

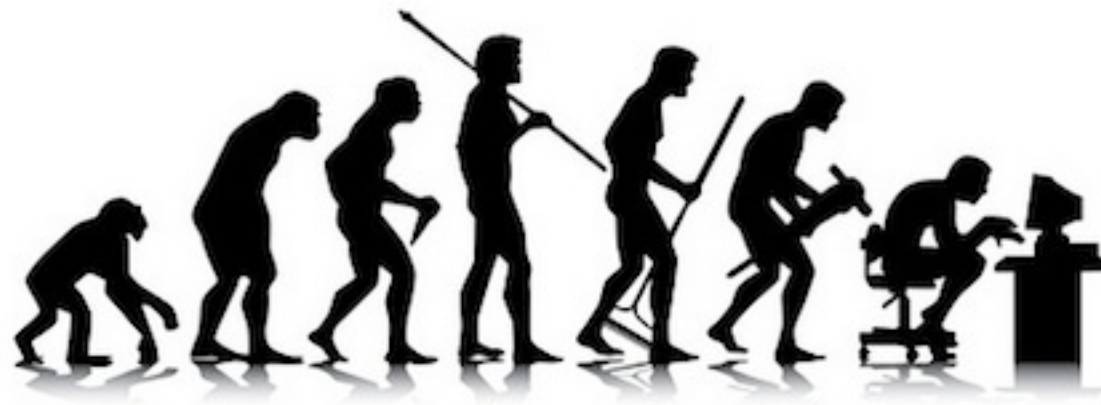
Evolutionary Computation

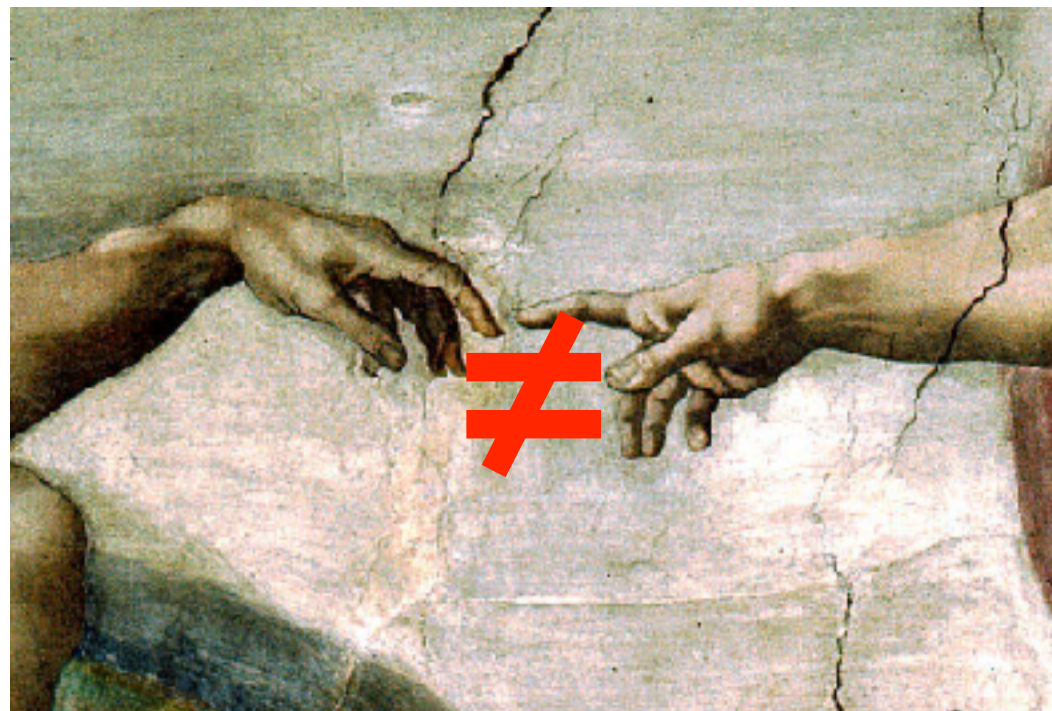
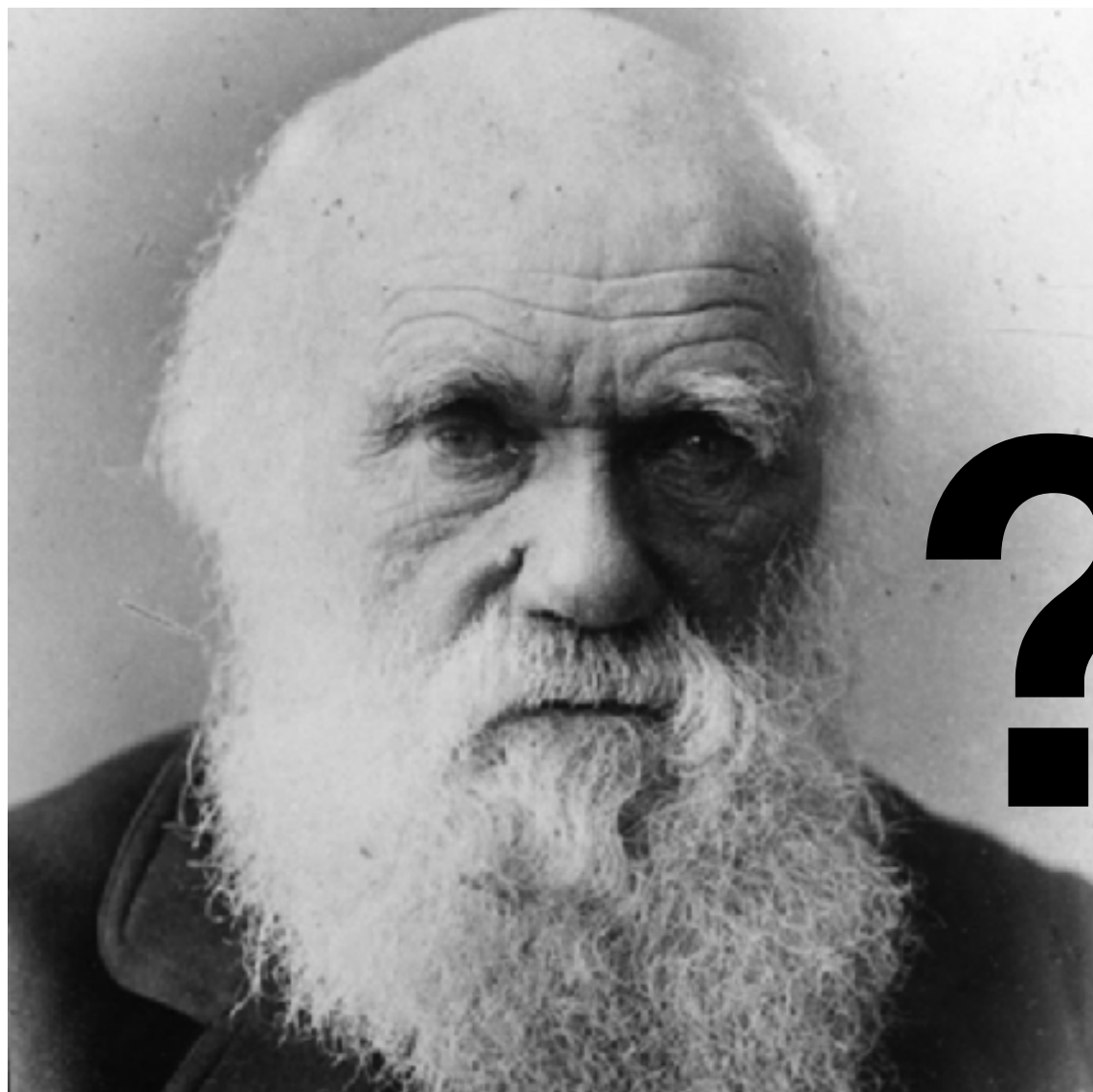
CS454, Autumn 2018

