Evolutionary Computation

CS454 AI-Based Software Engineering

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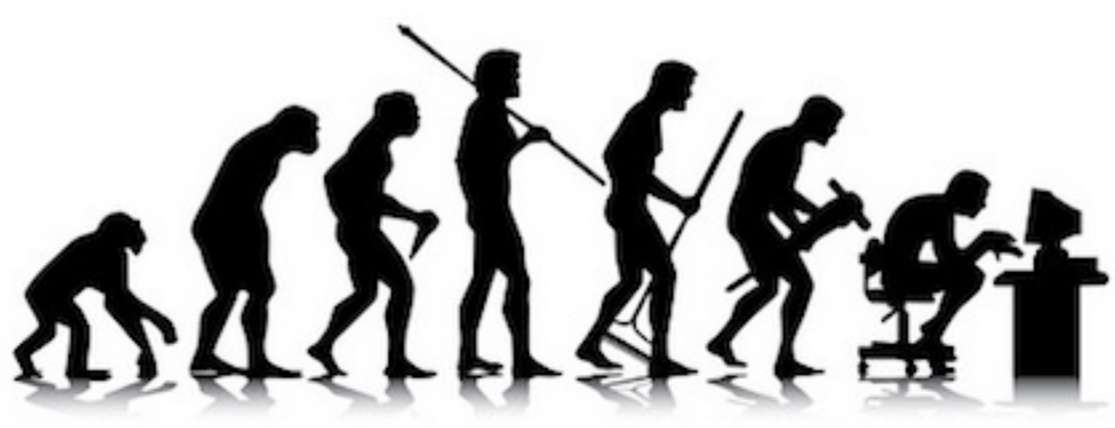
