Evolution: 1-3

- Foundations - *evolutionary dynamics*
- Phylogeny and Ontogeny - *evolution of development*
- Frontiers - *Demons, coevolution, niche construction and cultural change*

Replicator-Mutator (Quasispecies) Equation

$$\dot{g}_i = \sum_{j}^{2^n} g_j r_j(\mathbf{g}) m_{ij} - g_i \bar{f}$$

Kimura-Maruyama Equation - population genetics

$$\dot{g}_i = \sum_{i=0}^{N} \frac{r_{N-j} g_{N-j}}{\bar{f}} \frac{\mu^i}{i!} e^{-\mu}$$

Eigen Error Threshold

Delta function:

$$\mu < \frac{s}{L} = \frac{1}{L}$$

Kimura's Neutrality Inequality

Condition for Neutrality $sN < 1$

Evolution's Arrow

Eigen-Kimura

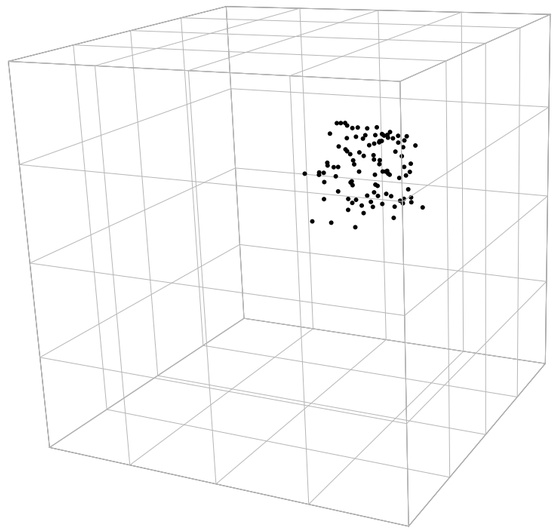
Information Storage

Principle

Evolutionary Information Storage

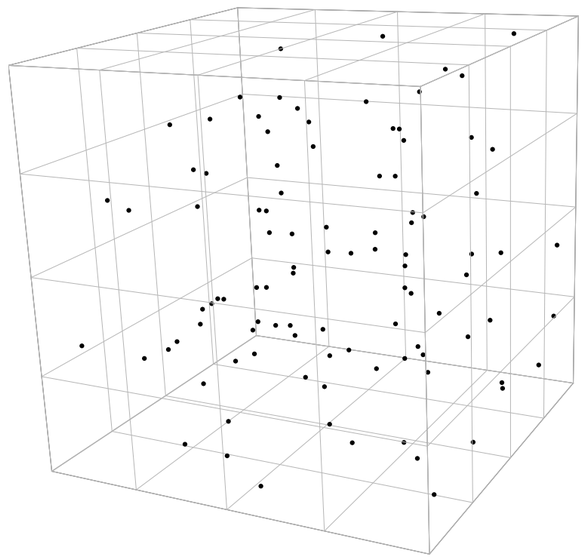
Information Conserved

$$\mu L < 1 < sN$$



Information Lost

$$\mu L > 1 < sN$$
$$\mu L < 1 > sN$$
$$\mu L > 1 > sN$$



"Darwinian" Selection for Compression

$$\mu L < 1 < sN$$

$$sN > \mu L$$

The Preference for Population Multiplicity, Individual Minimality & High Diversity.

So What's Missing?