Shin Yoo

(with slides borrowed from Jinsuk Lim @ COINSE)

What is **evolution**?



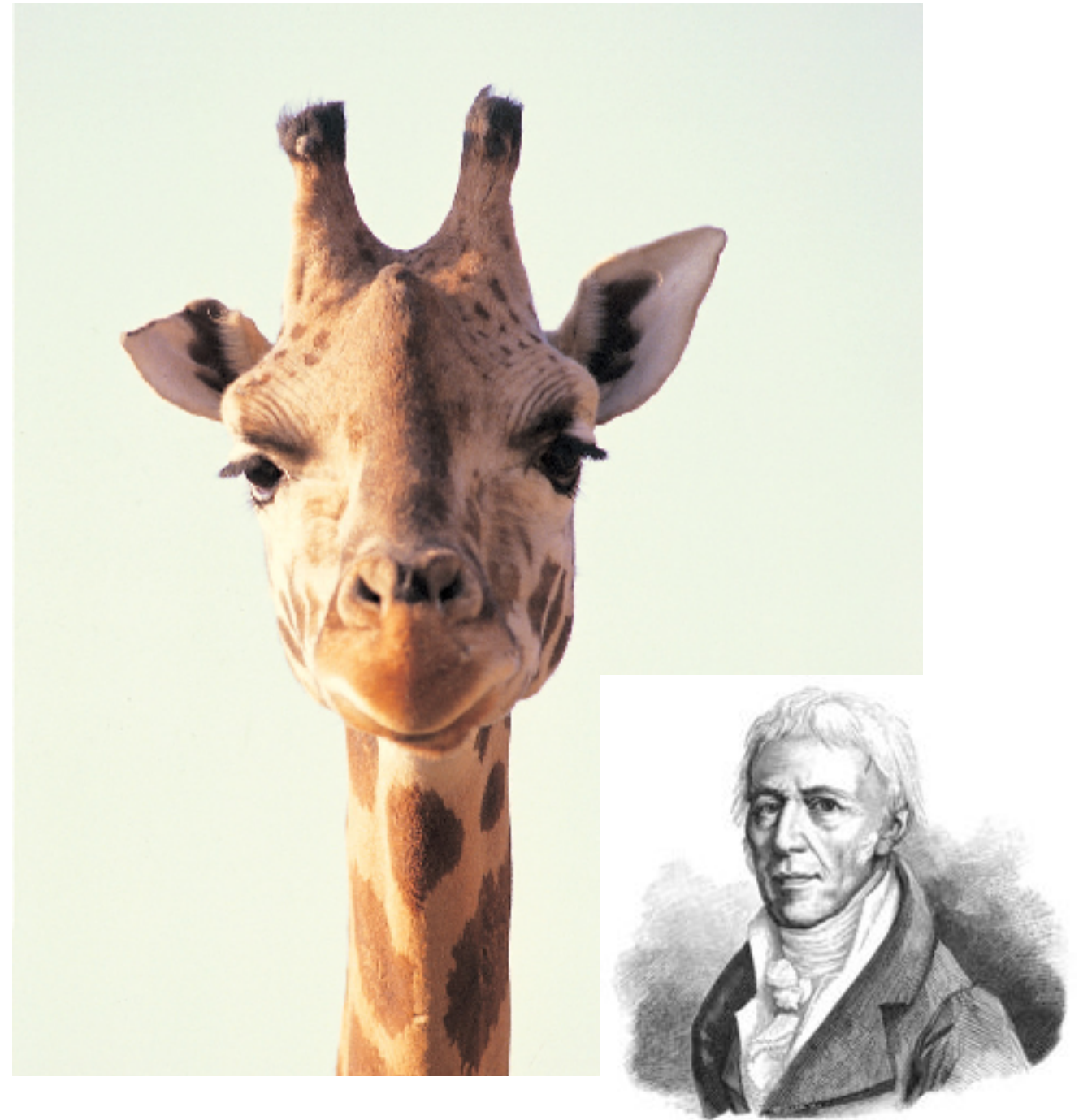


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Lamarckism (用不用說)

