Biological metaphors and crisis

Building self-healing, emergence and resilience into critical infrastructures

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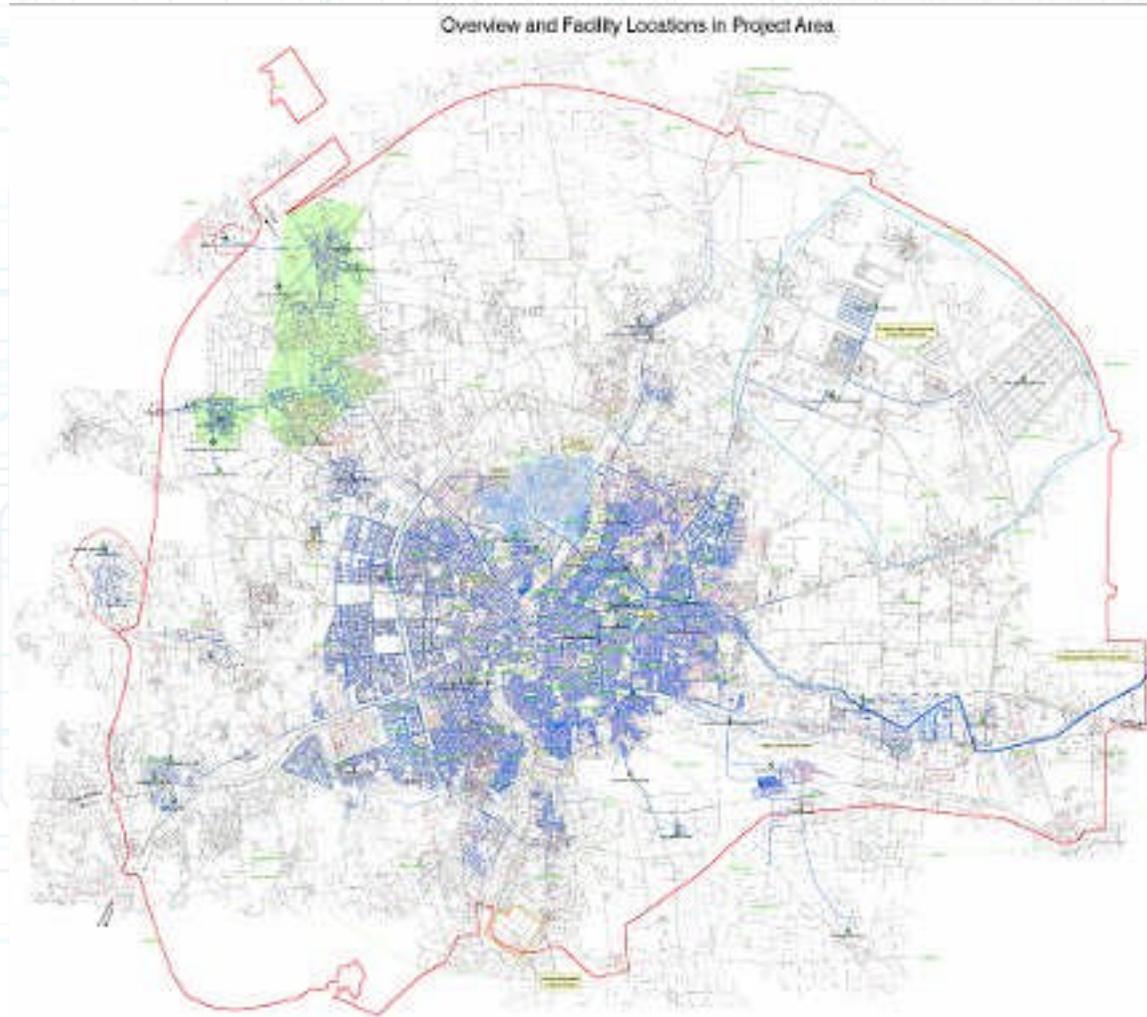* e.mcadam@abertay.ac.uk

