Horizontal gene transfer can rescue prokaryotes from Muller’s ratchet

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Reticulated Microbial Evolution
April 29, 2014, Kiel
Evolutionary consequences of genetic recombination

- have been extensively considered in relation to evolution of sexual reproduction in eukaryotes
- But, many prokaryotes also undergo genetic recombination → horizontal gene transfer (HGT)
  - How frequent is HGT? → HGT can be more freq. than mutations
    - *S. pneumoniae, N. meningitidis* (Feil et al ’00):
      - Event ratio: HGT/mutation ≈ 5-10
      - Base substitution ratio: HGT/mutation ≈ 100-50
    - Other various prokaryotes (Vos & Didelot ’09):
      - Base substitution ratio: HGT/mutation ≈ 100-50
- Is exchange of genetic information important for life in general?
HGT is different from meiotic recombination

- **Mechanisms of HGT**
  - Transformation
  - Transduction
  - Conjugation

- **Transformation**
  Cells absorb DNA in environment and undergo recombination

Exchange of genetic information happens indirectly via environmental DNA
Muller’s ratchet

- **Assumption:** Genome has undergone sufficient evolutionary adaptation
  - Mutations always decrease fitness

- Frequency distribution of mutations per genome (Haigh ’78)

- Mutations accumulate in finite population (Muller ’64; Felsenstein ’74)
Relationship between Muller’s ratchet and recombination

Case of eukaryotes (meiotic recombination)

- Recombination shuffles mutations between chromosomes

- Recombination can stop Muller’s ratchet  
  (Pamilo et al. ’87; Charlesworth & Charlesworth ’93)
How Muller’s ratchet is related to recombination

Case of prokaryotes (HGT)

- Recombination shuffles mutations via environmental DNA (eDNA)

- Deleterious mutations increase mortality of cells, so eDNA on average contains more mutations than the population (Redfield ‘88)
Model

- Model = population + eDNA pool

- Population dynamics
  - Wright-Fisher process
  - mutation + eDNA uptake (HGT)
  - fitness \( f_i = (1-s)^i \)

- eDNA pool dynamics
  - Input from dead bacteria
    - Death rate \( 1-f_i/f_{\text{max}} \)
  - Decay

![Diagram of the model showing population and eDNA pool with processes like lysis, horizontal gene transfer, and decay.]

Mutation & Selection

population

eDNA pool

Lysis

Horizontal gene transfer

Decay
HGT can stop Muller’s ratchet

\[ \Delta m_{\text{fix}} / \Delta t \propto U \approx 10^{-2} \]

- \( N = 1 \times 10^6 \) snm LLC = 10
- \( N = 1 \times 10^5 \) snm LLC = 10
- \( N = 1 \times 10^4 \) snm LLC = 10
- \( N = 2 \times 10^3 \) snm LLC = 10

\[ r \approx \text{(generation}^{-1}) \]

\[ \text{no. of mutations in genome} \]

\[ \text{population size} \]

\[ \text{recombination} \]

\[ \text{selection} \]
Potential benefit of indirect genetic exchange

- Incorporate population subdivision into model

  ![Diagram showing population subdivision and genetic exchange](image)

- Expectation
  - Each subpopulation is more susceptible to Muller’s ratchet
  - But, ratchets operate independently
    - → complementation between subpopulations
Population subdivision and “gene-sharing” help to maintain genetic information
Summary

• HGT helps the maintenance of genetic information on evolutionary timescales even if on average it introduces more deleterious mutations than it removes

• To maintain genomic information, it is more advantageous to partition individuals into multiple subpopulations and let them “cross-reference” each other’s genetic information

Takeuchi et al. (2014) G3 4:325
Acknowledgements

• Alexander Lobkovsky
• Yuri Wolf
• Paulien Hogeweg
• Nen Saito

• Japan Society for the Promotion of Sciences
• NIH Intramural Research Program