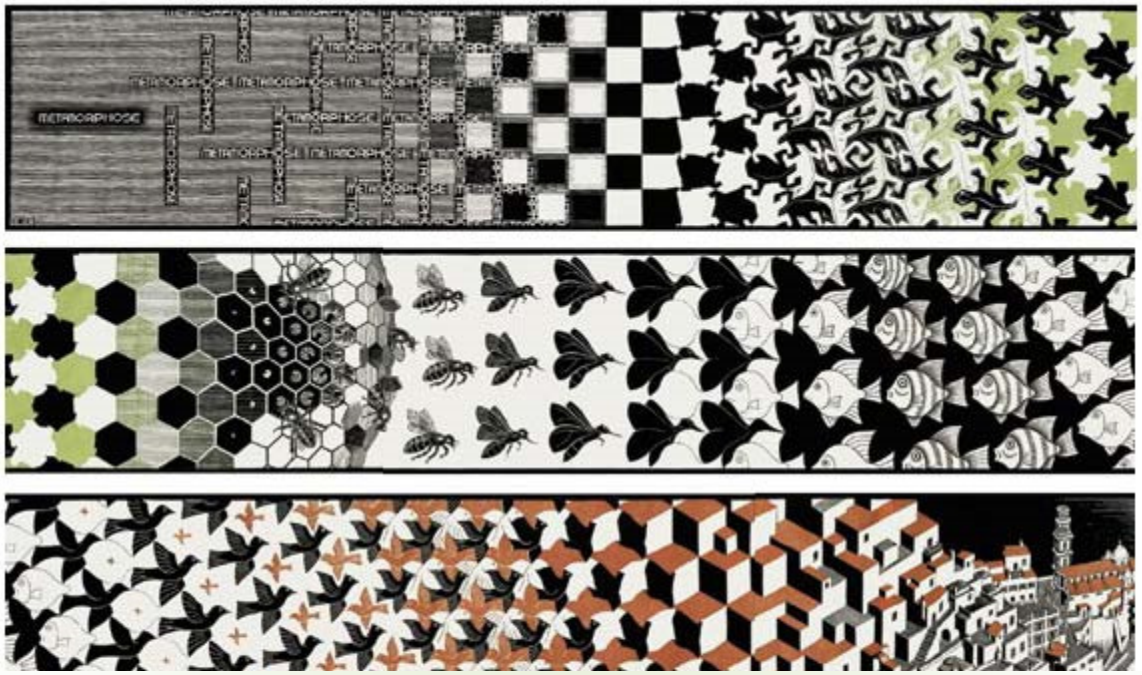
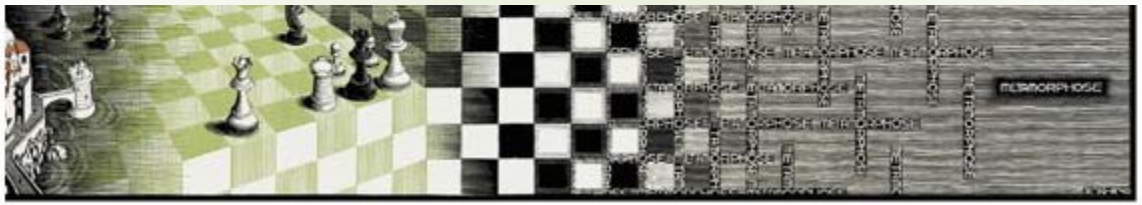


