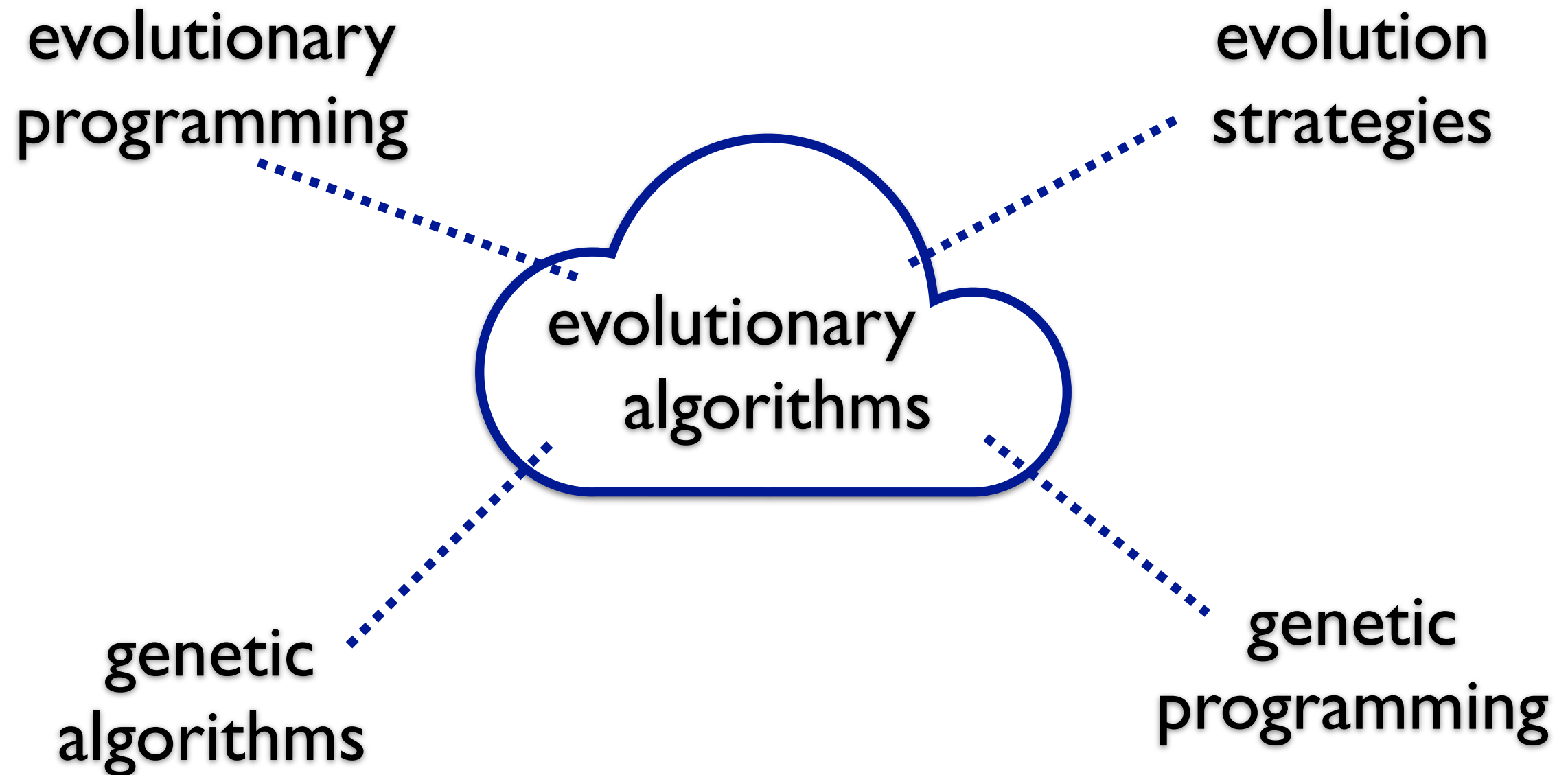


# 4 Evolutionary Computing Origins

# Field of Evolutionary Computing



# Inspiration from Biology

## nature:

- consider that an **environment** contains a population of individuals that strive for survival and reproduction
- the **fitness** of each **individual** represents its chances of survival and multiplying
  - determined by the environment, which includes its peers