- “Heritability of acquired characteristics”
- During lifetime, an organism will adapt to its environment and acquire certain traits.
- These traits are inherited to the offspring.
- Eventually, the species changes in the direction of adaptation.

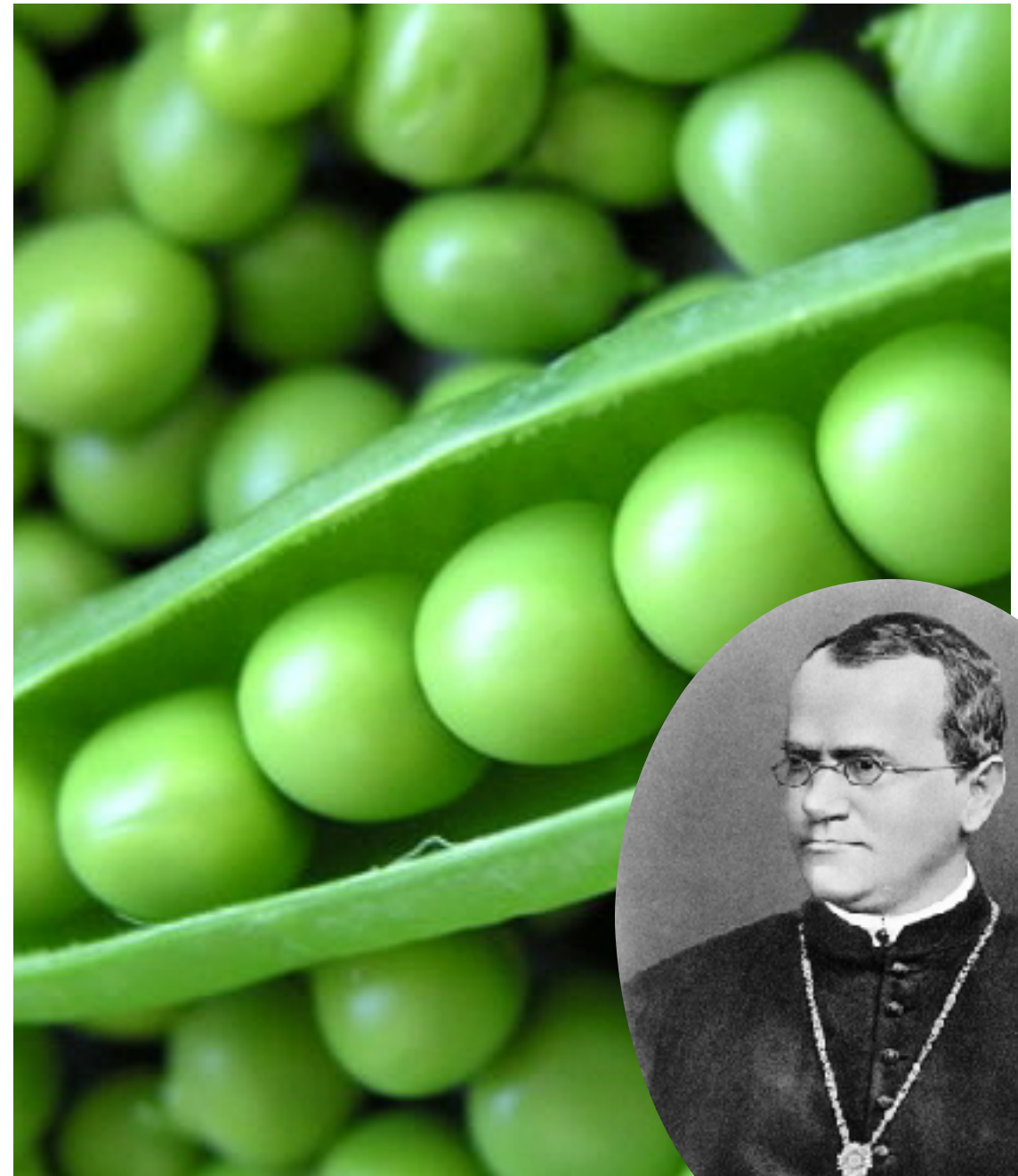


Is it correct?

- Does **NOT** explain the majority of what we call evolution; has been criticised for a long time.
- Interestingly, some people - such as George Bernard Shaw - thought that Lamarckism was more humane and optimistic than Darwinism: individuals can try to **develop a new habit** that are beneficial!
- Epigenetics: trait variations that are caused by environments (!)
 - Renewed interest, but still a topic of a big debate.

