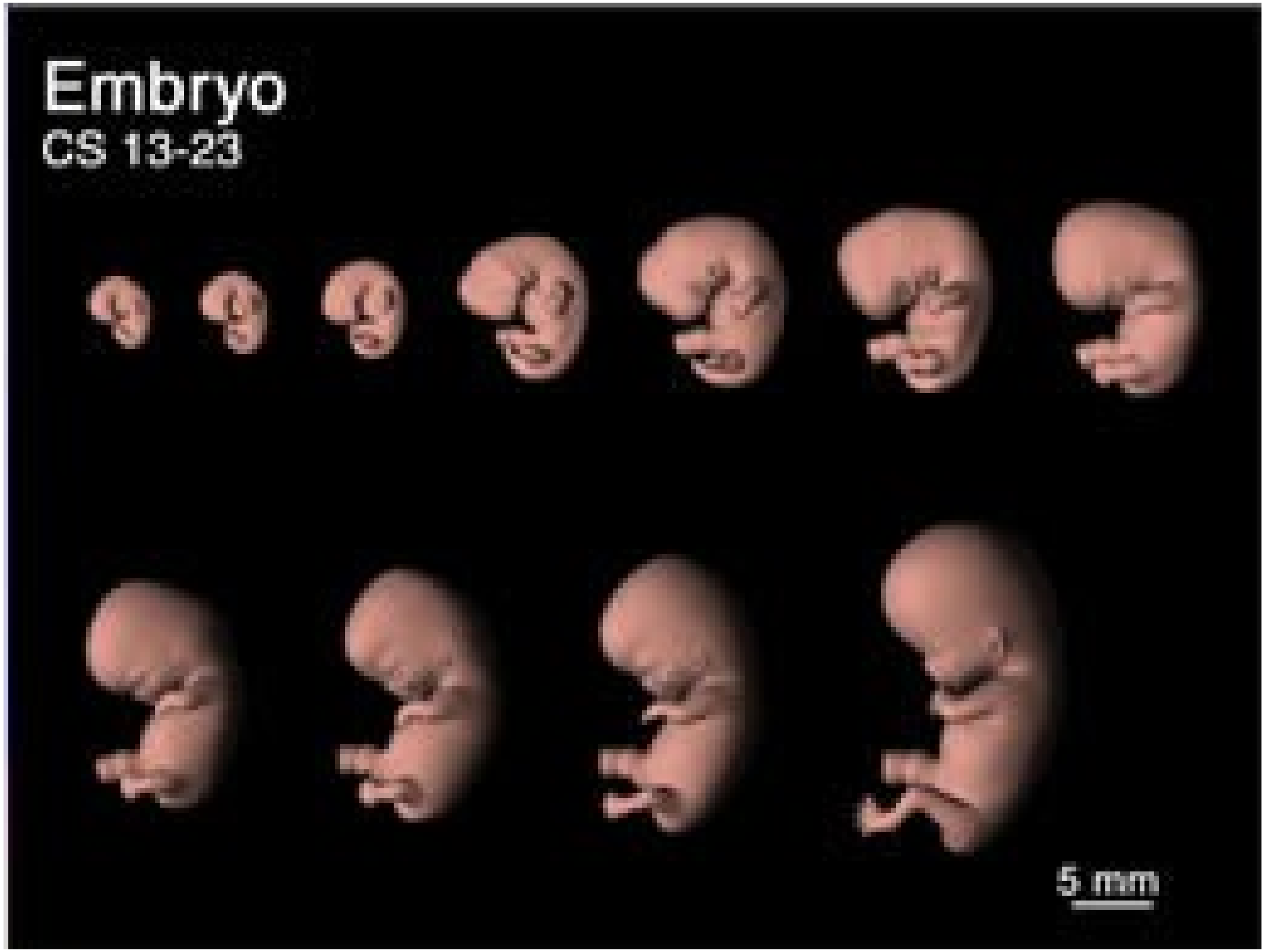
Evolution of morphogenesis



Article 1:

Evolving Mechanisms of Morphogenesis: on the Interplay between Differential Adhesion and Cell Differentiation

P. HOGEWEG*

- Morphogenesis by differential cell adhesion
- Morphogenesis is achieved without explicitly putting morphogenesis in the model, instead focusing on cell differentiation
- Makes the system "easy"
- Other factors which could lead to Morphogenesis are not accounted for