## computing:

- consider using a stochastic trial-and-error style process to solve a **problem**, with a collection of candidate solutions
- the **quality** of each **candidate solution** is how well it solves the problem
  - and determines the chance that it will be kept and used as a seed for constructing further candidate solutions

# Inspiration from Biology

## Evolution

environment

individual

fitness



## Problem Solving

problem

candidate solution

quality

*Table 2.1, Introduction to Evolutionary Computation*

# The Macroscopic View: Darwinian Evolution

## *Survival of the Fittest:*

- all environments have finite resources
  - so can only support a limited number of individuals
- life forms have basic instinct/lifecycles geared towards reproduction
  - therefore some kind of selection is inevitable
- those individuals that compete for the resources most effectively have increased chance of reproduction
  - the ones that are adapted, or 'fit', the environmental conditions best

# The Macroscopic View: Darwinian Evolution

## *Diversity Drives Change:*

- phenotypic traits:
  - behaviour / physical differences that affect response to environment
  - partly determined by inheritance, partly by factors during development
  - partly as a result of random changes
  - unique to each individual
- if phenotypic traits:
  - lead to higher chances of reproduction
  - and can be inherited by offspring
- then they will tend to increase in subsequent generations, leading to new combinations of traits...

# The Macroscopic View: Darwinian Evolution

## *Summary:*

- population consists of diverse set of individuals
- combinations of traits that are better adapted tend to increase representation in population
  - individuals are “units of selection”
- variations occur through random changes yielding constant source of diversity, coupled with selection means that:
  - population is the “unit of evolution”
- and note the absence of any “guiding force”

# Adaptive Landscape

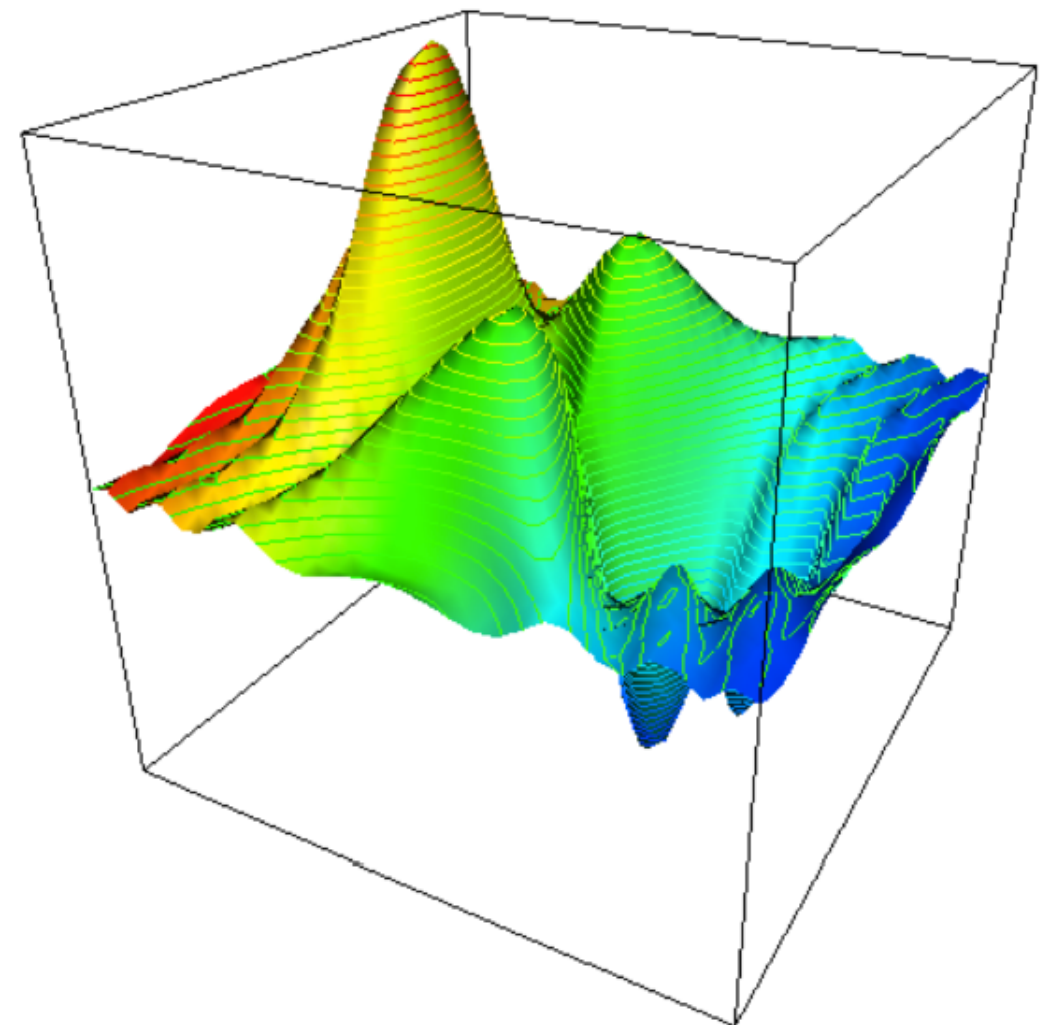
Wright (1932):

