Revolutionizing Health Management
Using Cybernetics

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Cybernetic health is going to disrupt the healthcare industry to provide a more effective and efficient approach to personal health management. Artificial Intelligence (AI), including machine learning, augmented reality and gamification, and data management, provide key components in implementing a cybernetic approach. This new approach to health is the result of the metanexus of genetics, biology, sensing data, and smartphones facilitating the application of medical knowledge to guide people in adapting their lifestyle, environment and socio-economic situation to better maintain their health and maximize their quality of life.

UNDERSTANDING CYBERNETICS

Cybernetics principles, proposed as a mechanism for control and communication in machines as well as living systems, have transformed the design of complex systems. Continuous measurements are a key component in closed-loop feedback control, which is essential for implementing systems that work in real-world noisy environments. From a simple thermostat-based air-conditioning system in a home to soon-to-be-popular autonomous cars, these principles are omnipresent.

In the simplest terms, cybernetics is about setting goals and devising action sequences to accomplish and maintain those goals in the presence of noise and disturbances (see Figure 1).

Figure 1: Feedback control — the main component of a cybernetics systems.

EXPLORING THE TRANSFORMATIVE EFFECTS OF CYBERNETIZATION

The founder of cybernetics, Norbert Wiener, saw the transformative power of his invention early on. In fact, his concerns about the social implications of automation in industry and the possibility of machines becoming more powerful than humans led him to stop pursuing research in this area.
The cybernetization of an existing approach is enabled by the availability of sensors that can estimate the system state and perpetually feed this information back to the system, letting it generate new control signals as required to move toward the desired goal or destination. Navigation systems present a good example of the effects of cybernetics.

Babylonian clay maps date back to about 2300 B.C. Over the centuries, maps evolved with technology, and around the year 2000, online maps became very popular. Powerful algorithms let people plan their routes using these digital maps, so users could print turn-by-turn directions for optimal routes based on different factors such as minimum distance or the avoidance of highways and toll-roads (see Figure 2).

![Figure 2: Once all maps were computerized, it became easy to use algorithms to find the optimal route between two points and generate turn-by-turn directions.](image)

The real revolution, however, came with the prevalence of sensing techniques. When GPS became easily available, inexpensive and sufficiently accurate, it started appearing not only in cars but also mobile phones and other devices, offering current location data. Crowd sourcing and other approaches then became powerful enough to determine real-time traffic. This enabled the cybernetization of the navigation space, as shown in Figure 3, and navigation systems became so effective and easy to use that most people don’t even think about using actual maps anymore. They simply expect to enter their destination on their mobile phone or car dashboard to receive step-by-step audio guidance, automatically rerouted as needed based on real-time information.

![Figure 3: The cybernetization of navigation systems required automatically knowing the current location and using it perpetually to determine routes, considering traffic and other factors.](image)

This is power of cybernetics, allowing the system to remain effective even in presence of noise and varying conditions.
APPLYING CYBERNETICS TO HEALTHCARE

The human body and other biological systems have an intricate play of real-time sensors and actuators function. Homeostasis is based on similar feedback principles. When something within the human body fails to function properly, the unstable condition results in a disease, and we try to cure this condition by fixing the defective components in the communication/control loop.

In current medical practice, this process of fixing the cybernetic loop is based on alerts from the person. However, in some cases, these alerts are too late, resulting in serious consequences. In other cases, the alerts remain below the level of consciousness for the person, but they are usually manifested in biological markers that can be measured using sensors. These measurements can be used to estimate the person’s health state, and, if required, corrective actions can be taken to return the person to the desired state. Such actions might include making lifestyle or environmental changes or taking medication. These actions would be determined based on biological and medical knowledge and a model of the person. This sensing loop for perpetually measuring the person’s health state and taking corrective action brings cybernetics to health management.

Progress in technology can extend the cybernetic loop for a person outside his or her body using emerging sensors and following cybernetic principles of continuous monitoring for proper communication and control. AI is very useful in enabling this loop, and machine-learning-based tools facilitate diagnosis and help estimate health states. Contextual reasoning will also help by guiding the person to take corrective actions based on all available medical and environmental knowledge.

DISRUPTING TODAY’S HEALTH CYCLE

Currently, most people think of their health only when they are sick. When they feel under the weather, they visit a doctor. A successful doctor’s visit results in the diagnosis of the person’s health state (possibly a disease) and a prescription for medicine and any other regimen that will help cure the disease or at least ease the discomfort. Usually, the doctor’s office then schedules a follow-up visit.