Model

- CPM
- Cell differentiation and differential adhesion
  - Using gene regulation (boolean network)
- Additions to the model
  - Cell death due to squeezing
  - Cell growth due to stretching
  - Cell division on threshold volume

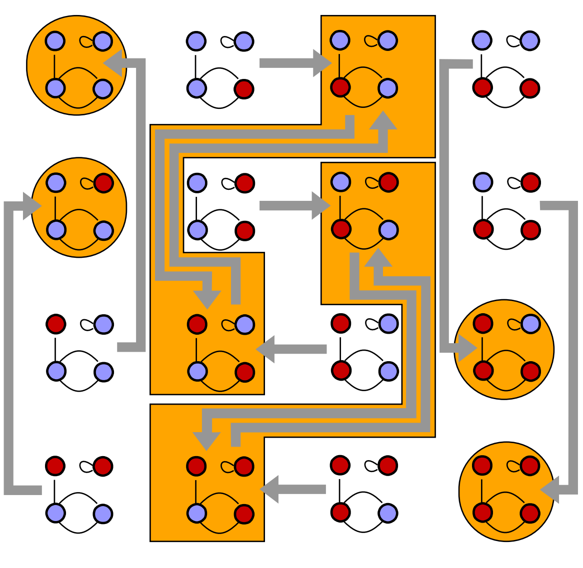
$$H = \sum \frac{J_{ij}}{2} + \sum J_{im} + \lambda(v - V)^2,$$

$$P_{i->j} = 1 \quad \text{iff} \quad \Delta H < -0.1,$$

$$P_{i->j} = e^{-(\Delta H + 0.01)} \quad \text{iff} \quad \Delta H \geq -0.1, \quad (1)$$

Gene regulation

- Boolean Network
- 24 Nodes: 10 for adhesion, 2 for environmental factors
- Maternal gene after division
- Update network using a randomly generated function
- Attractors



Adhesion

- "locks" and "keys" using genes

$$J_{ij} = \frac{1}{2}\left(\sum_{k=0}^{4} (M_k^{ij})^k + \sum_{k=0}^{4} (M_k^{ji})^k \right), \qquad (2a)$$

- This means cell adhesion is dependent on cell state
- This leads to differential adhesion

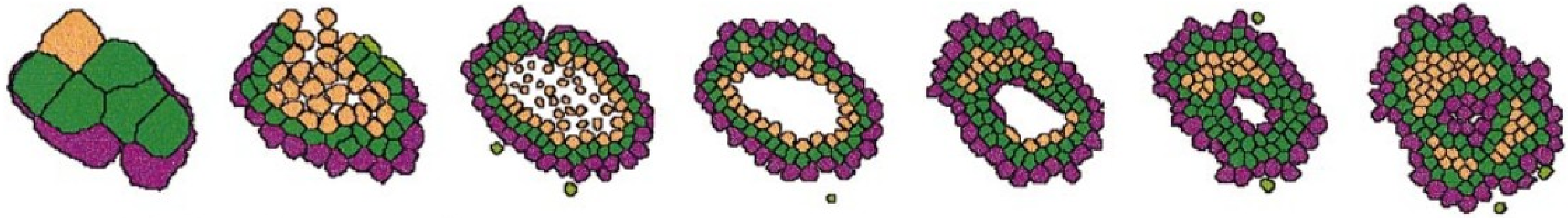
Running the model

- Every time step update the boolean network in all cells
  - Environmental factors (OR with neighbours)
- CPM asynchronous updating
- Initial state:
  - single cell, all nodes zero.
  - 7 pre-sheduled divisions

