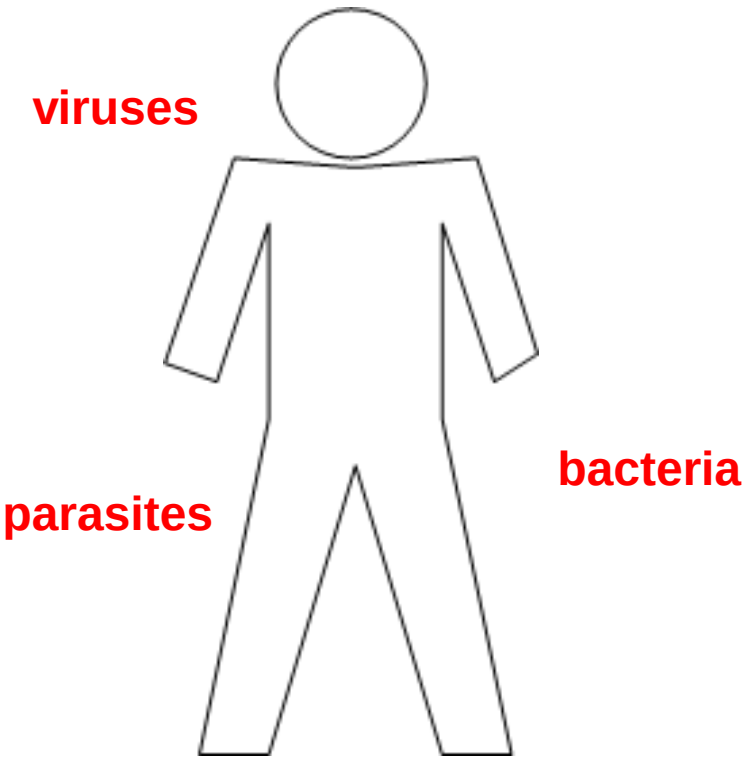
Artificial Immune System

Winter 2011

Motivation

- There is probably no system that can protect itself as effectively, on so many levels, and from so many different diseases and infections as the **human immune system**
  - Forbes 2004