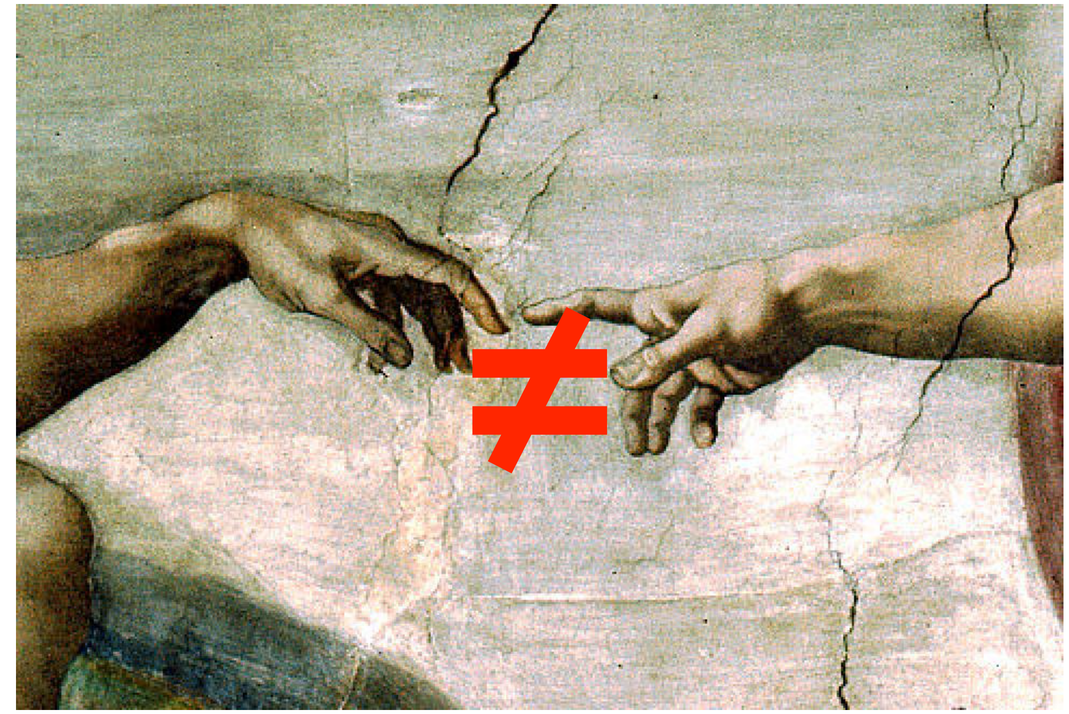
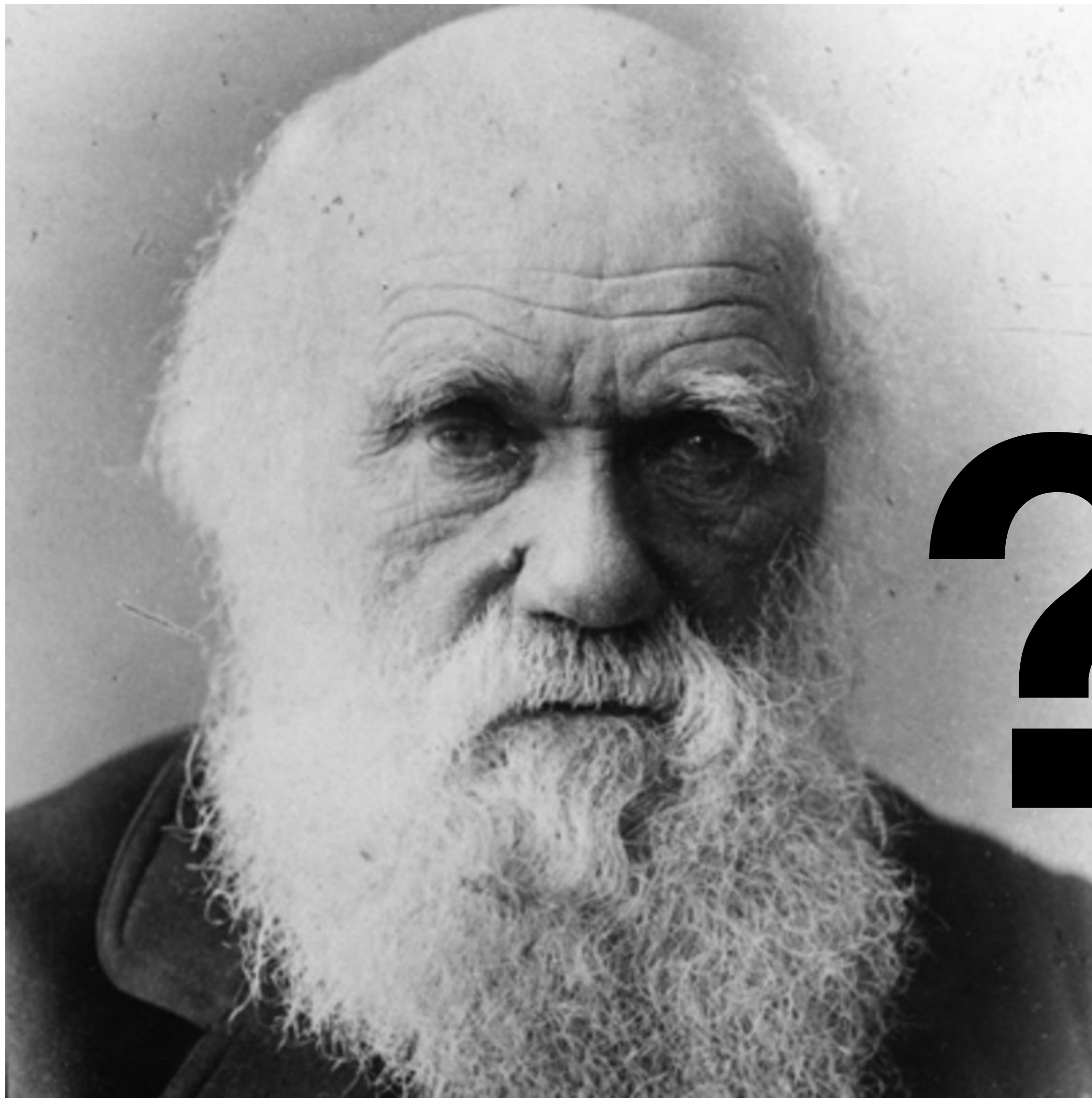
(with slides borrowed from Jinsuk Lim @ COINSE)