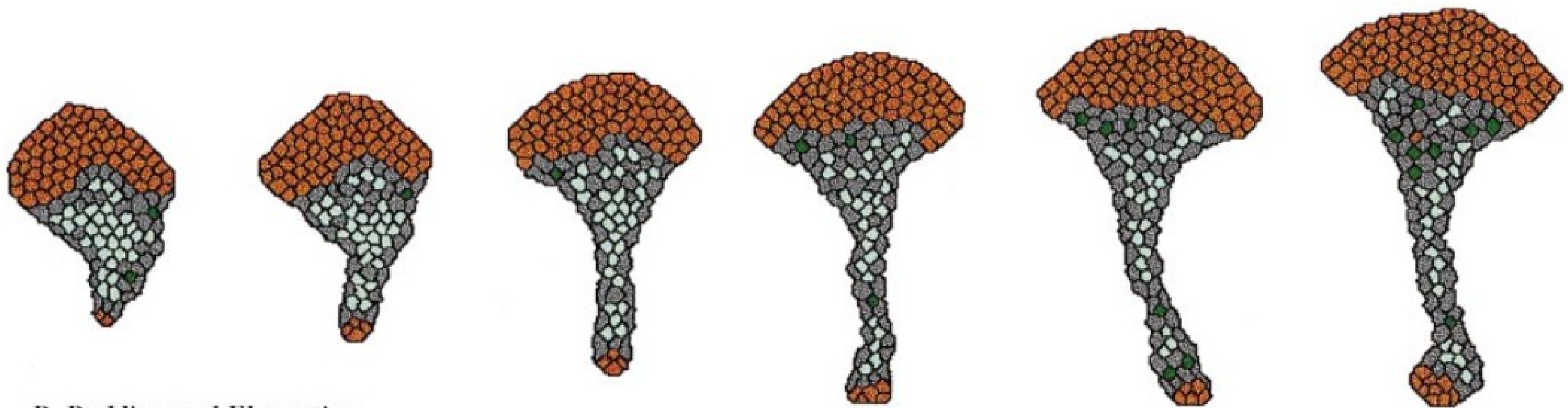
Evolution and Development model

- Fitness depends on amount of difference in gene expression (Hamming distance between different attractors)
- Start with random boolean networks →
  - For every boolean network run model →
  - Determine fitness for every network →
  - Choose best out of random sample →
  - Mutate best network and copy →
  - Repeat
- We get a few boolean networks with a high fitness which we study further

