Horizontal gene transfer can rescue prokaryotes from Muller's ratchet

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Evolutionary significance of genetic recombination

o   has been extensively considered in relation to evolution of sexual reproduction in eukaryotes

o   But, many prokaryotes also undergo recombination   → known as horizontal gene transfer (HGT)

- How frequent is HGT? → it can be more freq. than mutation

    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

o   Is exchange of genetic information important for life in general?
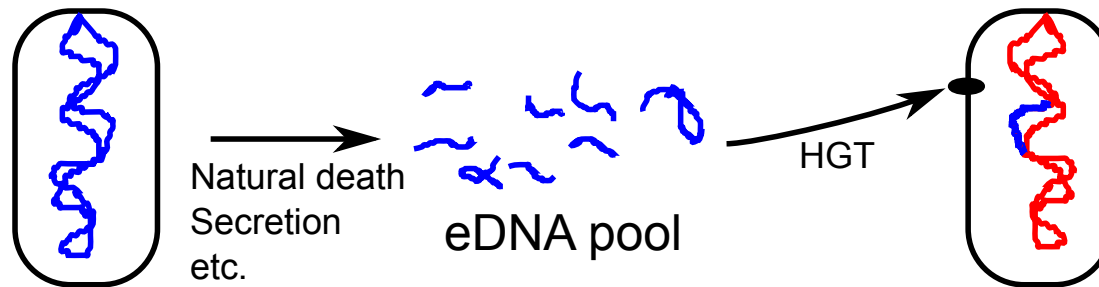
HGT is different from meiotic recombination

- Mechanism of HGT
  - Transformation ←
  - Transduction
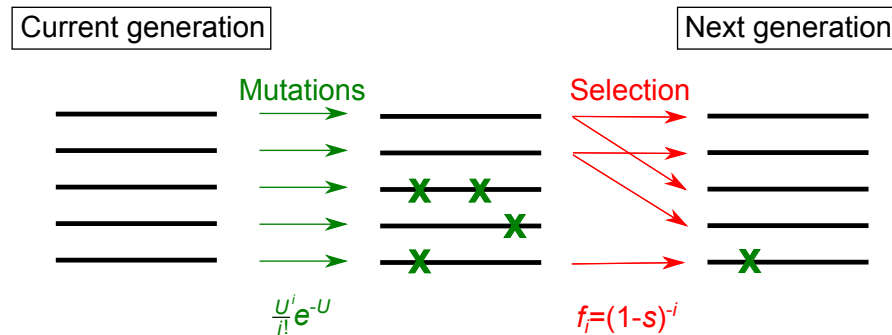 - Conjugation

- Transformation

 Cells absorb DNA in environment and undergo recombination

Natural death
Secretion
etc.

eDNA pool

HGT

Exchange of genetic information happens indirectly via environment

Muller's ratchet

○ **Assumption:** Genome has undergone sufficient evolutionary adaptation

→ Mutations always decrease fitness

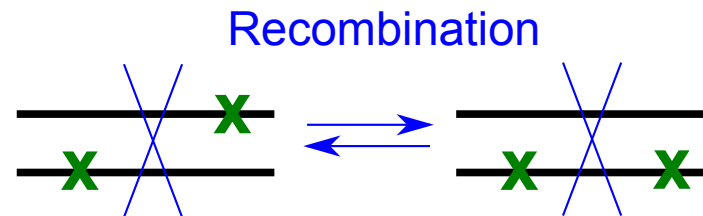○ Frequency distribution of mutations per genome (Haigh '78)

