

# Digital Genetics

----Chris Adami

Presented By Xin Shuai



# Main Contents

- 1. Why digital life/genetics is studied?
- 2. What constitutes digital life/genetics?
- 3. What can we conclude from experiments on digital genetics/life?



# **I Why Digital Life/Genetics is studied?**



# Comparison with Classical Biology

- Advantages:

- repeatable

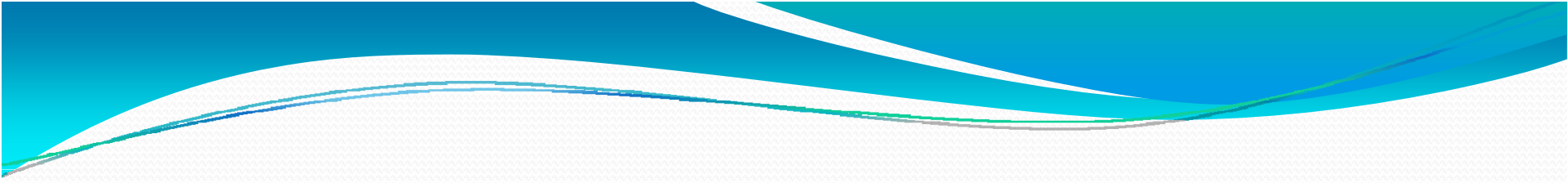
- controllable

- perfect 'fossil record'

- Limitations:

- neglect some biological details: transcription, translation & regulation

- too small to mimic a real organisms



# **II What Constitutes Digital Life/Genetics?**

# Avida VS Life

<b>Avida Platform</b>	<b>Real Life</b>
Avidan, i.e. Computer Programs	Single-celled Organisms: Bacteria
Simulated Computer	Living Environment: Petri dish
Code Replication & Execution	Metabolism: Gene Replication & Expression
Instruction	Nucleic acid
Numbers	materials used by cells for metabolism
Group of Instructions carrying out a particular function	Gene
The whole circular instructions	Genome
State of virtual CPU	State of organism
Sequence of instructions	Genotype
Sequence of state transitions of CPU	Phenotype
SIP (CPU time)	ATP (Energy)
Memory space	Resources

# Avida VS Darwinian Evolution

Basic Ingredients of Darwinian Evolution	Implementation in Avida
Replication	Executing code, copying it, into fresh memory and then dividing off the copy
Mutation	Explicit: 1)copy error;2)insertion & deletion;3)division defects Implicit: 1)division asymmetry;2)"parent" overwrites its own code;3)code recombination
Selection	Compete for SIP to speed up replication in a given total CPU time and memory space



# **III What Can We Conclude From Experiments on Digital Life/Genetics?**



# Hypothesis about evolution

- 1. Average direction of epistasis
- 2. Genetics of mutational robustness
- 3. Evolution of complex genes and genomes
- 4. Selective pressures on genome organization
- 5. Sex in digital organisms



# Analyzing Tools

- Functional genomic array: equivalent of knockout experiment to study the effect of all possible mutations within each gene
- Phylogeny tool: phylogenetic-depth tree

# Average direction of epistasis

$$w(n) = w(0) \exp(-\alpha n^\beta)$$

Lenski's fitness decay function (mutations are considered deleterious)

$\beta = 1$ , mutations are independent: simple genome

$\beta > 1$ , synergistic epistasis between mutations

$\beta < 1$ , antagonistic epistasis between mutations: complex genome

Relation between  $\alpha$  and  $\beta$ : smaller  $\alpha$  (robustness to single mutation) coexist with  $\beta = 1$ , indicates the evolutionary possibility towards synergistic interaction, which is said to be a necessity of sex evolution.

Other predictable experiments:

---epistasis between beneficial mutations

---epistasis between deleterious mutations

...



# Genetics of mutational robustness

- $\alpha$  reflects single mutational robustness
- Wilke. found that:
  - 1) mutational robustness is at the cost of reduced replication speed
  - 2) High mutation rates environment favors robust genome
  - 3) Low mutation rates environment favors high replication speed



## Evolution of complex genes and genome

- Lenski's experiment based on Functional complexity
- Surprising: the appearance of deleterious mutations on the line of descent, which is supposed to be eliminated by selection!
- Deleterious mutants are prerequisite of neutral and advantageous mutants nearby?
- The process of evolution are detoured!



# Selective pressures

- High mutation rates leads to decreased epistasis
- Low mutation rates and needs to compact information leads to overlapping genome
- Ofria & Adami simulated gene overlap through multiple expression and proved that overlapping genome impairs evolvability in the long run if genome length is unconstrained
- Natural selection shaped the genome to be long-run successful ?



# Sex in digital organisms

- Ofria's test:
- 1. Recombination promotes gene modularity?  
modules overlapped less and separate apart more in sexual populations. And modular genes can reduce aggravating epistasis

## 2. Transition from Asexual to Sexual?

Redundancy cannot be maintained by asexual makes such transition a Catch-22 situation. However, Other mechanisms may make it possible, like Red-Queen effect.



# Conclusions

- Digital genetics enriched classical evolutionary, functional and population genetics by addressing questions that cannot be tackled currently:
- 1) Evolution of gene regulation---multiple instruction pointers run at different speed
- 2) Mating selection in sexual reproduction
- 3) Interaction between parasites and hosts
- 4) Evolution of ecologies and formation of species



# Progress to Tierra

- 1. Preliminary distinction of information storage and information expression
- 2. Profound mutation interaction analysis
- 3. Introducing sex




# Questions remained

- 1. Is Avida a simulation or realization of life?(1)The environment of Avida is too simple, (2)the distinction of genotype-phenotype is not clear enough(3)no strong emergence, like semantic emergence or measurement, make AVIDA not a realization of life?
- 2. Does digital genetics capture the core characteristic of real genetics?
- 3. Does Avida only simulate RNA bacteria?



# Questions remained

- 4. According to Kondrashov's hypothesis, sex is evolved and maintained in populations with synergistic mutations. However, sex itself is the characteristic of complex organisms, which are dominated by antagonistic mutations!?
- 5. Even deleterious mutations have positive role in the process of evolution?

- 
- 6. Natural selection must have shaped genome to survive in the long-term. However I think natural selection is quite short-sighted!
  - 7. Missing some crucial aspects of gene, like regulation, Can satisfactory results about evolution be obtained?
  - 8. No good life theory to testify it?