Results



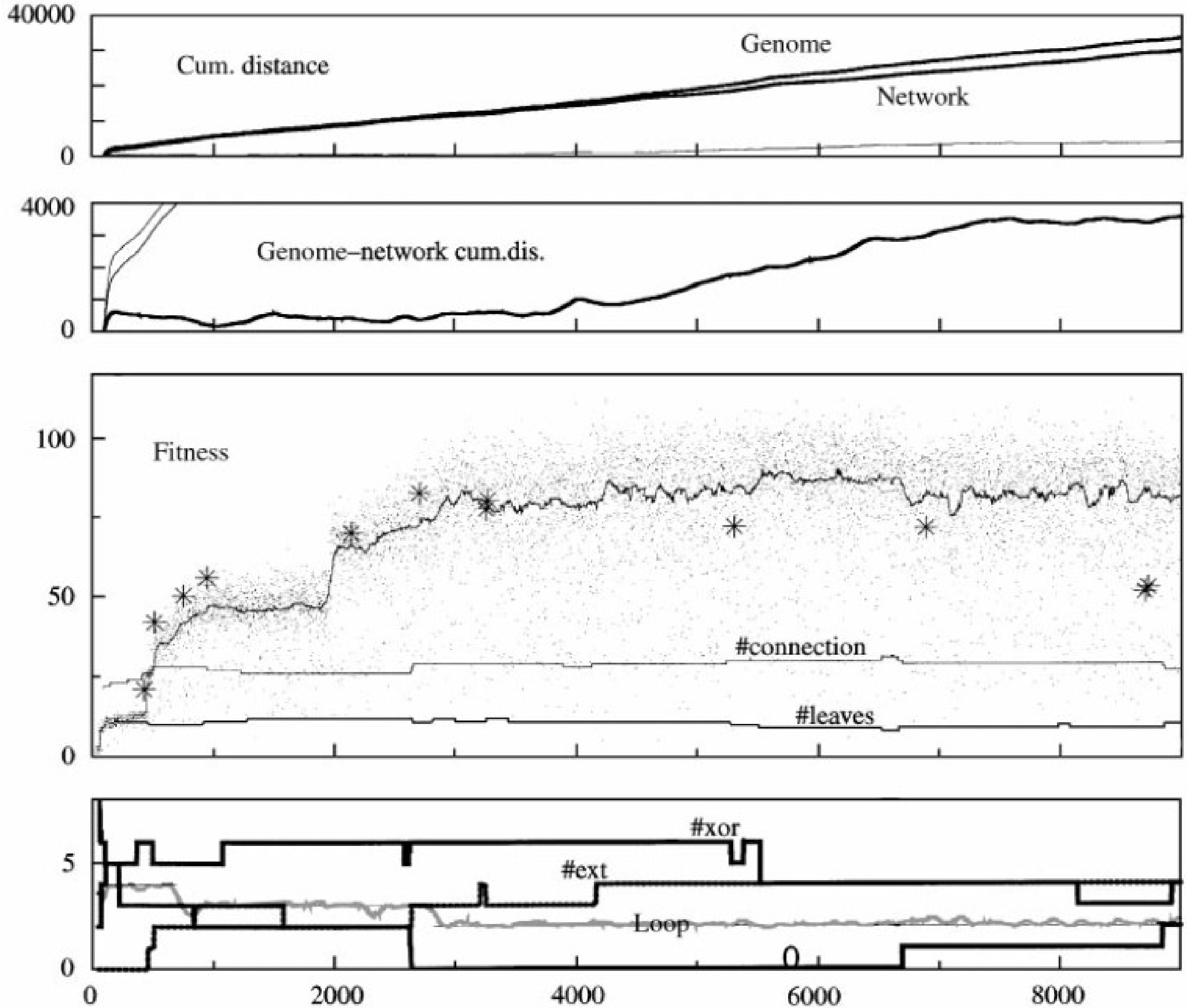
A. Cell migration and Engulfing



B. Budding and Elongation

C. Cell Death and Redifferentiation

Evolutionary Dynamics



Conclusion

- We achieve morphogenesis without explicitly setting cell differentiation and differential cell adhesion
- Although genetic variation is big within the model, the cells with highest fitness proliferate

Article 2: Adaptive dynamics under development-based genotype–phenotype maps

Isaac Salazar-Ciudad[1,2] & Miquel Marín-Riera[2]

- Look at different phenotype-fitness maps and determine their effect on evolution of morphogenesis
- Using a computational model of tooth development
- They look at 3 different phenotype-fitness maps

Model

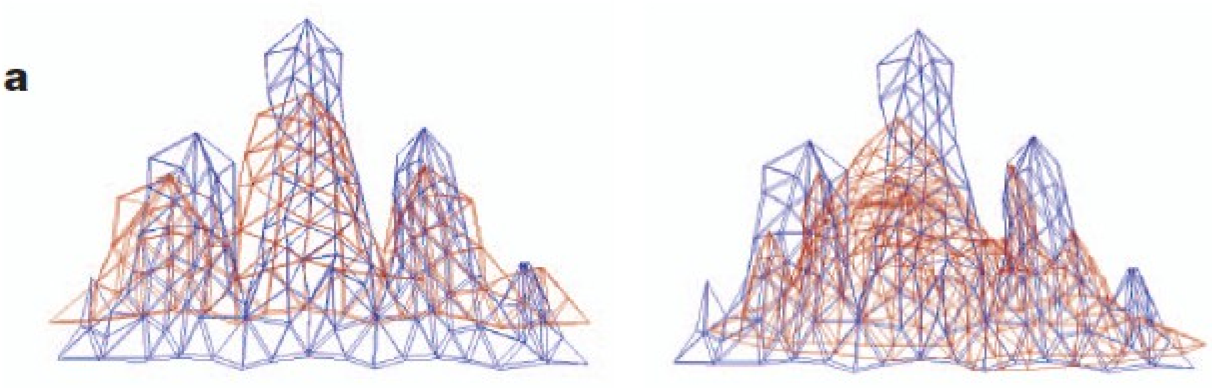
- Developmental model for teeth
  - Parameters of the model as proxy of the genotype
  - This gives a morphology
- Evolution model
  - Fitness is determined for each morphology
  - Apply selection criteria (highest fitness gets offspring)
  - The parameters are mutated in offspring

Phenotype fitness maps

- Compared to optimal morphology in 3 ways:
  - EMD(Euclidean morphological distance)
  - Landmark-distance
  - OPC(Orientation patch count)

EMD

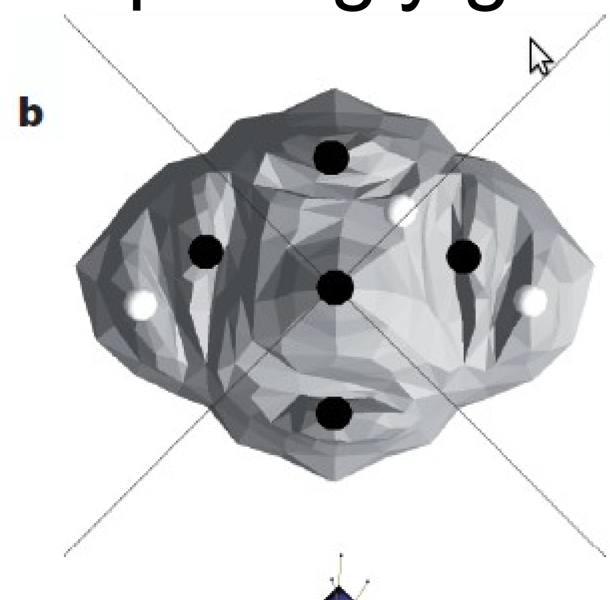
- The most strict criteria (involves all cells)
- Does not reach optimal morphology when the distance from initial morphology is large
- Quite stable