What is **evolution**?







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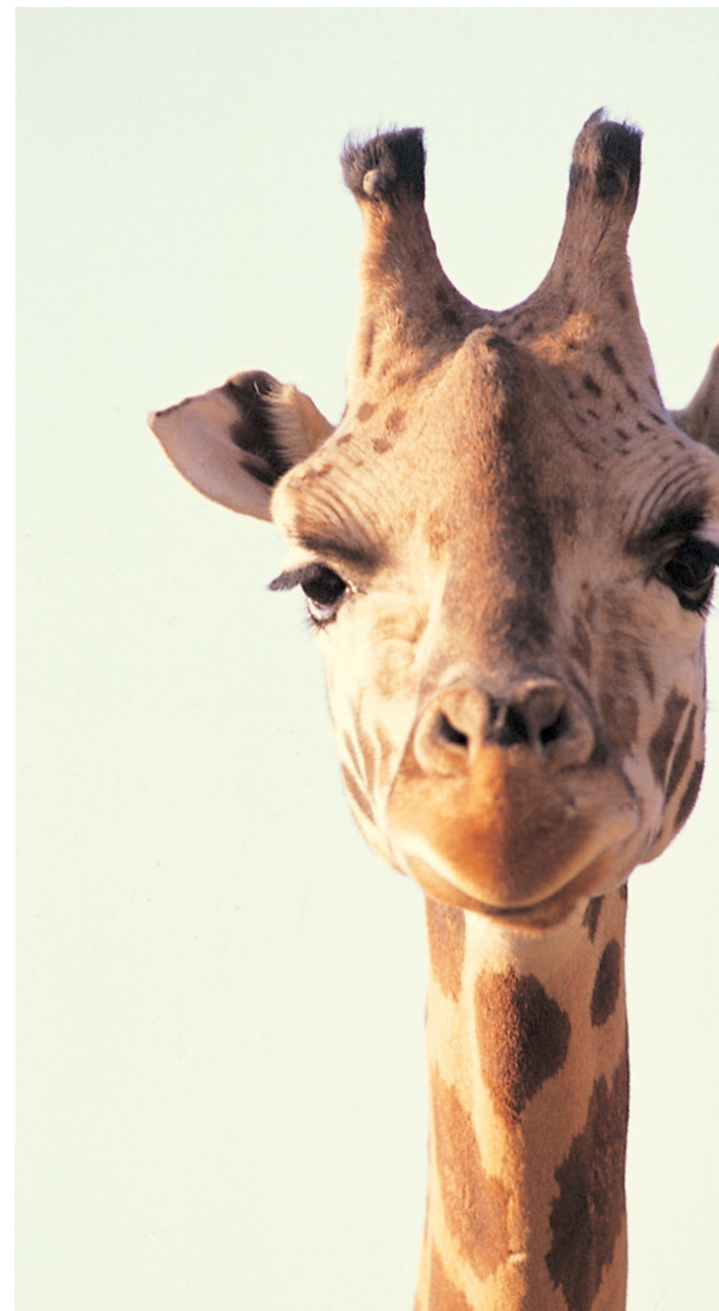
Lamarckism (用不用說)

- “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.

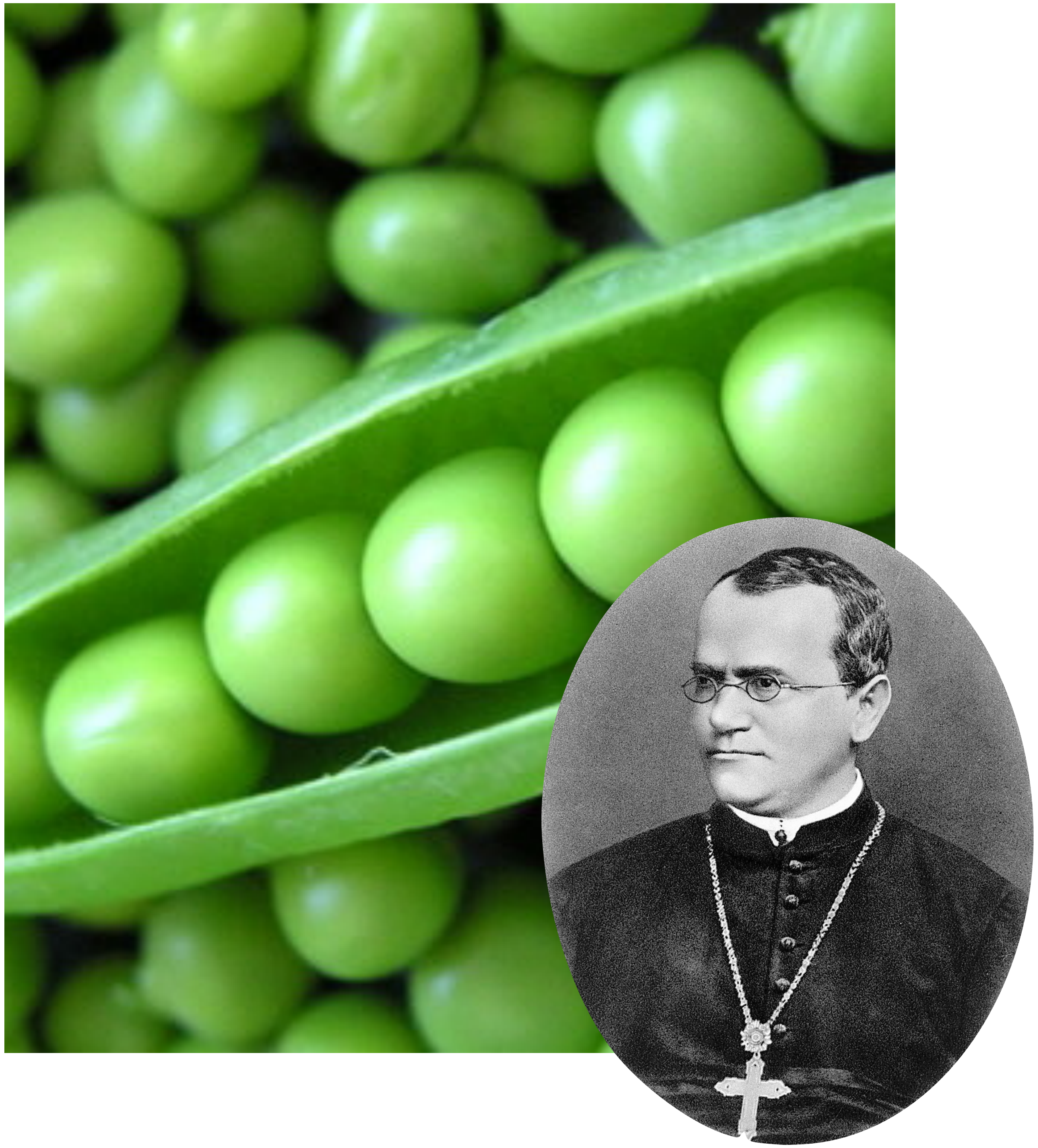
- Interestingly, some people - such as George Bernard Shaw - thought that Lamarckism was more humane and optimistic than Darwinism: individuals can try to **develop a new habit** that are beneficial!