Critical Infrastructure

Critical Infrastructure - Water

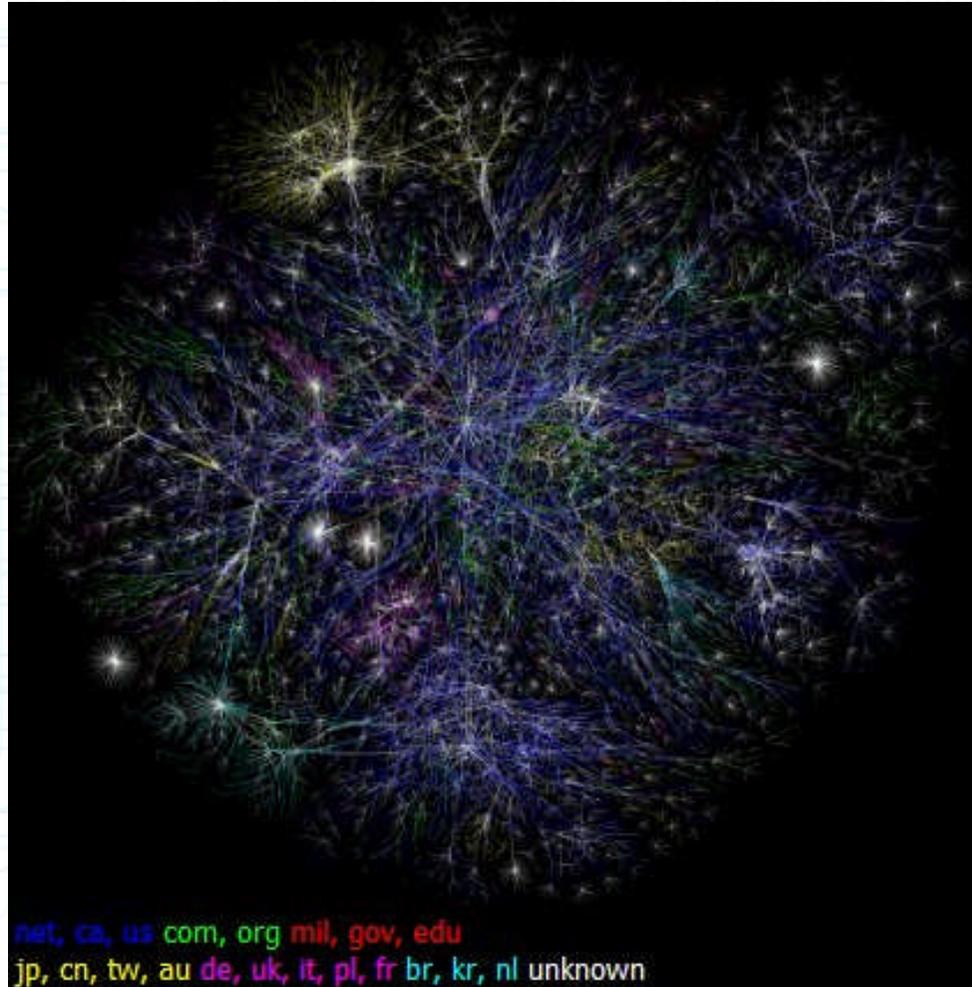# Critical Infrastructure - Water

Critical Infrastructure - Water

Overview and Facility Locations in Project Area

Critical Infrastructure - Telecom

Critical Infrastructure - Telecom

Critical Infrastructure - Telecom

The Opte Project - http://www.opte.org/
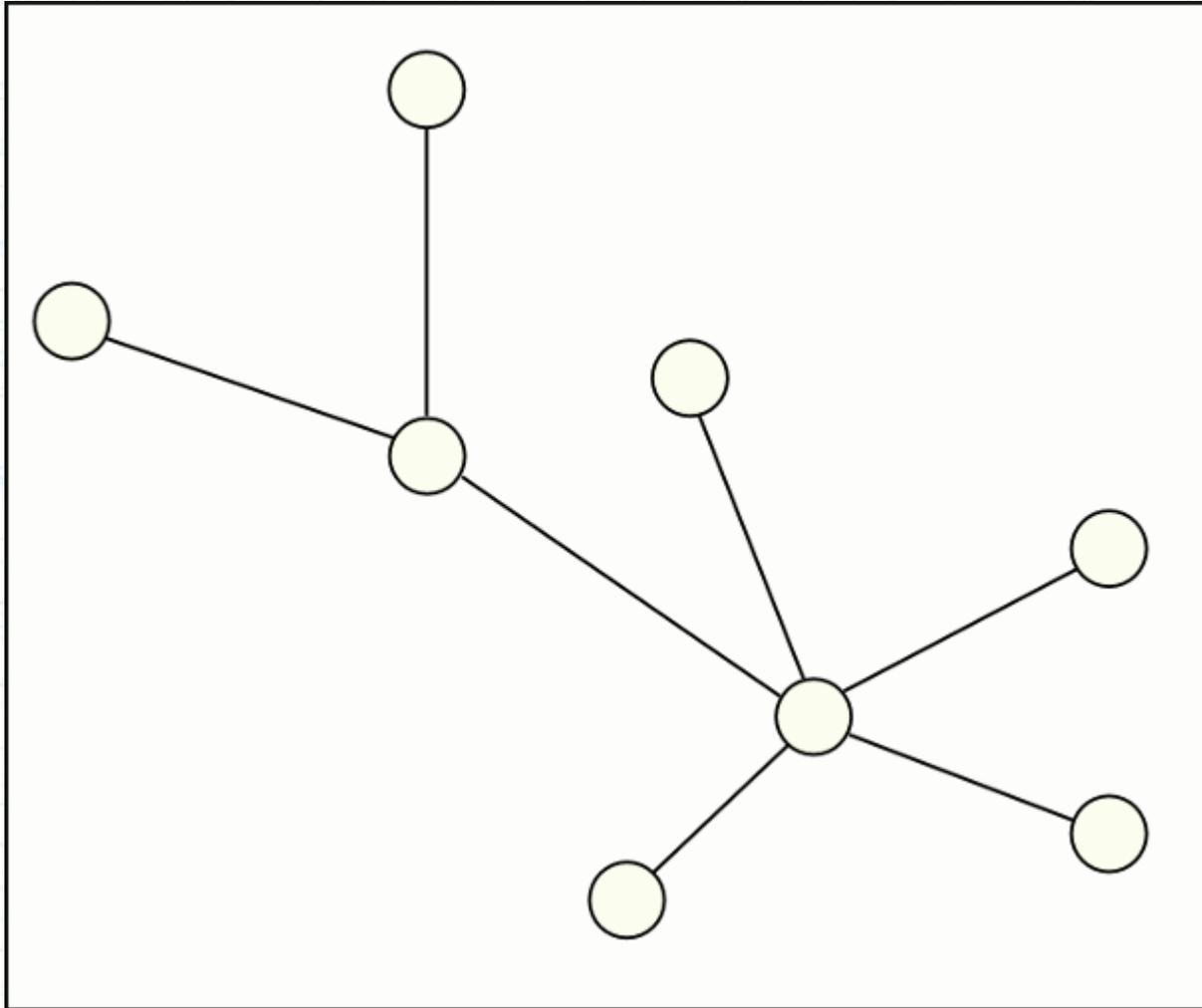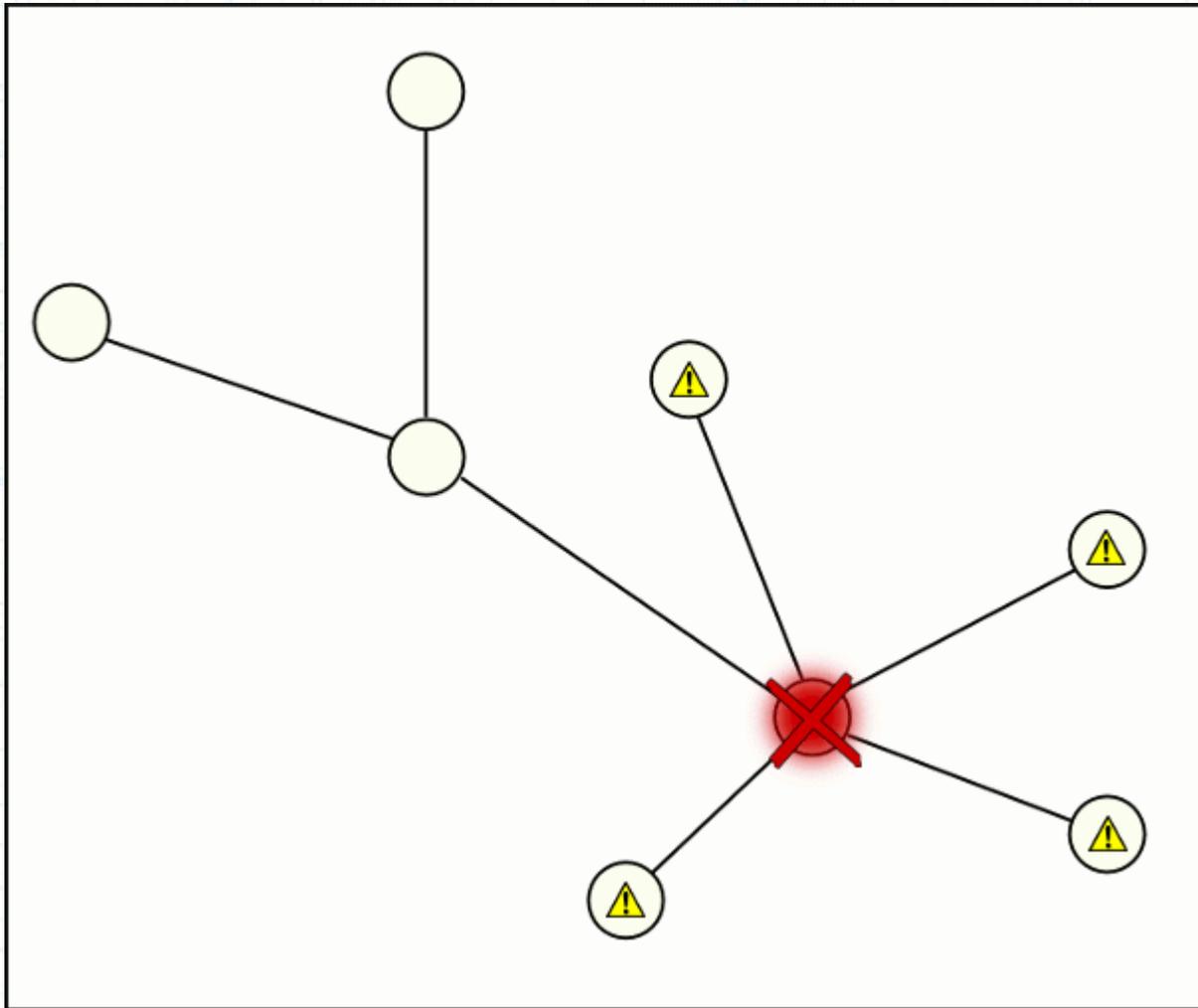
Critical Interdependency
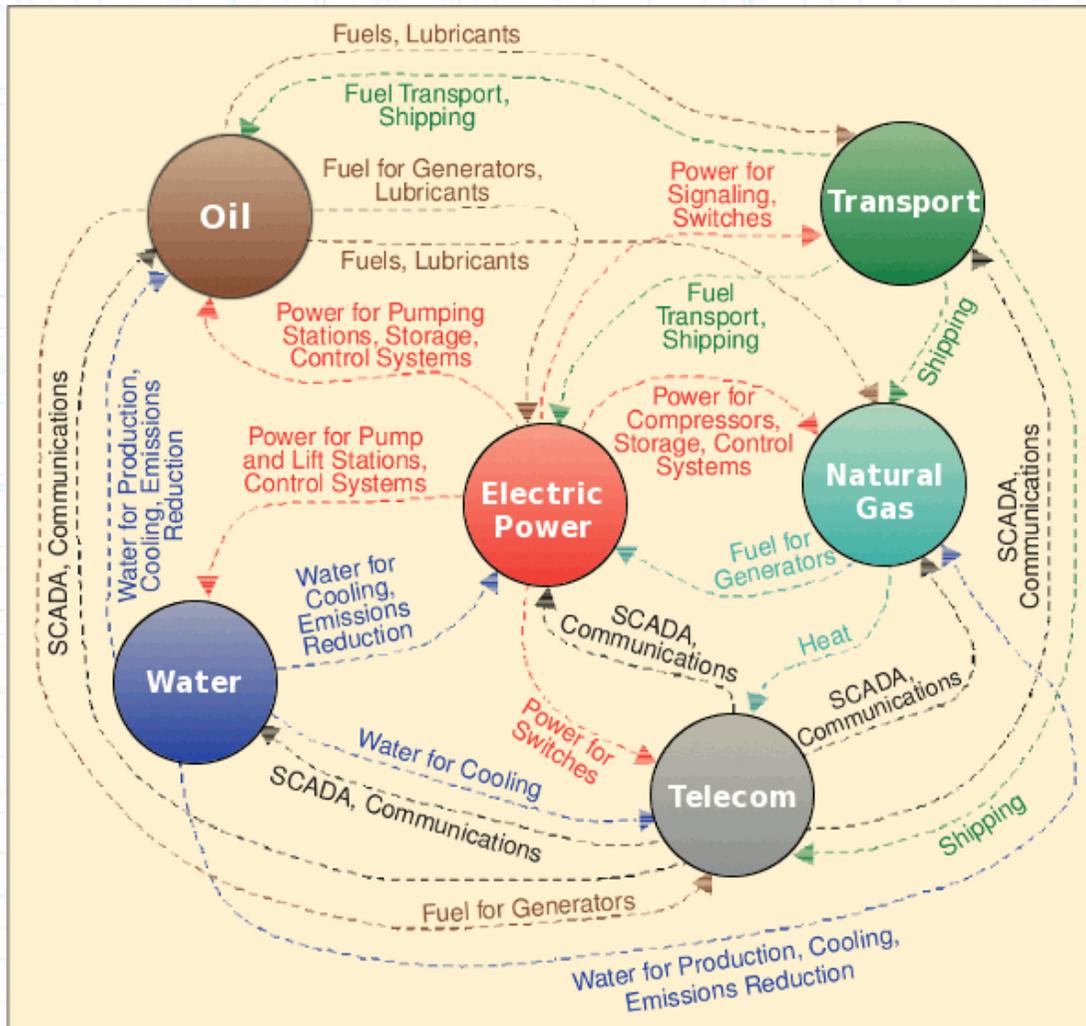
S. M. Rinaldi, J. P. Peerenboom and T. K. Kelly 2001