INTUITIONISTIC FUZZY ESTIMATIONS OF BIOLOGICAL INTERACTIONS



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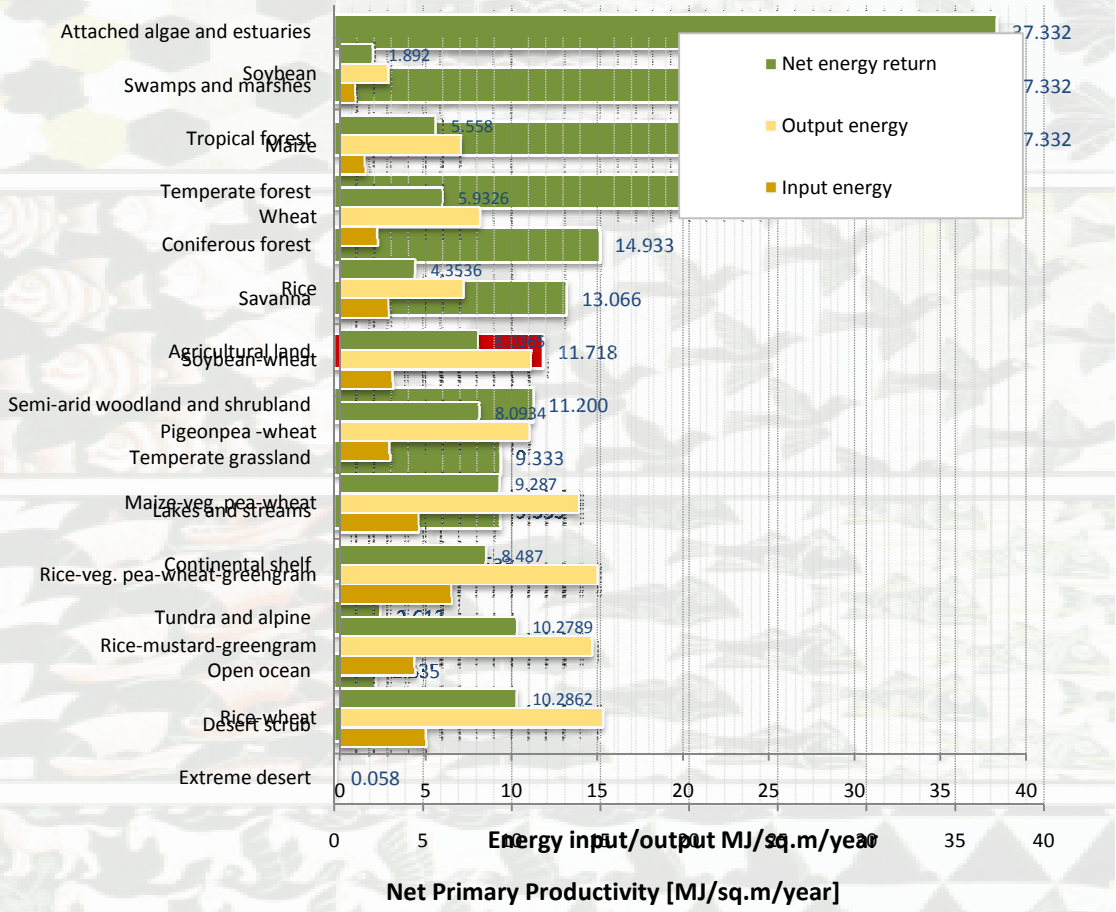
Human dominated Earth

- More than 75% ice-free Earth surface is altered as a result of human activities
- Only 11% of terrestrial net primary production comes from wilderness.
- Biodiversity
- Soil quality
- Forestation
- Climate



Adapted from Kormondy 1976;

The Natural Solution

- Agricultural land accounts for 20% of ice-free land use
- Cooperate rather than compete with nature – less energy/work better productivity
- Use ecosystem inspired techniques for agriculture (polyculture, forest gardening, companion planting, plant guilds, cover crops, intercropping, no tilt)
- Increased biodiversity, stability, productivity, sustainability
- The key factor to build and maintain such ecosystem inspired biomes is to understand the interactions between organisms