- Epigenetics: trait variations that are caused by environments (!)

    - Renewed interest, but still in the very early stage

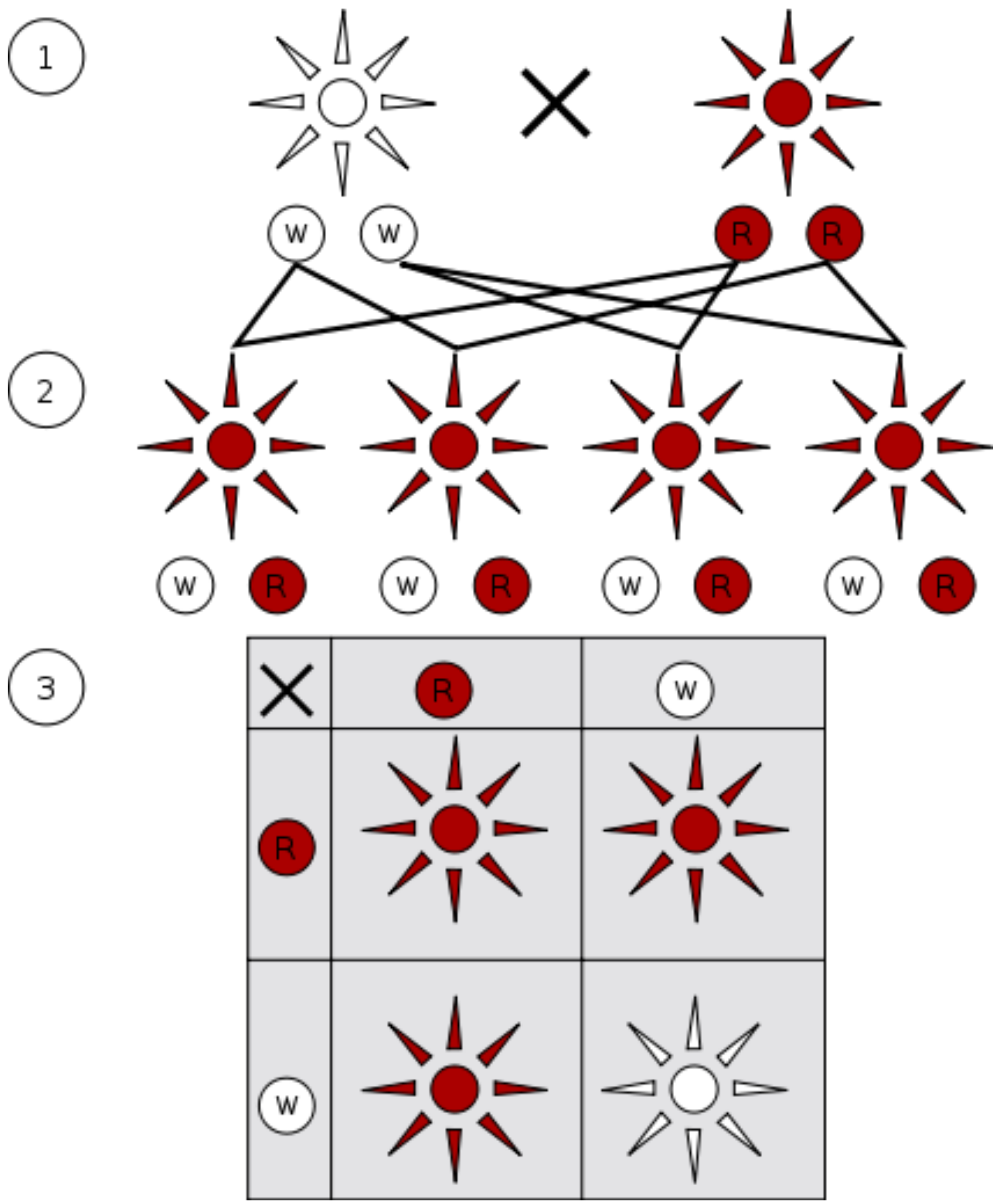
Mendelism