- can imagine a population with  $n$  traits as existing in a  $n+1$  dimensional space
  - a **landscape**
  - where height corresponds to fitness
- each different individual - each **phenotype** - represents a single point on the landscape
- population is therefore a 'cloud' of points, moving on the landscape over time as it evolves
  - as it *adapts*



# Adaptive Landscape

- each peak represents a range of successful trait combinations
- troughs belong to less fit combinations
- so selection ‘pushes’ population up the landscape
- evolution is the process of gradual advances of the population to high-altitude areas
  - powered by variation and natural selection



*Figure 2.2, Introduction to Evolutionary Computation*

# Adaptive Landscape: Genetic Drift

*but it's not all hill climbing:*

- population has a finite size, and random choices are made in the selection and variation operators
- so it is common to observe the phenomenon of **genetic drift**:
  - highly fit individuals may be lost from the population
  - population may suffer from a loss of variety in some traits
- can cause the population to 'melt down' the hill, and enter low-fitness valleys
- a good thing!
  - because it allows populations to escape from locally optima
  - giving them a chance to reach global optima

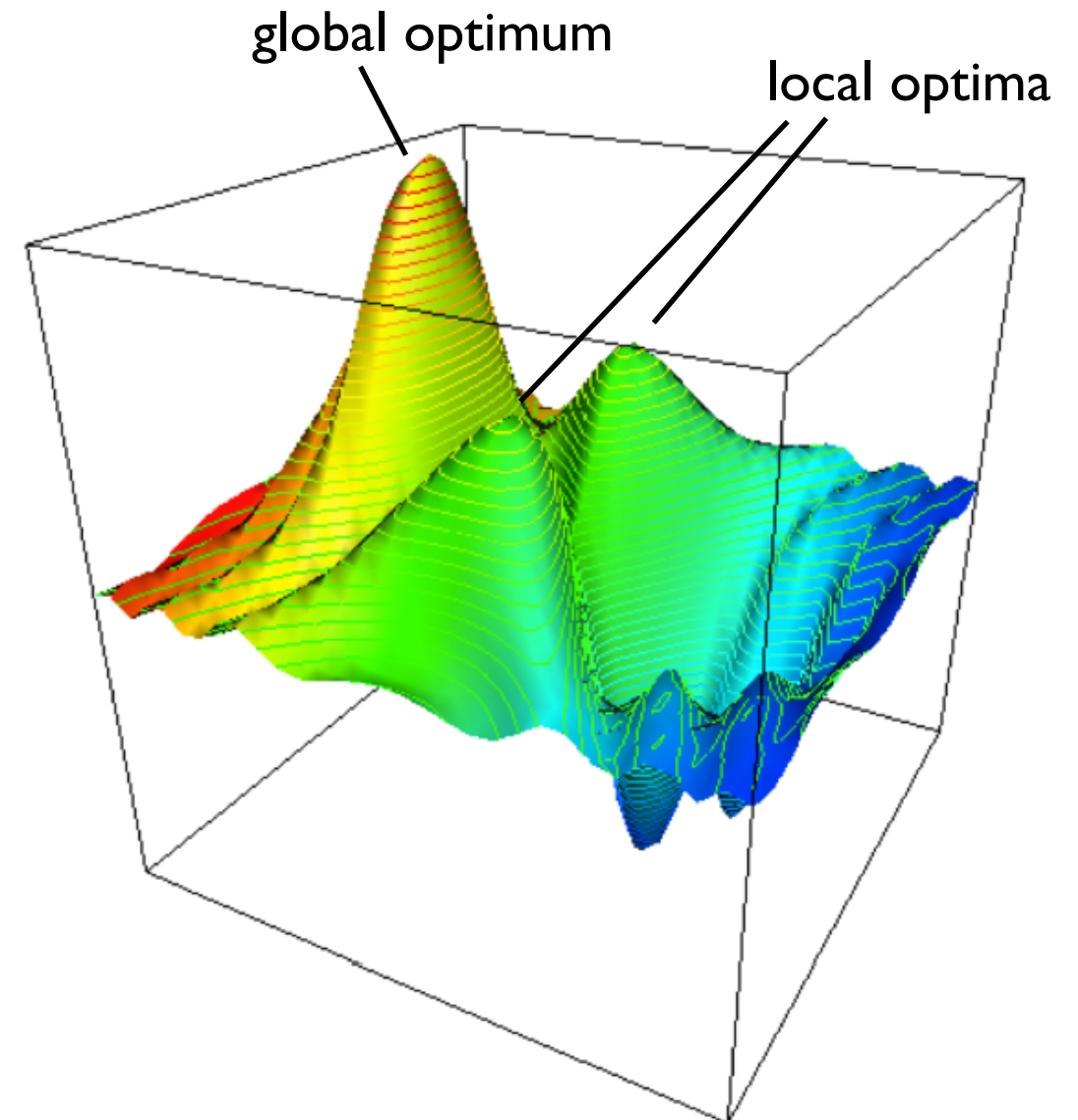


Figure 2.2, Introduction to Evolutionary Computation

# The Microscopic View: Molecular Genetics

- a fundamental observation from genetics is that each individual is a dual entity:
  - its phenotypic properties (outside) are represented at a genotypic level (inside)
  - an individual's genotype encodes its phenotype
- genotype consists of genes: the functional units of inheritance
  - one gene may affect many traits (pleiotropy)
  - many genes may affect one trait (polygeny)
- small changes in the genotype lead to small changes in the organism
  - for example: height, hair colour
- allele: one of the possible values that a gene can have
  - example: if a gene in bears determines fur colour, then a polar bear has the allele that specifies the colour white