IF Estimation of Biological Interaction

Interaction between two objects $x, y \in \aleph$ at least one of which is a living organism could be described as the intuitionistic fuzzy number:

$$\alpha_{\langle x,y\rangle} = \langle \mu(\langle x, y\rangle), \vartheta(\langle x, y\rangle)\rangle,$$

where: $\langle x, y\rangle$ is the ordered tuple of the two interacting objects, $\mu: \aleph^2 \to [0,1]$ is the positive effect of y over x, $\vartheta: \aleph^2 \to [0,1]$ is the negative effect of y over x, and $0 \leq \mu(\langle x, y\rangle) + \vartheta(\langle x, y\rangle) \leq 1$. Level of uncertainty $\pi: \aleph^2 \to [0,1]$ can be defined as $\pi(\langle x, y\rangle) = 1 - \mu(\langle x, y\rangle) - \vartheta(\langle x, y\rangle)$.

Neutralism

- Neutralism describes the relationship between two objects which interact but do not affect each other.

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x,y\rangle)=0,\ \pi(\langle y,x\rangle)=0$
0	0	$\begin{cases}\mu(\langle x,y\rangle)=\vartheta(\langle x,y\rangle)\\ \mu(\langle y,x\rangle)=\vartheta(\langle y,x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x,y\rangle)=0.5\\ \vartheta(\langle x,y\rangle)=0.5\\ \mu(\langle y,x\rangle)=0.5\\ \vartheta(\langle y,x\rangle)=0.5\end{cases}$

Amensalism

- Amensalism between two objects x, y involves y impeding the success of x while the x has no effect on y

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x, y\rangle) = 0,$ $\pi(\langle y, x\rangle) = 0$
-	0	$\begin{cases}\mu(\langle x, y\rangle) < \vartheta(\langle x, y\rangle) \\ \mu(\langle y, x\rangle) = \vartheta(\langle y, x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x, y\rangle) = 0 \\ \vartheta(\langle x, y\rangle) = 1 \\ \mu(\langle y, x\rangle) = 0.5 \\ \vartheta(\langle y, x\rangle) = 0.5\end{cases}$

Commensalism

- Commensalism between two objects x, y occurs when x benefits from y, while x has no effect on y

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x,y\rangle)=0,\ \pi(\langle y,x\rangle)=0$
+	0	$\begin{cases}\mu(\langle x,y\rangle) > \vartheta(\langle x,y\rangle)\\ \mu(\langle y,x\rangle) = \vartheta(\langle y,x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x,y\rangle)=1\\ \vartheta(\langle x,y\rangle)=0\\ \mu(\langle y,x\rangle)=0.5\\ \vartheta(\langle y,x\rangle)=0.5\end{cases}$

Competition

- Competition is an interaction between two objects that is mutually detrimental.

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x, y\rangle) = 0,$ $\pi(\langle y, x\rangle) = 0$
-	-	$\begin{cases}\mu(\langle x, y\rangle) < \vartheta(\langle x, y\rangle) \\ \mu(\langle y, x\rangle) < \vartheta(\langle y, x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x, y\rangle) = 0 \\ \vartheta(\langle x, y\rangle) = 1 \\ \mu(\langle y, x\rangle) = 0 \\ \vartheta(\langle y, x\rangle) = 1\end{cases}$

Mutualism

- Mutualism is an interaction between two objects, which is mutually beneficial.

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x, y\rangle) = 0,$ $\pi(\langle y, x\rangle) = 0$
+	+	$\begin{cases}\mu(\langle x, y\rangle) > \vartheta(\langle x, y\rangle) \\ \mu(\langle y, x\rangle) > \vartheta(\langle y, x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x, y\rangle) = 1 \\ \vartheta(\langle x, y\rangle) = 0 \\ \mu(\langle y, x\rangle) = 1 \\ \vartheta(\langle y, x\rangle) = 0\end{cases}$

Predation / Parasitism

- Predation or Parasitism between two x,y organisms is when x benefits at the expense of the y