Complex multicellularity

The parameters we are going to investigate

$$g_i \xrightarrow[\text{Energy + Resources}]{r_i} 2g_i$$

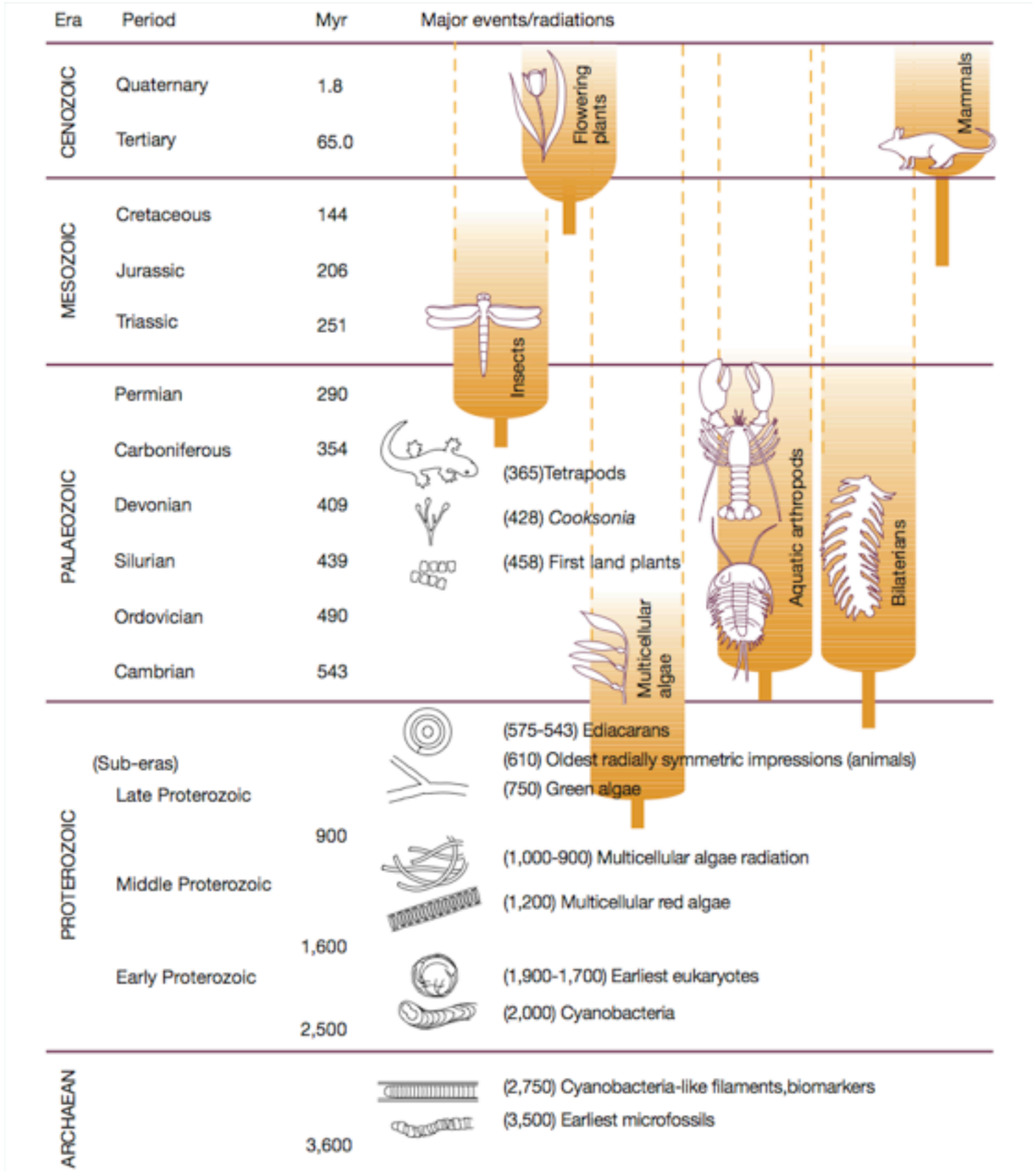
origins of replicative advantages

$$g_i + g_j \xrightarrow{c_{ij}} g_j$$

sources of density dependence

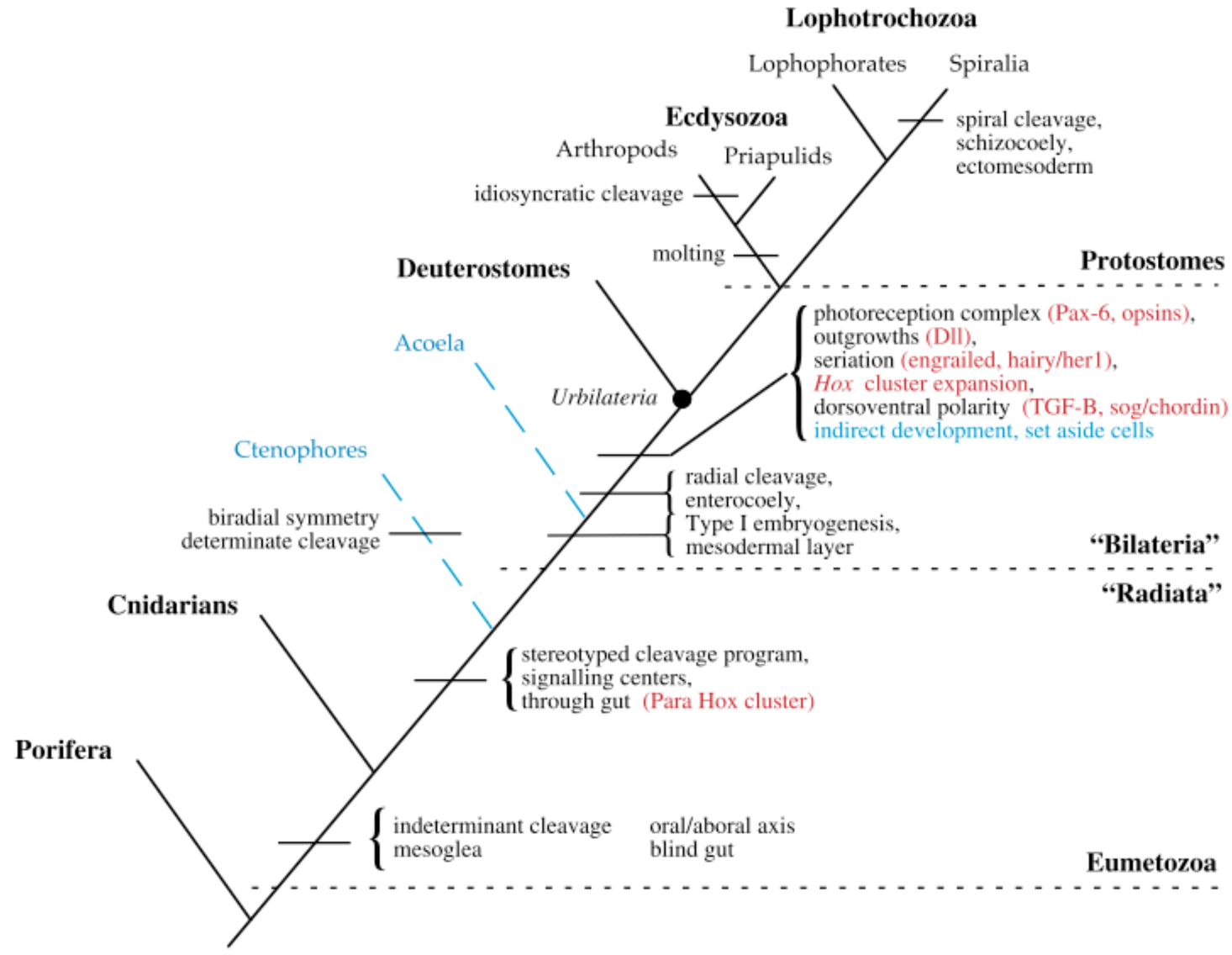
$$g_i \xrightarrow{d_i} p_i$$

limitations of genetic models



Carroll, S. Nature 409. 2001

Developmental Innovations

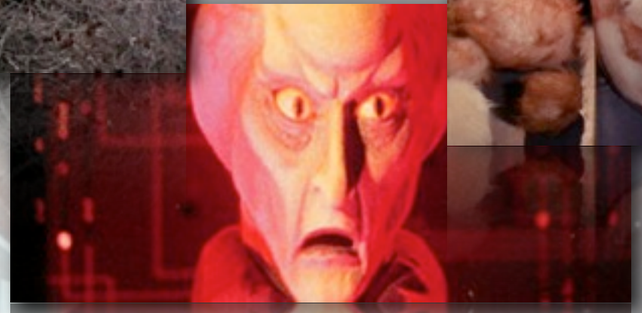


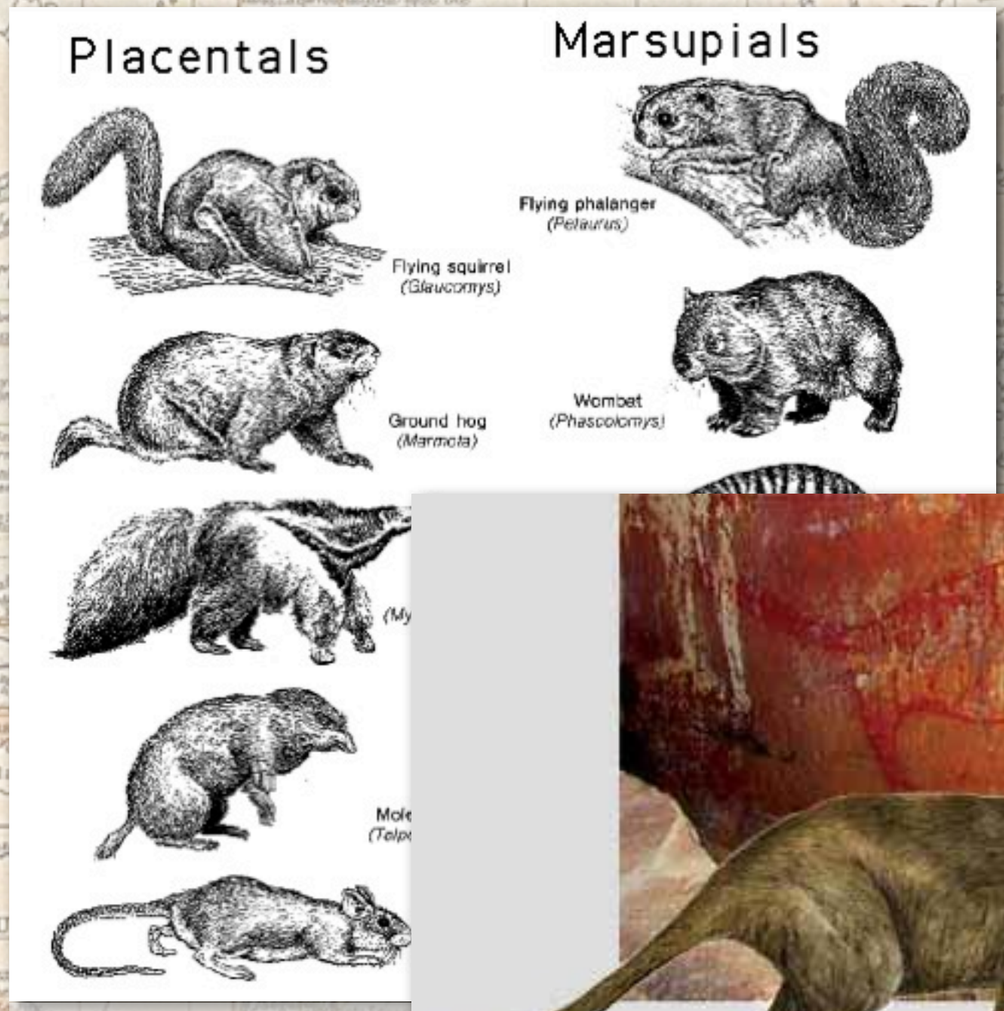
Knoll, A. & Carroll, S. Science 284. 1999

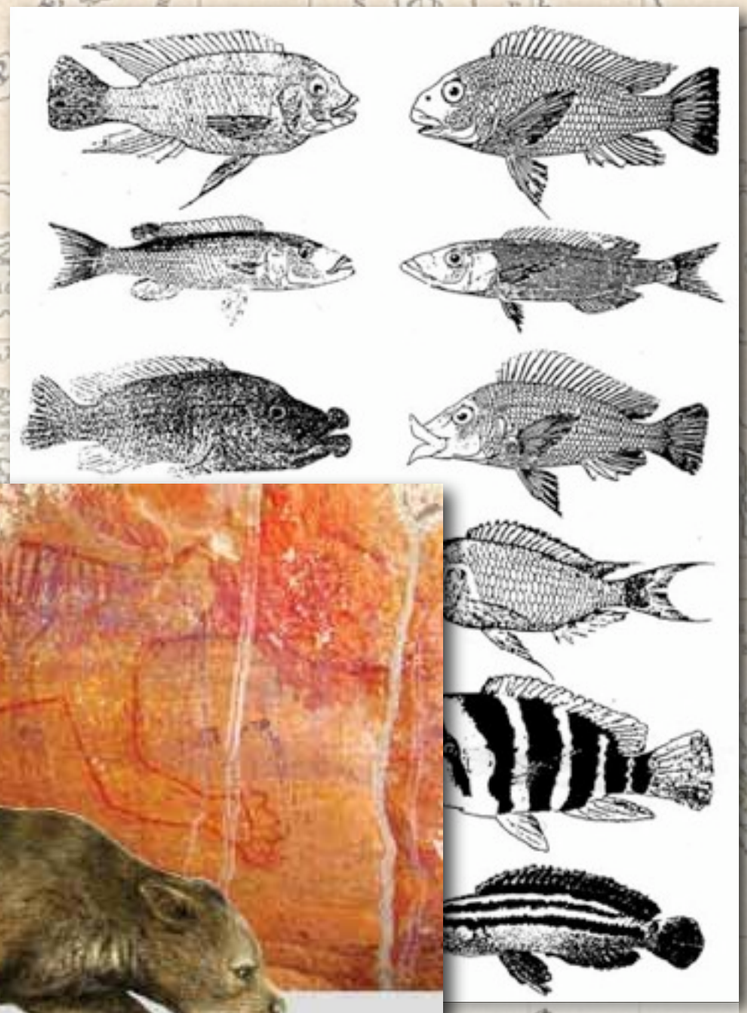
Key Theory Issues in EvoDevo

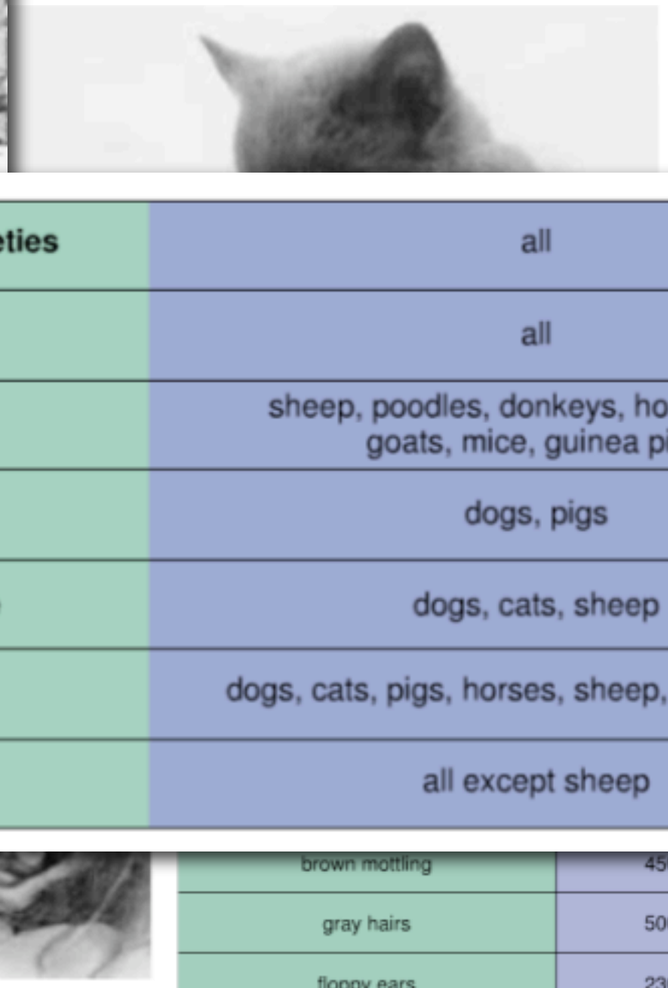
- Deviations from uniformitarianism (the cambrian disparity)
- Putative sparseness of the morphospace (many to one property)
- Violations of phenotypic isotropy - issues of accessibility
- Convergence is surprisingly frequent
- Macroevolution guided by regulatory genes rather than structural

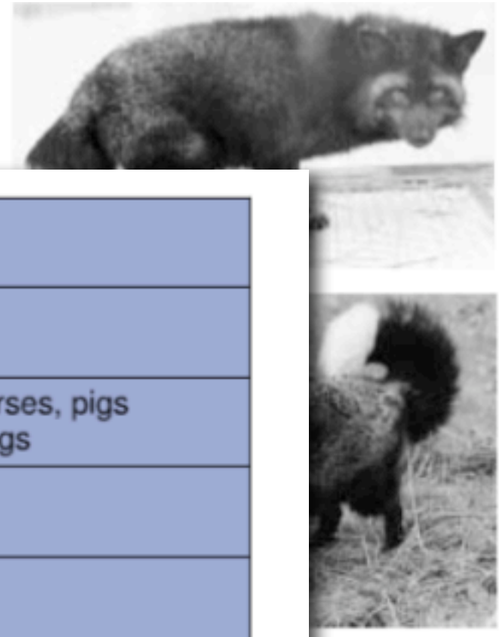
Universal Convergence - The Star Trek multiverse Bauplan




Placentals
Marsupials
Flying squirrel
(Glaucomys)
Flying phalanger
(Petaurus)
Ground hog
(Marmota)
Wombat
(Phascolomys)







appearance of dwarf and giant varieties	all
piebald coat color	all
wavy or curly hair	sheep, poodles, donkeys, horses, pigs goats, mice, guinea pigs
rolled tails	dogs, pigs
shortened tails, fewer vertebrae	dogs, cats, sheep
floppy ears	dogs, cats, pigs, horses, sheep, goats, cattle
changes in reproductive cycle	all except sheep

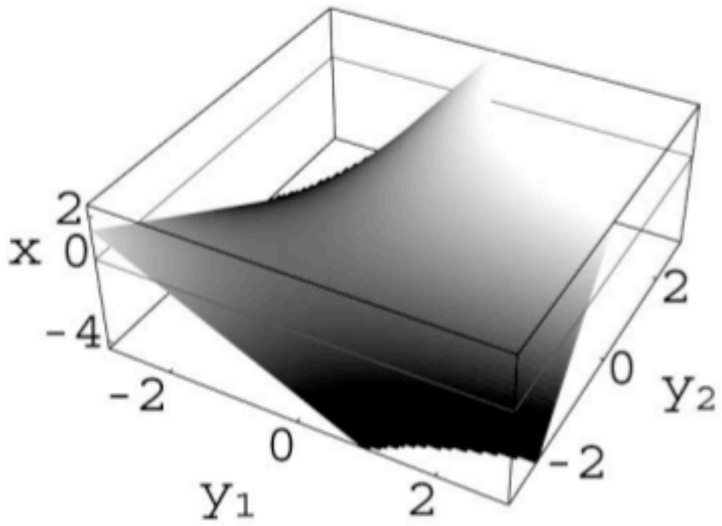
			increase in frequency
			(percent)
			+1,646
brown mottling	450	86	+423
gray hairs	500	100	+400
floppy ears	230	170	+35
short tail	140	2	+6,900
tail rolled in circle	9,400	830	+1,033