# Genotype Determines Phenotype

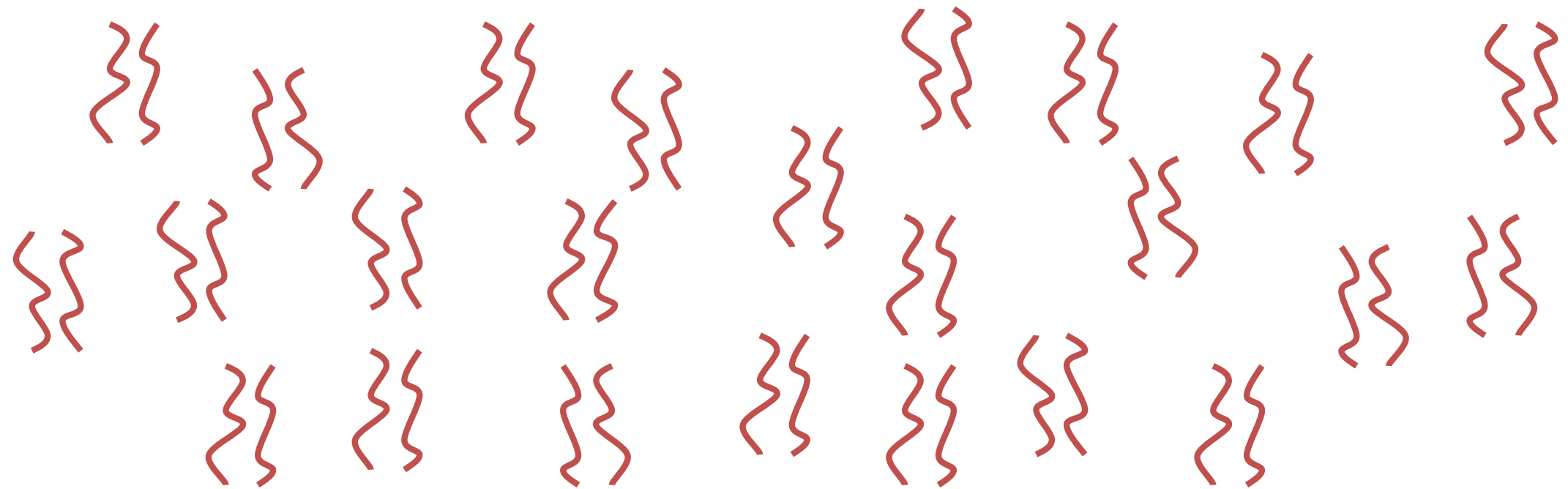
- phenotypic variations are always caused by genotypic variations
- genotypic variations are the consequences of either:
  - gene mutations
  - gene recombinations through sexual reproduction
- the genotype contains all the information necessary to build the particular phenotype

# Genes and the Genome

- genes are encoded in strands of DNA called **chromosomes**
- most cells are **diploid**, holding **two copies** of each chromosome
  - whereas **haploid** cells only have one copy of each chromosome (more on this in a moment)
- the complete genetic material in an individual's genotype is called the **genome**
- within a species, most of the genetic material is the same

# Genetics Example: Homo Sapiens

- human DNA is organised into 23 pairs of chromosomes
- together these define the physical attributes of the individual:

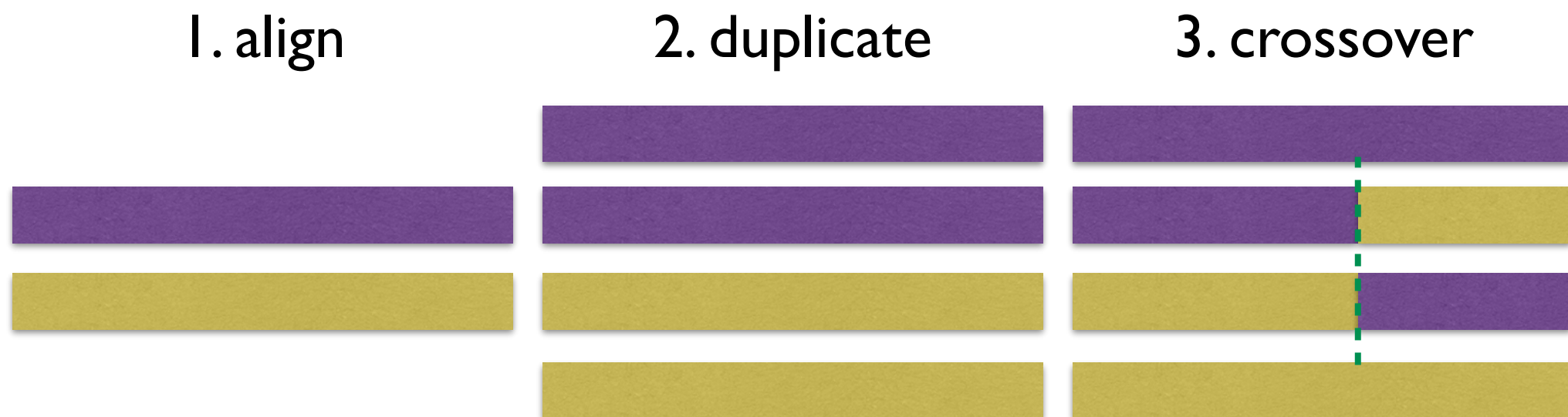


# Reproductive Cells

- **gametes** - sperm and egg cells - contain just one copy of each of the individual chromosomes
  - so they are haploid
- they are formed by a special form of cell splitting
  - called **meiosis**
- during meiosis the pairs of chromosome undergo an operation called crossover

# Meiosis

- chromosome pairs align and duplicate