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



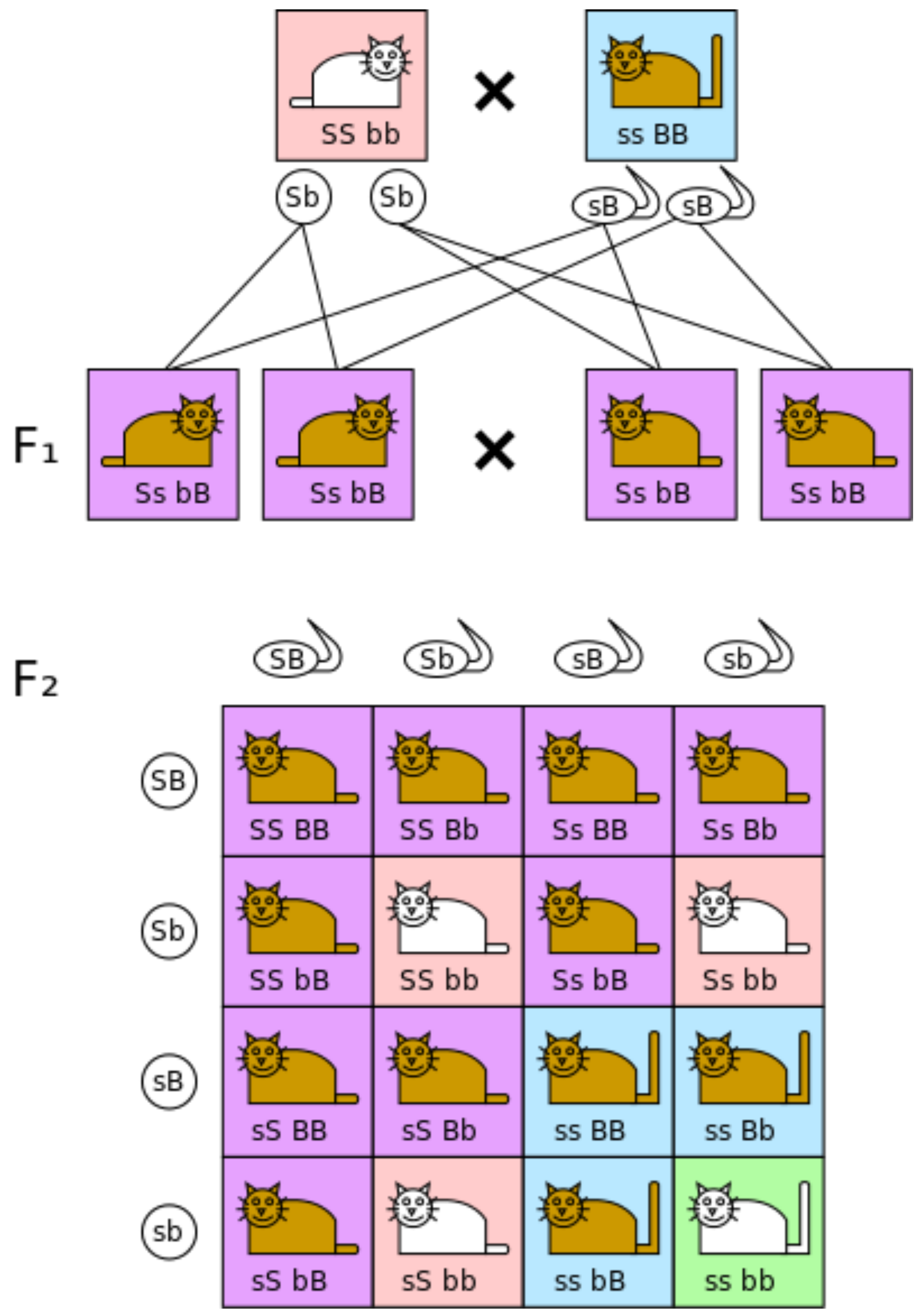
Law of Segregation

- 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".