Consider this process from the patient perspective:

1) You are not feeling good. Some of your health state parameters are not in their normal range, resulting in an uneasy and abnormal state. Once the state is beyond your tolerance, you reluctantly see a doctor.
2) An assistant takes routine measurements of biomarkers, including weight, temperature, heart rate, and blood pressure. When the doctor comes, she usually listens to signals inside your body using a stethoscope and asks questions related to your health status and your family and health history. She is trying to estimate your current health state and build and update your personal model.
3) To get a better understanding of your health parameters, the doctor further examines your body and checks your vital signs. If these measurements don’t provide enough data for the doctor to estimate your health situation, she orders imaging or pathology tests to obtain further data about your internals. This data is essential in estimating your health situation.
4) Combining all observations and using all medical knowledge, the doctor estimates your current health state, characterizes it as one of the known disease states and determines its level of severity.
5) The doctor uses your personal model and current health state, her own medical knowledge about diseases and general environmental knowledge to recommend corrective actions in the form of prescriptions and a regimen. These may involve medication, lifestyle or environmental changes, or some other treatment.
6) You try to follow the regimen. Taking medications is easy; making lifestyle changes (such as controlling your diet) is often more difficult. There is generally no mechanism to verify compliance. The assumption is that you are interested and able to comply, but there are not many good approaches to remind people about complying with the prescription and suggestions.

7) Depending on the severity of the disease, the doctor might want to see you periodically to repeat Steps 2–6 as needed. The period depends on criticality: you might revisit the doctor’s office, be admitted to the hospital, or receive critical care.

What does this process reveal? The lifeblood of your health is your data.

Data is converted into actionable information. Knowledge from different fields, particularly from the medical sciences and about the environment, is used in estimation and recommendation. Data comes in a variety of forms and is measured using a variety of different “sensors,” such as personal feelings, vital-sign measurements, imaging and pathology reports, the doctor’s estimation based on the data collected via his or her audio-visual-tactile senses, and many more.

In this process, the first three steps involve data acquisition, Step 4 is state estimation, Step 5 is recommendations from a professional using knowledge of the field, Step 6 is compliance by the patient, and Step 7 is follow-up or repetition at regular intervals to manage further complications. These steps form a MEGI cycle: Measure, Estimate, Guide, and Influence, as shown in Figure 4. This cycle has evolved over a long period and has stabilized to its current form as discussed here.

During the Measure step, data is collected from many relevant sources, from the person, by the doctor, and by different pathologists and imaging teams (upon request by the doctor). Using the data, the doctor estimates patient’s health state to diagnose the problem.

**Figure 4:** The Measure, Estimate, Guide, Influence (MEGI) cycle is the norm. It has many built-in delays and components that would work effectively if AI and data science were used with the right sensors. Another problem is that this is an open-loop system.

Diagnosis is usually in the form of a disease and its level of severity. This Estimation step is what is most important in current healthcare. Once you get the right diagnosis, medical and other knowledge guides the prescriptions and regimens.

The Guide step is to personalize these prescriptions and regimens based on the specific patient and his or her personal situation.
Doctors encourage their patients to follow the prescriptions and regimens and usually request a follow-up visit, at which point the cycle is repeated. This can occur within months, weeks or days, or in severe cases, the person might be admitted to hospital for frequent repetition of the cycle. In extreme cases, a surgery followed by admission to an Intensive Care Unit might be advised.

**CYBERNETIZING THE MEGI CYCLE**

Can we “cybernetize” the MEGI cycle — that is, apply the principles of cybernetics to the cycle? In the current MEGI cycle, there are many human elements and the ultimate operation is not a closed-loop system. Many measurements involve humans — the patient, doctor, pathologists and radiologists and so on. The guidance and influence parts also involve doctors and other people. So, can we apply a cybernetics approach to personal health to gain the benefits of self-regulation as has happened in many other complex systems?

Given how progress in sensors, computing and AI has disrupted so many fields, it’s natural to ask whether MEGI can be cybernetized. Personal healthcare is one of the most important areas for disruption because of the implication for our quality of life. The financial impact is also likely to be staggering.

Common sensors (accelerometers, gyroscopes, GPS, cameras, and microphones) are now found in almost every smartphone, and other measurement technologies are appearing, including those that measure temperature, perspiration, heart rate, sleep, galvanic skin resistivity, blood oxygen, blood sugar and blood pressure, making cyber health possible.

The cybernetization of the MEGI cycle will result in a major disruption in personal health.

**CREATING A PERSONAL HEALTH NAVIGATOR**

Let’s now map the seven steps discussed above in a cybernetics version of the MEGI cycle with the following components.