Effect on x	Effect on y	Intuitionistic Fuzzy Definition	Extreme crisp case $\pi(\langle x,y\rangle)=0,\ \pi(\langle y,x\rangle)=0$
+	-	$\begin{cases}\mu(\langle x,y\rangle) > \vartheta(\langle x,y\rangle)\\ \mu(\langle y,x\rangle) < \vartheta(\langle y,x\rangle)\end{cases}$	$\begin{cases}\mu(\langle x,y\rangle)=1\\ \vartheta(\langle x,y\rangle)=0\\ \mu(\langle y,x\rangle)=0\\ \vartheta(\langle y,x\rangle)=1\end{cases}$

Interaction matrix

- We can construct the following Indexed matrix

	O_1	O_2	$\cdots$	O_m
O_1	$\alpha_{\langle 1,1\rangle}$	$\alpha_{\langle 2,1\rangle}$	$\cdots$	$\alpha_{\langle m,1\rangle}$
O_2	$\alpha_{\langle 1,2\rangle}$	$\alpha_{\langle 2,2\rangle}$	$\cdots$	$\alpha_{\langle m,2\rangle}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
O_m	$\alpha_{\langle 1,m\rangle}$	$\alpha_{\langle 2,m\rangle}$	$\cdots$	$\alpha_{\langle m,m\rangle}$

where $O_1, O_2, \cdots O_m$ are the interacting objects and $\alpha_{\langle i,j\rangle}$ are the intuitionistic fuzzy estimations of the interactions between object O_i and O_j, where $i, j = 1,2, \ldots m$

Initialization

- Initially all interactions are unknown and

$$\pi_{\langle i,j \rangle} = \pi_{\langle j,i \rangle} = 1$$

	O_1	O_2	$\cdots$	O_m
O_1	$\langle 0,0 \rangle$	$\langle 0,0 \rangle$	$\cdots$	$\langle 0,0 \rangle$
O_2	$\langle 0,0 \rangle$	$\langle 0,0 \rangle$	$\cdots$	$\langle 0,0 \rangle$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
O_m	$\langle 0,0 \rangle$	$\langle 0,0 \rangle$	$\cdots$	$\langle 0,0 \rangle$

Update Rule

Let $E^k_{\langle i,j\rangle}$ be the k-th observation of the effect of object j on object i

$$E^k_{\langle i,j\rangle} = \langle \mu_{E^k}(\langle i,j\rangle), \vartheta_{E^k}(\langle i,j\rangle)\rangle,$$

where $i, j \in \aleph \;\&\; 0 \leq \mu_{E^k}(\langle x,y\rangle) + \vartheta_{E^k}(\langle x,y\rangle) \leq 1$

then the k-th intuitionistic fuzzy interaction estimation for the objects I, j can be obtained as a weighted combination of the $a^{k-1}_{\langle i,j\rangle}$ and the observation $E^k_{\langle i,j\rangle}$

Update rule

$$a^{k}_{\langle i,j \rangle} = \langle \mu_{\alpha^k}(\langle i,j \rangle), \vartheta_{\alpha^k}(\langle i,j \rangle) \rangle$$

$$\mu_{\alpha^k}(\langle i,j \rangle) = \frac{(k-1)\mu_{\alpha^{k-1}}(\langle i,j \rangle) + \mu_{E^k}(\langle i,j \rangle)}{k}$$

$$\vartheta_{\alpha^k}(\langle i,j \rangle) = \frac{(k-1)\vartheta_{\alpha^{k-1}}(\langle i,j \rangle) + \vartheta_{E^k}(\langle i,j \rangle)}{k}$$