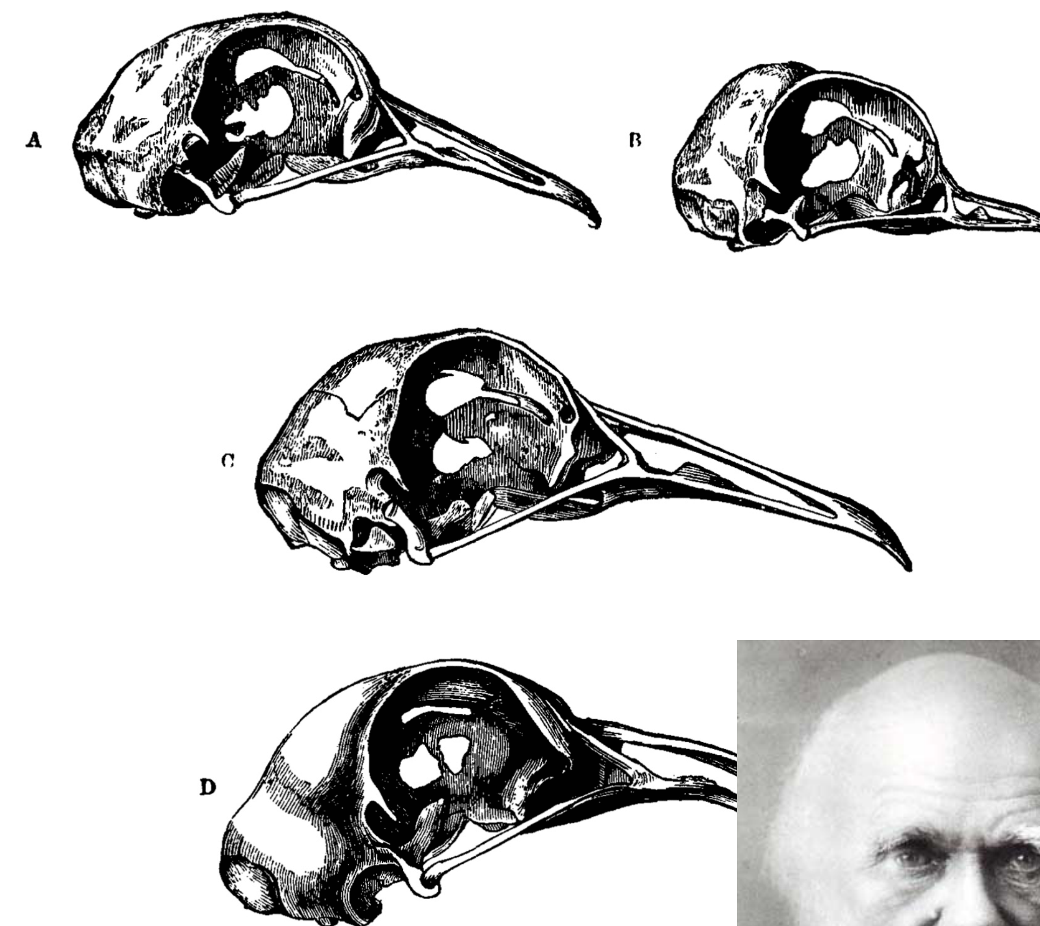
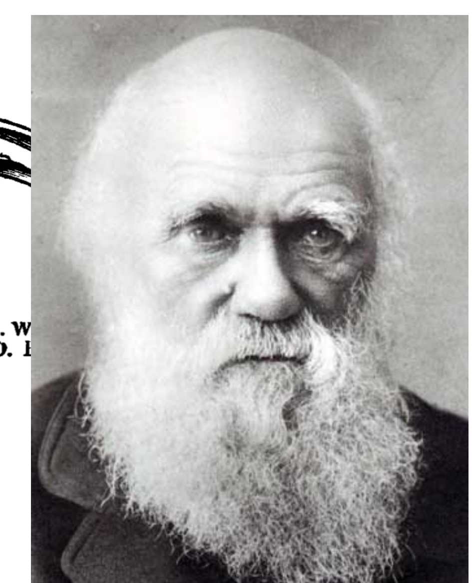


