THE ORIGINS OF CELLULAR ARCHITECTURE

8. Evolutionary Scaling Laws in Cell Biology.

- Describing allometric relationships.
- Scaling laws in cellular bioenergetics.
  - Metabolic rate.
  - Lifetime energy requirements of a cell.
  - The speed limit on cell-division rates.
- The limits to natural selection imposed by the drift barrier.
- Membrane bioenergetics and the prokaryote-eukaryote transition.
  - Energy production and the mitochondrion.
  - Cellular investment in ribosomes.
  - The mitochondrion as a driver of eukaryotic evolution.

9. Cell Growth and Division.

- Ribosomes and cell growth.
- Models for cellular growth.
- Control of cell size at maturity.
  - Molecular mechanisms of division-size determination.
  - Environmental determinants of cell size.
- Scaling of intracellular features.
- Phenotypic variation in cell size and division time.
  - Stochastic partitioning of cell contents at division.
- Phenotypic variation and adaptation.
  - Environmental variation and the efficiency of selection.
  - Inheritance of environmental effects.
  - The adaptive value of phenotypic variation.

10. The Cell Life Cycle.

- The eukaryotic cell cycle.
  - Phylogenetic diversity.
  - Network complexity.
- Mitosis.
- Meiosis.
  - Origin and evolutionary modifications.
  - Rapid evolution of meiosis-associated proteins.
  - Recombination mechanisms.
  - Evolutionary consequences of sexual reproduction.
- Mating types.
  - Mating-type determination.
  - Mating-type number.
  - Cell fusion.
  - Coevolution of pheromones and their receptors.
- Sexual systems in unicellular and multicellular organisms.
  - Isogamy vs. anisogamy.
  - Sex ratio.
  - Sex chromosomes.

- Photosynthesis.
  - The transformation of solar to chemical energy.
  - The world's most abundant enzyme.
- Osmoregulation.
- Circadian rhythms.

19. Enzymes and Metabolic Pathways.

- Enzymes.
  - Basic enzymology
  - Degree of molecular perfection.
  - Enzyme promiscuity.
- Pathway flux control.
  - Pathway position and the strength of selection.
  - Speed vs. efficiency.
- Pathway expansion and contraction.
  - Stochastic meandering of pathway architecture.
  - The origin of novel enzymes.
- Pathway participant remodeling.
  - Nonorthologous gene replacement.
  - Internal pathway expansion via multifunctional enzymes.
  - Pathway duplication and divergence.

INFORMATION PROCESSING

20. Intracellular Errors.

- Transcript fidelity
- Translational fidelity.
- Biophysics of substrate discrimination and the cost of proofreading.
- The limits to selection on error rates.
- The evolutionary consequences surveillance-mechanism layering.
- Adaptive significance of errors.

21. Intracellular Communication: Transcription.

- Transcription factors and their regulatory motifs.
- Biophysics of recognition.
- Facilitated diffusion and the search for regulatory motifs.
- Evolution of the regulatory vocabulary.
- Evolutionary rewiring of transcription networks.

22. Environmental Sensing and Extracellular Communication.

- Bacterial signal-transduction systems.
  - Origin and diversification.
  - Coevolutionary integration of components.
  - Emergence of new pathways.
- Interconvertible proteins and ultrasensitivity.

The cost of signal transduction.
Similarities and differences in eukaryotic systems.
Chemotaxis.
Accuracy of environmental assessment.
Phenotypic bimodality and bet-hedging.
Adaptive fine-tuning vs. inadvertent by-products of pathway structure.

ORGANISMAL COMPLEXITY

23. Endosymbiosis.
Mitochondria.
Origins.
Energetic boost or burden.
Functional remodeling.
The extreme population-genetic environments of mitochondria.
Mutation rates.
Modes of inheritance.
Muller's ratchet.
Organelle genome degradation.
Animal mitochondrial tRNAs.
Coevolutionary drive and compensatory mutations.
Plastid evolution.
Addiction to endosymbionts.

24. Origins of Organismal Complexity.
Deconstructing the great chain of being.
Genome complexity and organismal complexity.
A shake-up of genomic organization in the ancestral eukaryote.
Multicellularity.
Multicellularity and cooperativity in bacteria.
The costs of multicellularity.
The emergence of cell-type specialization.
Closing comments.

FOUNDATIONS

2.1. The proton-motive force and the evolution of ATP synthase.
2.2. Evolution prior to self-replication.
2.3. The limits to replication fidelity and genomic maintenance.

4.1. The amount of neutral nucleotide variation maintained at selection-drift equilibrium.
4.2. Relationship of the recombination rate to physical distance between sites.

5.1. Divergence under uniform selection.
5.2. Mean probabilities of alternative alleles at steady state.
5.3. The detailed-balance solution for the evolutionary distribution of alternative molecular states.

7.1. Intracellular diffusion.
7.2. Rates of encounter by molecular diffusion.
7.3. The Boltzmann probability distribution for alternative molecular states.
7.4. The yield of cellular biomass per ATP usage.

8.1. The cost of building a cell.
8.2. Connecting metabolic rates with growth potential.

9.1. The scaling of ribosome number and cell growth rate.
9.2. Nutrient limitation and cell growth.
9.3. Scaling models for the development of cellular features.
9.4. Parent-offspring resemblance and the response to selection.
9.5. Transient response to selection without genetic change.

11.1. The physiological damage load in a cell lineage.

13.1. Association / dissociation equilibria.

14.1. The CCT chaperonin complex.
14.2. Evolution of a digital trait.

15.1. Probability of preservation and subdivision of labor by duplicated interactions.

16.1. The eukaryotic cellular investment in the cytoskeleton.
16.2. The physical challenges to cellular locomotion.
16.3. The construction costs of flagella.

17.1. The relationship of bioenergetic costs to the strength of selection.
17.2. The biosynthetic costs of nucleotides and amino acids.
17.3. The mutational hazard of excess DNA.
17.4. Numbers of molecules required in a cellular lifespan.
17.5. The biosynthetic costs of lipid molecules.

18.1. The response of uptake rate to nutrient concentration.
18.2. Encounter and capture rates.
18.3. The cost of osmoregulation.

19.1. Michaelis-Menten enzyme kinetics.
19.2. Evolutionary sensitivity of pathway steps.
19.3. Optimization of the glycolytic flux rate.
19.4. Extension / contraction of a metabolic pathway.

20.1. Kinetic proofreading.
20.2. The evolutionary bounds on the transcript-error rate.

21.1. Number of transcripts per cell.
21.2. Occupancy probability for a transcription-factor binding site.
21.3. The biophysics of TFBS localization.
21.4. The evolutionary dispersion of TFBS matching profiles.

22.1. Behavior of a monocycling system.
22.2. Accuracy of environmental sensing.

23.1. Messenger RNA editing.

FIGURES

TABLES

SUPPLEMENTAL TABLES

4.1. Mutation-rate and effective population size estimates.

7.1. Dry weights and volumes of individual cells.
7.2. Fractional contributions of major biomass components to the cell dry weights.
7.3. DNA content vs. cell size.

8.1. Caloric content of cells.
8.2. Number of ribosomes per cell in different species.

15.1. Relationship between genome size and cell volume.