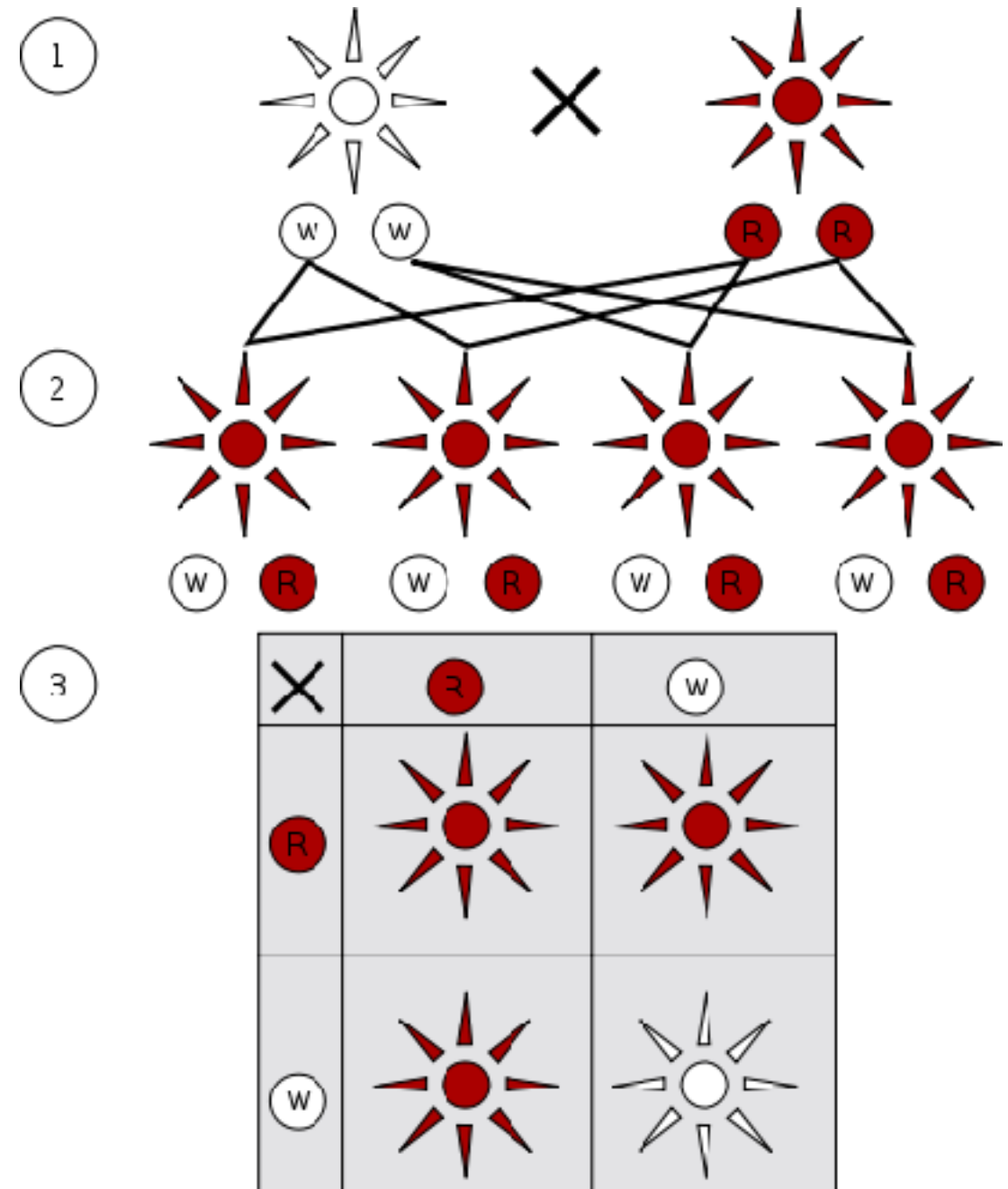
Mendelism

- Hereditary “unit” (he called them “factors”, now we know them as “genes”)
- Explained the mechanism of inheritance.



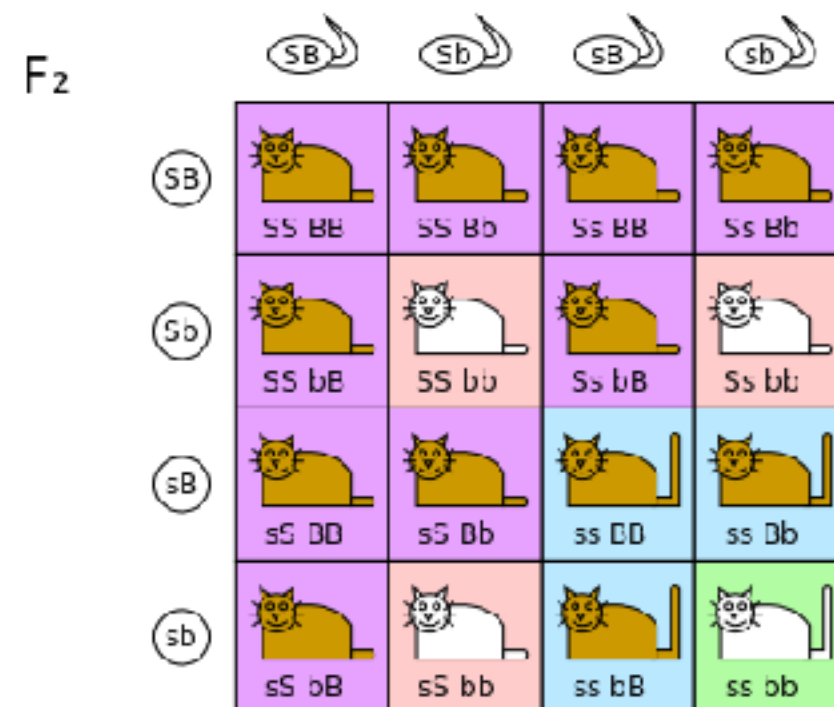
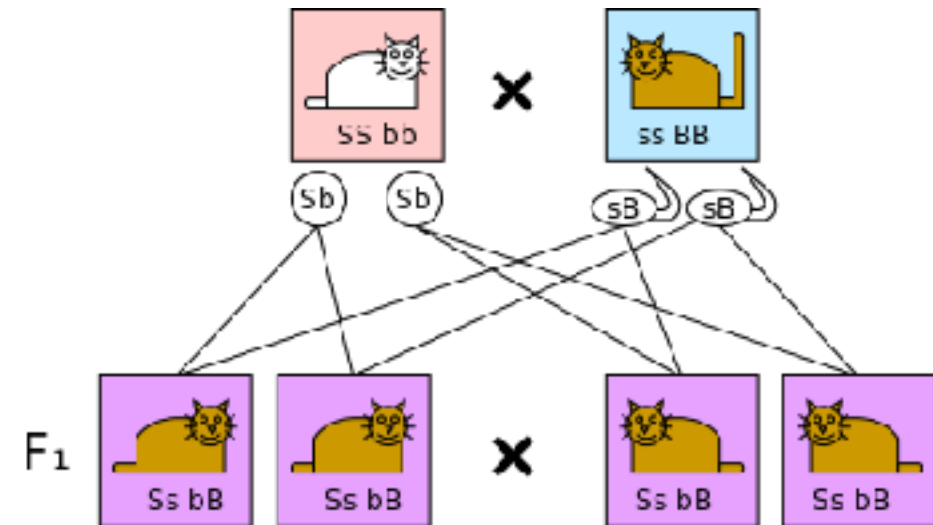
Law of Segregation