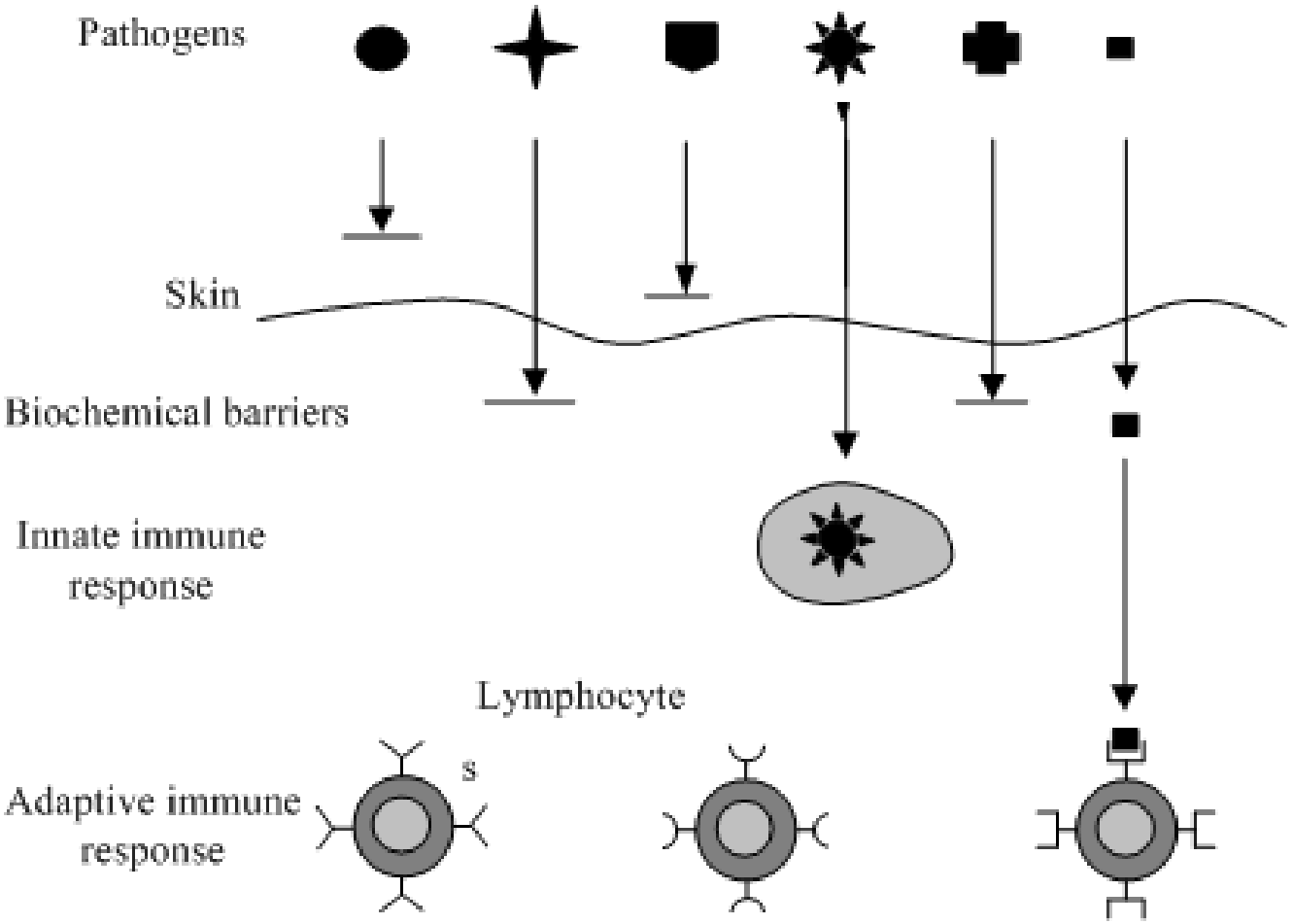
Human immune system

- All living organisms are continuously exposed to substances that are capable of causing them harm.
- The human immune system is a complex network of organs containing cells that recognize foreign pathogens in the body and destroy them.
- Pathogens include viruses, bacteria, and parasites

Two kinds of immunity

- Innate immune system
  - Capable of recognizing molecular patterns in pathogens, signaling other immune cells to start fighting against the pathogens
- Adaptive immune system
  - Adapt to the molecular patterns previously seen and maintain a stable memory of known patterns

Layers of protection

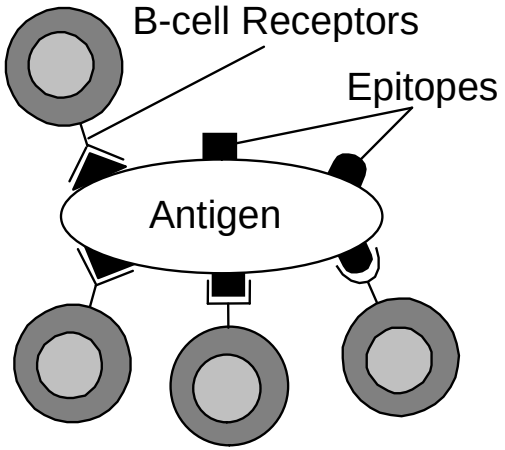


Lymphocytes

- Heart of the immune system (white blood cell)
- Two types of cells
  - T-cell: generated within the bone marrow and migrated in the thymus (an organ located in the upper anterior portion of the chest cavity)
  - B-cell: maturated in the bone marrow (tissue in the hollow interior of bones)

Receptors and Epitopes

- Both T- and B-cells have surface receptors capable of recognizing molecular patterns present on antigens (binding with epitopes)