Critical Problems – Initial State

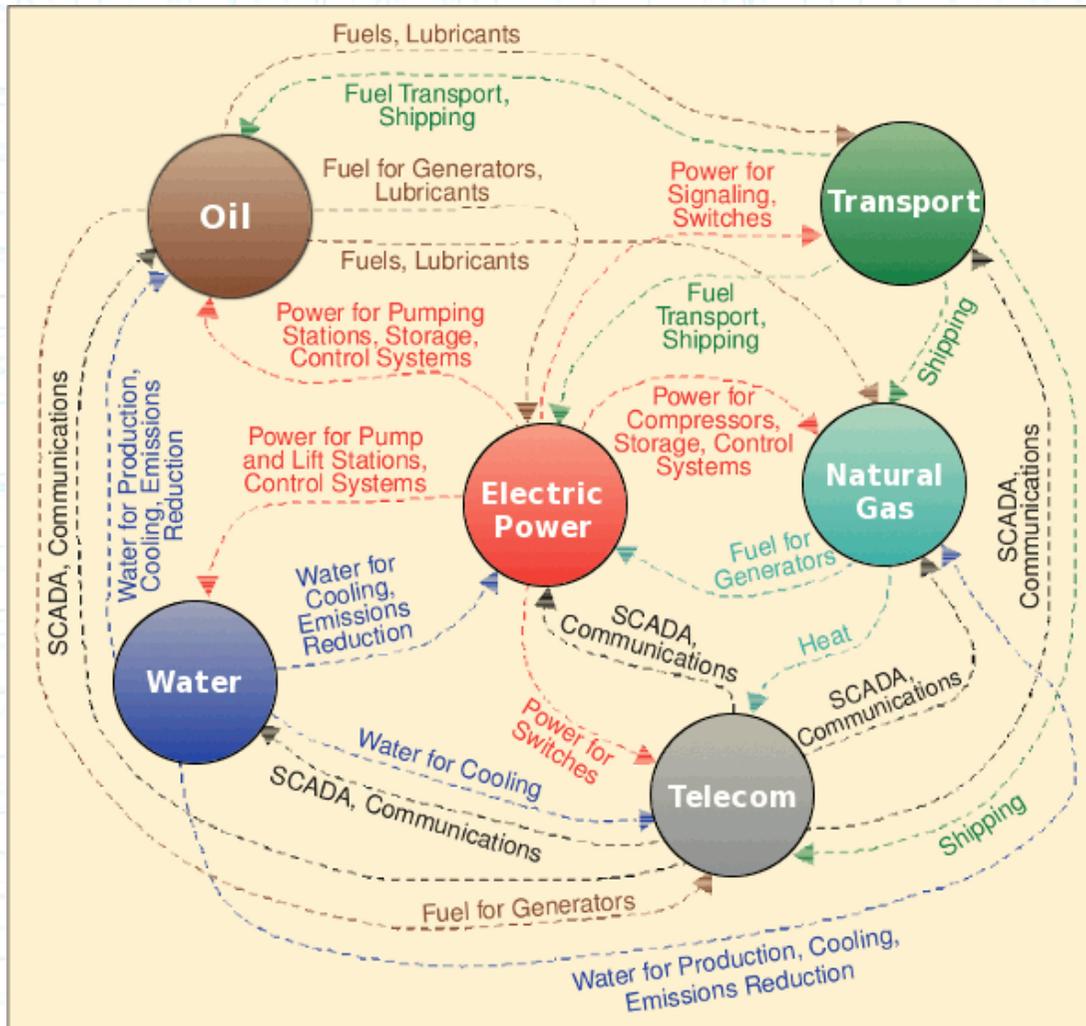# Critical Problems – Key Node Failure
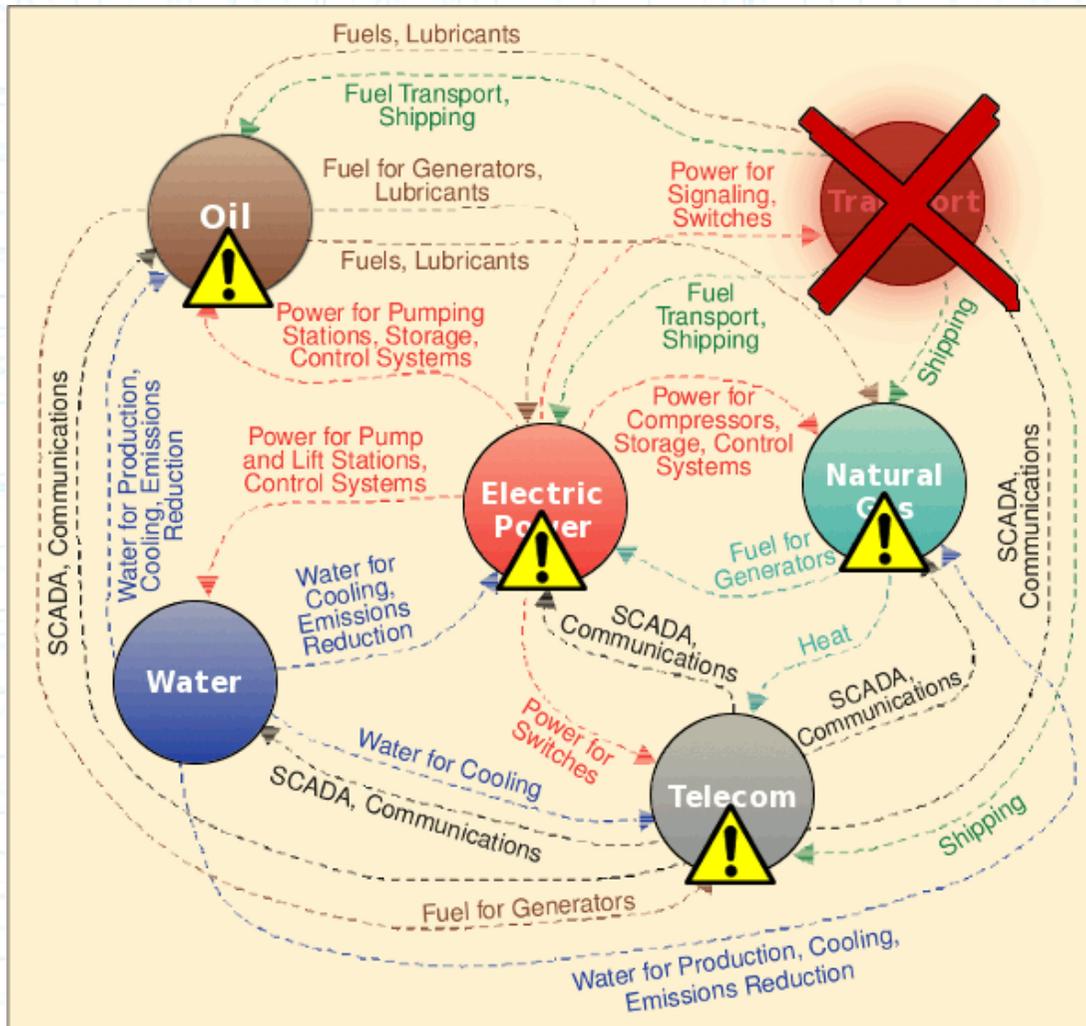
Critical Problems