- inner pairs link at a **centromere** and swap parts of themselves:

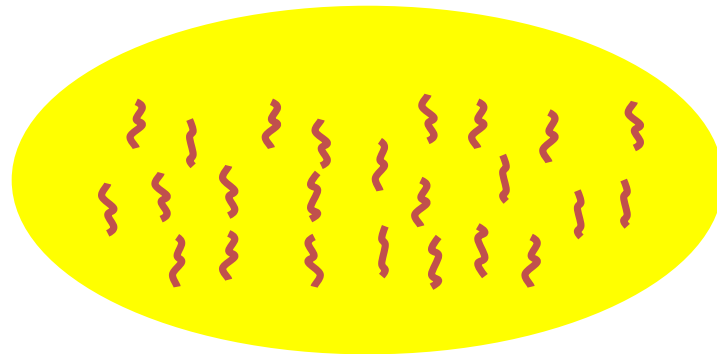


- outcome is one copy of each maternal/paternal chromosome plus two entirely new combinations
- so crossover allows new gene combinations to be created and 'tested'
  - making it a useful technique for evolutionary computation

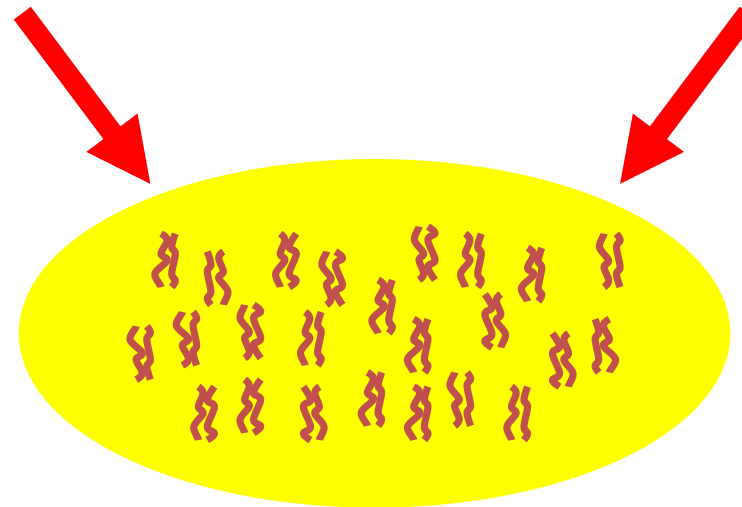
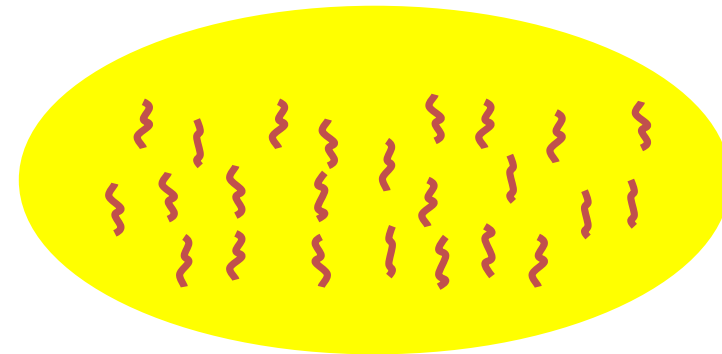