Fig. 24.—Skulls of Pigeons viewed laterally, of natural size. A. W
livia. B. Short-faced Tumbler. C. English Carrier. D. I

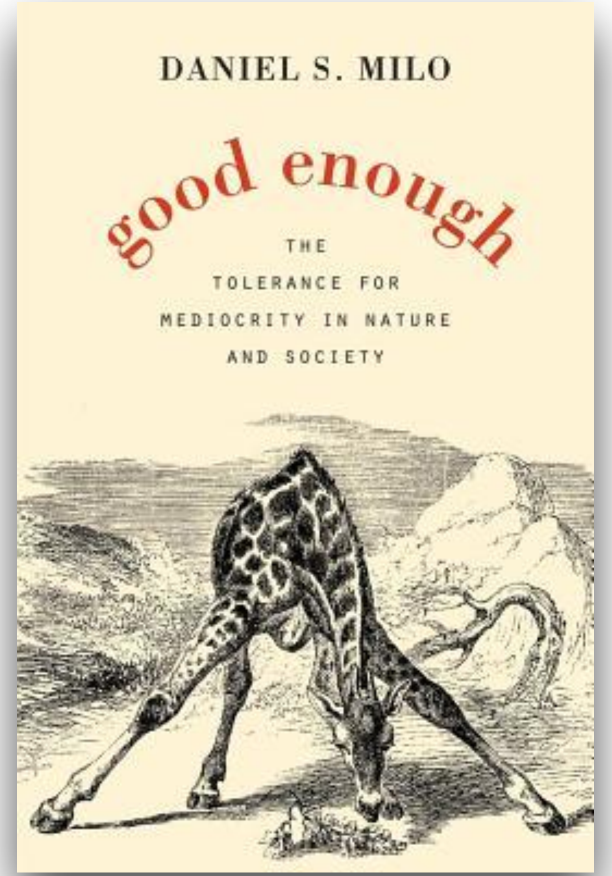


What is it exactly?

- 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).

Is it really the "survival of the fittest"?

- Nature neither optimises nor has any intention.
- If you are "good enough", you survive. Or, sometimes, a series of random events can result in genetic drift.
- A highly recommended reading: "Good Enough: The Tolerance for Mediocrity in Nature and Society" by Daniel S. Milo
- Intentional "optimisation" via evolution is a purely artificial concept, and is separate from what takes place in nature.



Genotype vs. Phenotype

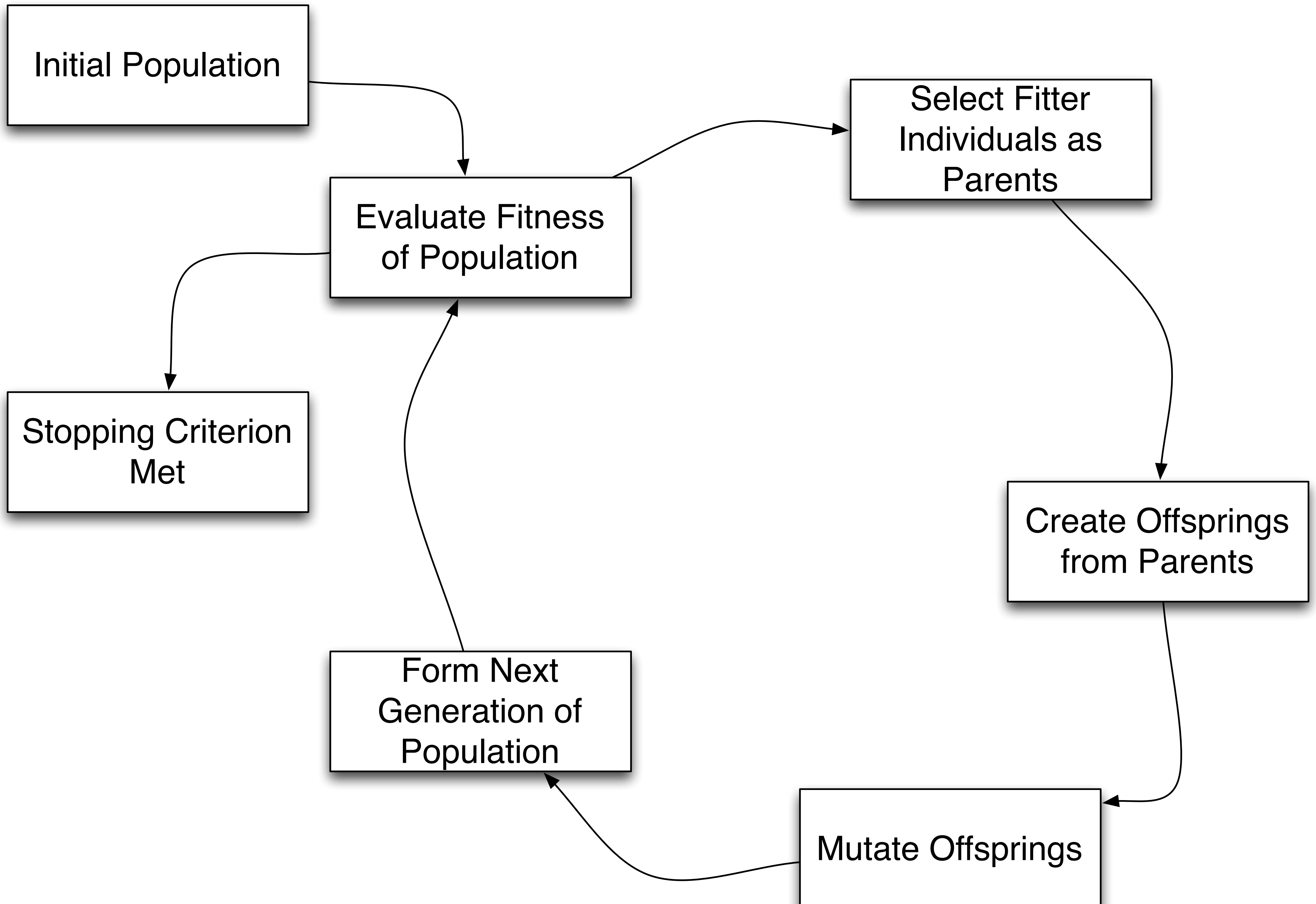
- **Genotype**: that part of the genetic material that determines a specific characteristic of an individual
- **Phenotype**: the characteristic manifested by a specific genotype