Challenges

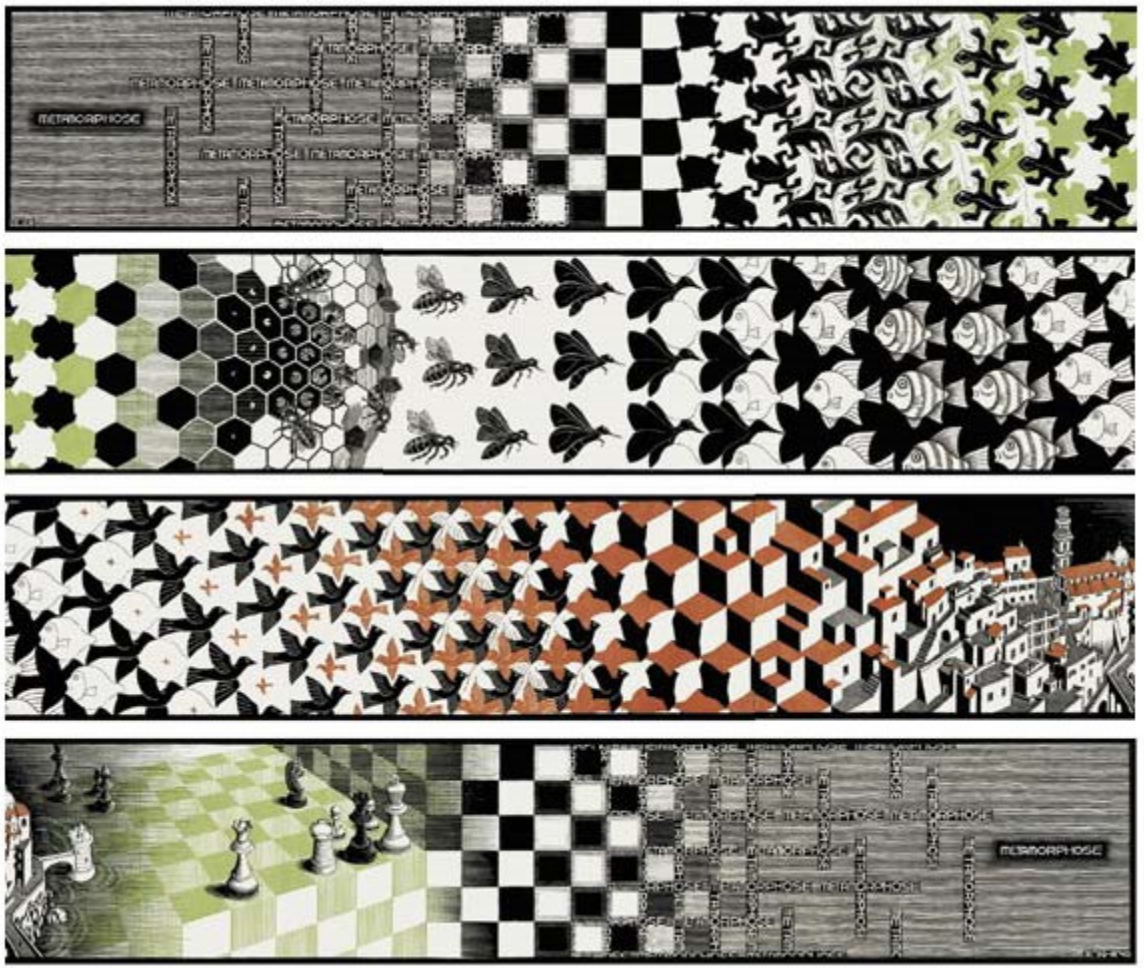
Natural interactions are

- Dynamic and
  - in short term depend on the state and needs of the organism (like life stage , deficiencies, stresses…)
  - and evolve in long term
- Interconnected and occur between multitude of species.
- Multidimensional and can be beneficial in certain aspects while detrimental in others
- The hole is greater than the sum of it’s components
- Lost traditional knowledge and scarcity of modern experimental data

Next steps

- Using species taxonomy we can use the above algorithm to update the information for related species or apply it for different taxonomic rank like family, genus or class.
- Scale and magnitude – if we have two relations that are positive which one will have bigger impact
- Extract information form multispecies interaction
  - apply the above algorithm for one versus the rest
  - use existing knowledge to guide the reduction of uncertainty: if current knowledge can explain the interaction use it otherwise search for examples that might provide the explanation
- Make a simulation and verify it against experimental data

Thank you!



and Escher…