# Fertilisation

Sperm cell from Father



Egg cell from Mother



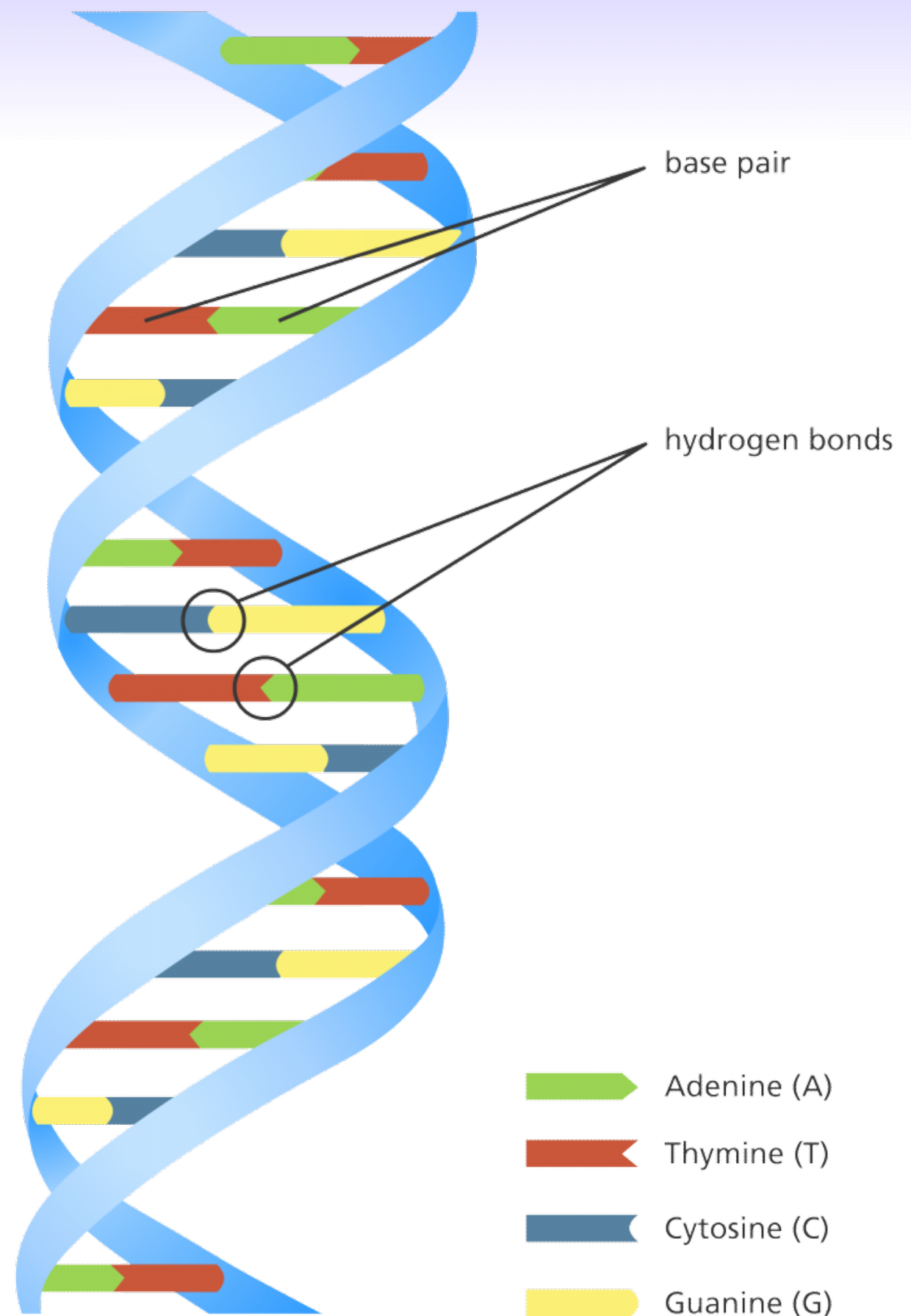
New person cell (zygote)