Activation

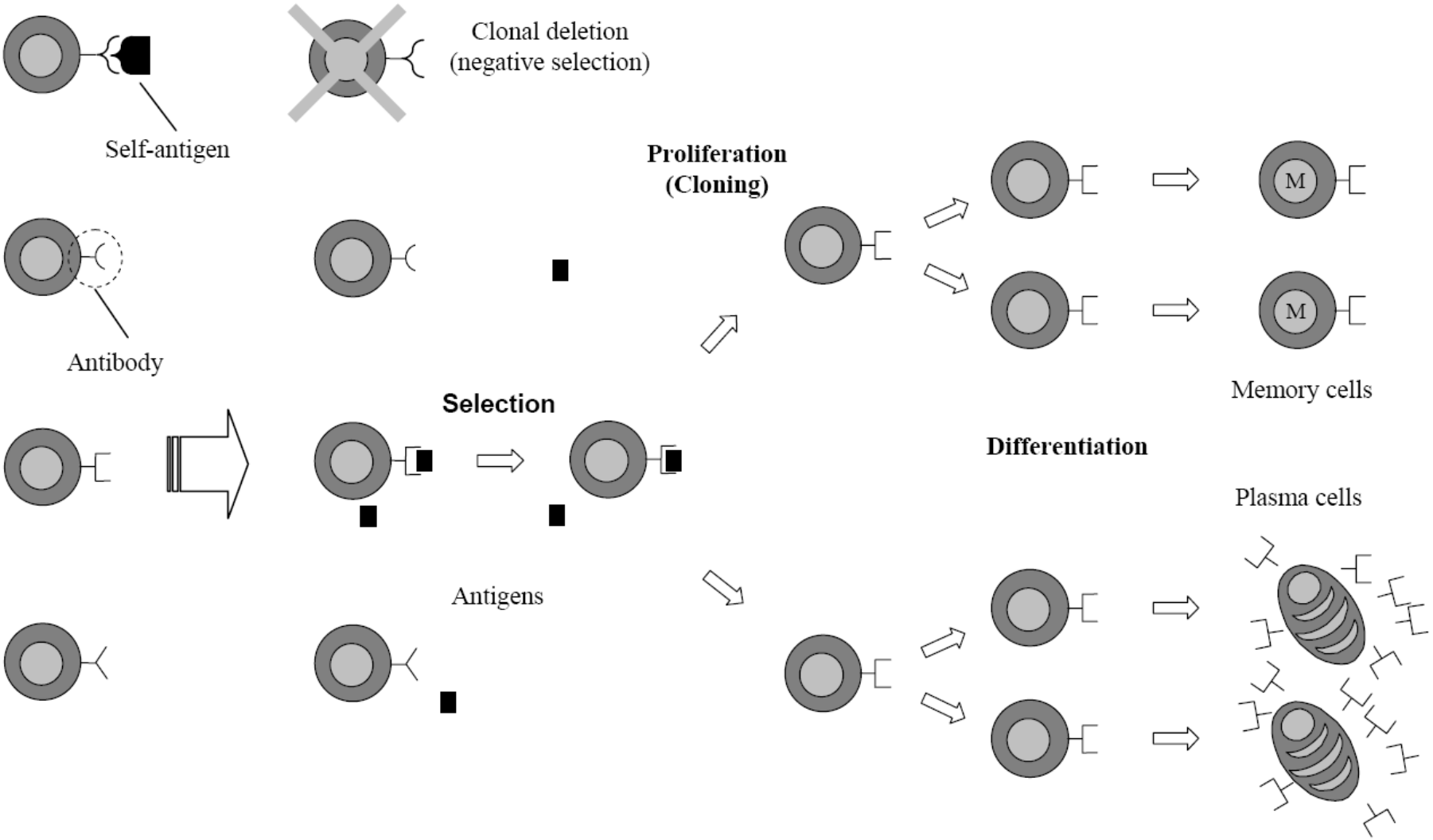
- When the receptors bind to epitopes, a lymphocyte becomes activated
- A lymphocyte will only be activated when the number of its receptors binding to epitopes exceeds a threshold
- Activation triggers a series of reactions that can lead to elimination of the pathogens

Affinity

- The T- and B-cells can multiply themselves through a cloning process
- The receptor molecules are generated by the recombination of gene segments concatenated from gene libraries
- Degree of interaction between receptor and epitope is **affinity**

Clonal Selection Theory

- B-cells with higher affinity with antigens are selected and stimulated to proliferate
- During proliferation, mutation may occur; thus, allowing the receptor to become more adapted to the antigen
- Higher mutation rate for lower affinity


Clonal deletion
(negative selection)
Self-antigen
Proliferation
(Cloning)
M
M
Antibody
Memory cells
Selection
Differentiation
Plasma cells
Antigens

Negative Selection Theory

- Immature T-cells migrate into the thymus where some of them differentiate and others are purged due to strong recognition of self
- Key is to distinguish the body's own cells and molecular from those that are foreign