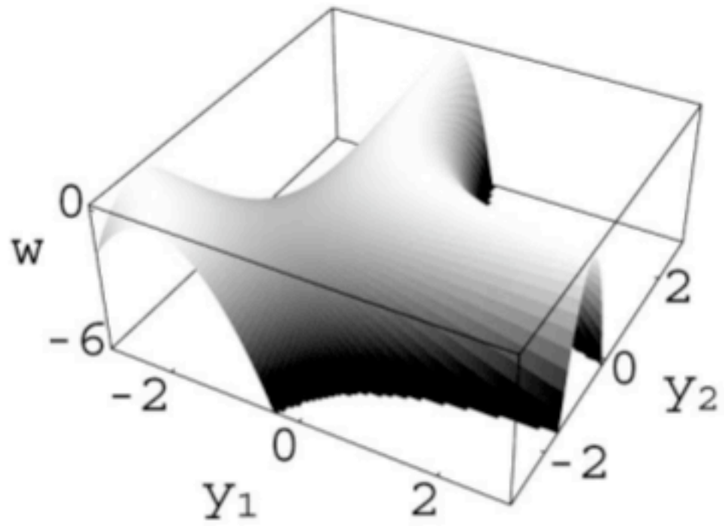
Epistasis

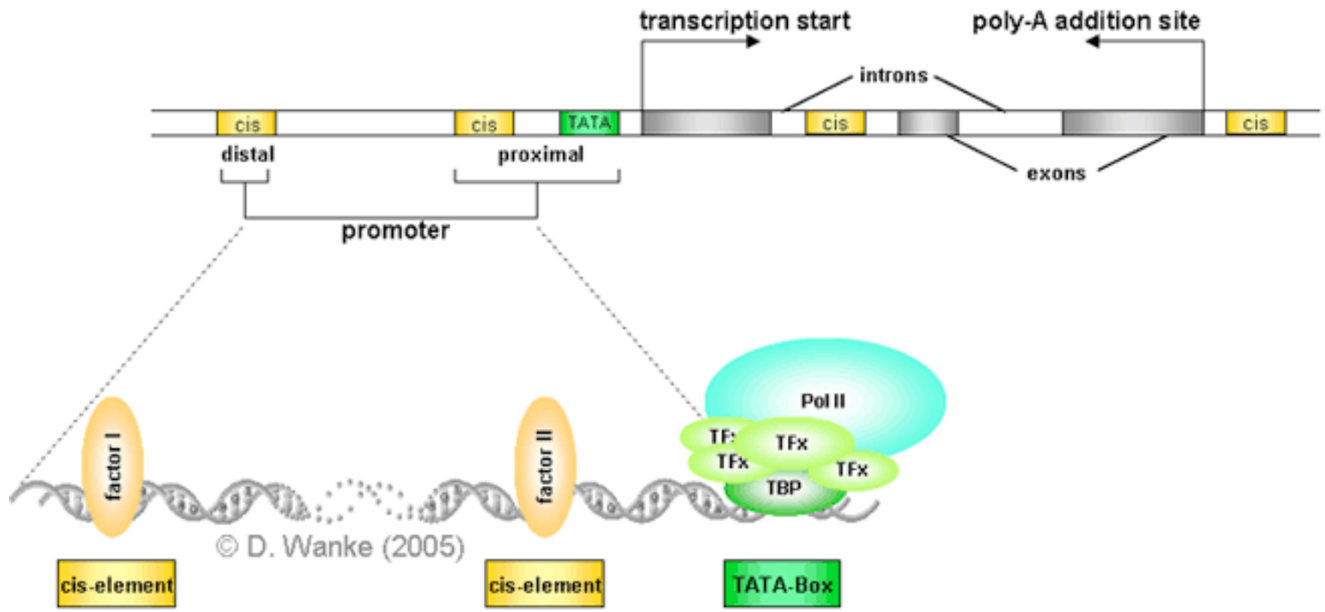
$$z = x + e$$

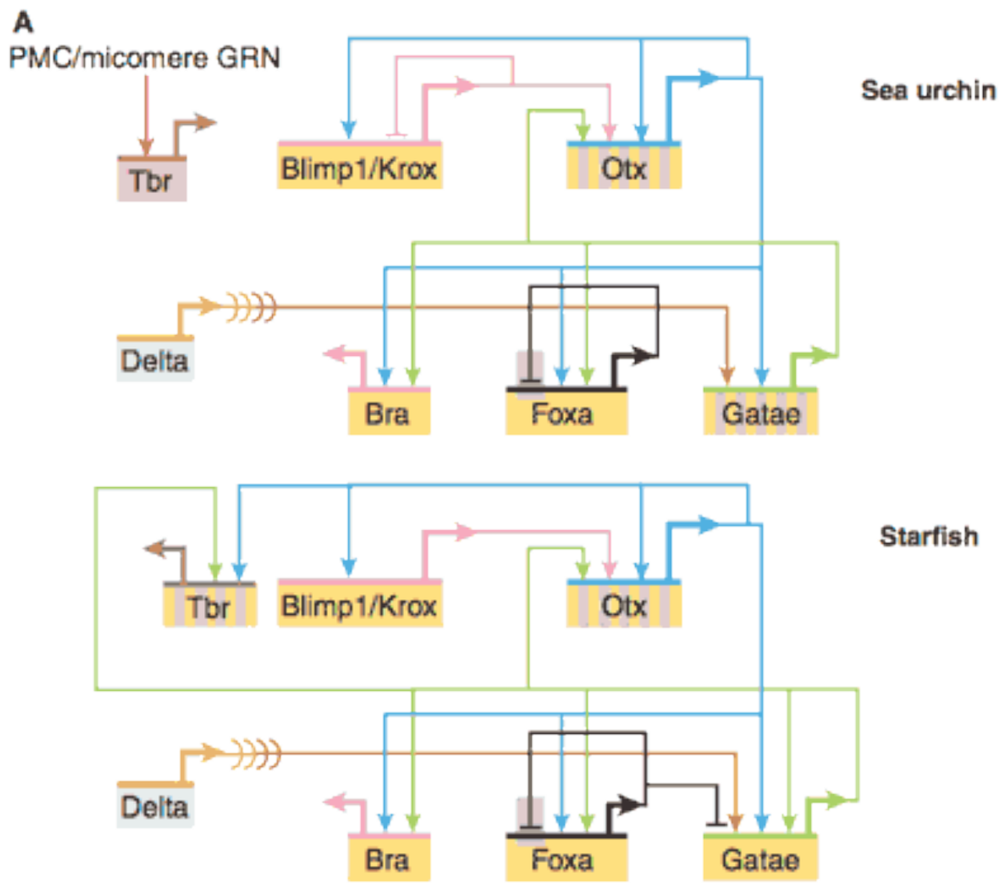
$$x = x_r + \sum_i y_i + \sum_{i,j>i} \epsilon_{ij} y_i y_j$$

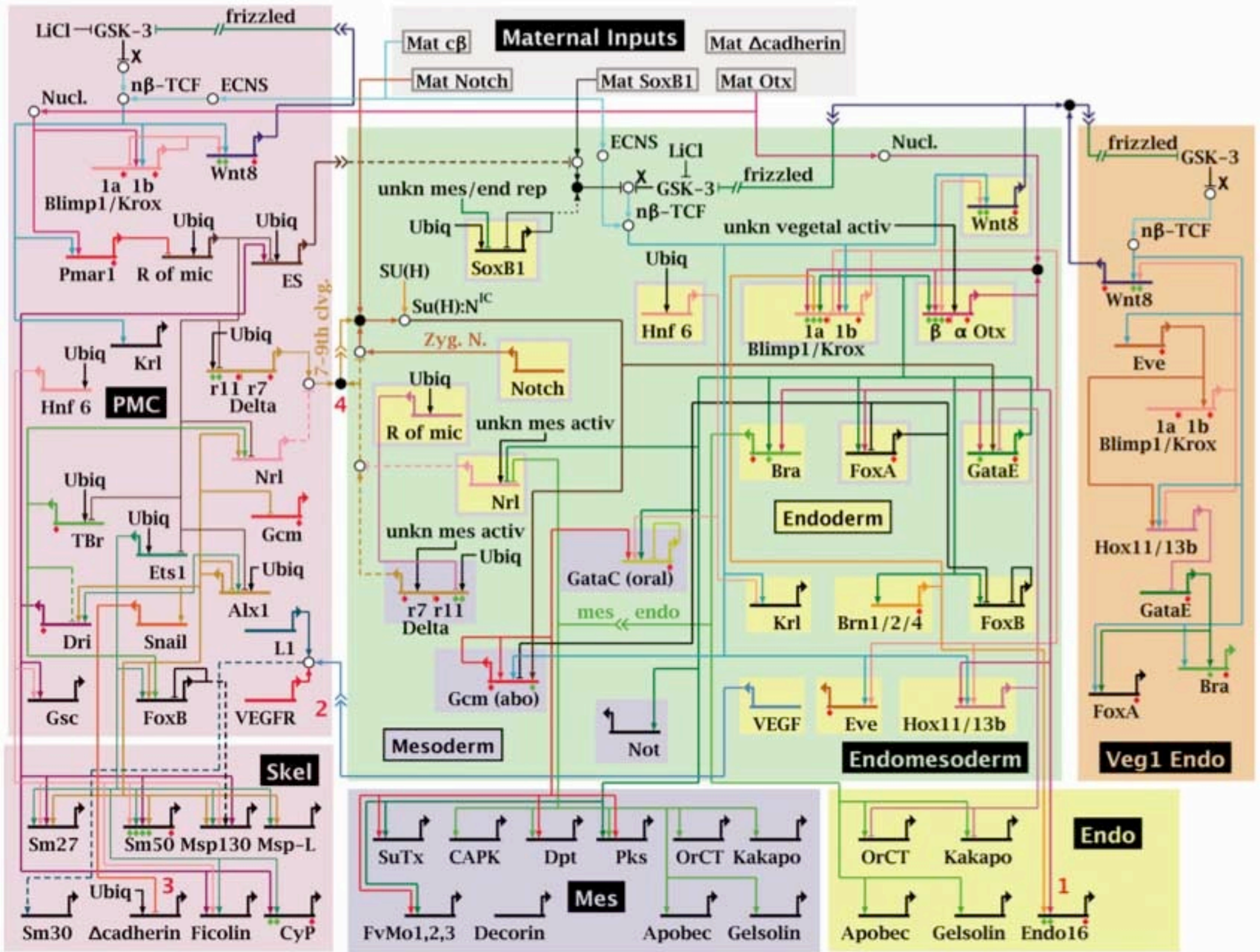
$$f_i = \frac{\partial}{\partial y_i} x|_y = 1 + \sum_{j \neq i} \epsilon_{ij} y_j$$





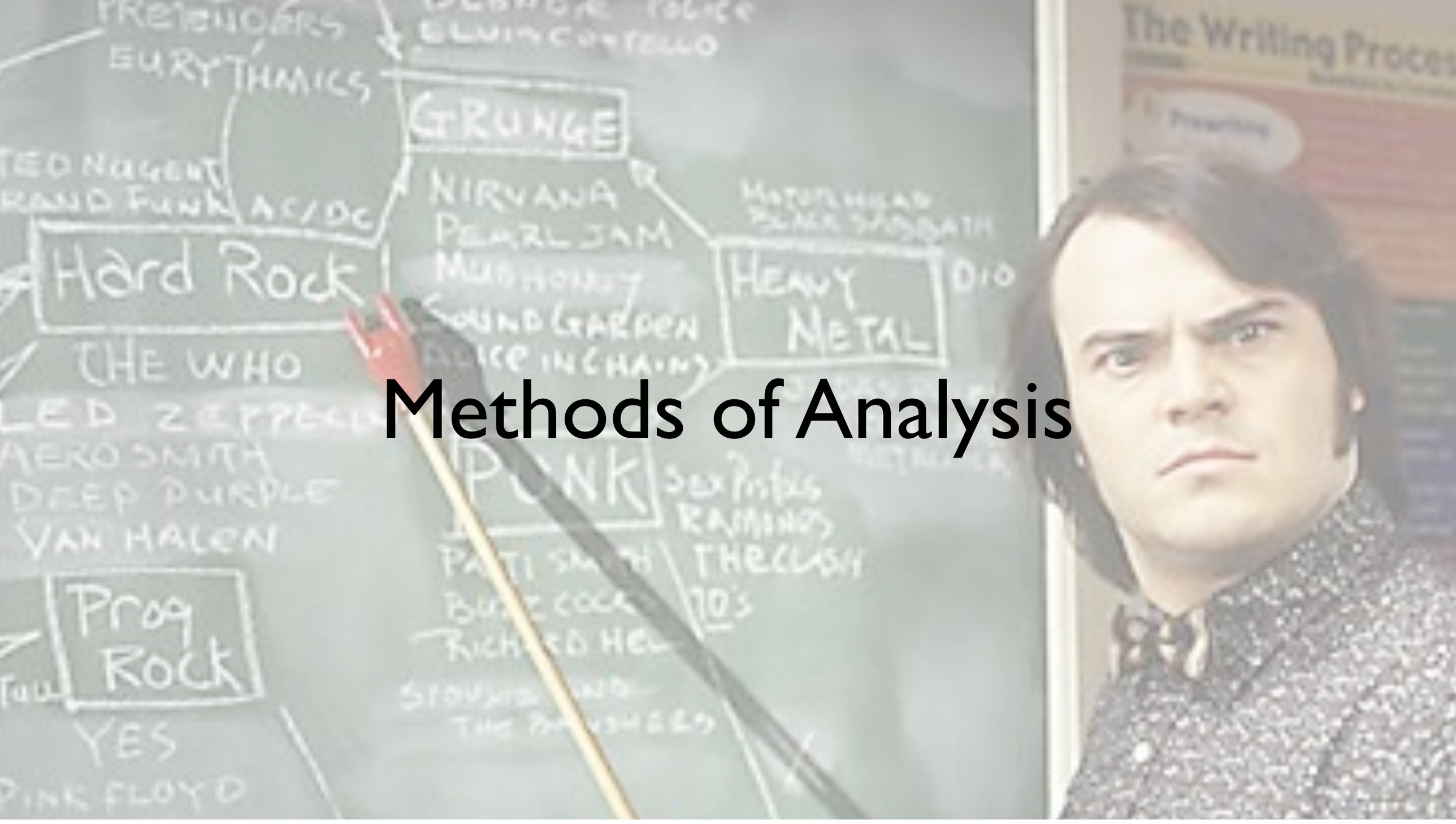

transcription start
poly-A addition site
introns
cis
cis
TATA
cis
cis
distal
proximal
exons
promoter
factor I
factor II
Pol II
TFx
TFx
TFx
TFx
TBP
© D. Wanke (2005)
cis-element
cis-element
TATA-Box


A
PMC/micomere GRN
Tbr
Blimp1/Krox
Otx
Sea urchin
Delta
Bra
Foxa
Gatae
Tbr
Blimp1/Krox
Otx
Starfish
Delta
Bra
Foxa
Gatae



Ubiq=ubiquitous; Mat = maternal; activ = activator; rep = repressor;
unkn = unknown; Nucl. = nuclearization; χ = β-catenin source;
nβ-TCF = nuclearized b-β-catenin-Tcf1; ES = early signal;
ECNS = early cytoplasmic nuclearization system; Zyg. N. = zygotic Notch