National Rail Enquiries 2007
http://www.nationalrail.co.uk/passenger_services/maps/
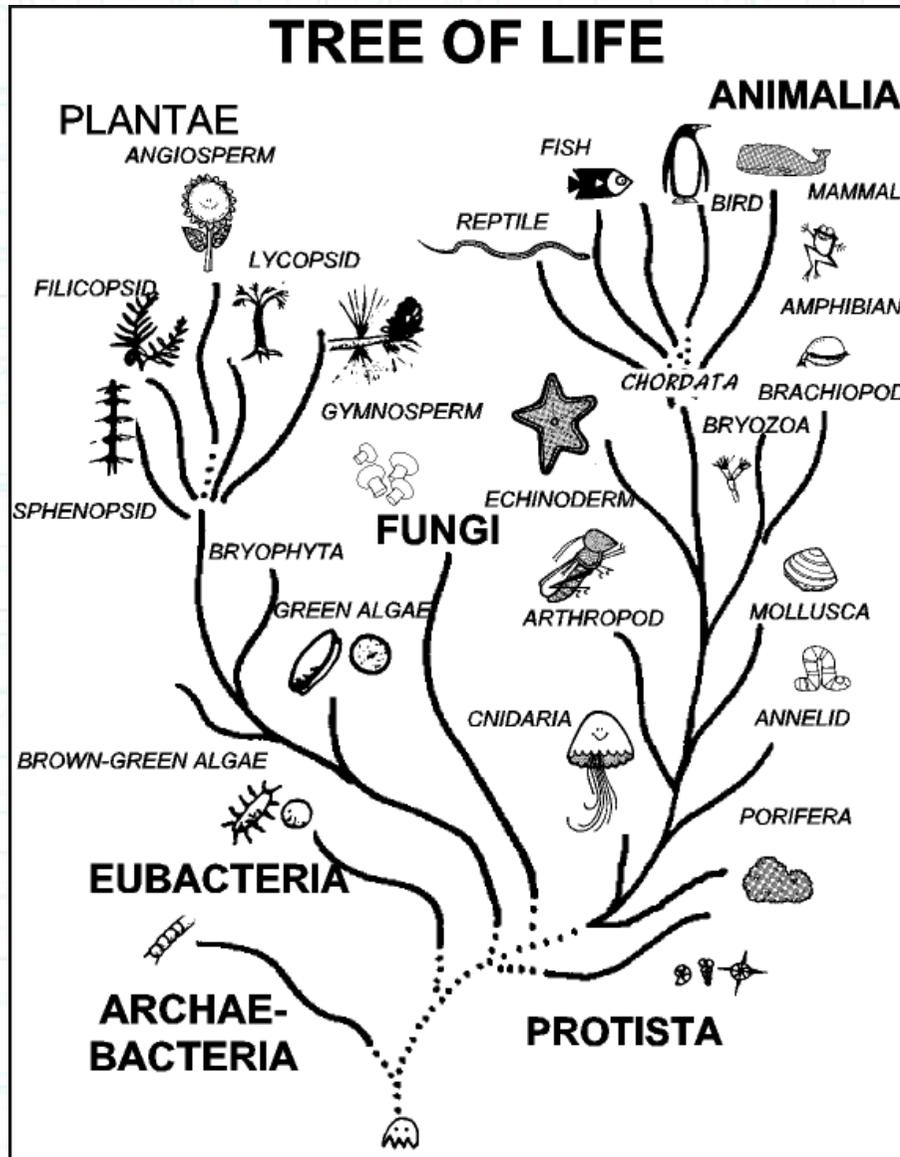
Critical Problems