# After Fertilisation

- the new zygote rapidly divides, creating many cells, all with the same genetic contents
- although all cells contain the same genes, depending on, for example where they are in the organism, they will behave differently
- this process of differential behaviour during development is called ontogenesis
- all of this uses, and is controlled by, the same mechanism for decoding the genes in DNA

# Genetic Code

- all proteins in life on earth are composed of sequences built from the 20 different amino acids
- DNA is built from four nucleotides A, G, T, C, which form base pairs in a double helix spiral
  - A always bonds with T
  - G always bonds with C
- triplets of these form codons, each of which codes for a specific amino acid
- there are 64 ( $4^3$ ) possible codons
- 61 of which code for the 20 amino acids
  - so there's lots of redundancy



# Transcription and Translation



- a central claim in molecular genetics is that the flow is one way:

genotype  $\Rightarrow$  phenotype

phenotype  $\nRightarrow$  genotype

# Mutation

- occasionally some of the genetic material changes very slightly during this process
  - a replication error, or mutation
- so a child can have genetic material information not inherited from either parent
- the outcome of this can be:
  - **catastrophic**: offspring is not viable (most likely)
  - **neutral**: new feature does not influence fitness
  - **advantageous**: new feature improves fitness
- redundancy in the genetic code forms a good way of error checking

# Gene Pool:

## another way of looking at things

- recall that the genome of the new individual is not identical to that of its parents, because of crossover and mutation...
- so genotype variations are created, which in turn translate to phenotype variations and thus are subject to selection...
- so genes are also subject to the game of survival and reproduction
- so we can view also evolution from the perspective of genes
- instead of thinking about populations of individuals, we could think about a 'gene pool'
- containing genes which compete and replicate over time, being evaluated as they reoccur in different individuals

# Motivations for Evolutionary Computing

## *Stealing Nature's Best Ideas:*

- we want automated problem solvers
- and nature is full of them!
- two most obvious candidates for inspiration:
  - the human brain
  - the evolutionary process
- designing problem solvers based on the human brain is neurocomputing
- the second option forms the basis of evolutionary computing

# Motivations for Evolutionary Computing

*There's Not Enough Time to Check Everything:*

- the pace of change is rapid
  - leaving less and less time available for thorough problem analysis and tailored algorithm design
- problems have got more complex
- so there's a need for algorithms that are:
  - applicable to a wide range of problems
  - do not need much tailoring for specific problems, and
  - deliver good (not necessarily optimal) solutions within acceptable time
- evolutionary algorithms are well suited for this, and allow automated solution methods



# Motivations for Evolutionary Computing

## *Curiosity:*

- EC allows the opportunity to perform experiments differently from traditional biology
  - to see things as they could be
- also lets us see if we can abstract the fundamental mechanisms at play in the real world
  - although we have to be careful not to extrapolate the results too far in our conclusions
  - or to over-simplify

# Reading & References

- slides largely based on, or adapted from, Chapter 2 slides for Eiben & Smith's *Introduction to Evolutionary Computing*
- while we will continue to take inspiration from nature, from now on we'll focus on how to build evolutionary algorithms using computers
- so there's no need to pick up a biology book for this course!
- but if you're interested, maybe visit the website for the Human Genome Project