Evolutionary Transitions and Top-Down Causation

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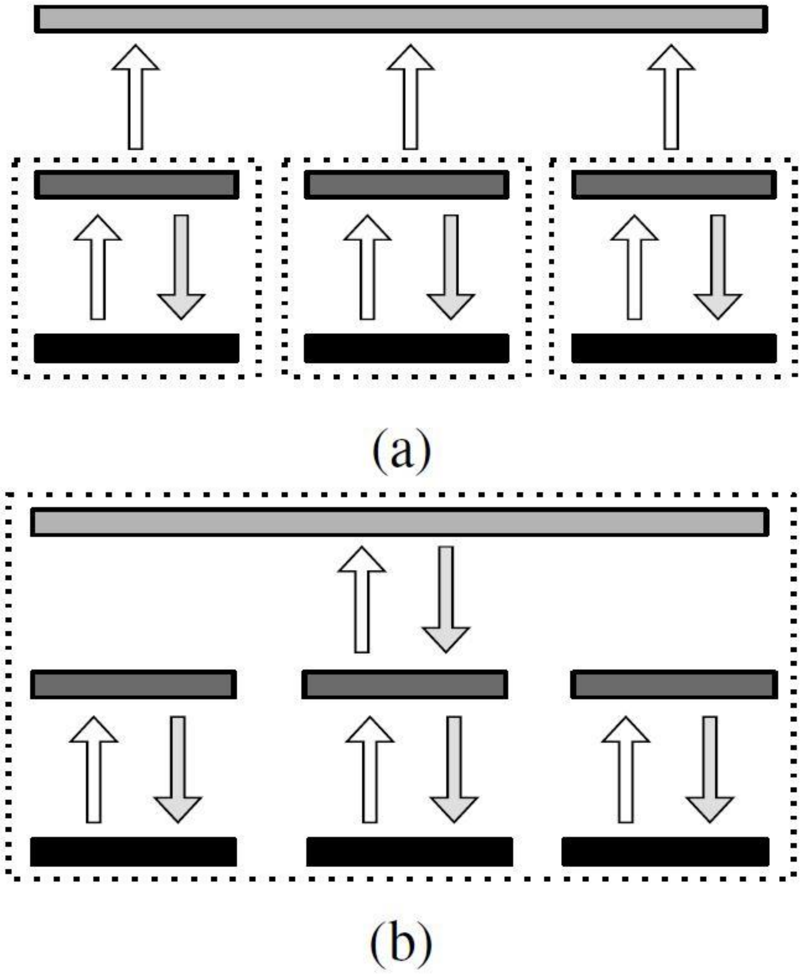
Jumps in Complexity

- Ex: Single cell to multicellular life
- Bottom-up: low level mechanisms cause higher level behavior
- Top-down: high level organization constrains lower level interactions



Toy Model

$$x_{i,n+1} = (1-\epsilon)\underbrace{f_i(x_{i,n})}_{\text{Logistic Map}} + \epsilon \underbrace{m_n}_{\text{Contextual Information}} \quad ; \quad (i = 1, 2, \ldots N) \quad (1)$$

$$f_i(x_{i,n}) = r_i x_{i,n}\left(1 - \frac{x_{i,n}}{K}\right) \quad (2)$$

$$m_n = \frac{1}{N}\sum_{j=1}^{N} f_j(x_{j,n}) \quad (4)$$

$$M_n = \frac{1}{N}\sum_{j=1}^{N} x_{j,n} \quad (3)$$

- $X_{i,n}$ = population of subgroup *i* at time *n*
- ε = global coupling strength
- f_n = discrete logistic growth function
- m_n = average logistic growth of subgroups