S. M. Rinaldi, J. P. Peerenboom and T. K. Kelly 2001

Critical Problems
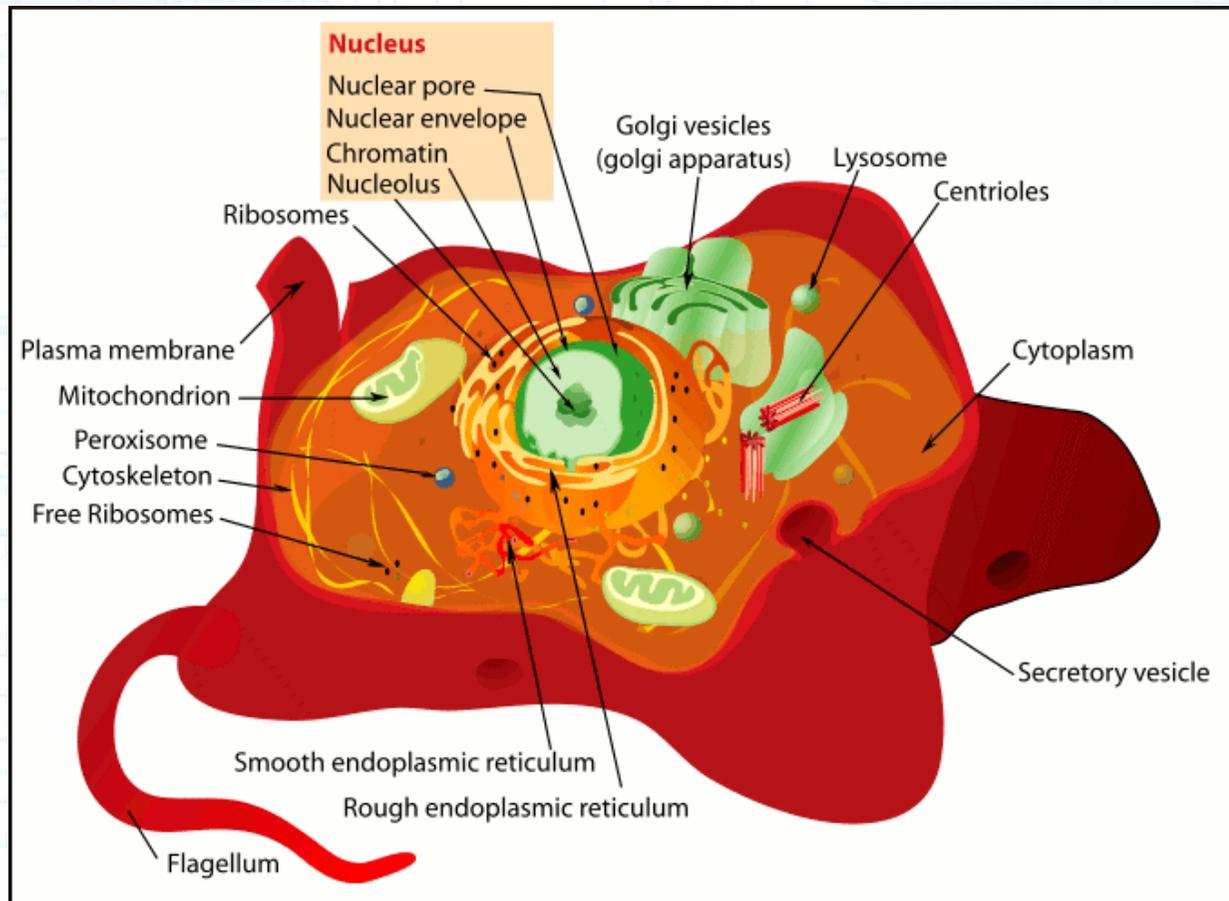

S. M. Rinaldi, J. P. Peerenboom and T. K. Kelly 2001

Biological Metaphors

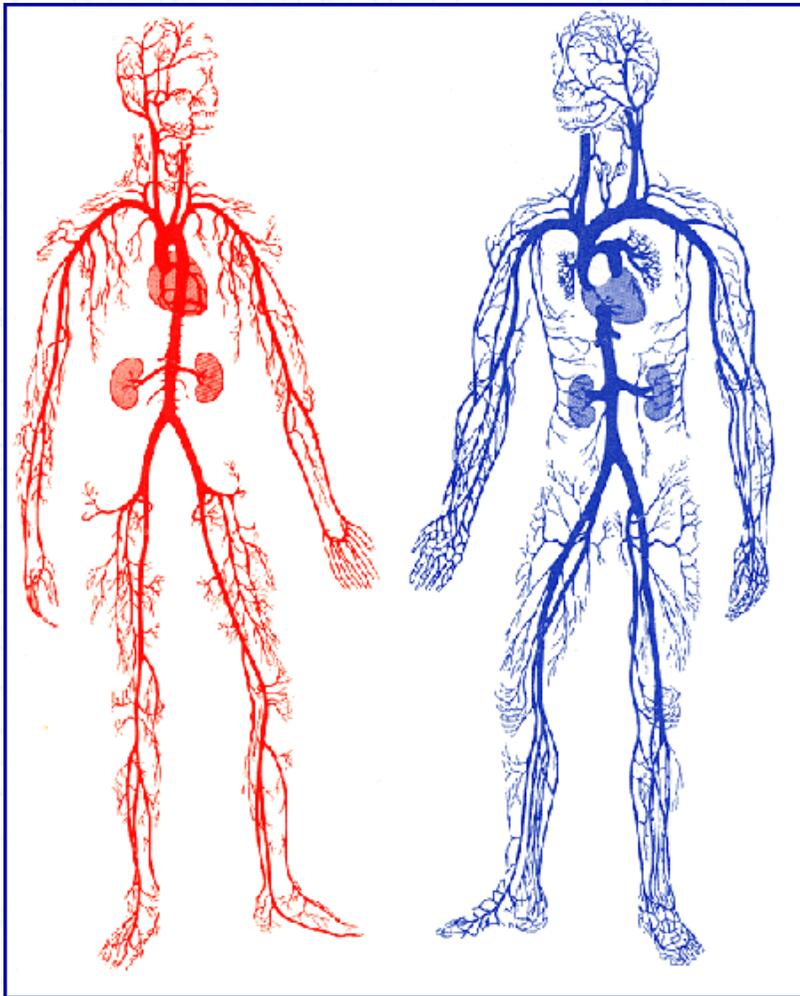N. Short. 2009. The Remote Sensing Tutorial. Section 20: Astronomy and Cosmology. http://rst.gsfc.nasa.gov/