- Individuals contain a pair of alleles. During reproduction, the pair is separated; a child inherits one of these alleles, randomly chosen.



Law of Independent Assortment

- Informally: separate genes for separate traits are passed independently from parents to offsprings.
- Colour and tail length are independent; any combination is possible.



Law of Dominance

- Recessive alleles will be masked by dominant alleles.
- Little evidence that tongue-rolling is a dominant Mendelian trait though.
- Martin, N. G. No evidence for a genetic basis of tongue rolling or hand clasping. J. Hered. 66: 179-180, 1975.



Darwinism

- An attempt to theorise the emergence of new species.
- It should be noted that Alfred Wallace independently arrived at a very similar conclusion at the same time. Wallace's paper prompted Darwin to publish "On the Origin of Species".

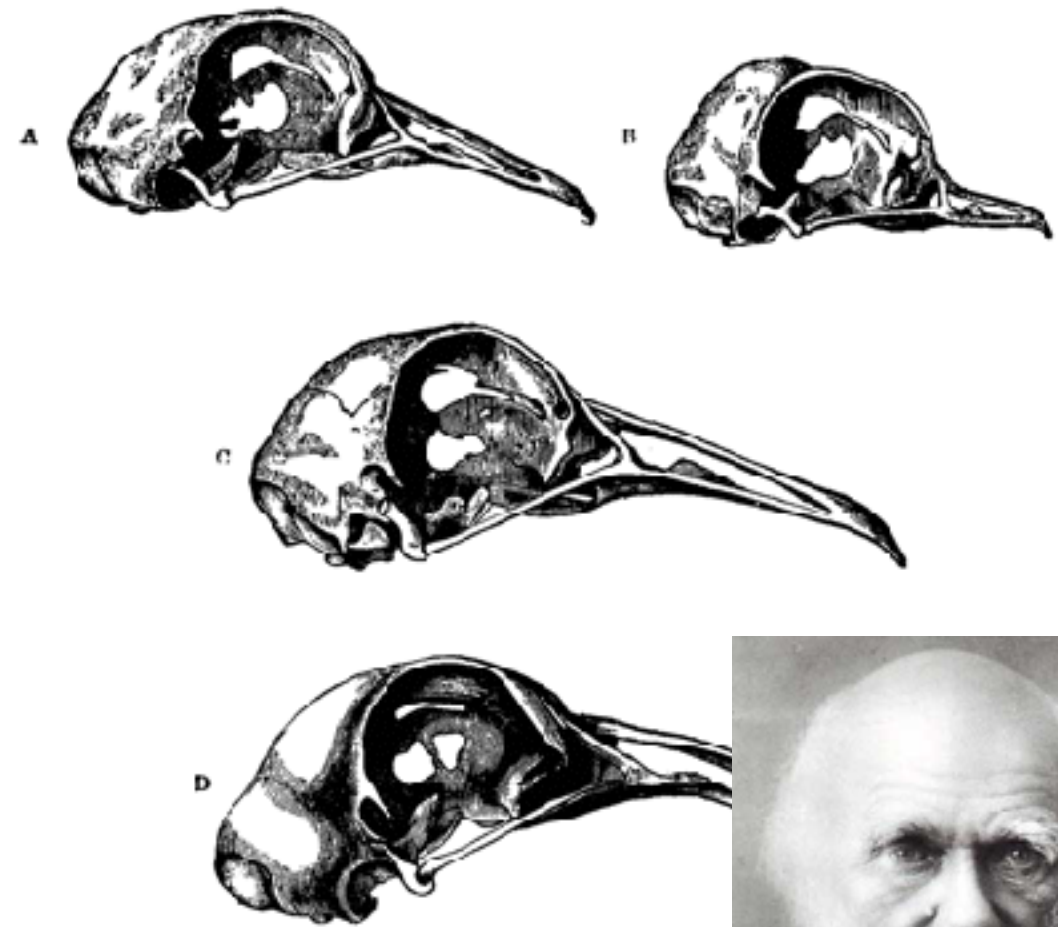
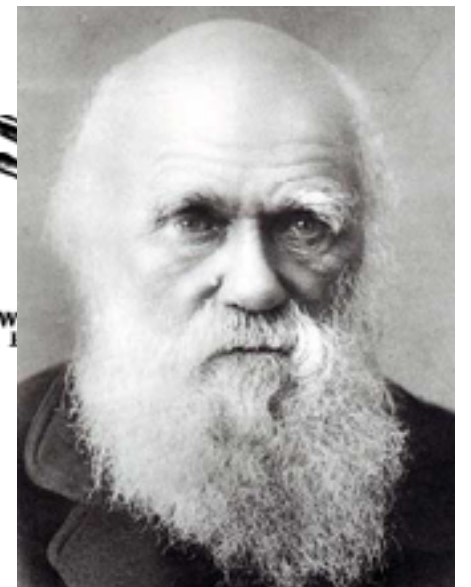


