

Project: Future of Medicine

By Markus Kirkilionis

February 20, 2015

1 Introduction

The aim of this project is to investigate the role of novel scientific developments in an evolutionary push to establish more efficient diagnosis and treatments in a future medicine. It is evident that there are two key factors that have recently emerged, which will have a major impact on medicine:

- data revolution
- data analysis revolution

In this project we like to clarify what is currently driving these two factors, and where a new type of mathematical systems analysis (combining different theoretical techniques mentioned below) can help to facilitate the transition to which medicine is currently exposed.

2 Data revolution

The data revolution in itself has two major contributions:

- novel experimental technologies
- novel information and communication technologies (ICT)

2.1 Novel experimental techniques

Novel experimental techniques can be found on nearly all levels relevant for an empirical medicine:

- Advances in microscopy, allowing to investigate cellular processes in vivo

- Massive bio-molecular screening capabilities
- Massive genetic sequencing capabilities
- Robotic mass screening of potentially pharmaceutically relevant biomolecules
- others (and there are many more)

2.2 Novel information and communication technologies (ICT)

Computer technology and communication between computing devices (the combination of intranets and the internet) has improved so considerably that there is hope that the data assembled by novel experimental techniques can be stored, analyzed, and used in direct treatment of patients:

- Medical records can be stored in data bases, analyzed and compared statistically on a massive scale
- Diagnosis is not the issue of single physicians or laboratories, but the experience of the whole medical community, including computer based expert systems, can be used to full advantage at future 'connected' GP locations
- Surgery can be done remotely or even automatically, driven by massive sensory and knowledge input, from modern precision sensors and self-learning data bases.
- Patients can interact with the health system remotely, including access to data bases
- Data retrieval from books and journal papers (text mining)
- others (and there are many more)

3 Data analysis revolution

The data assembled and distributed by techniques as discussed earlier will need to be assessed with their potential to improve medical knowledge, both in diagnosis and treatment. There are two very distinct techniques (you could even call them 'philosophies') how to gain knowledge from data:

- The scientific method
- The learning method

3.1 The scientific method

The scientific method is based on conjectures and refutations (see [1]). The logical problem of science is that it should state true facts only, and therefore cannot rely on empirical induction (the 'black swan problem', see [2]). Therefore it needs to make hypothesis (conjectures), which then lead to predictions in the empirical world, which then can be either temporarily positively tested (verified, given the experimental boundary conditions), or refuted. The scientific method in this sense is a learning method, but it is empirically predictive, not empirically extrapolating, in the way (inductive) learning methods (see below) are constructed. It needs to be checked what modern scientific-based data analysis methods can achieve for medicine in this respect:

- (Predictive) Molecular dynamics, predicting novel pharmaceutical components
- (Predictive) Bioinformatics, using data from genetic sequencing
- (Predictive) Image analysis, using data from modern microscopy techniques
- (Predictive) Biological pathway analysis, 'Systems Biology' in general
- (Predictive) Numerical simulation of tissues and organs, we call this here creation of 'functional analogues' of reality
- others (and there are many more)

3.2 The learning method

Despite the hypothesis driven scientific method, inductive, associative, statistical, generally 'extrapolation-based' methods have a strong presence, mainly due to the fact that they are implementable on modern computers in the form of learning algorithms. Typically there are algorithms (such as back-propagation) with which the learning algorithm is trained in a finite number of steps, and then it usually can 'detect' a certain situation (in this context we call this 'diagnosis') in new data sets (for example encountering new patients). There are a number of different types of learning algorithms, each with own strength and weaknesses:

- Artificial neural networks, including Boltzmann machines
- Bayesian statistics, including Bayesian networks
- Hidden Markov models
- Learning Automata
- others (and there are many, many more)

Essentially any high-parametric mathematical equation defined on a structure, such as a network, equipped with a learning algorithm (including global optimization), that compares and adapts its state with the help of given data, can be interpreted as a learning method. The success of supercomputers equipped with learning algorithms can be seen from the example of 'Watson', a novel supercomputer by IBM. It is a general purpose machine, and can be trained on any arbitrary data set. It has some years ago won prizes in associative, knowledge-based TV shows, competing against humans, see the figure below.



Figure 1: Watson in action

Watson has also been trained on cancer data, and according to specialists in the field, has gained expert knowledge far superior to any human. However, as a side remark, Watson is not creating any own data, i.e. it does not do any experiments.

4 What to do in this project ?

This project can be taken by several students, it is even better if a group of people would work on it. On an MSc level, the student should produce a report filled with actual references for all subjects raised in this project structure. In addition, each student should take up one area of specialization, and report on the mathematics and methods associated with the field. Depending on the specialization, I will contact appropriate specialists who can give expert input to the student. The most important outcome from this project is to gain an overview over present developments in medicine, and to outline opportunities for a future improved medicine.

References

- [1] K. Popper: Conjectures and Refutations.
- [2] K. Popper: The Logic of Scientific Discovery.