(from Neher & Shraiman '12)
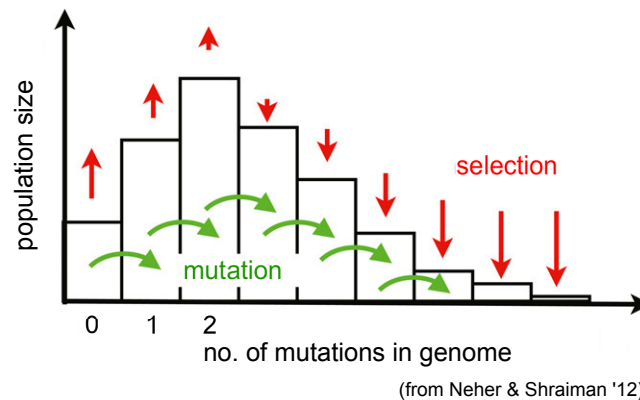
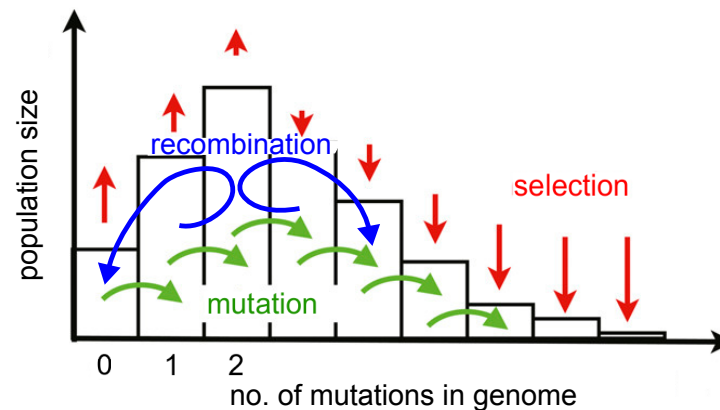○ Mutations accumulate in finite population (Muller '64; Felsenstein '74)

Relationship between Muller's ratchet and recombination

Case of eukaryotes (meiotic recombination)

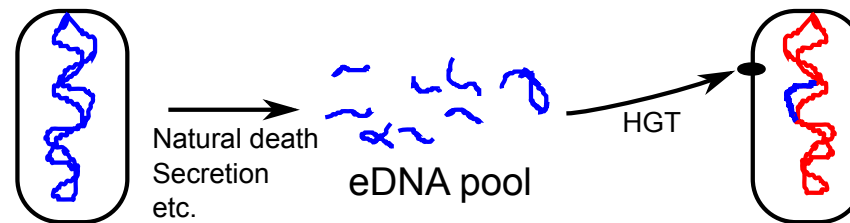○ Recombination shuffles mutations between chromosomes

○ Recombination can stop Muller's ratchet
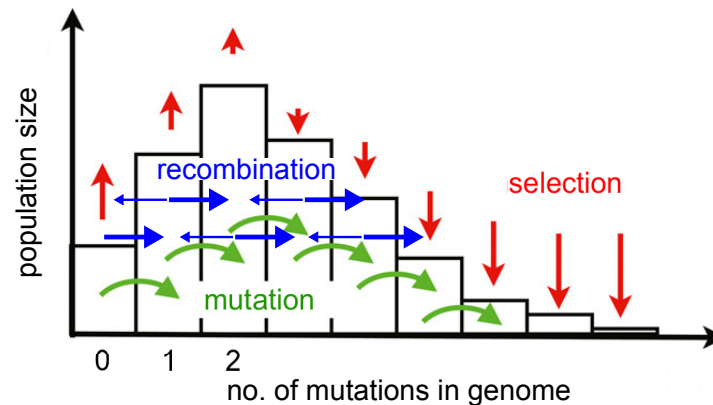 (Pamilo et al. '87; Charlesworth & Charlesworth '93)

How Muller's ratchet is related to recombination

Case of prokaryotes (HGT)

- Recombination shuffles mutations via environmental DNA (eDNA)
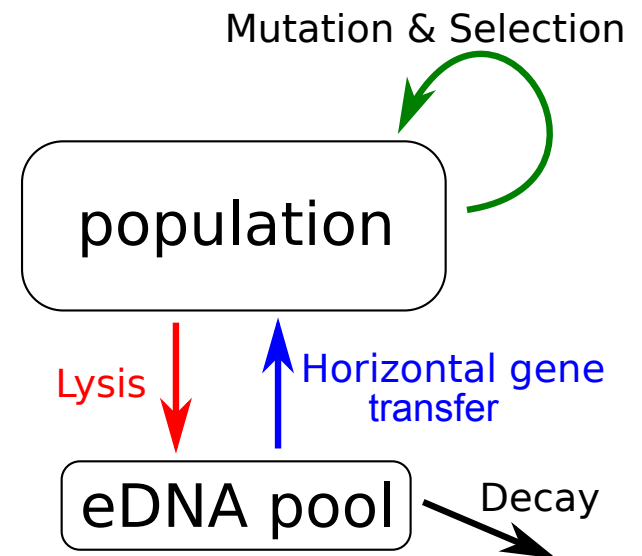

Natural death
Secretion
etc.