Fig. 24.—Skulls of Pigeons viewed laterally, of natural size. A. *W. livia*. B. Short-faced Tumbler. C. English Carrier. D. I.



What is it exactly?

- If all offspring survived to reproduce the population would grow (fact).
- Despite periodic fluctuations, populations remain roughly the same size (fact).
- Resources are limited and are relatively stable over time (fact).
- A struggle for survival ensues (inference).
- Individuals in a population vary significantly from one another (fact).
- Much of this variation is heritable (fact).
- Individuals less suited to the environment are less likely to survive and less likely to reproduce; individuals more suited to the environment are more likely to survive and more likely to reproduce and leave their heritable traits to future generations, which produces the process of **natural selection** (inference).
- This slowly effected process results in populations changing to adapt to their environments, and ultimately, these variations accumulate over time to form new species (inference).

Does it explain everything?

- Genetic drift: nature does not select, it merely samples randomly, resulting in frequency of specific alleles.
 - A much more neutral view on evolution.
- Both work at the same time.

Genotype vs. Phenotype

- **Genotype**: that part of the genetic material that determines a specific characteristic of an individual
- **Phenotype**: the characteristic manifested by a specific genotype

Genotype vs. Phenotype

- For example, 0-1 knapsack problem: given N items with individual weights and values, fill a knapsack that can hold X kilograms with the maximum value possible.
- Genotype: a bit string of length N ; 1 if corresponding item is chosen, 0 if not.
- Phenotype: the weight and the value of the filled knapsack.

Evolutionary Pressure

- Also known as selection pressure: anything that affects the reproductive success rate exerts **evolutionary pressure**.
- One critical link in Darwinian evolution: fitter individuals are assumed to have better reproductive success rate.