Representation

- A scheme to create abstract models of immune cells
- Shape-spaces
  - Real-valued
  - Integer-valued
  - Binary
  - Symbolic
    - Various types: “ages”, “weights”

Measurement of Affinity

- Euclidean distance $D = \sqrt{\sum_{\forall i} (A_i - B_i)^2}$
- Manhattan distance $D = \sum_{\forall i} | A_i - B_i |$
- Hamming distance $D = \sum_{\forall i} \delta_i$ where $\delta_i = 1$ if $A_i = B_i$; $\delta_i = 0$ otherwise
- *r*-contiguous bits
  - Number of contiguous matching bits
- *r*-chunk matching
  - Only *r* contiguous positions are specified

Affinity Threshold

- Suppose the threshold=7; using Hamming distance
- Antibody [1 0 1 0 1 0 1 0 1 0]
- Antigen 1 [1 0 0 0 1 1 1 0 1 0]
- Antigen 2 [0 1 1 1 1 0 1 1 1 0]
- Which antigen can be matched?

Immune Algorithms

- Clonal Selection
- Bone Marrow
- Negative Selection

Clonal Selection Algorithm (Pattern recognition)

1. Initialization
   - Create a population of antibodies
2. Antigenic presentation
   1. Affinity evaluation
   2. Clonal selection and expansion
      - Select n_1 antibodies with highest affinity; generate clones of these individuals proportionally to their affinity with antigens: the higher the affinity, the higher the number of copies

Clonal Selection Algorithm (Pattern recognition)

3. Affinity maturation
   - Mutate all the copies with a rate inversely proportionally to the affinity
   - Add the mutated individuals to the population
   - Reselect the best individuals to be kept as the memory of the antigen
4. Metadynamics
   - Replace a number of low affinity individuals by (randomly generated) new ones
5. Cycle

Clonal Selection Algorithm (Optimization)

- Similar to previous slides
- Differences
  - No antigen to be recognized; affinity may be the similarity of solutions
  - The whole antibody population will compose the memory set

Optimization Algorithm (1)

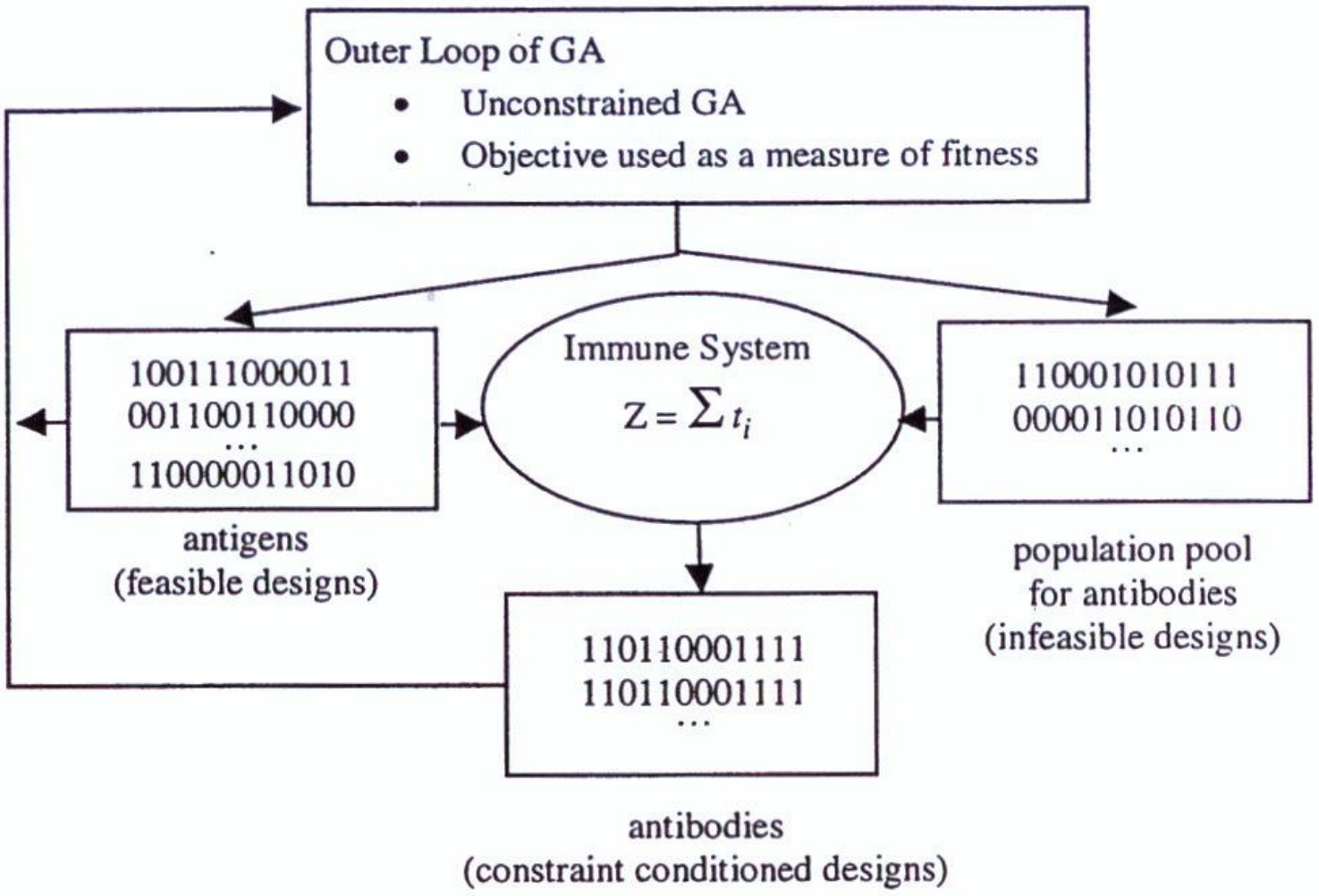
- Randomly initialize a population of cells (solutions)
- **While stopping criterion is not met do**
  1. Determine the fitness of each cell and normalize the vector of fitness.
  2. Generate a number of clones for each cell.
  3. Mutate each clone proportionally to the fitness of its parent cell, but keep the parent cell.
  4. Determine the fitness of all individuals of the population.
  5. For each cell, select the clone with highest fitness and calculate the average fitness of the population.