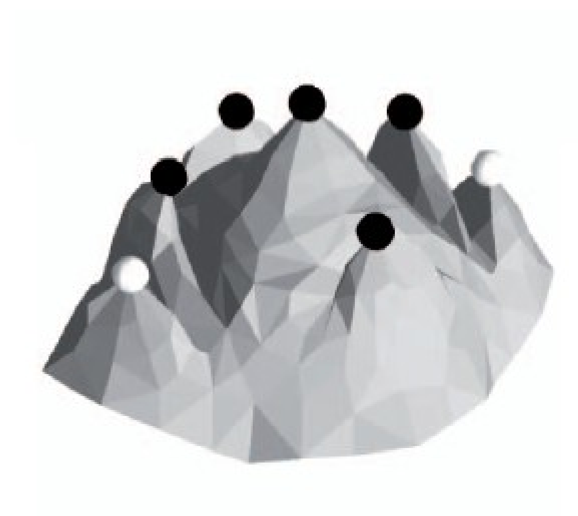


$$D = \frac{\sum_{k=1}^{n_1} d_{\min 12k} + \sum_{k=1}^{n_2} d_{\min 21k}}{n_1 + n_2}$$

Landmark distance

- Not as strict as the EMD
- Distinction is made of looking at different number of landmarks
- Looks only at a few important landmarks
- Surprisingly gives worst results



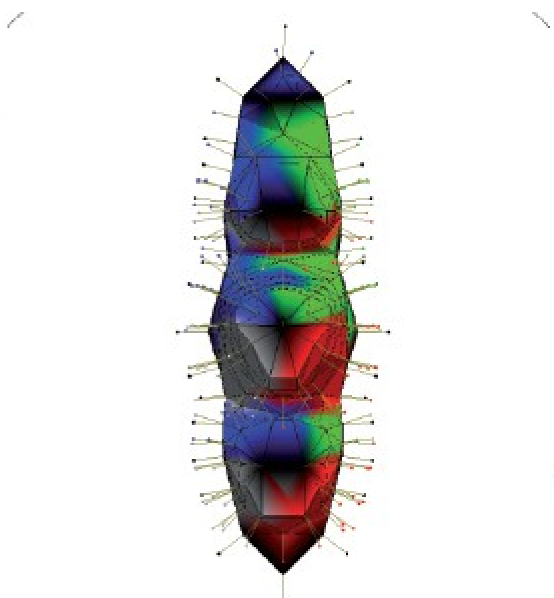


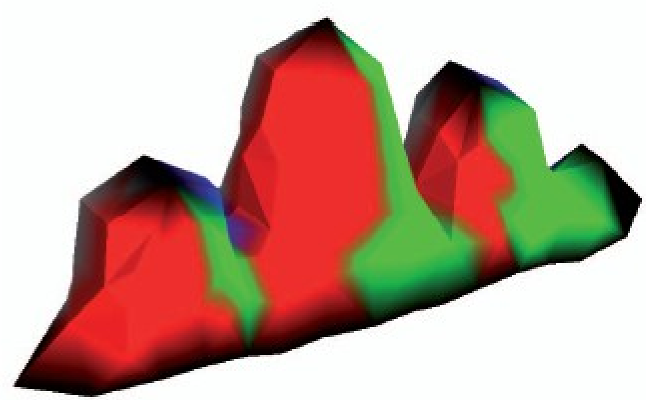
$$d_{\mathrm{lan}} = \sqrt{\sum_{k=1}^{n_t} (c_k - o_k)^2}$$

OPC

- Least strict of the criteria
- Only looks at amount of “patches” of cells
- Surprisingly gives best results, especially when deviation from optimum is large