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.
- Remember: exploitation vs. exploration.
  - Too much pressure: premature convergence.
  - Too little pressure: search goes nowhere.


Initial Population
Evaluate Fitness of Population
Select Fitter Individuals as Parents
Create Offsprings from Parents
Mutate Offsprings
Form Next Generation of Population
Stopping Criterion Met

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

1<u>93</u>562

24<u>3</u>690

12<u>3</u>456

1212<u>14</u>

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

193562 → 193514

243690

121214 → 121262

123456

Choose Parents

Crossover

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

121214

123456

Choose Parents

893514

123262

Mutation

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

$\bar{f}, \sigma_f, c$ 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}	$P_{selLR} \quad (s=2)$	$P_{selLR} \quad (s=1.5)$
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? (either FPS or ranking selection)
  - Roulette Wheel Sampling
  - Stochastic Universal Sampling
  - Tournament Selection
  - Overselection

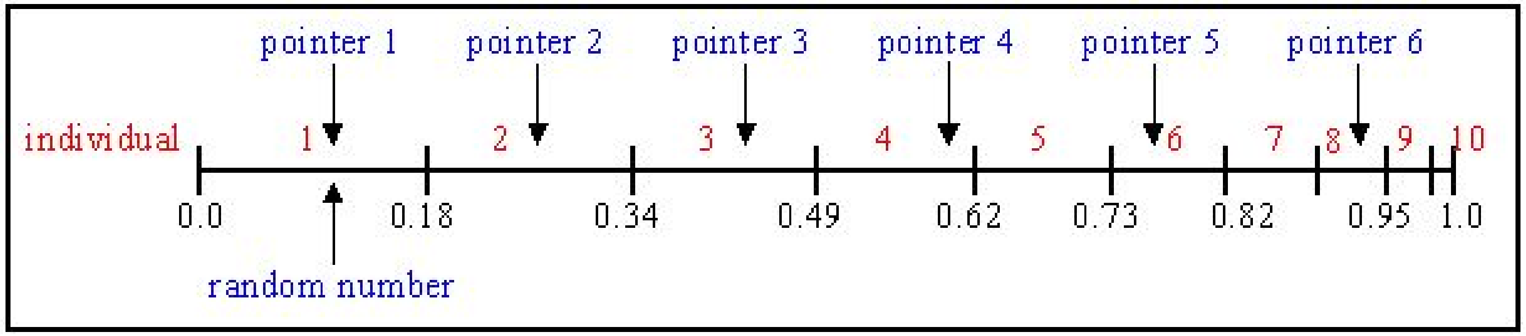
Roulette Wheel Sampling

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

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

Overselection

- Intentionally oversample from the “better” individuals. For example:
    - 80% of selections made from the top 20%
    - 20% of selections made from the remaining 80%