Optimization Algorithm (2)

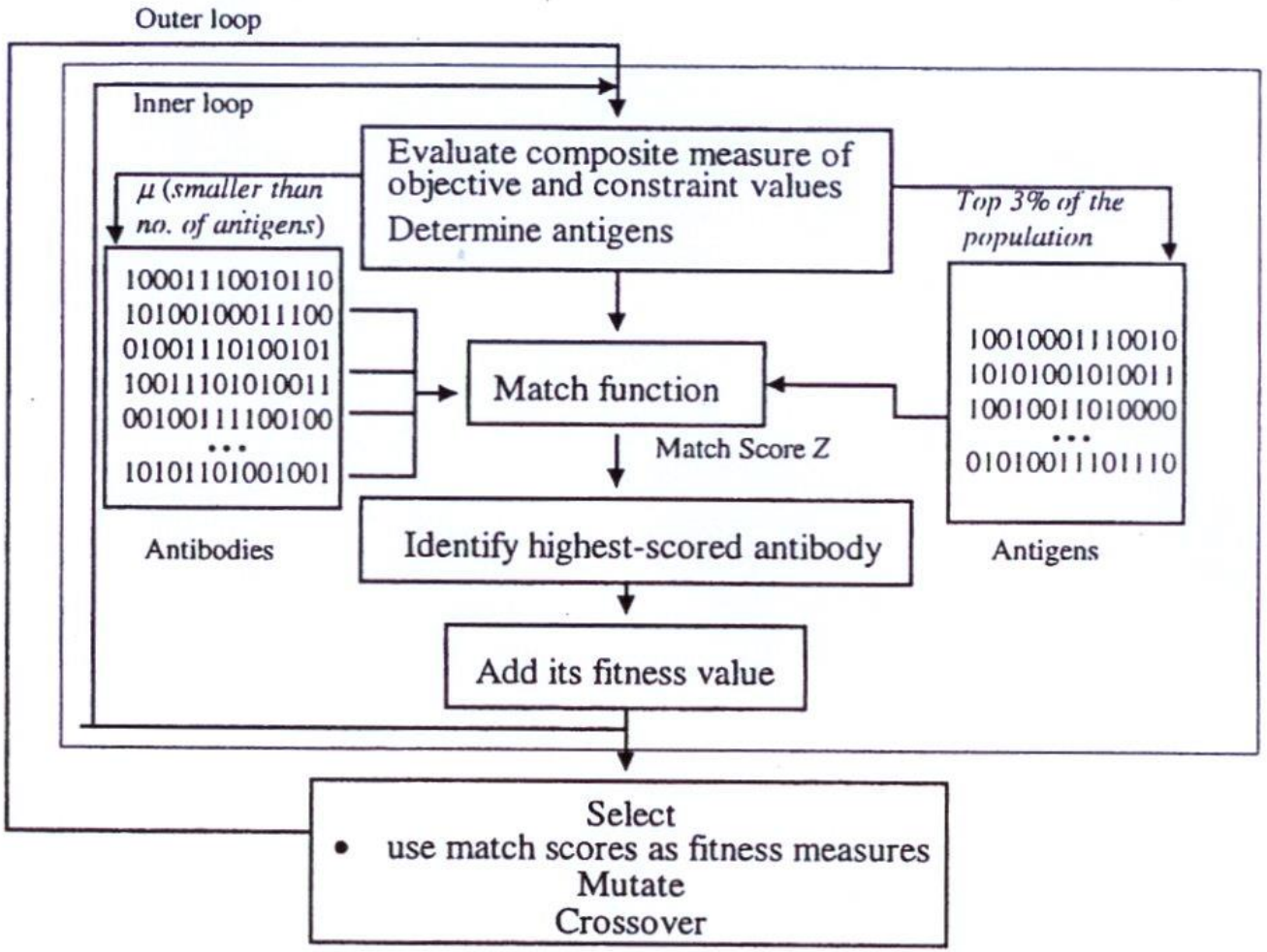
6. If the average fitness of the population is not significantly different from the previous iteration, then continue. Else, return to Step 1
7. Determine the affinity (e.g., Euclidean distance between cells) of all cells. Suppress all but the highest fitness of those cells whose affinities are less than the suppression threshold (i.e., encourage diversity) and determine memory cells (cells being kept after suppression).
8. Introduce a percentage of randomly generated cells and return