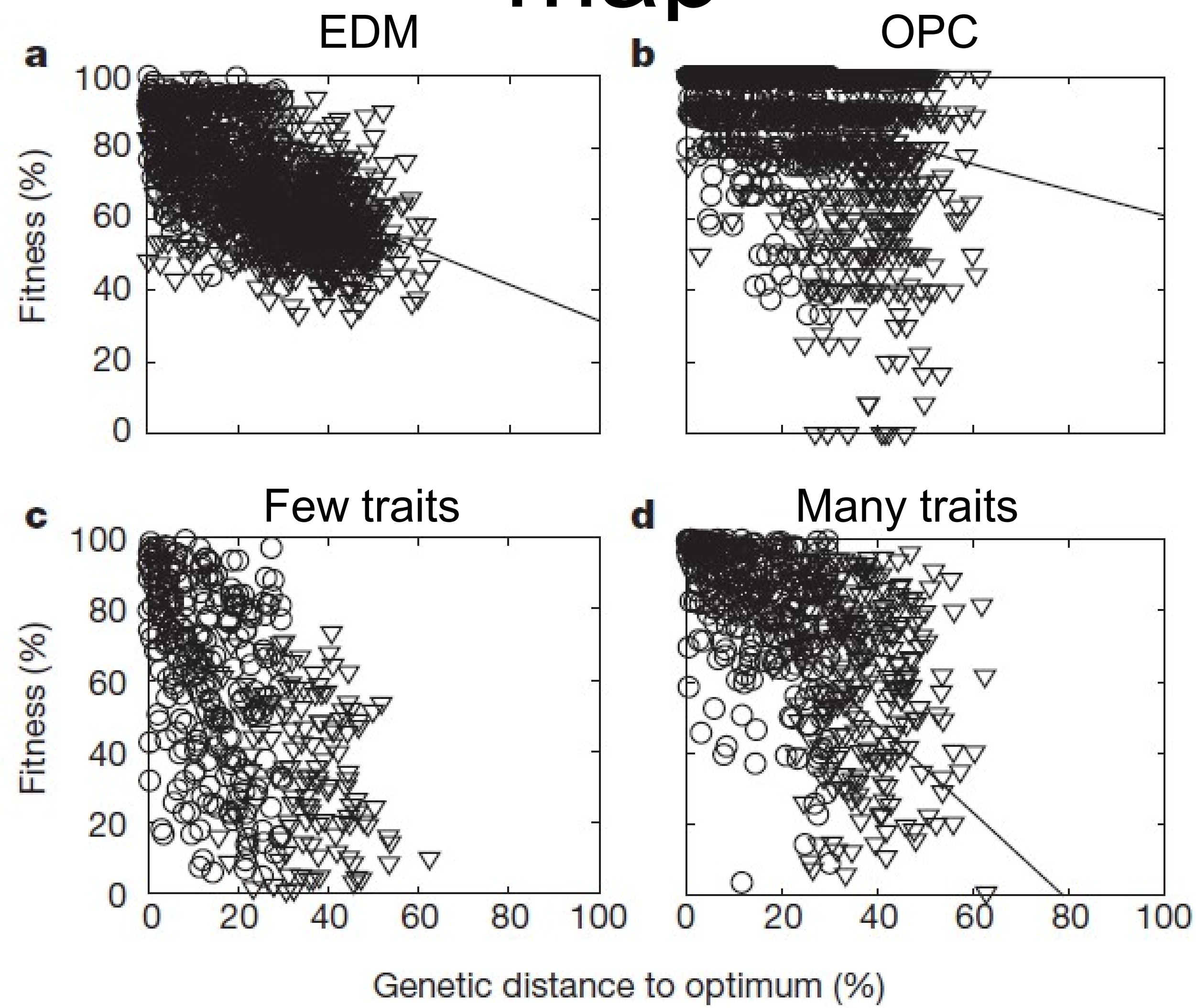
c





$$d_{\mathrm{OPC}} = \left(\frac{c - c_{\mathrm{opt}}}{c_0}\right)$$

Degeneracy of phenotype-fitness map



Article 2: Conclusion

- If maximum fitness depends on many traits results suggest it is only possible to achieve if initial condition is not far from optimum
- Degenerate (OPC) and few traits base phenotype-fitness maps lead to more substantial and sustained morphological adaptation

Conclusion

- Morphogenesis is not as complicated of a process as we expected
- Evolution can lead to Morphogenesis
- Which phenotype-fitness map is used influences the morphogenical evolution
- Genotype-phenotype maps are very complex and thus our models are very crude

Any Questions