DNA Computation

Hiroshi Higuchi

Outline

- **Introduction to DNA**
- Adlemanís experiment
- Cutting Edge Technologies
- Pros and Cons
- Conclusion

What is DNA?

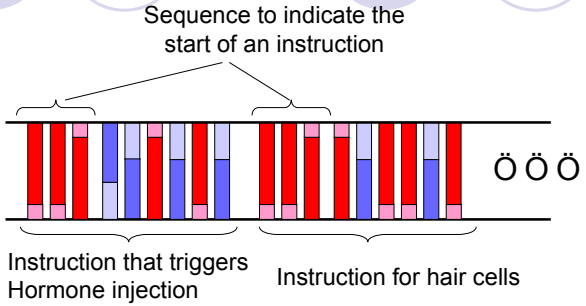
- DNA stands for Deoxyribonucleic Acid
- DNA represents the genetic blueprint of living creatures
- DNA contains ì instructionsî for assembling cells
- Every cell in human body has a complete set of DNA
- DNA is unique for each individual

Double Helix

- ì*Sides*î
  Sugar-phosphate backbones
- ì*ladders*î
  complementary base pairs
  Adenine & Thymine
  Guanine & Cytosine
- Two strands are held together by weak hydrogen bonds between the complementary base pairs

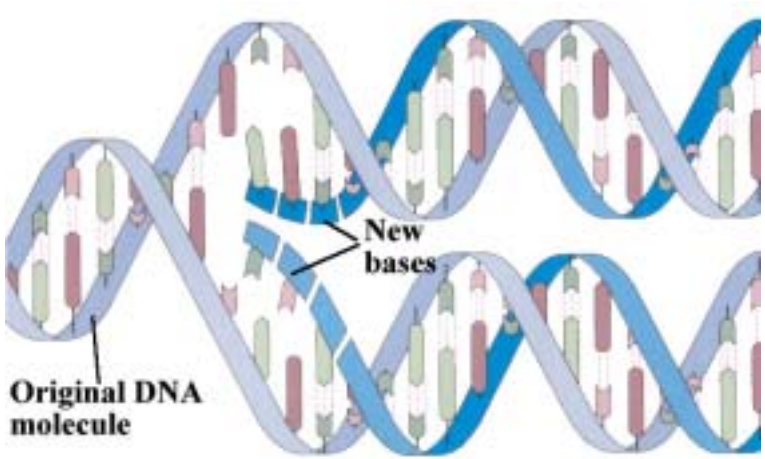
Source: ì Human Physiology: From Cells to System 4th Ed.î, L. Sherwood, Brooks/Cole, 2001, C-3

Instructions in DNA



- Instructions are *coded* in a sequence of the DNA bases
- A segment of DNA is exposed, transcribed and translated to carry out instructions

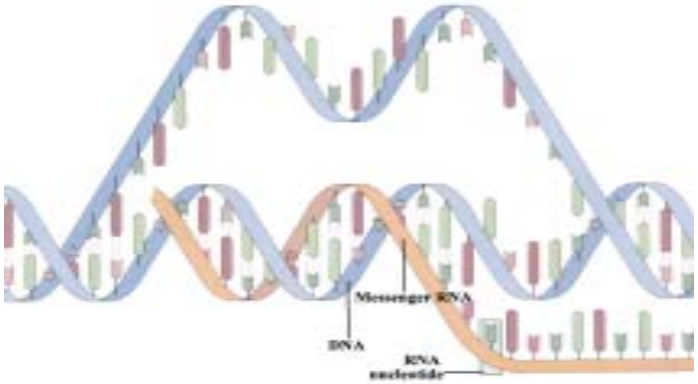
DNA Duplication



Source: ìHuman Physiology: From Cells to System 4th Ed.î, L. Sherwood, Brooks/Cole, 2001, C-5

Protein Synthesis

- DNA → RNA → Proteins → *actions*



Source: ìHuman Physiology: From Cells to System 4th Ed.î, L. Sherwood, Brooks/Cole, 2001, C-6

Can DNA Compute?

- DNA itself does not carry out any computation. It rather acts as a massive memory.
- BUT, the way complementary bases react with each other can be used to compute things.
- Proposed by Adelman in 1994

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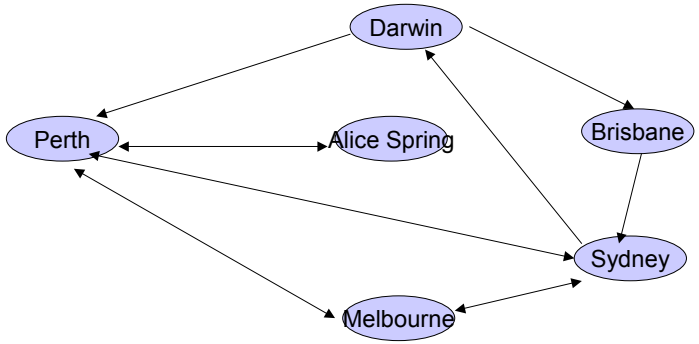
Adlemanís Experiment

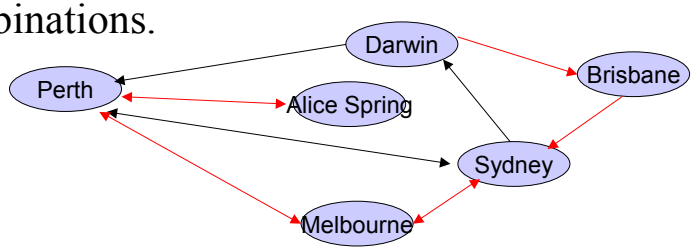
- Hamilton Path Problem
  (also known as the travelling salesperson problem)



Is there any Hamiltonian path from Darwin to Alice Spring?