- **EndWhile**

AIS for constraint handling

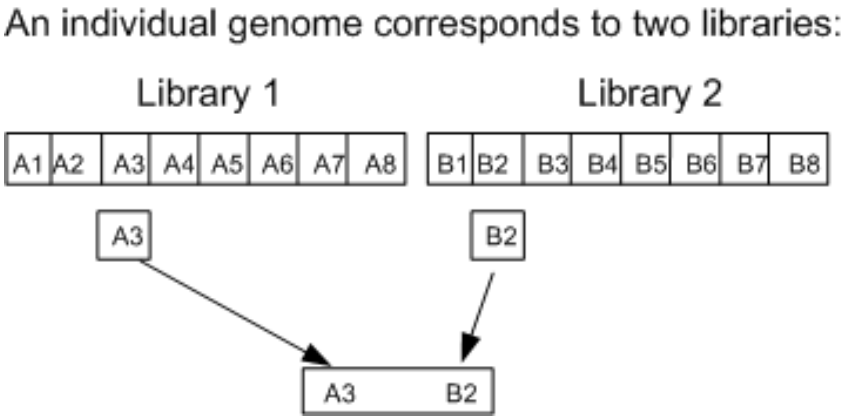


AIS for accelerating convergence



Bone Marrow Model

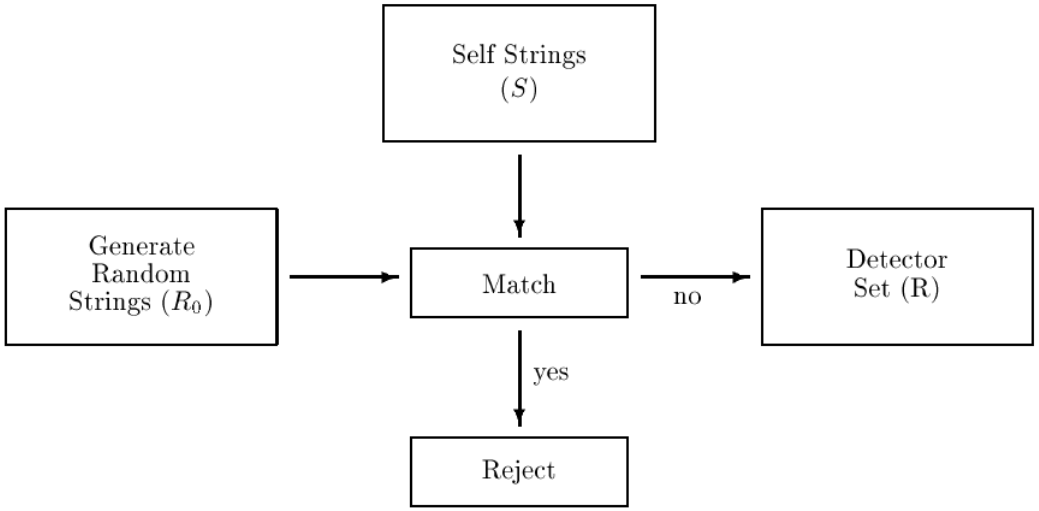
- Gene libraries are used to create antibodies from the bone marrow; antibody production through a random concatenation from gene libraries
- Analogous to “competitive templates” in messy GA

