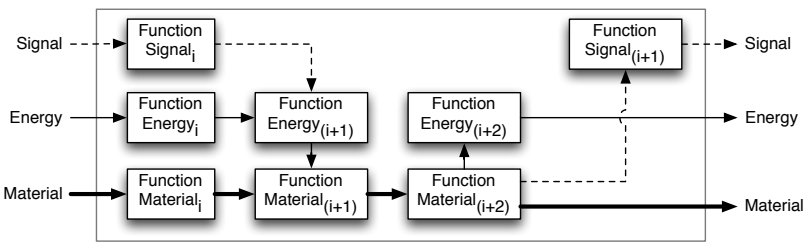

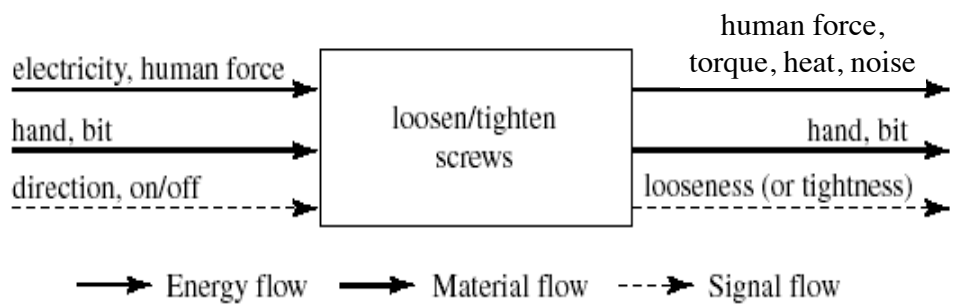

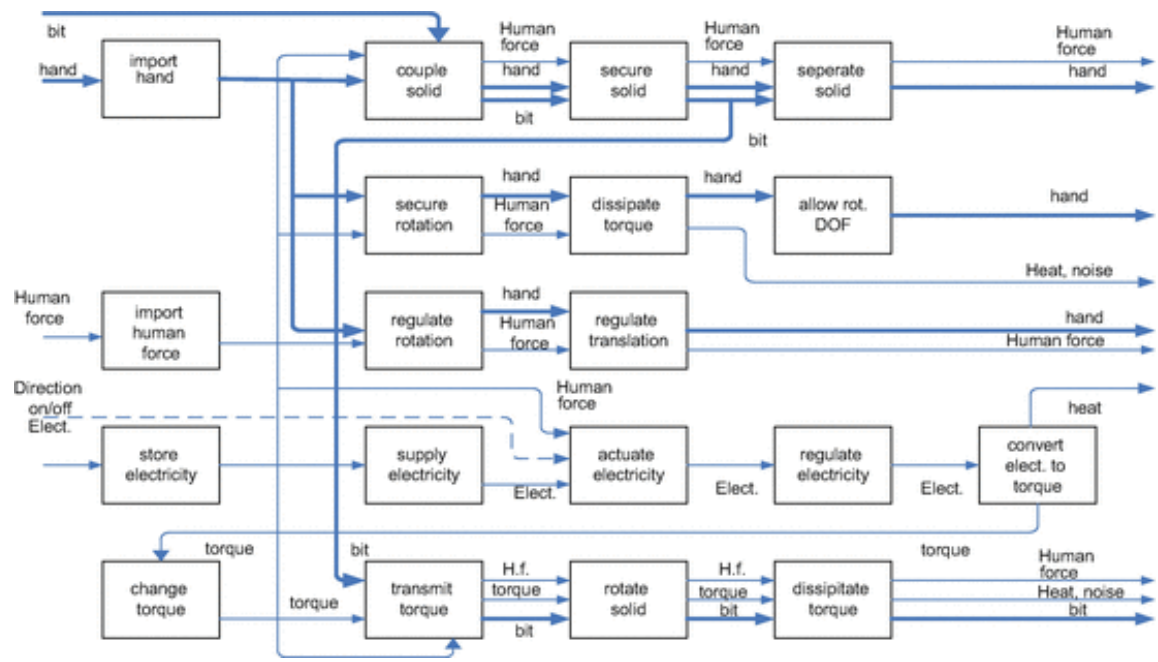

(Otto and Wood 2001)

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FM References

- Hirtz J, Stone R, McAdams D, Szykman S, Wood K (2002) “A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts,” Research in Engineering Design Vol.13 (2):65-82

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