Biological Metaphors
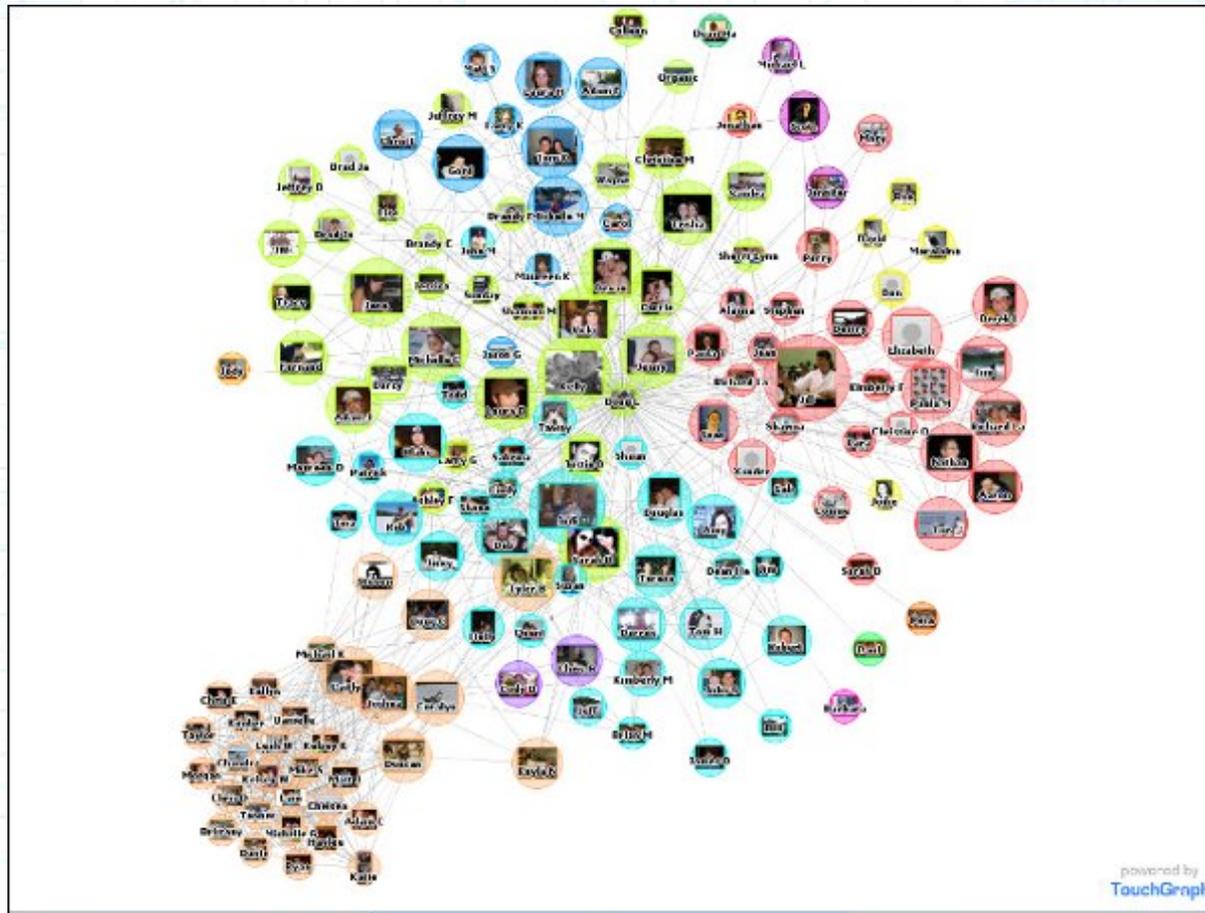
Within a cell

Biological Metaphors
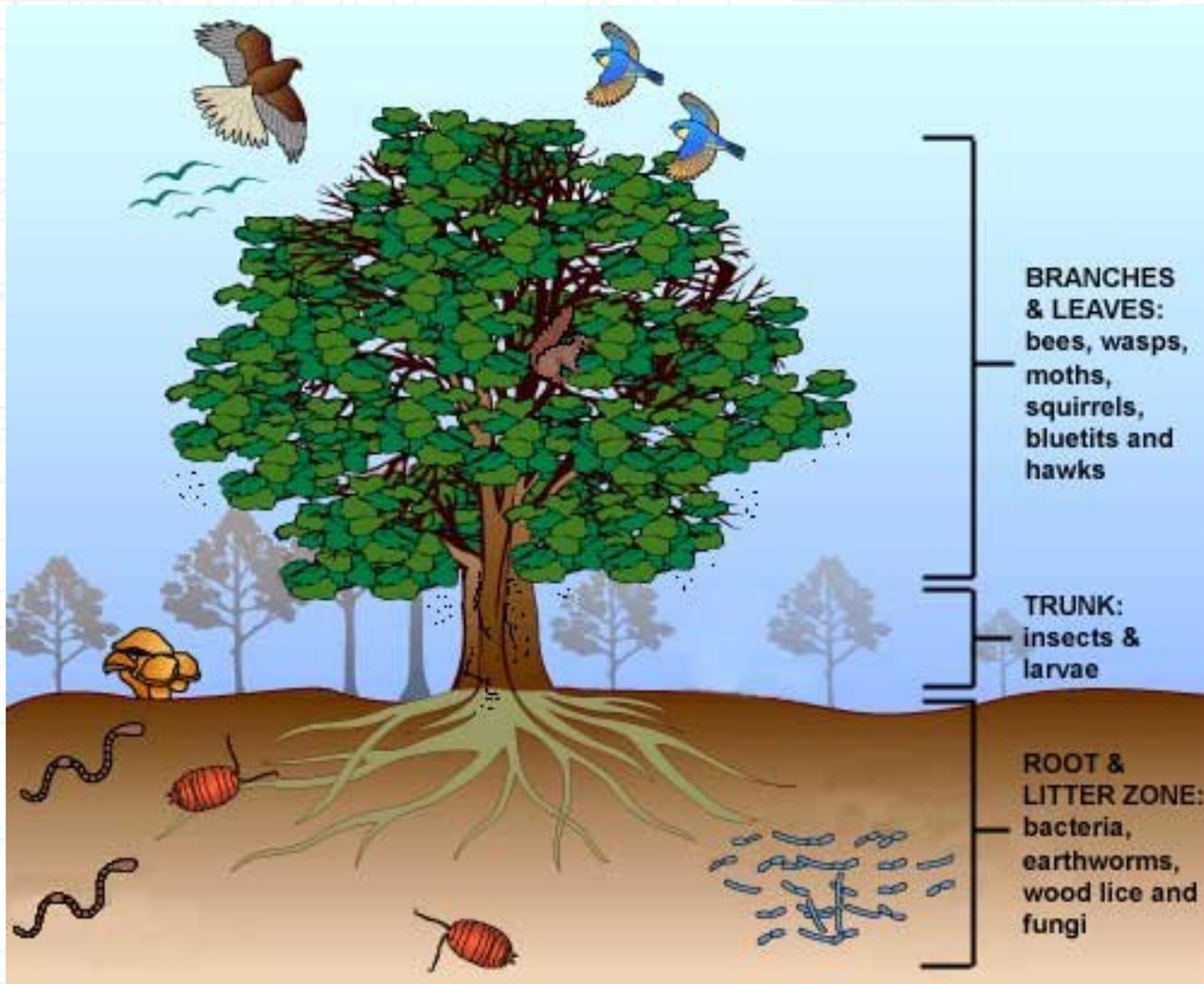
Within an organism

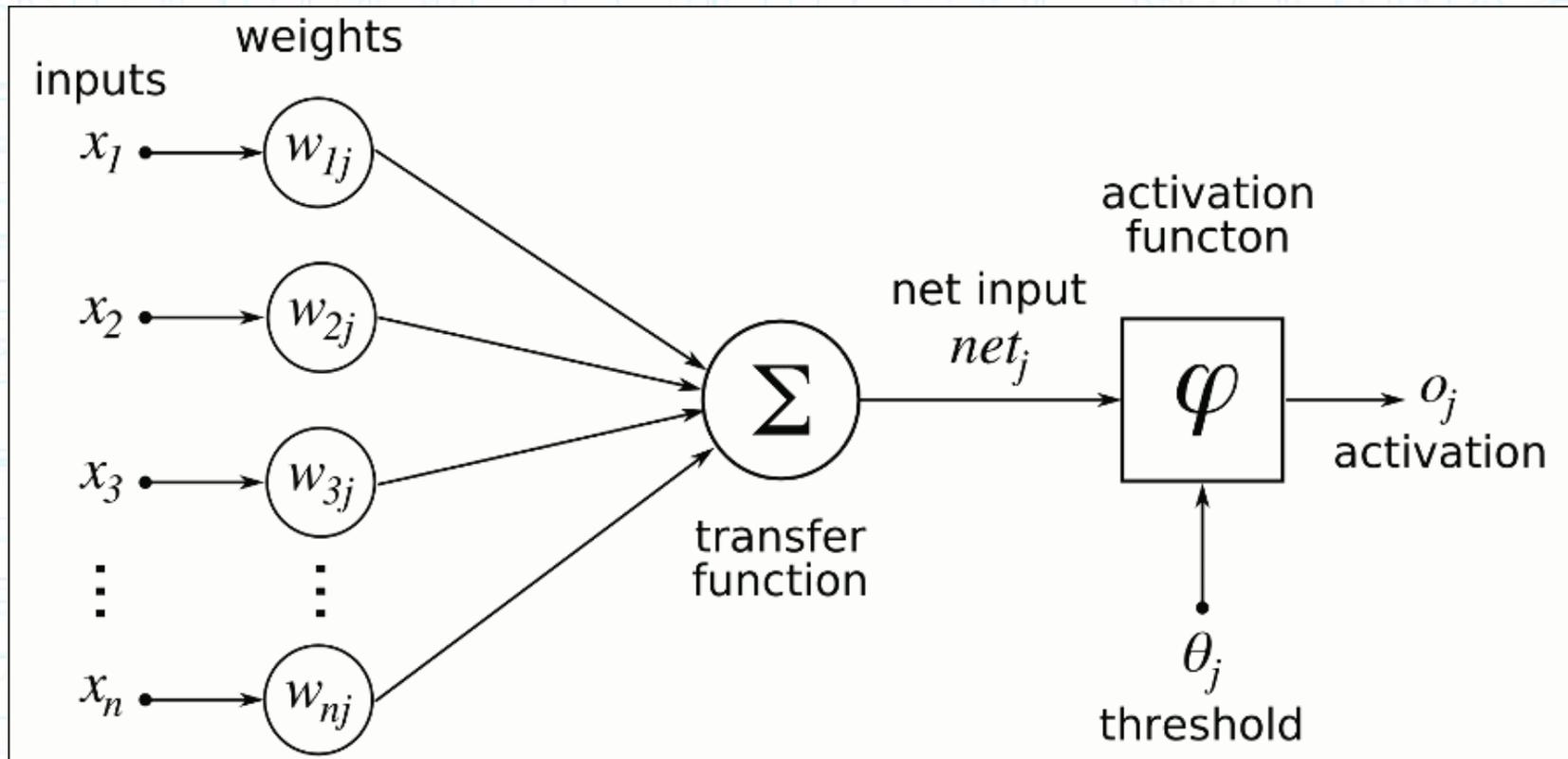# Biological Metaphors

Within a species
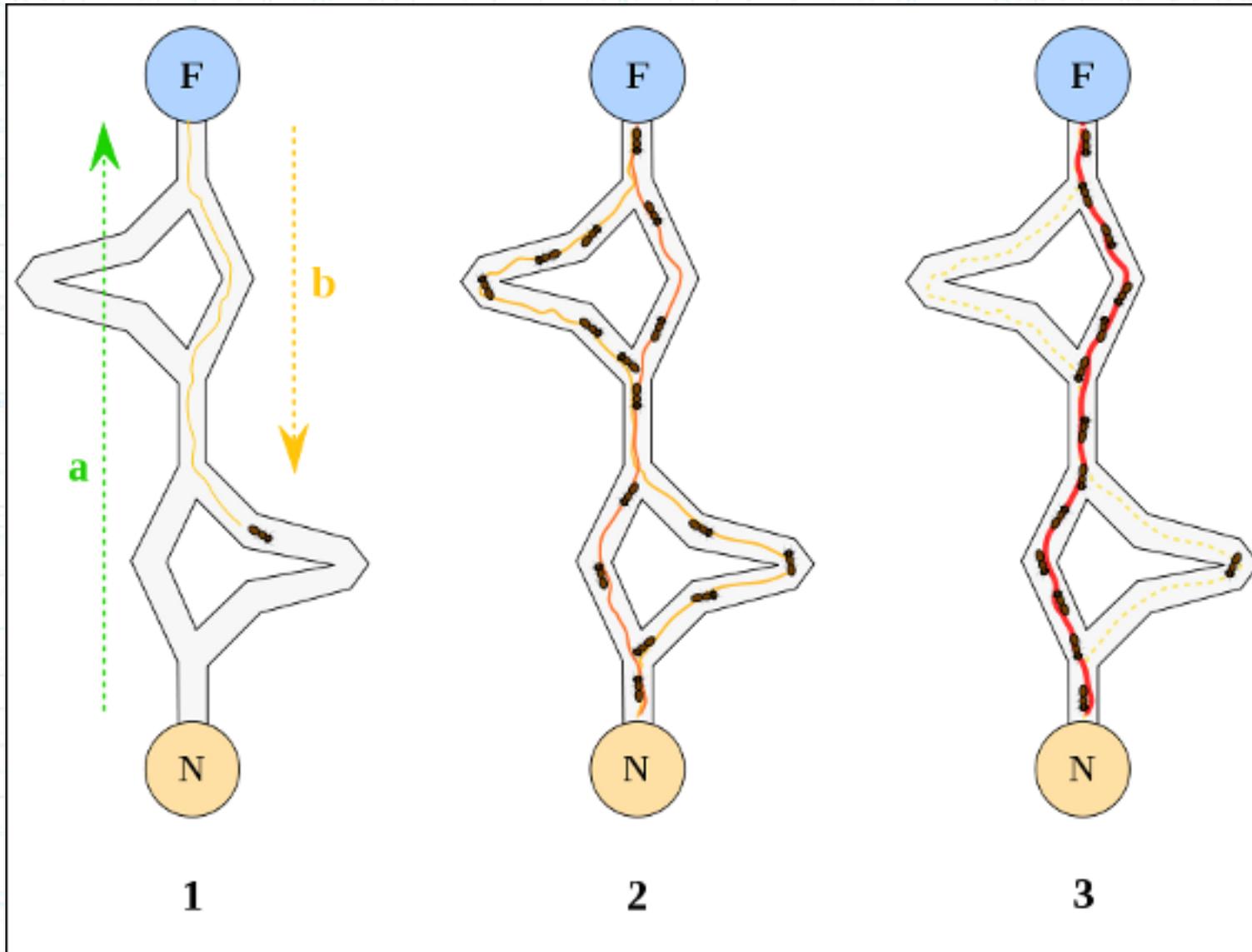
Biological Metaphors

Within an ecosystem

Metaphors In Use
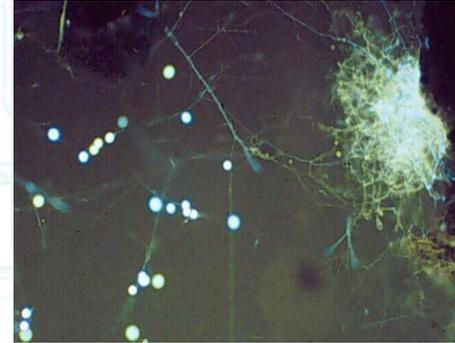
Metaphors In Use

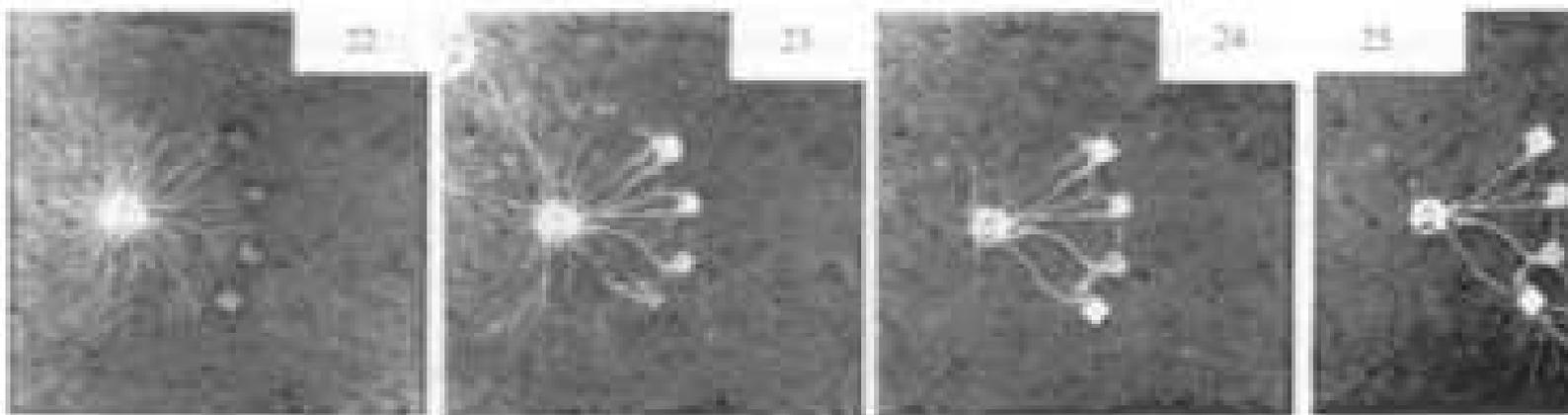# Fungi

Fungal Networks

Fungal Network Properties

- Tenacious

- Ubiquitous

- Massive

- Longevous

- Diverse

Fungal Network Properties

- Resource management

- Decentralisation

- Failure response

Emergence in Fungi

- Elements
  - hyphae

- Respond to local stimuli

- Global patterns
  - Communication
  - Biomass manipulation
  - Response to failure

Fungal Model

- Trait-based approach

- Series of partial differential equations

$$\frac{\partial b_i}{\partial t} = \zeta \left[\frac{\partial}{\partial x} D_b \frac{\partial b_{ni}}{\partial x} + \beta_2 \left(\alpha \pi^{\theta} - \beta \pi \right) b_{ni} \right] + \beta_2 \left(\alpha \pi^{\theta} - \beta \pi \right) b_i \qquad 1.1 \text{ insulated biomass concentration}$$

insulated biomass = hyphal insulation + immobilisation of mobile biomass - mobilisation of non insulated biomass

$$\frac{\partial b_{ni}}{\partial t} = (1 - \zeta) \left[\frac{\partial}{\partial x} D_b \frac{\partial b_{ni}}{\partial x} + \beta_2 \left(\alpha \pi^{\theta} - \beta \pi \right) b_{ni} \right] \qquad 1.2 \text{ non insulated biomass concentration}$$

non insulated biomass = diffusion of non-ins biomass + immobilistaion of mobile biomass - mobilistaion of non insulated biomass - hyphal insulation