Methods of Analysis



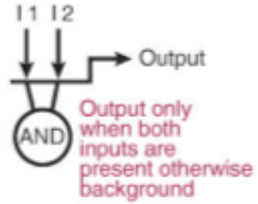
1. AND LOGIC

ELECTRONIC DIAGRAM

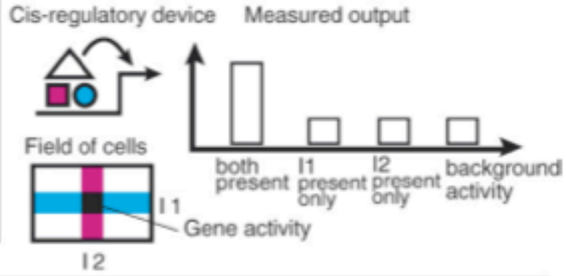
LOGIC DIAGRAM

I1	I2	Output
0	0	0
0	1	0
1	0	0
1	1	1

CIS-REGULATORY MODULE DIAGRAM



BIOCHEMICAL DIAGRAM



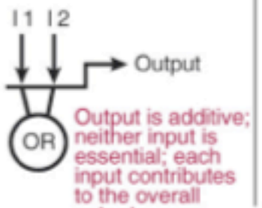
2. OR LOGIC

ELECTRONIC DIAGRAM

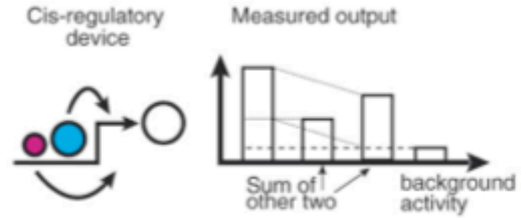
LOGIC DIAGRAM

I1	I2	Output
0	0	0
0	1	1
1	0	1
1	1	2

CIS-REGULATORY MODULE DIAGRAM



BIOCHEMICAL DIAGRAM



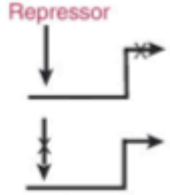
3. NOT LOGIC

ELECTRONIC DIAGRAM

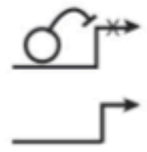
LOGIC DIAGRAM

I	Output
0	1
1	0

CIS-REGULATORY MODULE DIAGRAM



BIOCHEMICAL DIAGRAM

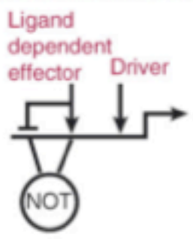


4. COMPOUND LOGIC

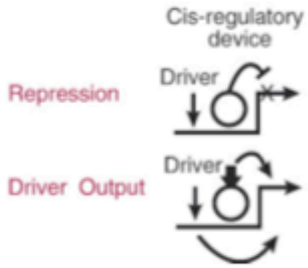
LOGIC DIAGRAM

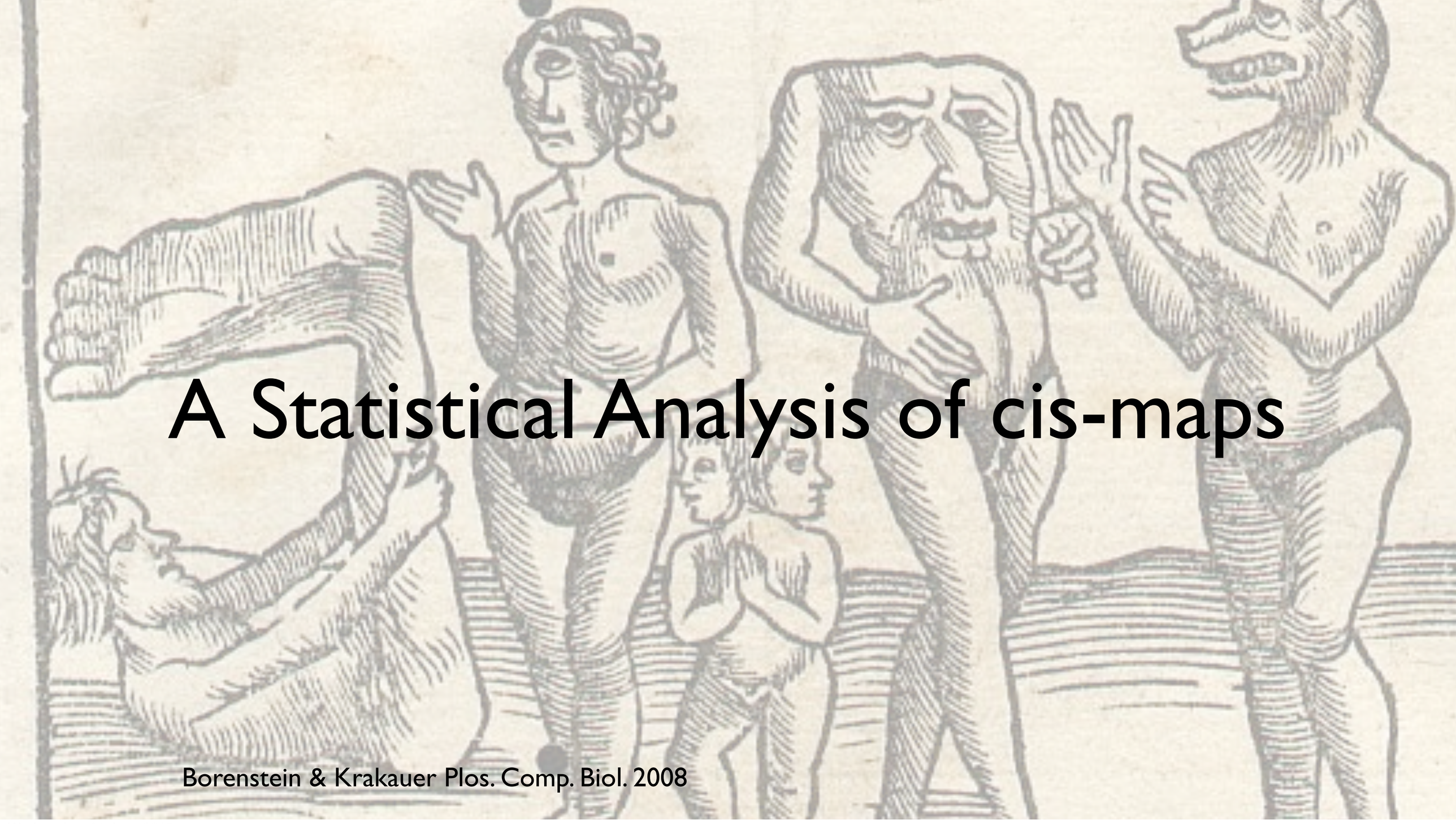
Ligand	Consequence	Driver	Output
Not Present	Presence of repression	1	0 (Repression)
Present	Absence of repression	1	1 (Driver Activity)