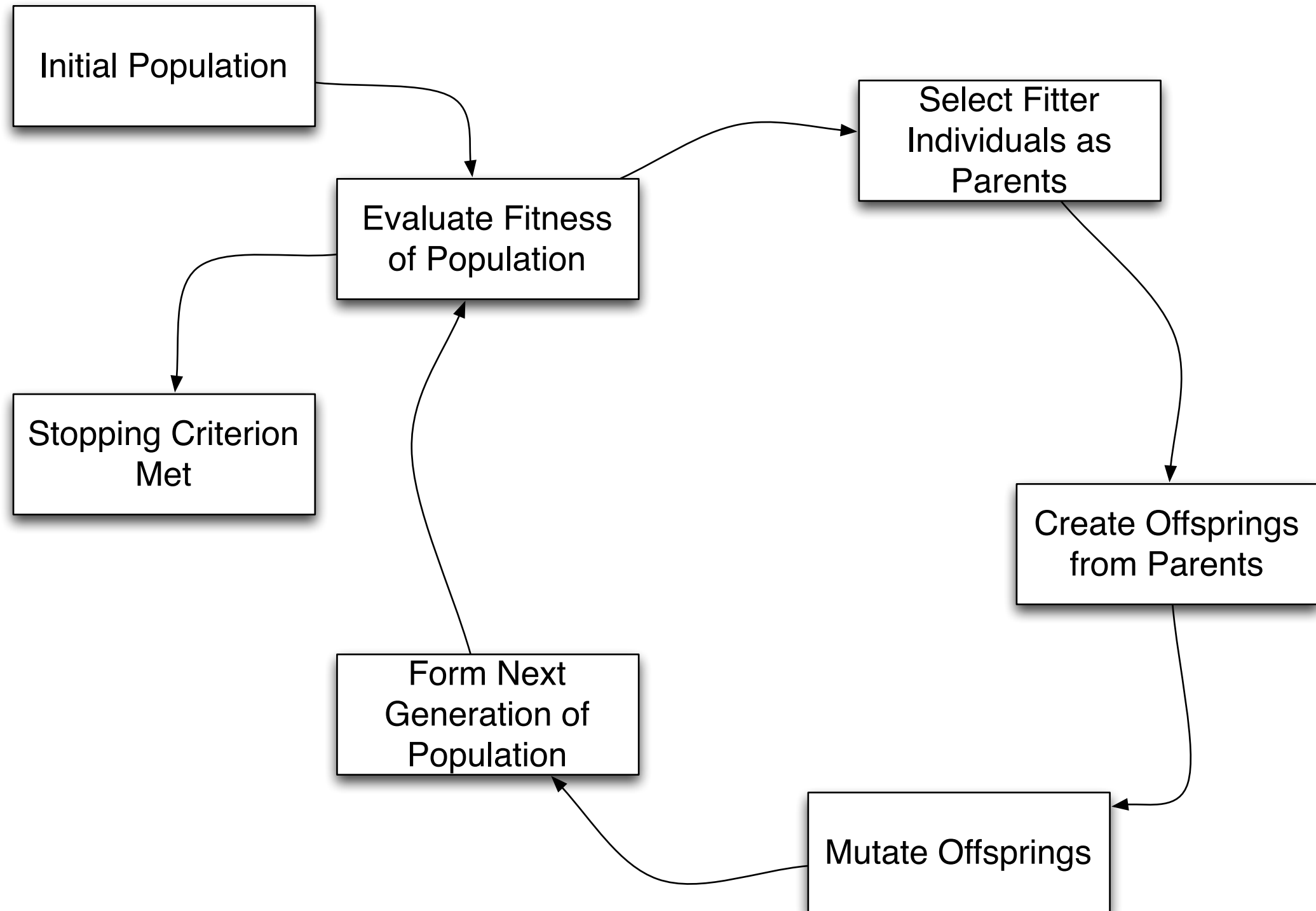
Adaptation vs. Optimisation

- Does nature adapt or optimise?
- Experiments with artificial co-evolution often result in stale and stagnant populations: they co-adapt, rather than doing arms-race.
- Optimisation through Darwinian evolution may be a purely artificial concept.

Okay, now back to
algorithms. Let's start with
Genetic Algorithms.

Artificial Evolution

- Artificial evolution as computation and, especially, as optimisation.
- Apply selection pressure so that a species (a population) evolves towards better fitness values.
- We have to emulate the entire evolutionary loop.
- Remember: exploitation vs. exploration.
 - Too much pressure: premature convergence.
 - Too little pressure: search goes nowhere.



Suppose we break a 6 digit numeric password with GA

- Let's assume that we have a tool that tells us how many digits are correct [#yessomewhatunrealistic](#)

Password: 893714

193562

243690

123456

121214

Randomly Generated Initial Population

Suppose we break a 6 digit numeric password with GA

- Let's assume that we have a tool that tells us how many digits are correct [#yessomewhatunrealistic](#)

Password: 893714

193562 Score: 2

121214 Score: 2

243690 Score: 1

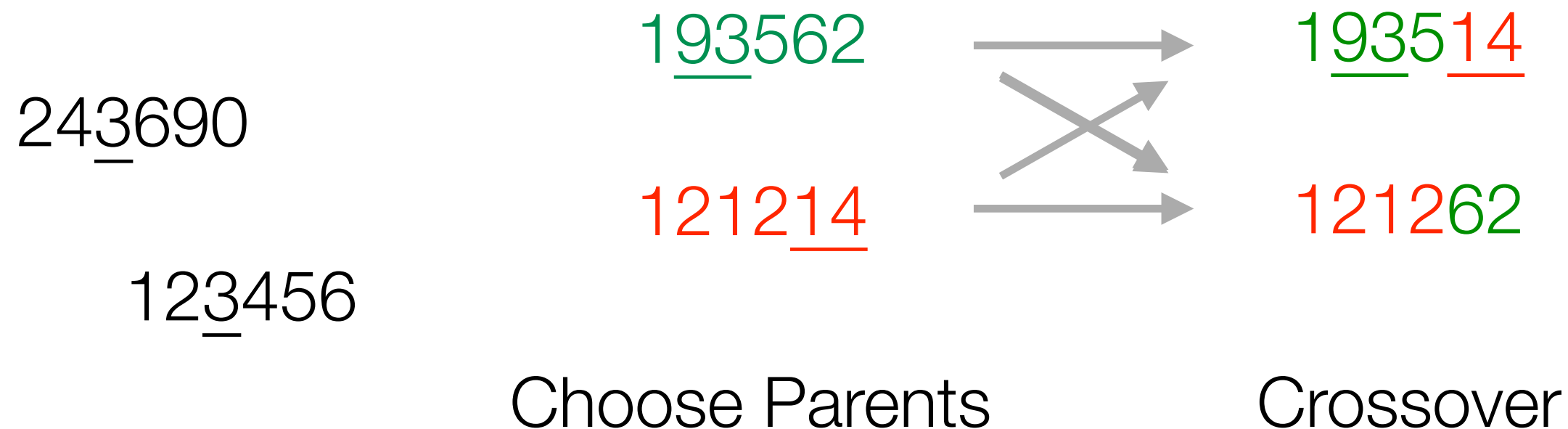
123456 Score: 1

Evaluation

Suppose we break a 6 digit numeric password with GA

- Let's assume that we have a tool that tells us how many digits are correct [#yessomewhatunrealistic](#)

Password: 893714



Suppose we break a 6 digit numeric password with GA

- Let's assume that we have a tool that tells us how many digits are correct [#yessomewhatunrealistic](#)

Password: 893714



Initial Population

- Usually initialised randomly: this introduces the **variance** among individuals.
- We mean phenotype variance. Depending on problems, genotype variance may not always result in phenotype variance.

Selection Operators

- We apply selection operators to the population, to choose two parent individuals.
- This is one of two places where we apply evolutionary pressure: we should make sure that the fitter you are, the more successful you are in terms of reproduction.
- This is also relatively universal - i.e. not dependent on the choice of representation

Fitness Proportional Selection (FPS)

- The probability of selecting an individual is proportional to its **absolute fitness** over the rest of the population.
- Given an individual i , its fitness f_i and population size μ ,

$$P_{FPS}(i) = \frac{f_i}{\sum_{j=1}^{\mu} f_j}$$

Issues with FPS

- Outstanding individuals tend to take over the population quickly, leading to **premature convergence**.
- When fitness values are close together, there is **almost no selection pressure**.

Individual	Fitness for f	Sel. prob. for f	Fitness for $f + 10$	Sel. prob. for $f + 10$	Fitness for $f + 100$	Sel. prob. for $f + 100$
A	1	0.1	11	0.275	101	0.326
B	4	0.4	14	0.35	104	0.335
C	5	0.5	15	0.375	105	0.339
Sum	10	1.0	40	1.0	310	1.0

Selection pressure rapidly falls as fitness is linearly translated...