- K = carrying capacity
- r_i = fitness

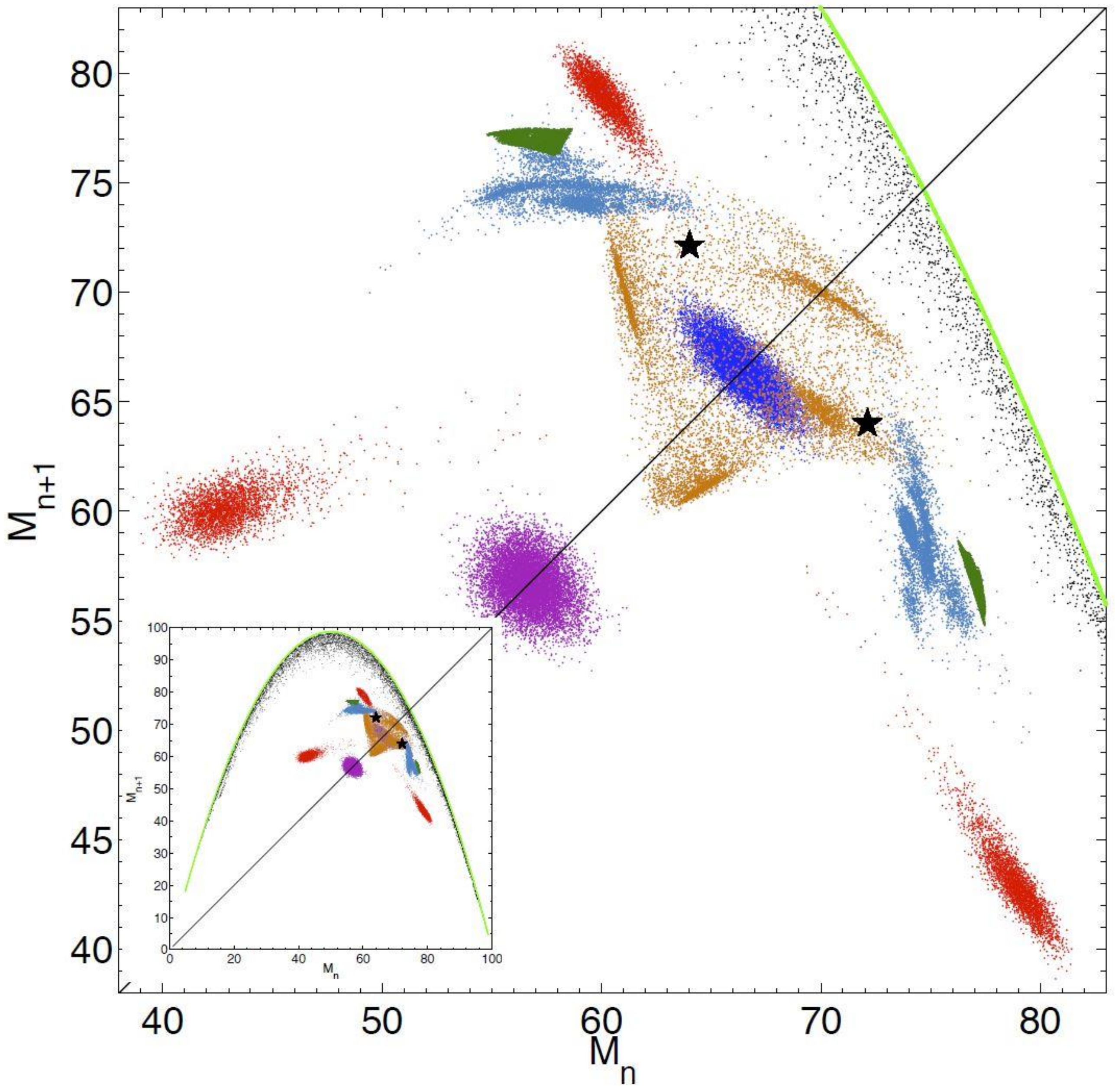
- N = number of subgroups
- M_n = average population of subgroups

Transfer Entropy

$$T_{Y\rightarrow X}^{(k)} = \sum_{n} p(x_{n+1}, x_n^{(k)}, y_n^{(k)}) \log \left[\frac{p(x_{n+1}|x_n^{(k)}, y_n^{(k)})}{p(x_{n+1}|x_n^{(k)})} \right] \tag{5}$$

$$T_{X\rightarrow Y} = H\left(Y_t \mid Y_{t-1:t-L}\right) - H\left(Y_t \mid Y_{t-1:t-L}, X_{t-1:t-L}\right)$$

Return Map



Transfer Entropy vs Global Coupling Strength