CIS-REGULATORY MODULE DIAGRAM



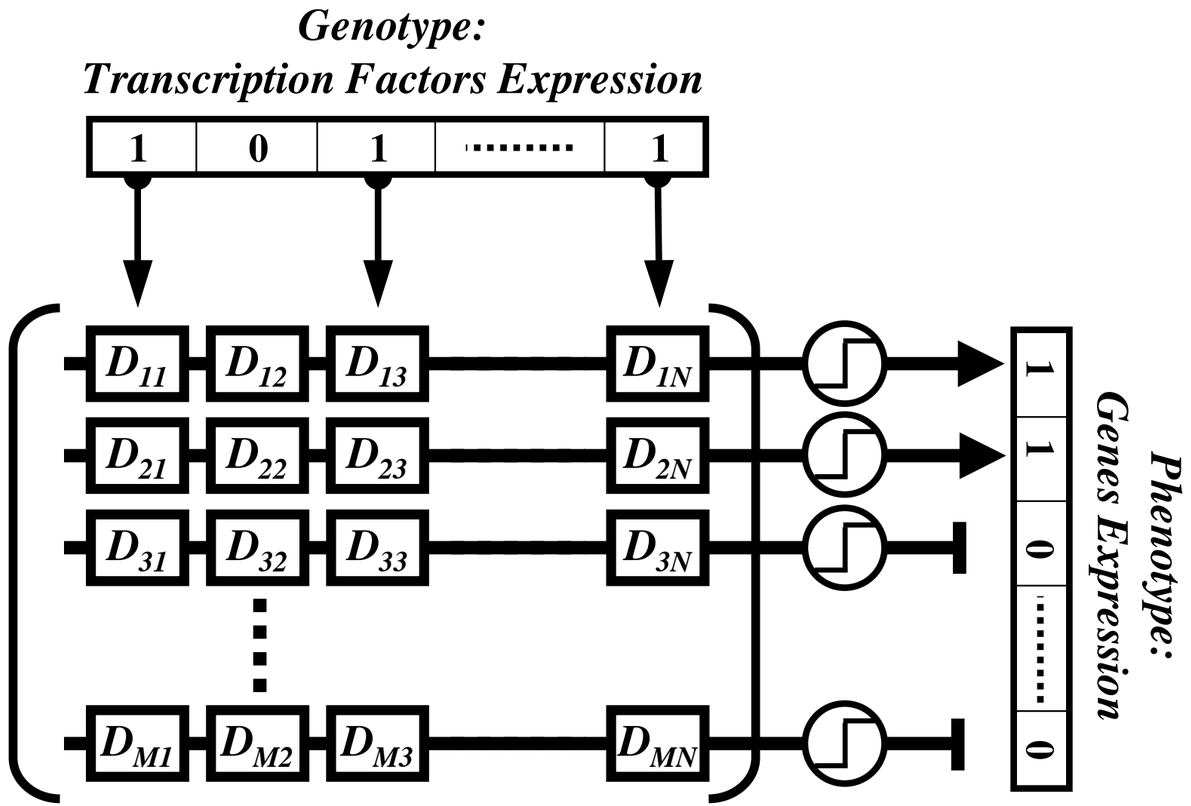
BIOCHEMICAL DIAGRAM





A Statistical Analysis of cis-maps

Borenstein & Krakauer Plos. Comp. Biol. 2008



$$p(D_{ij} = +1 | c_{ij} = 1) = q \qquad \vec{p} = H(D\vec{g})$$

Single Projection

$$\vec{p} = H(D\vec{g})$$

Recurrent Projection

$$\vec{p_t} = H(D\vec{p}_{t-1})$$

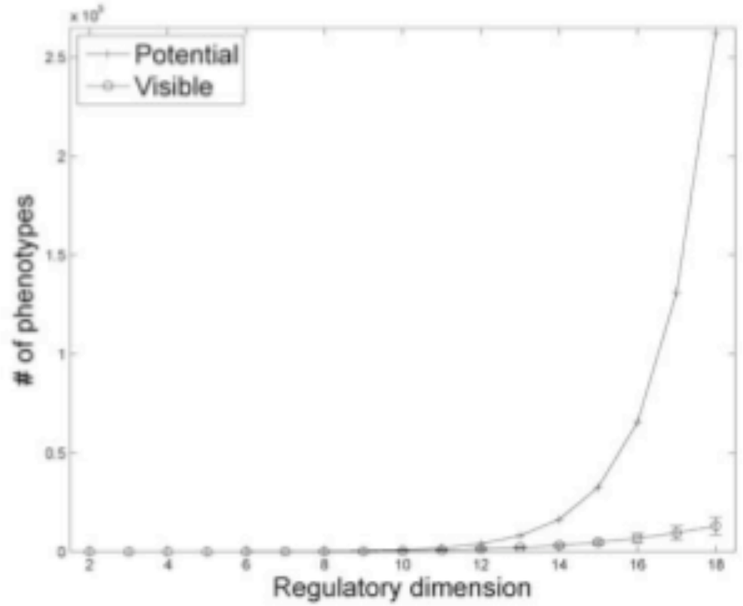
Recurrent Random Projection

$$\vec{p_t} = H(D_t\vec{p}_{t-1})$$

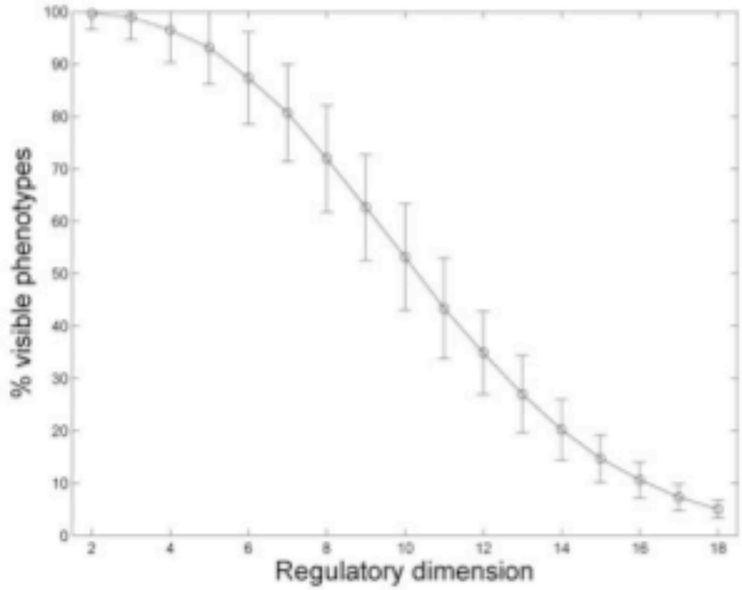
Hidden Phenotypes

Diversity

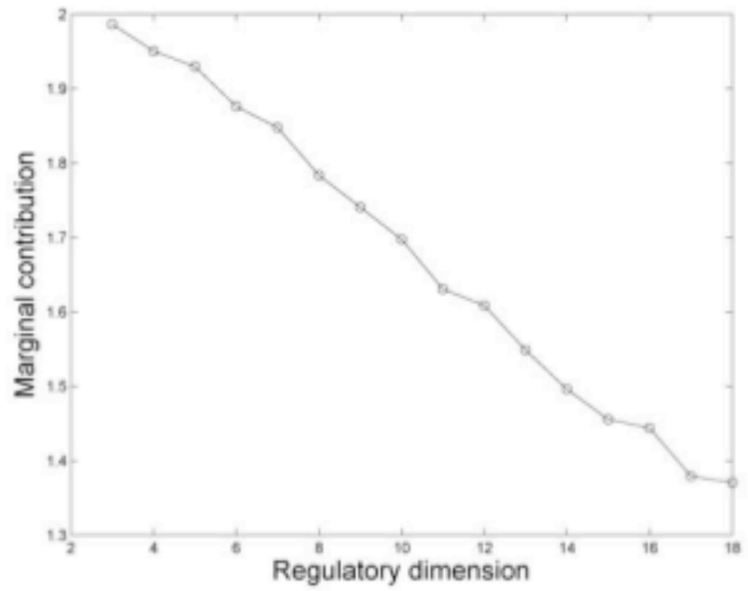
A



B

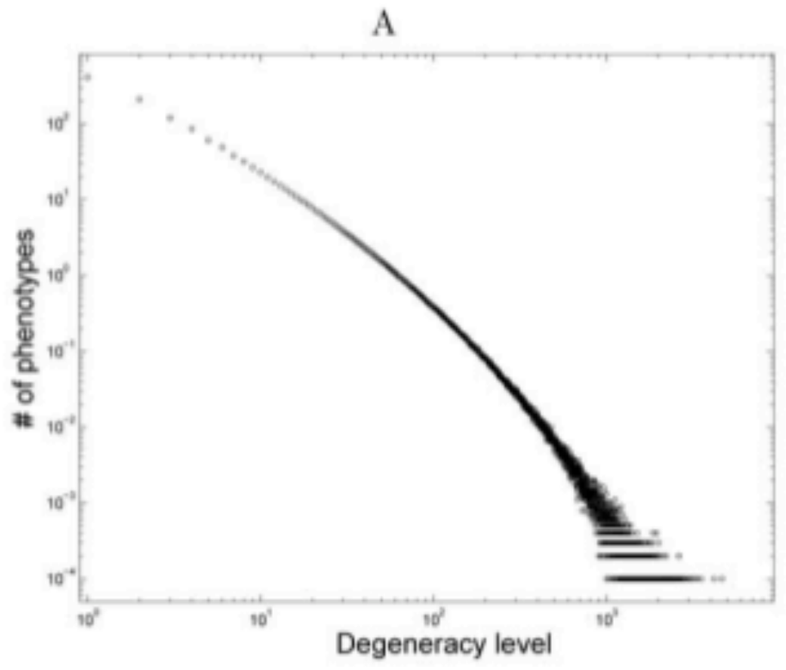


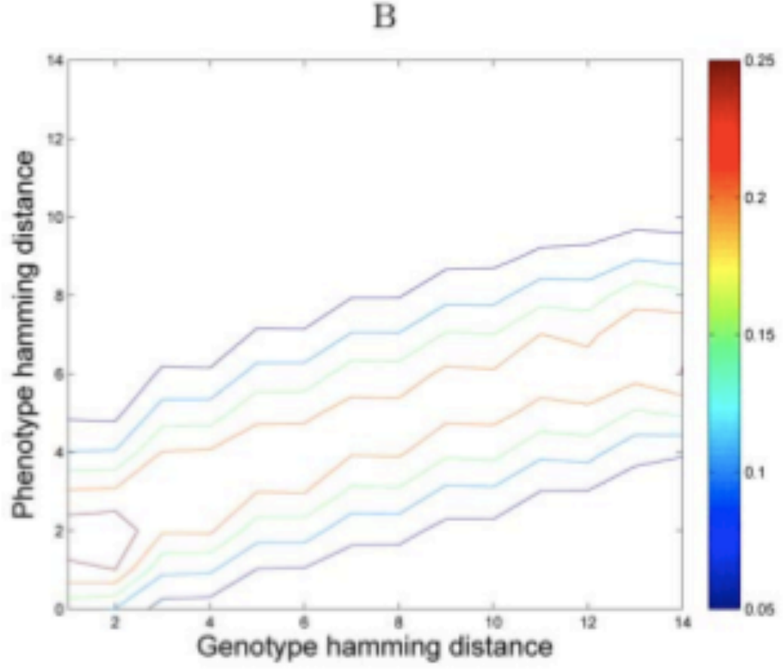
C

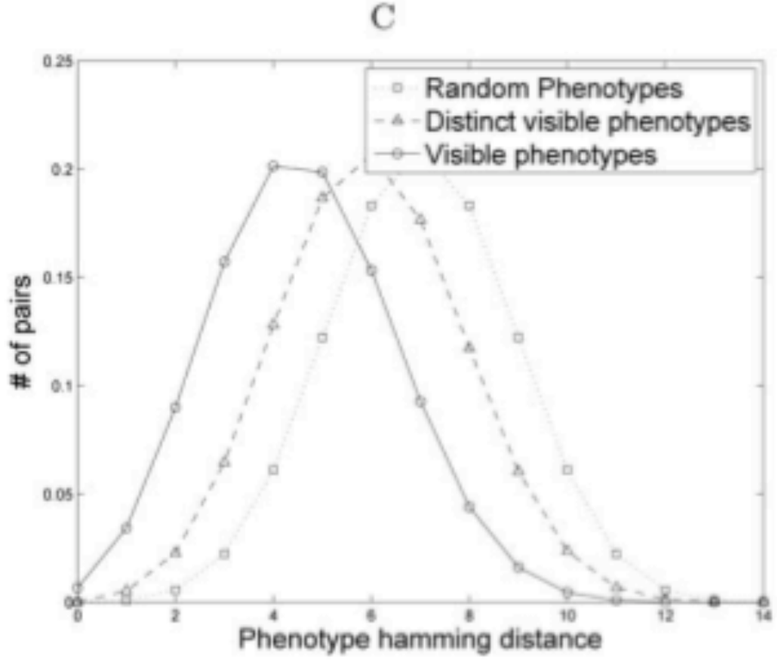


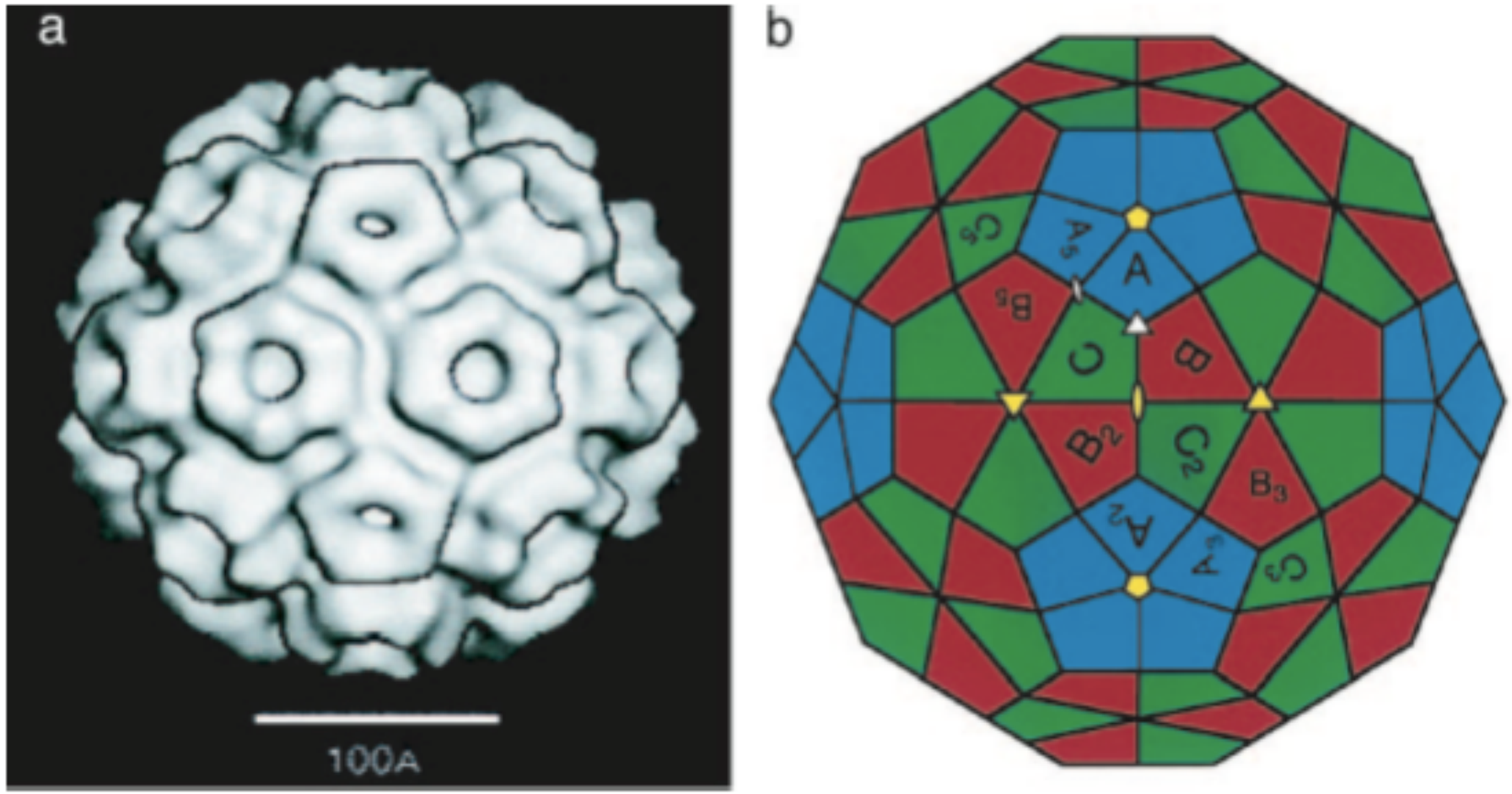
Localization of visible sub-space

Dispa


A
# of phenotypes
Degeneracy level

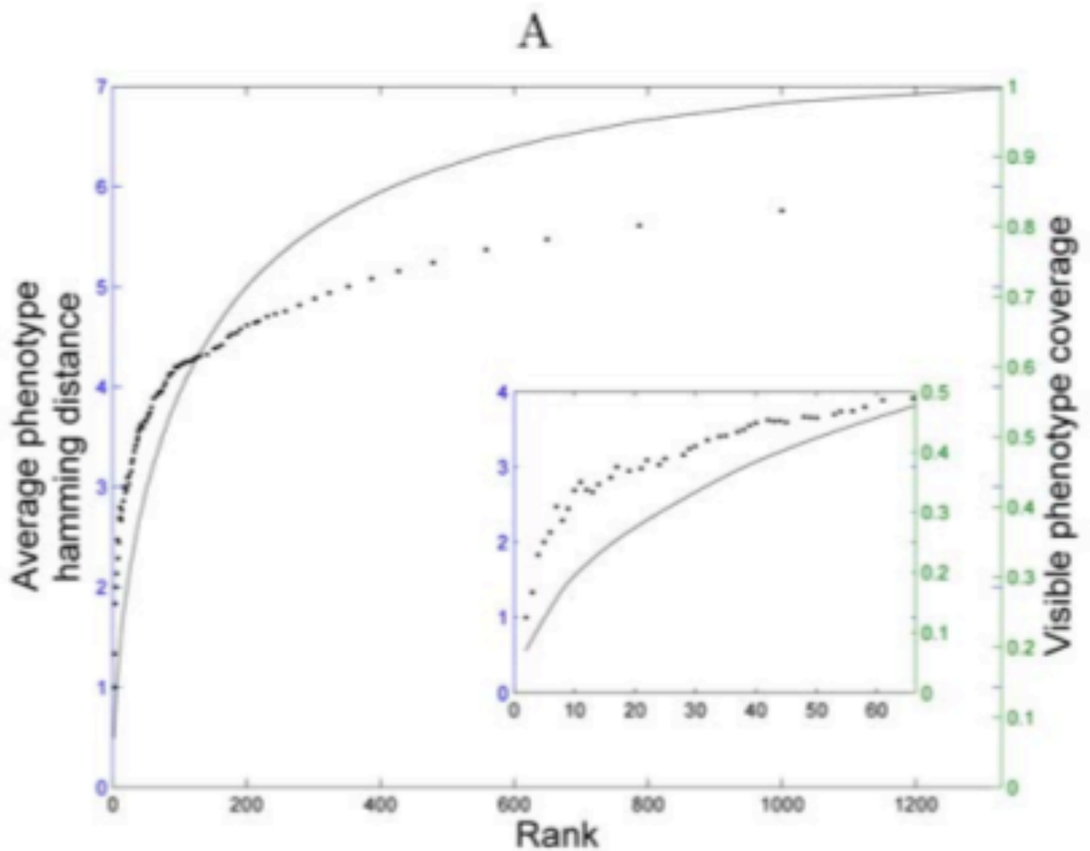

B
Phenotype hamming distance
Genotype hamming distance

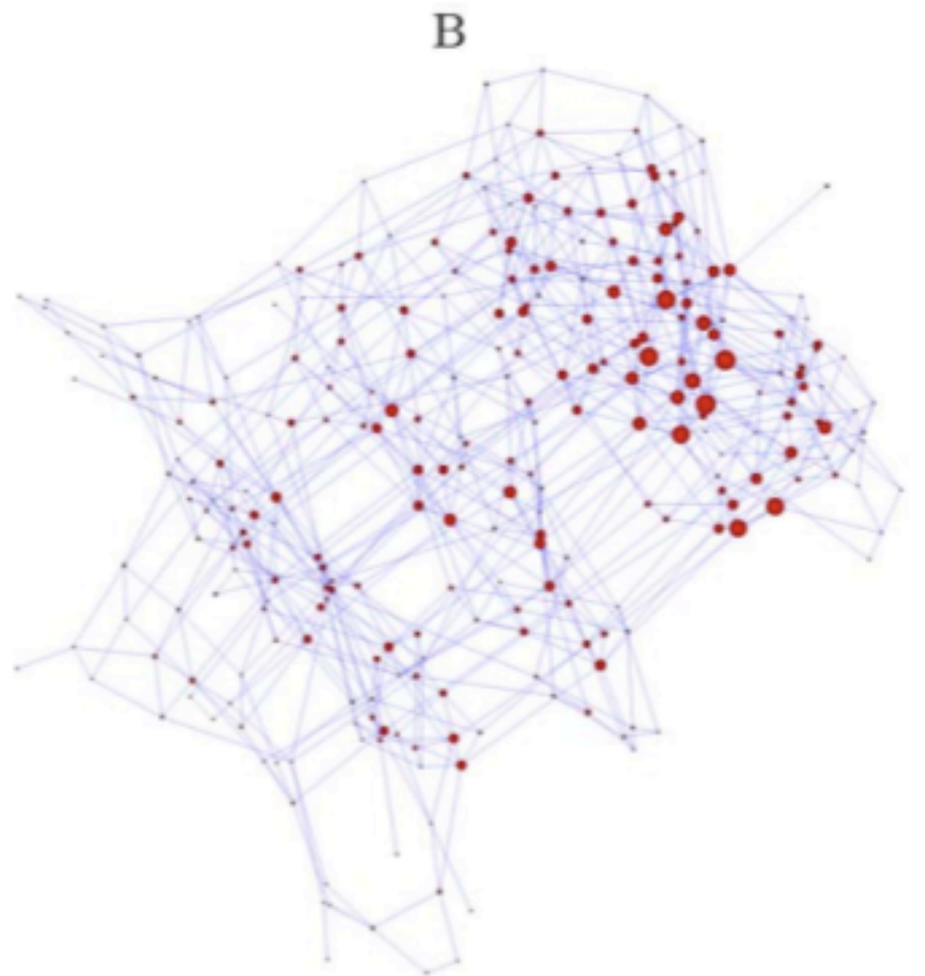

C
Random Phenotypes
Distinct visible phenotypes
Visible phenotypes
# of pairs
Phenotype hamming distance


a
100A
b
A
B
C
A5
B5
C5
B2
C2
B3
A2
A3
C3

Structure of visible sub-space

Common Phenotypes are Similar