**Measurement:** Using a smartphone and augmenting wearable sensors already on the market with emerging sensors that can measure many bodily functions, we could identify normal bodily parameters to determine the health state. A device, likely a smartphone or its equivalent, would continuously collect all of these measurements. This data would measure most of the information related to the person’s health state. Only under very specific situations would special measurements be required. (Steps 1-3 above.)

**Estimation:** All those measurements could be used to estimate the person’s health using mathematical as well as medical knowledge-based techniques. This estimation could indicate proximity to a disease. The goal of estimation would be to measure your health state without assigning the state to a specific disease or other semantic labels. (Step 4 above.)

**Guidance:** If the user wanted to change his or her health state, the user would issue a request and the system would use medical, environmental and other relevant knowledge sources to provide the right guidance in terms of lifestyle or environmental changes or medications for getting to the desired state. This guidance would be perpetual until the user achieved the desired state. (Step 5 above.)
**Influence and Compliance:** Providing guidance alone is not enough. Guidance must be situationally actionable and easy to use and follow. In most cases, mechanisms for nudging, incentivizing and inspiring might be required, along with subtle approaches for measuring compliance. (Steps 6-7 above.)

What is equally important is to implement this cycle on an almost continuous basis by performing all of these steps frequently to make sure that the person’s health state remains in a safe zone. This implementation rate can be directly determined by the system.

The above steps are for dealing with non-emergency health situations. The system could function autonomously most of the time but could direct the user to a nearby resource in an emergency situation.

**ADDRESSING THE CHALLENGES**

Of course, numerous challenges must be addressed before we can reap significant benefits from cyber health. The following are major challenges in implementing cybernetic health. Figure 5 shows a cybernetic health system representing future health.

**Figure 5:** A cybernetic health system is a closed-loop system based on continuous measurement. Guidance is based on a knowledge-based recommendation engine. The main system components are shown here.

**Building Personal Models:** Each individual is a unique system that must be modeled to effectively estimate this person’s health state and provide precise guidance. The personal model captures how a person reacts to different stimuli under specific conditions.

To model a person, some relatively longer-term information comes from her genome modulated by the proteome, transcriptome and epigenome and reflected in the metabolome. Lifestyle, environment and socio-economic factors also play an important role in building the model of a person. This model is not static; it changes with age and other life conditions, so model building is a dynamic process.
**Estimating Health States:** Based on measurements of different biomarkers, the health state of a person must be estimated. In current medical practice, this step is same as diagnosis of a disease condition. To better understand health, more quantitative approaches require defining more health state objectives. The health state can be classified as a disease state in the same way as a combination of basic color components may be called pink or purple, but to manage colors more precisely, one must consider the primary components. A person’s health state characterizes health objectively and can be assigned different symbolic labels, like diabetes. To implement predictive, preventive and precise medicine, it is important to objectively characterize health. Disease centric estimation looks at the health state through colored glasses and is likely to result in biased decisions.

Estimation techniques for health states will require deep biological knowledge. Formal state-space models might emerge over time with associated observability and controllability conditions. In the interim, however, we might need to build rule-based modeling techniques to implement other aspects of the complete system.

**Organizing Situationally Actionable Knowledge:** Prescriptions and specifications of regimens to deal with diseases are common techniques currently used in medicine. These techniques are based on available medical knowledge and other relevant knowledge sources including environmental knowledge. Effectively, all knowledge sources are organized to find and recommend appropriate actions in a given situation.

These knowledge sources might need to be organized at a finer granularity to deal with changing the health state rather that getting the person out of the disease state. Moreover, depending on the perspective of the designer, different knowledge sources might be used.

**Influencing and Encouraging Compliance:** Once a recommendation about lifestyle and medications is made, the person is responsible for following up and complying with the specifications. As is well known, for various reasons, influencing people to follow the recommendations has been a challenge. Techniques must be developed to influence people and help them with compliance.

**EXPLOITING OPPORTUNITIES**

Cybernetic health is becoming a possibility because of the metanexus of biology, genetics, sensors, computing, and mobile devices. Progress in these areas opens up the possibility of building personal models and using them in a cybernetic framework. In addition to the obvious advantages of a closed-loop feedback system, the ability to measure biomarkers and take frequent (even instantaneous) actions allows this “personal navigation system” to function satisfactorily even when the model and the measurements are not perfect.

Another major opportunity is created by the smartphone, which is fast becoming a surrogate of the person — for measurements as well as for alerts and actions.

Furthermore, cyber health is not only for implementing personal health navigation. All of the data collected for an individual could be shared and aggregated to build powerful population models related to diseases to provide recommendations in different situations.

Effectively, we have an opportunity to help each individual using this approach as well as to advance our understanding of diseases and expedite research of potential cures. The availability of massive data by combining individual data is unprecedented. We need to build on it.

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