eDNA pool

HGT

- Deleterious mutations increase mortality of cells, so eDNA on average contains more mutations than the population
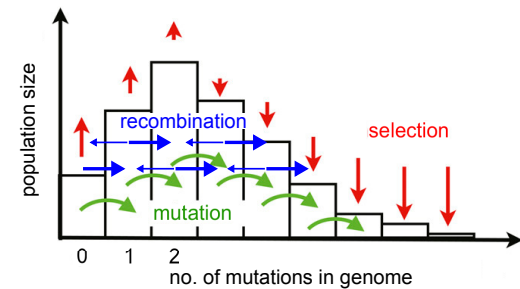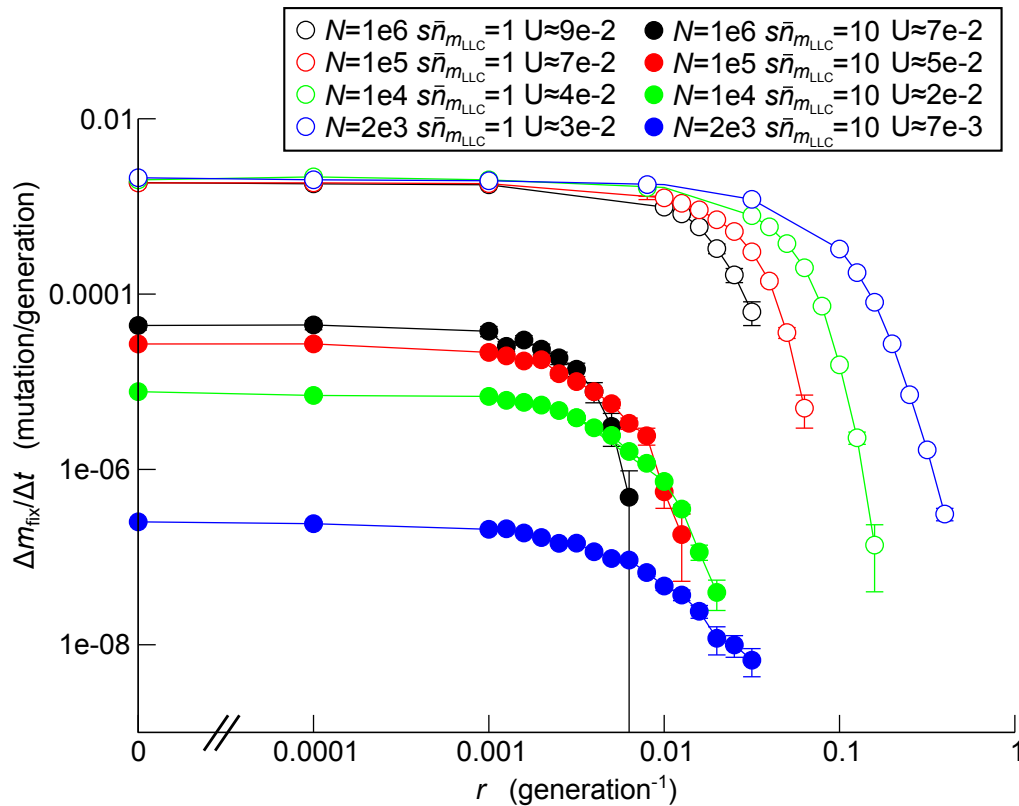
Model

o Model = population + eDNA pool

o Population dynamics

  • Wright-Fisher process

  • mutation + eDNA uptake (HGT)