Hierarchical Projections:

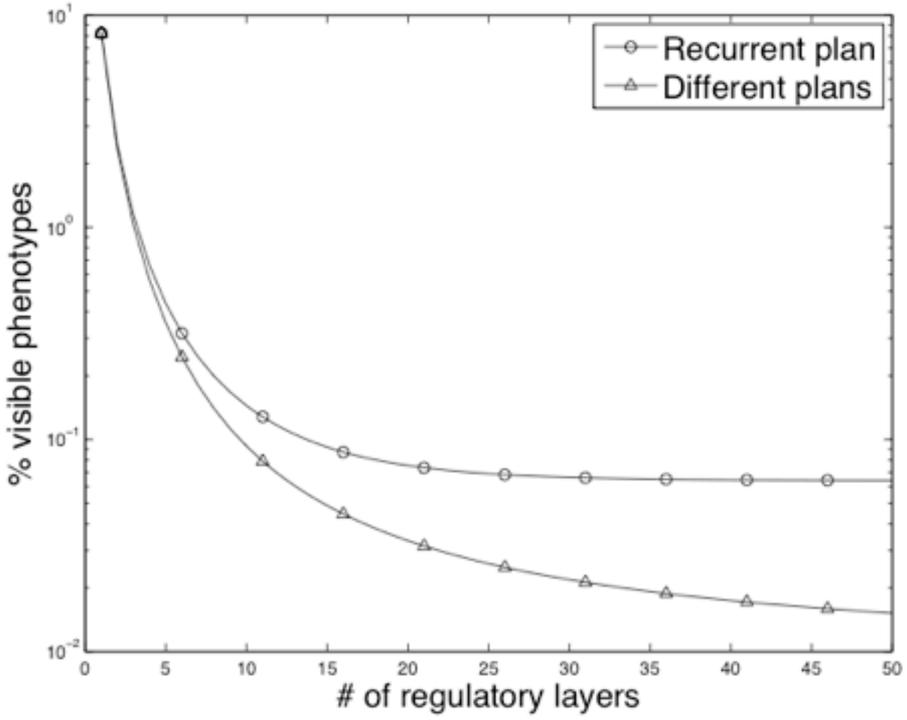
Recurrent Projection

$$\vec{p_t} = H(D\vec{p}_{t-1})$$

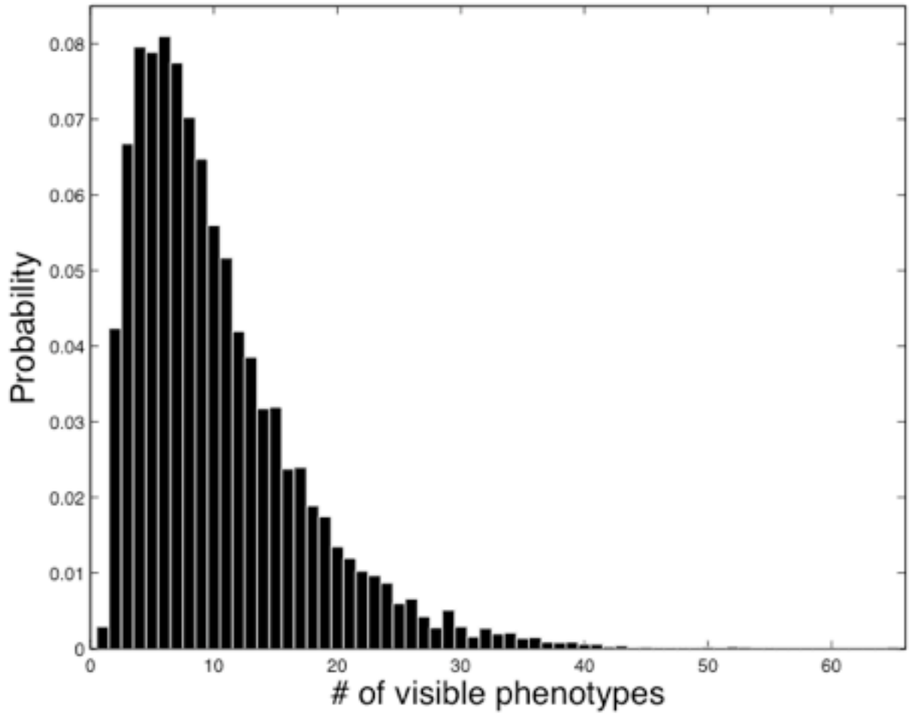
Recurrent Random Projection

$$\vec{p_t} = H(D_t\vec{p}_{t-1})$$

A

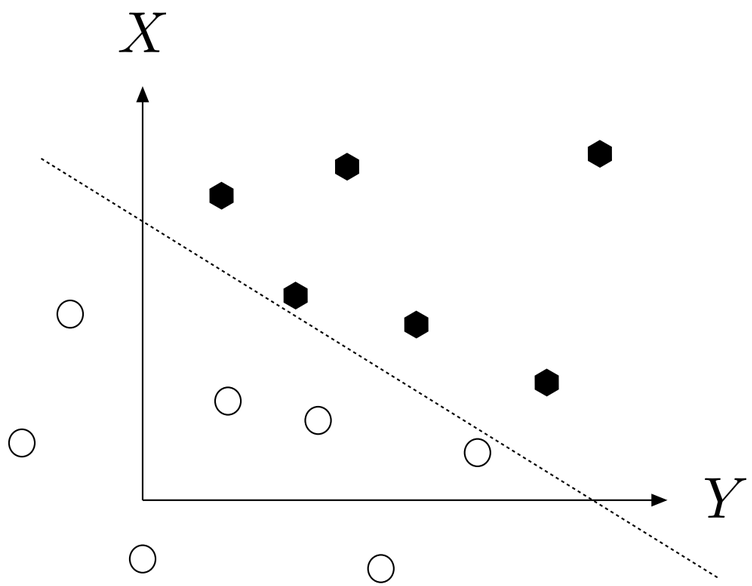

Recurrent plan
Different plans
% visible phenotypes
# of regulatory layers

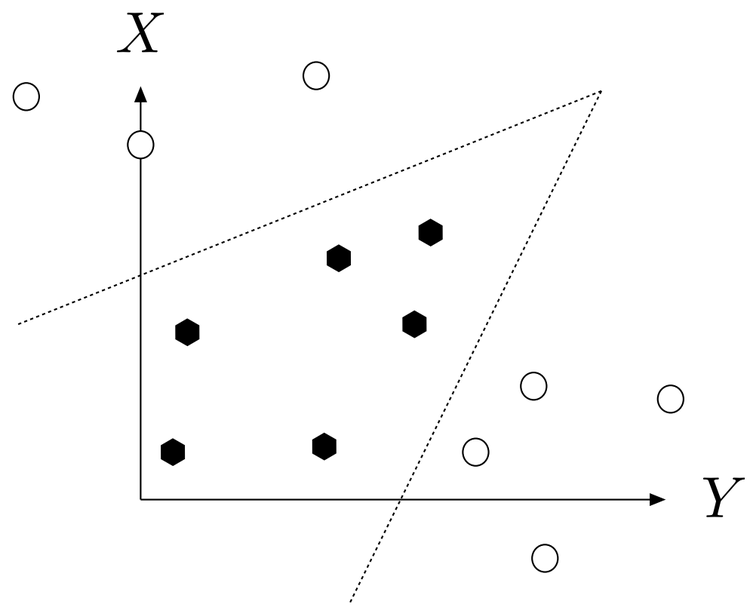
B


Probability
# of visible phenotypes

Some Theoretical Connections (for the fastidious)

Linear & Polyhedral separability of activation patterns in phenotypic feature space





- NP-complete to determine polyhedral separability of 2 sets of points

- NP-complete to determine whether k-lines can separate 2 sets

- For k lines polynomial time to determine whether sets are separable

Cybenko Theorem: universal function approximation with superpositions of sigmoids

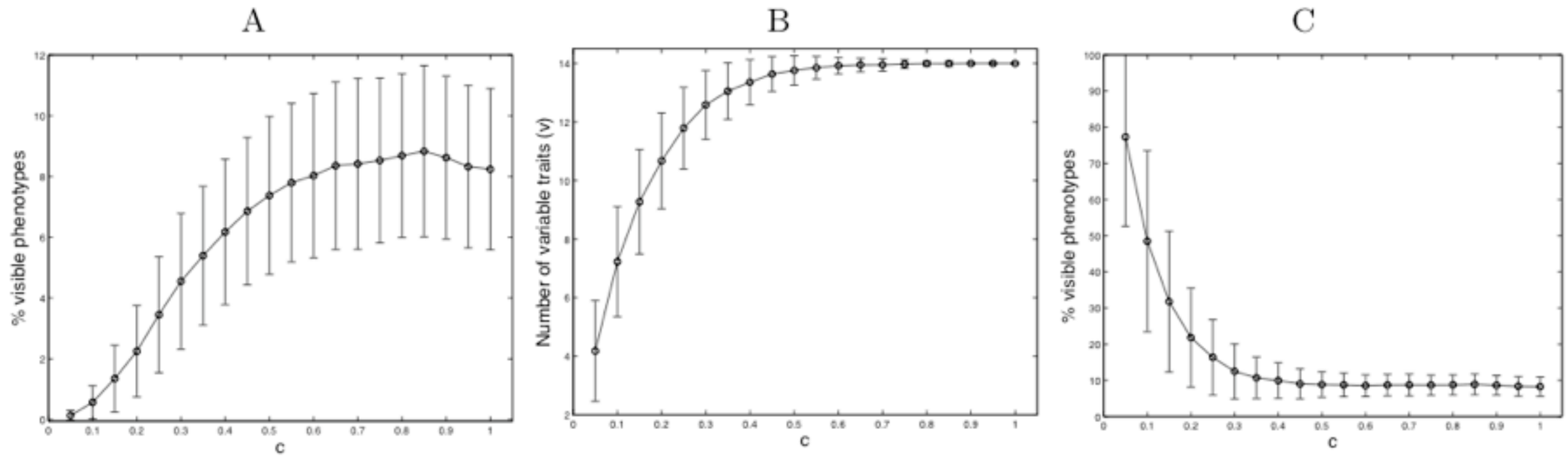
$$G(\mathbf{x}, \mathbf{w}, \alpha, \theta) = \sum_{\mathbf{i=1}}^{\mathbf{N}} \alpha_\mathbf{i} \sigma(\mathbf{w_i^T x} + \theta_\mathbf{i})$$

$$|G(\mathbf{x}, \mathbf{w}, \alpha, \theta) - f(x)| < |\epsilon|, \mathbf{x} \in [\mathbf{0}, \mathbf{1}]^\mathbf{n}$$