Adlemanís Experiment (Contíd)

- Solution by inspection is:
  Darwin → Brisbane → Sydney → Melbourne → Perth → Alice Spring
- BUT, there is no deterministic solution to this problem, i.e. we must check all possible combinations.



Adlemanís Experiment (Contíd)

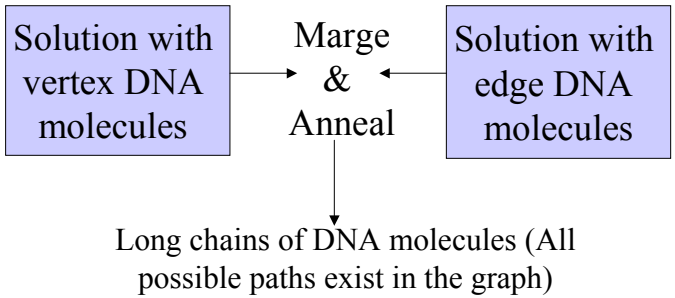
1. Encode each city with complementary base - *vertex molecules*
   Sydney - TTAAGG
   Perth - AAAGGG
   Melbourne - GATACT
   Brisbane - CGGTGC
   Alice Spring ñ CGTCCA
   Darwin - CCGATG

Adlemanís Experiment (Contíd)

2. Encode all possible paths using the complementary base ñ *edge molecules*
   Sydney → Melbourne ñ AGGGAT
   Melbourne → Sydney ñ ACTTTA
   Melbourne → Perth ñ ACTGGG
   etcÖ

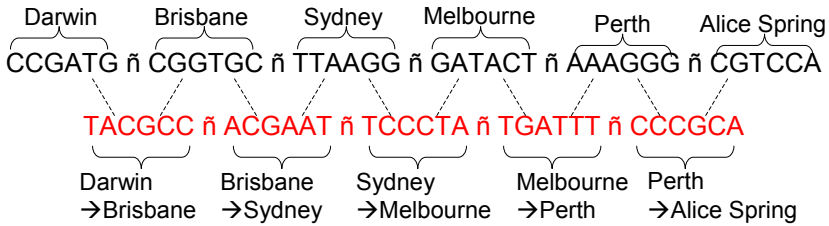
Adlemanís Experiment (Contíd)

3. Marge vertex molecules and edge molecules.
   All complementary base will adhere to each other to form a long chains of DNA molecules



Adlemanís Experiment (Contíd)

- The solution is a double helix molecule:



Operations

- Melting
  breaking the weak hydrogen bonds in a double helix to form two DNA strands which are complement to each other
- Annealing
  reconnecting the hydrogen bonds between complementary DNA strands

Operations (Contíd)

- Merging
  mixing two test tubes with many DNA molecules
- Amplification
  DNA replication to make many copies of the original DNA molecules
- Selection
  elimination of errors (e.g. mutations) and selection of correct DNA molecules

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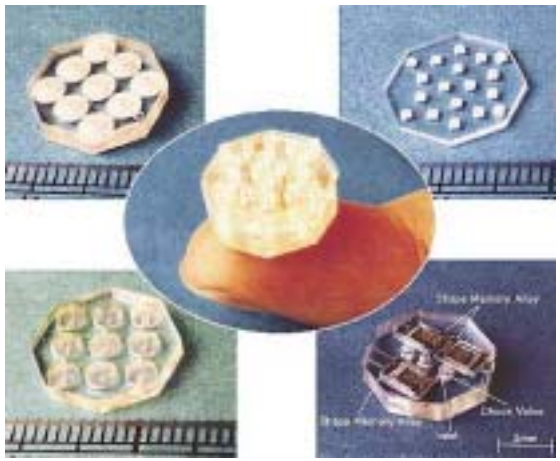
DNA Chip

Source: Stanford Medicine Magazine, Vol 19, 3 Nov 2002
http://mednews.stanford.edu/stanmed/2002fall/translational-dna.html

Chemical IC



Source: Tokyo Techno Forum 21, 21 June 2001
http://www.techno-forum21.jp/study/st010627.htm

The Smallest Computer

- The smallest programmable DNA computer was developed at Weizmann Institute in Israel by Prof. Ehud Shapiro last year
- It uses enzymes as a program that processes on on the input data (DNA molecules).
- http://www.weizmann.ac.il/mathusers/lbn/new_pages/Research_Biological.html

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Pros and Cons

+ Massively parallel processor
  DNA computers are very good to solve Non-deterministic Polynomial problems such as DNA analysis and code cracking.
+ Small in size and power consumption

Pros and Cons (Contíd)

- Requires constant supply of proteins and enzymes which are expensive
- Errors occur frequently
  a complex selection mechanism is required and errors increase the amount of DNA solutions needed to compute
- Application specific
- Manual intervention by human is required

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Conclusion

- Many issues to be overcome to produce a useful DNA computer.
- It will not replace the current computers because it is application specific, but has a potential to replace the high-end research oriented computers in future.
- Nanotechnology?

References

- ì**Molecular Computation of Solutions to Combinatorial Problems**î, *L.M. Adleman*, Science Vol.266 pp1021-1024, 11 Nov 1994
- ì**Computing With Cells and Atoms** ñ an introduction to quantum, DNA and membrane computingî, *C.S. Calude and G. Paun,* Taylor & Francis, 2001
- ì**The Cutting Edge Biomedical Technologies in the 21st Century**î, Newton, 1999
- ì**Human Physiology**: From Cells to Systems 4th Ed.î, *L. Sherwood*, Brooks/Cole, 2001