  • fitness $f_i = (1-s)^i$

o eDNA pool dynamics

  • Input from dead bacteria

    Death rate $1-f_i/f_{max}$

  • Decay

Mutation & Selection

population

Lysis
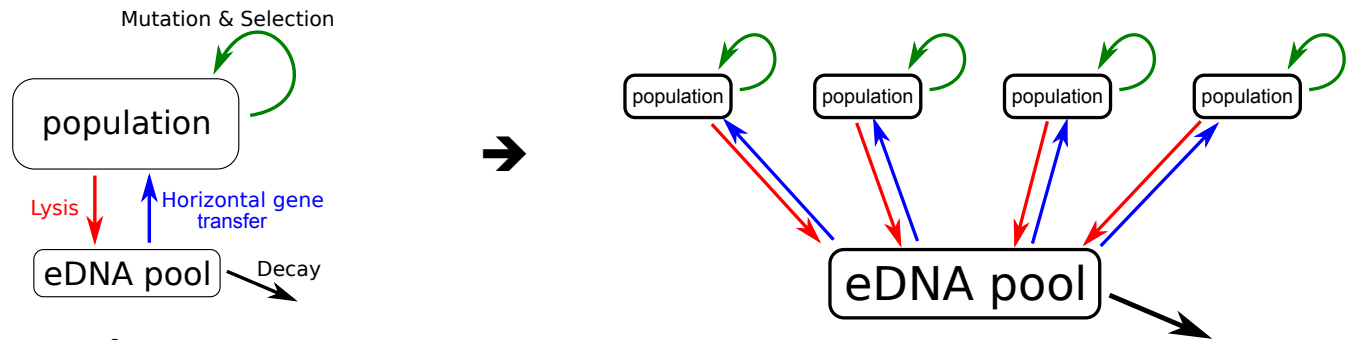
Horizontal gene transfer

eDNA pool
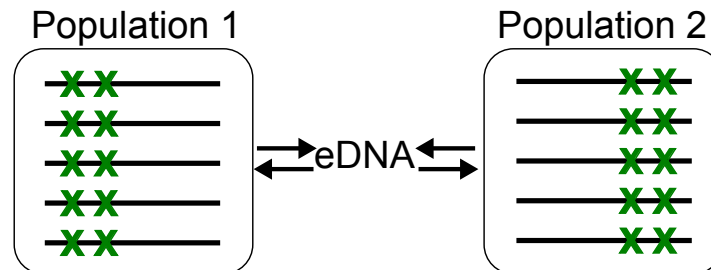
Decay

HGT can stop Muller's ratchet

Potential benefit of indirect genetic exchange

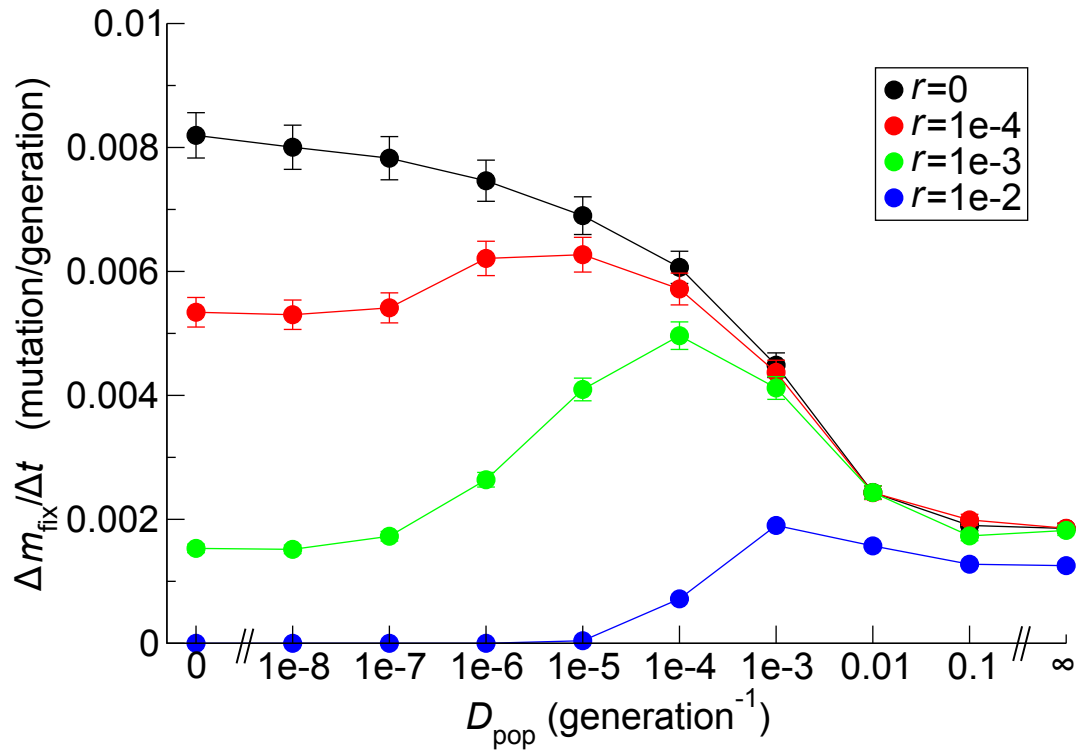○ Incorporate population subdivision into model

○ 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 facilitates evolutionary maintenance of genetic information even if it on average tends to increase deleterious mutations

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

Acknowledgements