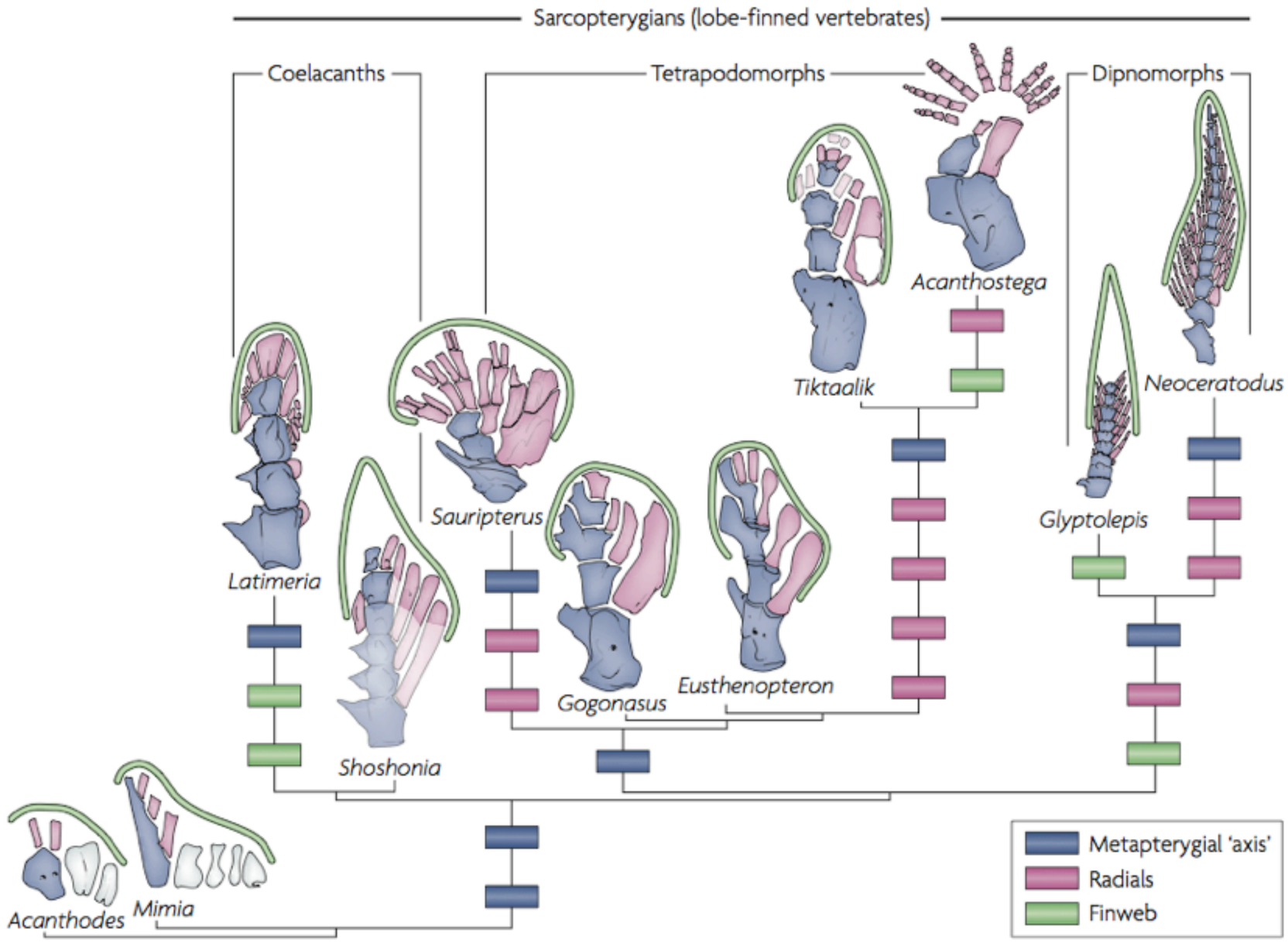
- Products of random matrices essential in chaotic dynamics
- In d=1 case, limiting distribution of random products, log(X)
- Problems of non-commutativity of matrix
- Infinite products of 2 by 2 linear projections is a solved problem.

Sparseness: freedom or constraint?

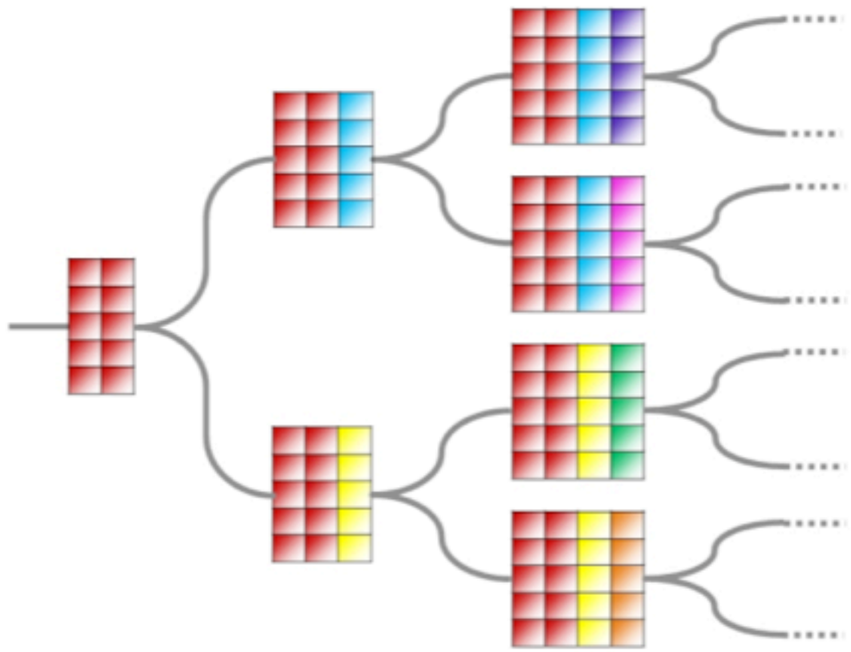
The Origins of Regulatory Freedom


A
B
C
% visible phenotypes
Number of variable traits (v)
% visible phenotypes
c
c
c

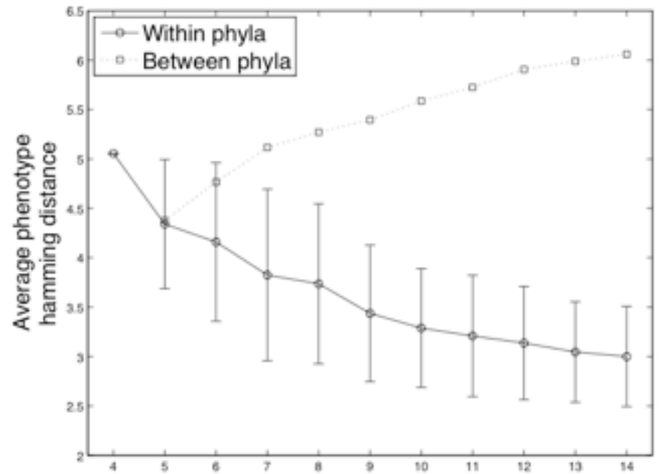
Developmental Evolution



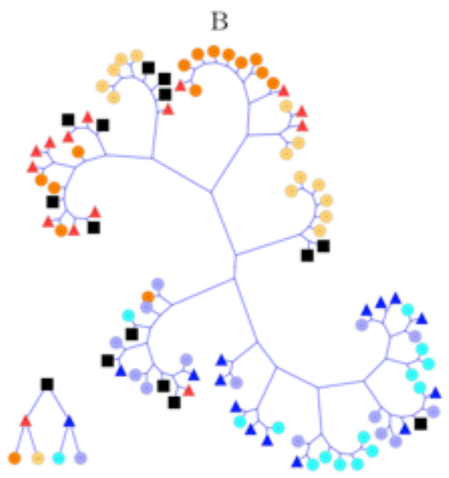
R. Raff. Nature Reviews Genetics. 8. (2007)



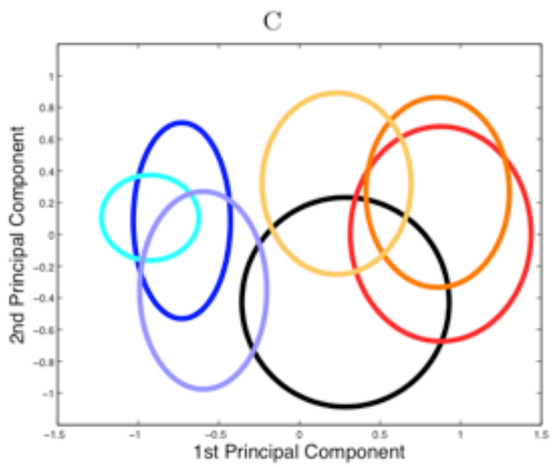
A


Within phyla
Between phyla
Average phenotype hamming distance
Regulatory dimension / Time