$$\frac{\partial n}{\partial t} = \frac{\partial}{\partial x} D_n \frac{\partial n}{\partial x} - \beta_1 \left(\alpha \pi^{\theta} - \beta \pi \right) \left(b_{ni} + b_i \right) + \left(\lambda_1 b_{ni} + \lambda_2 b_i \right)_e \qquad 1.3 \text{ mobile biomass concentration}$$
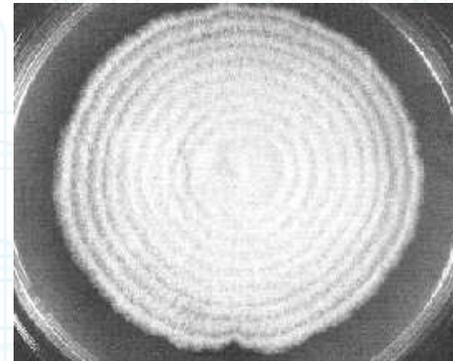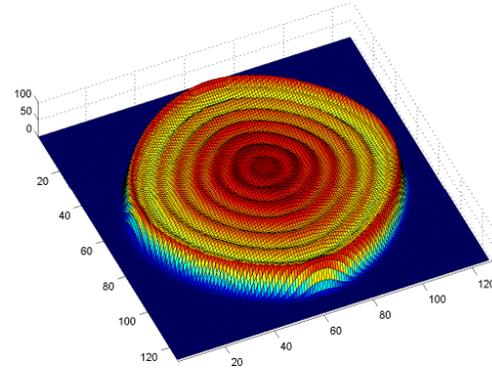
mobile biomass concentration = diffusion of mobile biomass - immobilisation of mobile biomass + mobilisation of non insulated biomass + uptake

$$\frac{\partial s}{\partial t} = s_o - \left(\lambda_1 b_{ni} + \lambda_2 b_i \right)_e \qquad 1.4 \text{ external substrate concentration}$$

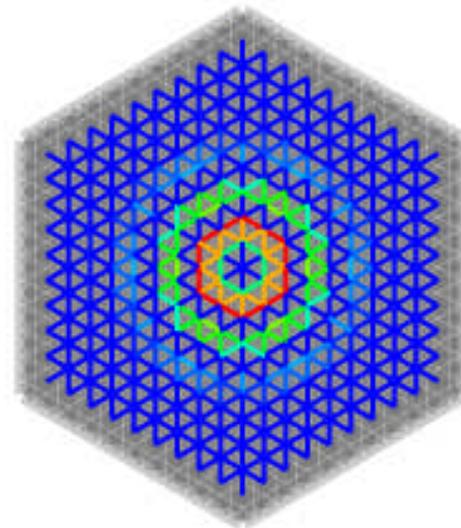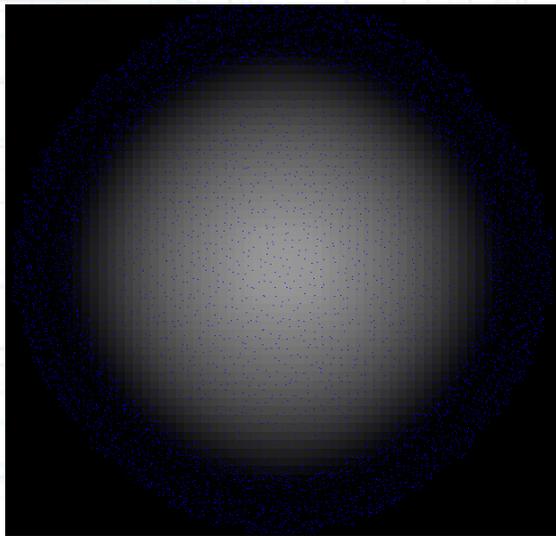substrate concentration = initial concentration - uptake

Fungal Model
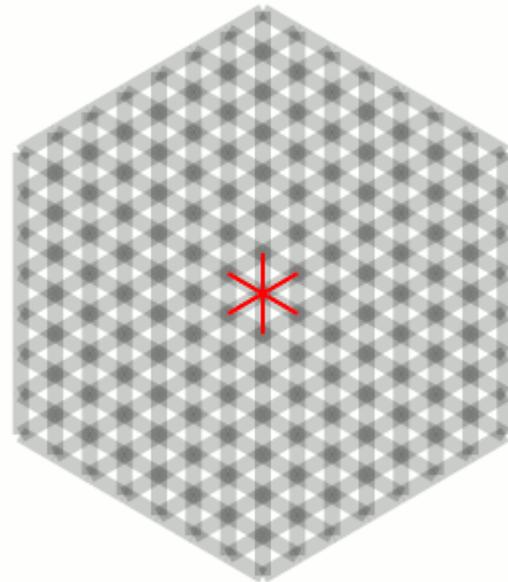
- Uptake

- Recycling

- Redistribution

- Growth

Reformulation

- Grid-based → graph-based
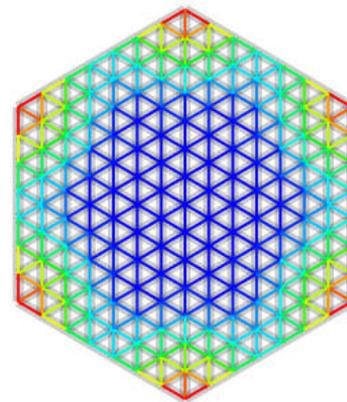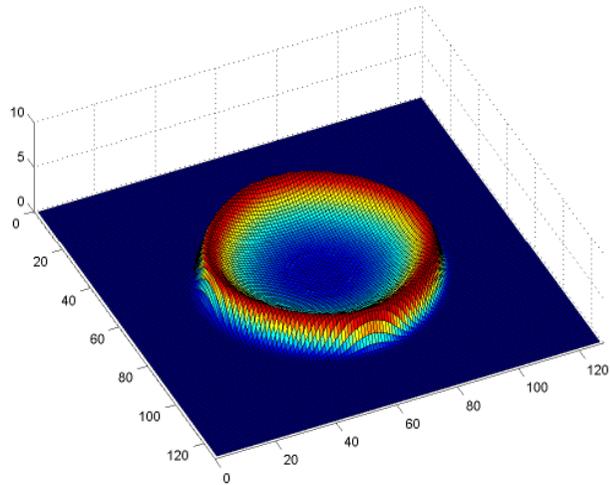
- Links model to application

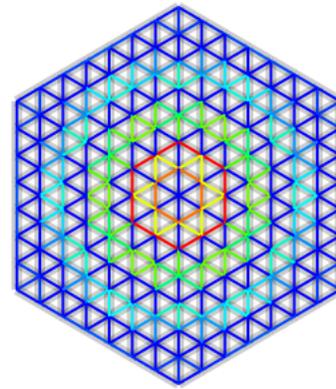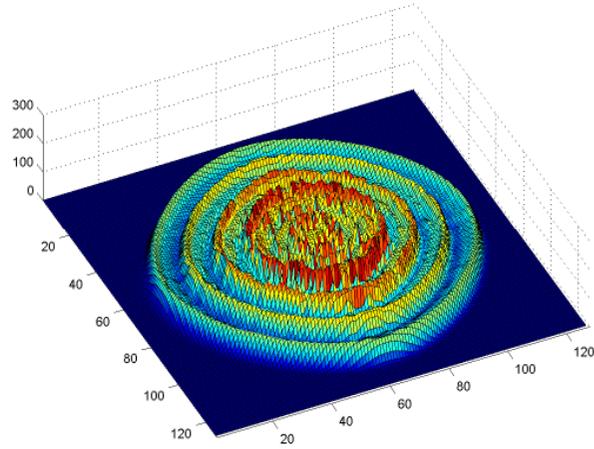- Network theory

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Reformulation

Challenges

- Conceptual transformation

- Edge-based graph

- Verification

- Technical challenges

Preliminary Verification

Future - Application

- How to apply the metaphor
  - Types of biomass
  - Traits

- Infrastructure to focus on

Future

- Validation
  - Sensitivity analysis

- Metrics
  - Graph theory metrics
  - Robustness
  - Efficient resource use