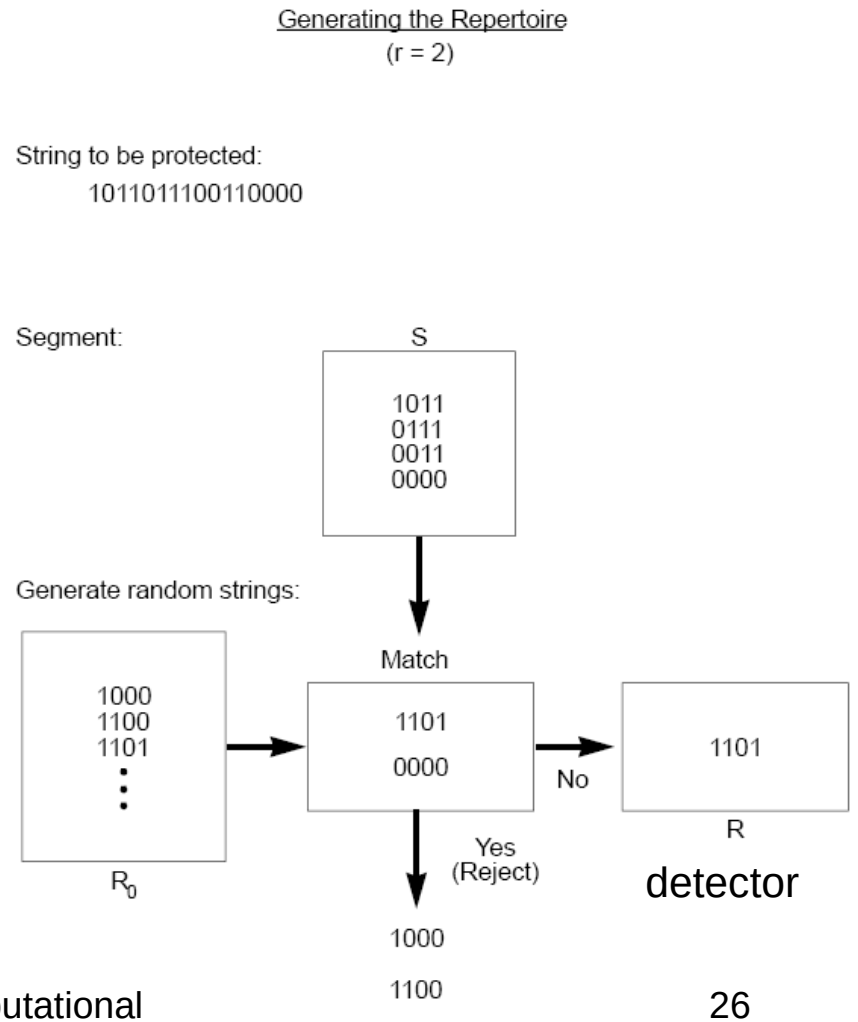


Negative Selection

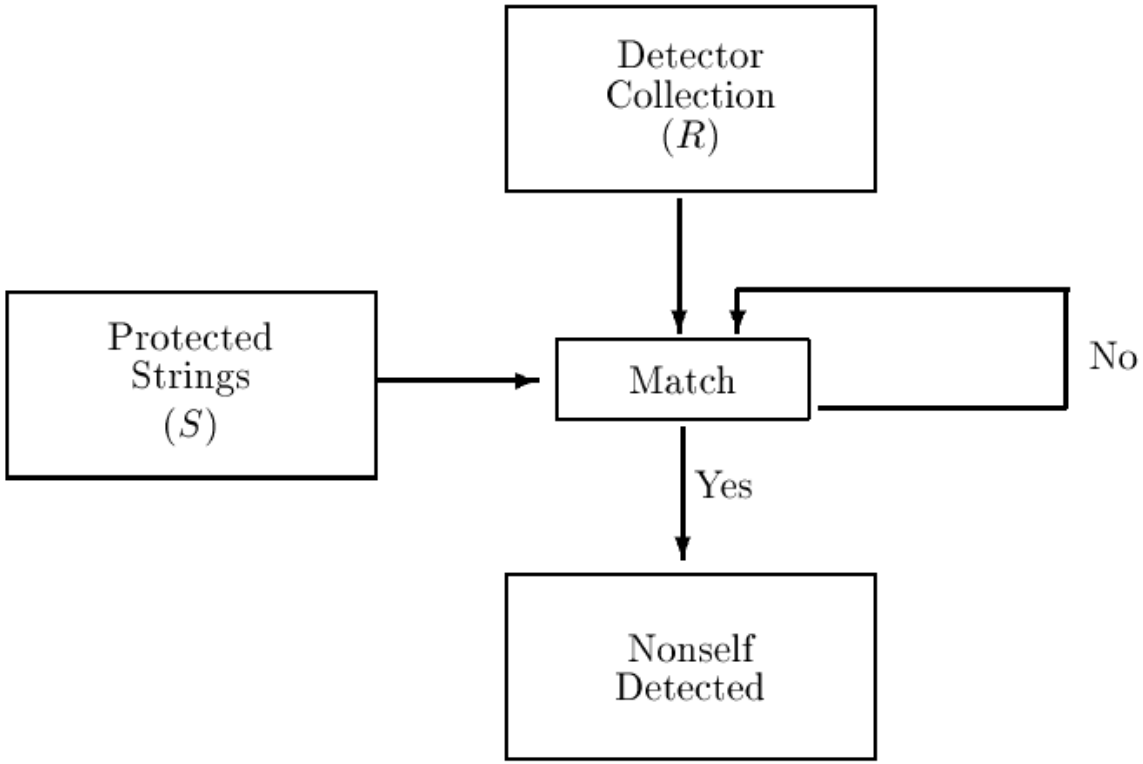
- Mostly used in detection of virus or network intrusion
- Routinely scanning for unique patterns that are known previously may render the systems vulnerable to attack by new means
- Changes to computer files may be made by self (legitimate users or corrupted data) or other (unauthorized users or virus)
- A small set of detectors has a high probability of noticing a change to the original data; the number of detector remains constant as the size of the data grows

Negative Selection (Censoring)





Negative Selection (Monitoring)



Possible Advancement

- Using decoy program, a trap to collect unknown viruses
- The decoy program is dummy program that is not changeable. If decoy program is modified, it is virus infection

Variety of Applications

- Virus detection (Forrest et al. 1994)
- Network intrusion detection (Hofmeyr & Forrest 2000)
- Pattern recognition (de Castro and Timmis 2002)
- Hardware fault diagnosis (Ishida 1996; Bradley & Tyrell, 2000)
- Robot behaviour (Lee and Sim 1997)
- Constrained optimization (Hajela & Yoo 1999)
- General optimization (Coello et al. 2005)
- Structural design (Miyamoto et al. 2004)

Closing Remarks

- Our introduction of human immune system is highly simplified, many details are left out
- AIS is young and rapidly growing
- Originally been used for Computer Security. Now, AIS has a wide variety of applications
- Multiobjective optimization may be performed by using the concept of dominance as the fitness
- AISWeb http://www.artificial-immune-systems.org/