B



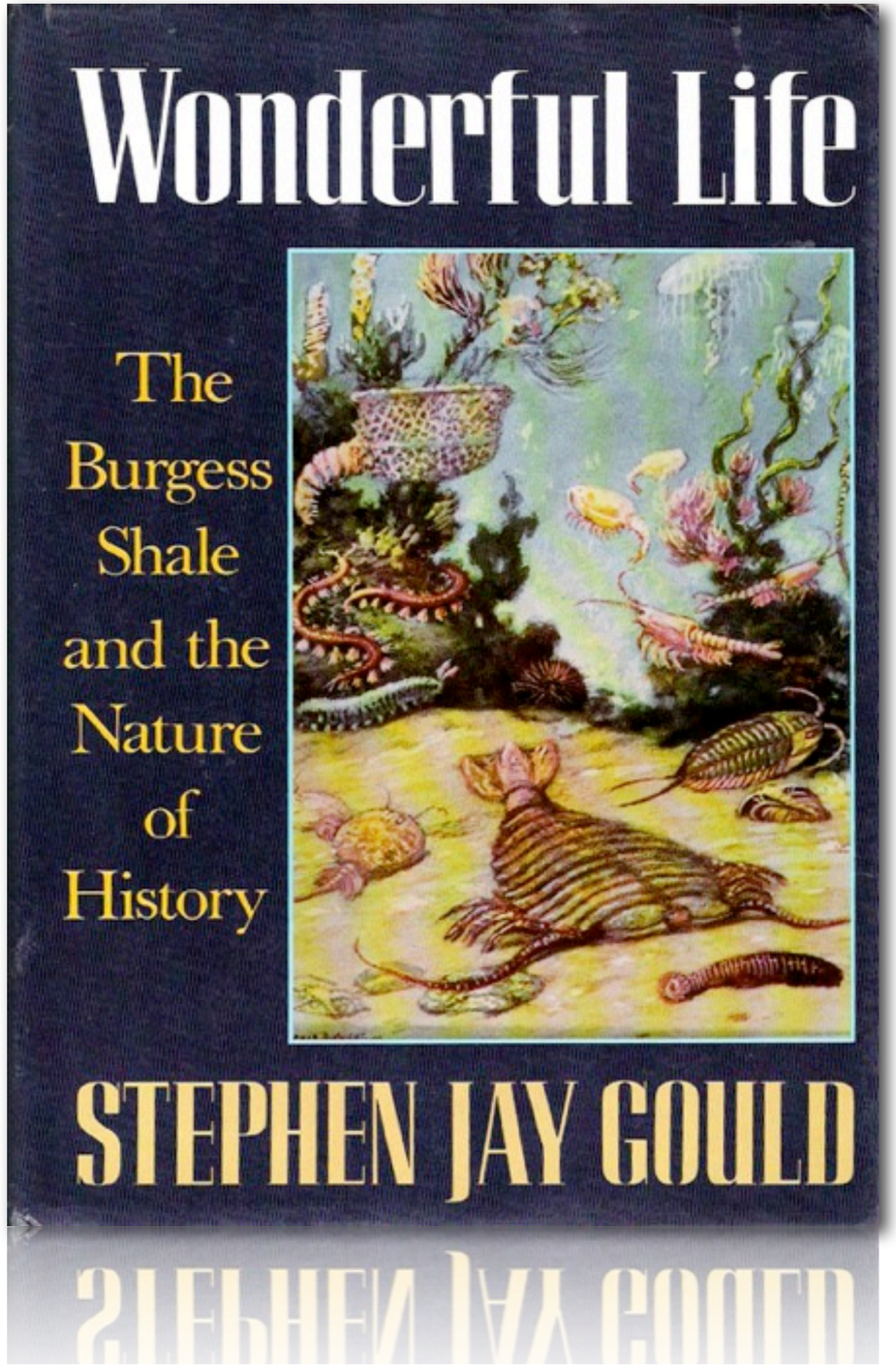
C

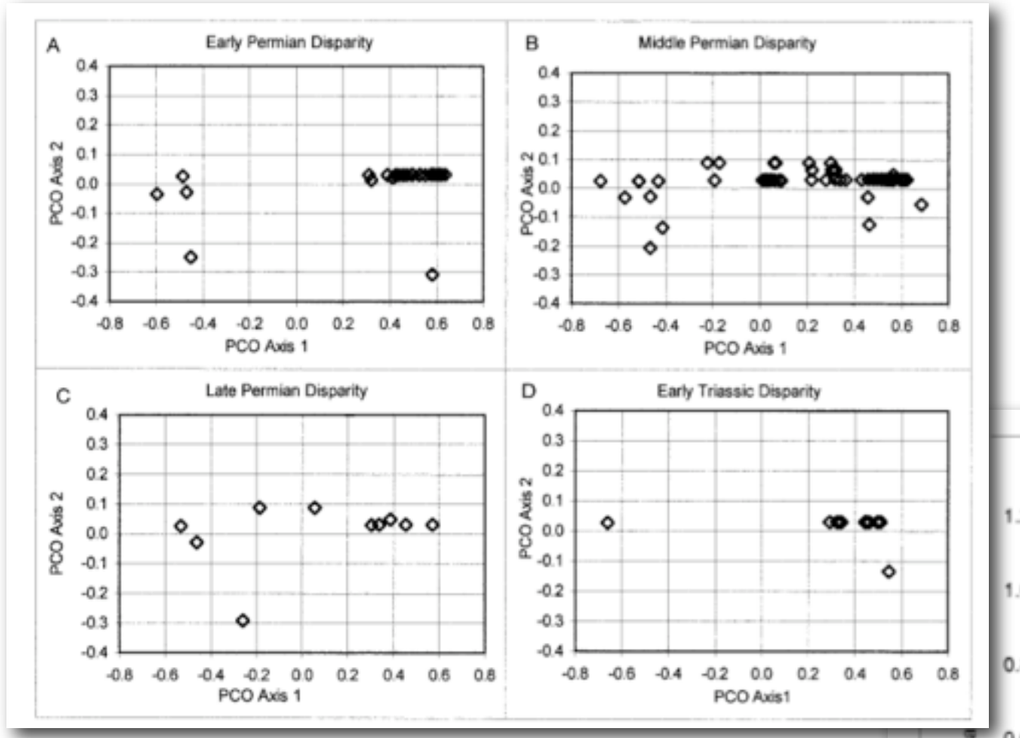

2nd Principal Component
1st Principal Component

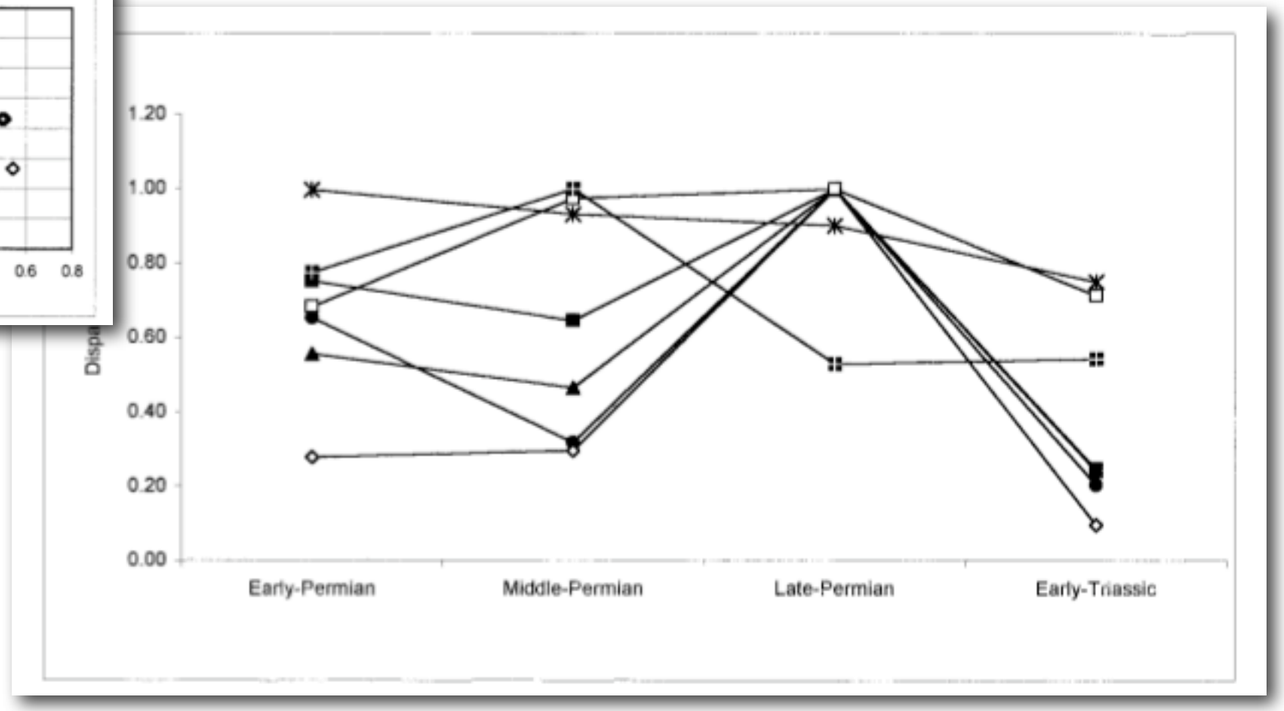
- Ancestral diversity low (low dimension)

- Ancestral Taxa more disparate than derived taxa

- Ancestral taxa sample a large space of phenotypes more uniformly







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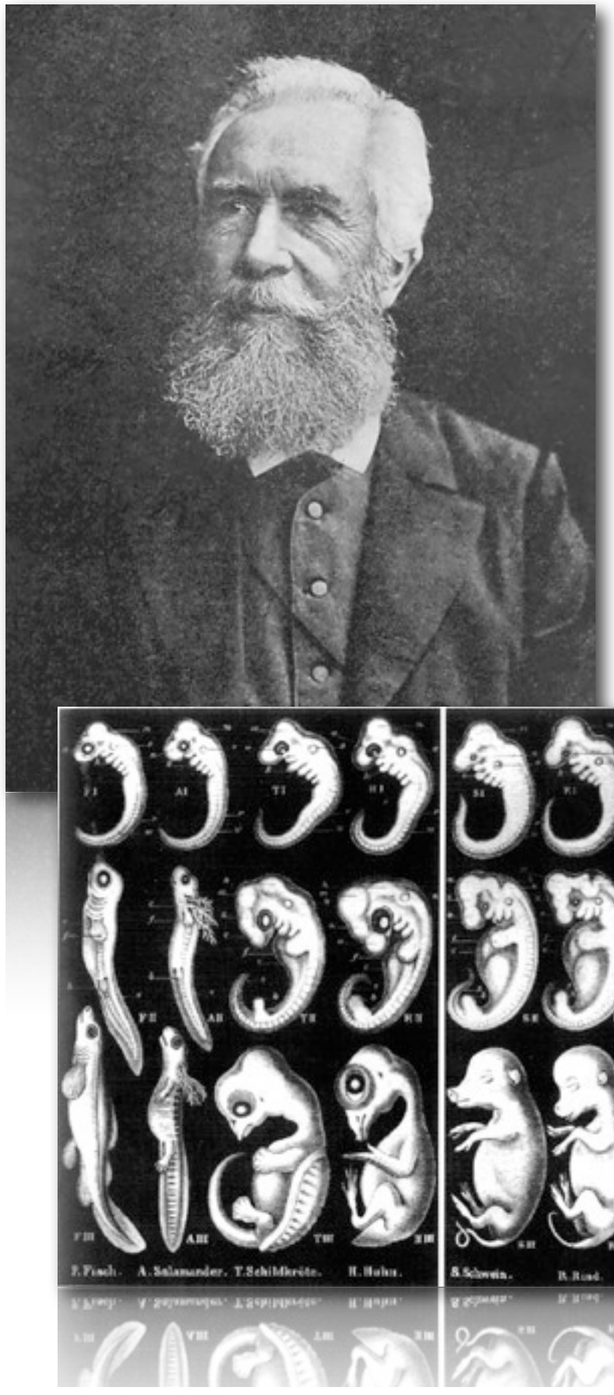

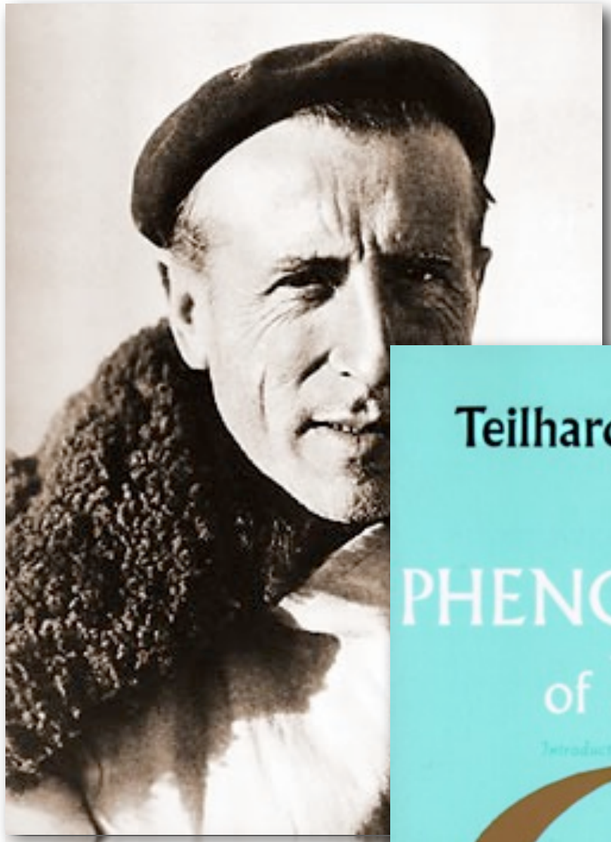

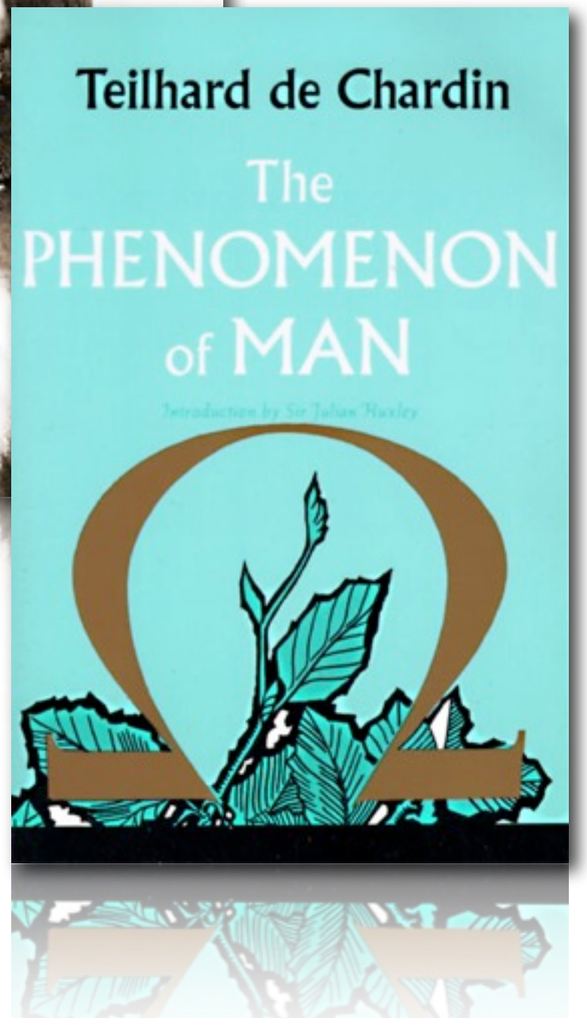
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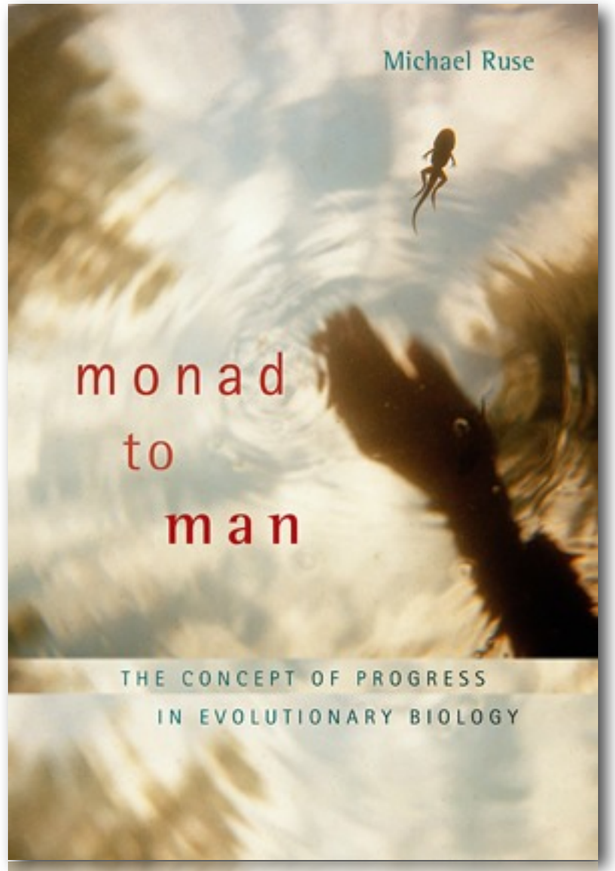
of MAN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