Improving FPS

- **Windowing:** At each generation, fitness is transformed by subtracting $\beta(t)$ from the raw fitness.
- Usually, $\beta(t)$ is the minimum fitness of the current population, *i.e.*,

$$\beta(t) = \min_{y \in P} f(y)$$

- **Sigma scaling:** $f'(x) = \max(f(x) - (\bar{f} - c \cdot \sigma_f), 0)$

\bar{f}, σ_f, c are mean, standard deviation and hyperparameter (usually 2)

Ranking Selection

- Sort the population by fitness and allocate selection probabilities **according to the individuals' rank.**
- Maintains constant selection pressure, as opposed to FPS.
- Given a population of μ , the best individual is ranked $\mu - 1$ and the worst 0 .
- **Linear ranking vs Exponential ranking**

Linear ranking

- Parameterised by a value s ($1 \leq s \leq 2$)

$$P_{linear}(i) = \frac{2 - s}{\mu} + \frac{i(s - 1)}{\sum_{j=0}^{\mu} j}$$

Individual	Fitness	Rank	P_{selFP}	$P_{selLR} (s = 2)$	$P_{selLR} (s = 1.5)$
A	1	0	0.1	0	0.167
B	4	1	0.4	0.33	0.33
C	5	2	0.5	0.67	0.5
Sum	10		1.0	1.0	1.0

FPS versus Linear Ranking

Exponential Ranking

- Exponential ranking is used for greater selection pressure.

$$P_{exp}(i) = \frac{1 - e^{-i}}{\sum_{j=0}^{\mu} 1 - e^{-j}}$$

Sampling from the selection probabilities

- How to sample individuals according to the selection probabilities? (FPS or ranking selection)
- **Roulette Wheel Sampling**
- **Stochastic Universal Sampling (SUS)**
- **Tournament Selection**
- **Overselection** (refer to book)

Roulette Wheel Sampling

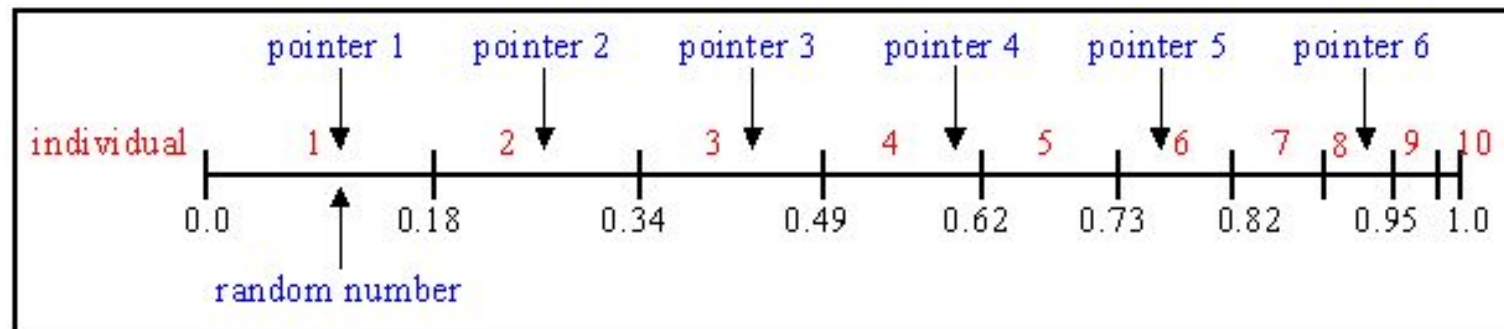
- Given some order over the population from 1 to μ , compute the **cumulative probabilities** $[a_1, a_2, \dots, a_\mu]$ and:

```
BEGIN
/* Given the cumulative probability distribution a */
/* and assuming we wish to select  $\lambda$  members of the mating pool */
set current_member = 1;
WHILE ( current_member  $\leq$   $\lambda$  ) DO
    Pick a random value r uniformly from [0,1];
    set i = 1;
    WHILE (  $a_i < r$  ) DO
        set i = i + 1;
    OD
    set mating_pool[current_member] = parents[i];
    set current_member = current_member + 1;
OD
END
```



Intuitively, each individual is assigned with roulette area whose size corresponds to its selection probability: then spin the roulette to select one sample.

Stochastic Universal Sampling



```
BEGIN
/* Given the cumulative probability distribution a */
/* and assuming we wish to select  $\lambda$  members of the mating pool */
set current_member = i = 1;
Pick a random value r uniformly from  $[0, 1/\lambda]$ ;
WHILE ( current_member  $\leq \lambda$  ) DO
    WHILE ( r  $\leq a[i]$  ) DO
        set mating_pool[current_member] = parents[i];
        set r = r +  $1/\lambda$ ;
        set current_member = current_member + 1;
    OD
    set i = i + 1;
OD
END
```

When more than one sample is required, SUS is preferred. If we are sampling N individuals, think of this as a roulette wheel with N arms.

Tournament selection

- What if fitnesses cannot be measured on an absolute scale?
- e.g. On evolving game strategies, fitnesses of two strategies can be evaluated only by playing against each other.
- Or if computing selection probabilities is impossible?
- e.g. On a distributed setting, acquiring global knowledge of the fitnesses may not be possible.
- **Tournament selection** solves these problems.

Tournament selection

- Select **k** random individuals from the population (*with or without replacement*) and pick the best out of them.
- Add it to the mating pool until full.
- Increasing **k** increases selection pressure.
- The simplest, most widely used selection mechanism.