

THE COLLECTION OF BIOMETRIC DATA AND ITS IMPACT ON  
HEALTHCARE PROVIDERS

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A dissertation submitted to University o Dublin in partial fulfillment of the  
requirements for the degree of Master of Science in Heath Informatics

2005

## **DECLARATION**

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university.

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## **DISSERTATION SUMMARY**

There is a revolution in healthcare that will make a huge impact on our lives. Whether one is being treated in a physician's office, hospital, emergency room or biological samples are being investigated in a laboratory, the converging and emerging advances in technology the resulting depth of knowledge is nothing short of amazing

The pervasiveness of biometric devices has the potential to instigate unprecedented levels of preventative and corrective actions that can be chosen by healthcare providers as a result of this biometric data collection. The use of this biometric information will have a major impact on treatment outcome.

Unfortunately, the less positive aspect of this revolution will be the avalanche of data being thrust upon care givers exacerbating a situation where patient safety is being seriously compromised. Every new biometric device will be accompanied by additional streams of data. These devices will be interconnected and will act in concert. E.g., nanotech gene identifier allied with mems drug delivery allied with biometric telemetry will require significant communication to act in concert, control of which could be governed by decision support systems. The data will need to be captured as part of an Electronic Health Record (EHR). The challenge will be how to present this data to the care givers in a manner that is comprehensible, timely and useful.

To realize the benefits of this revolution in healthcare attention must be directed to the way in which information is derived and presented to care givers. Account must be taken of human cognitive and physiological capabilities and limitations. Advances in Data visualization and cognitive systems must and will make significant strides to bridge the divide between how data is used currently and its

true potential. The combination of these two disciplines could provide something really useful.

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## CHAPTER 1. INTRODUCTION

### 1.1. Introduction

The dissertation will present an examination of the potential effect of data and information growth in the provision of healthcare.

Whether one is being treated in a physician's office, a hospital, an emergency room, or biological samples are being examined in a laboratory, converging as well as emerging healthcare advances continue unabated. These include in-vivo and in-vitro diagnostic and therapeutic devices. This double edged sword of better, faster and more data and potential information overload needs to be presented in a way to facilitate human physiological and cognitive capabilities. Their respective limitations must be addressed in order to truly reap the benefits and eliminate the negative effects that these additional streams of data can have in the provision of care.

With the exponential growth of data presented to care givers comes a bewildering amount of information from which to make critical decisions in the provision of care. Given human physiological and cognitive limitations the introduction of error in decision making may inevitably increase. Errors as a result of information overload are estimated at a 6 x increase. *(14 Williams J).*

Interestingly if we look at the top 10 list of reasons for Malpractice *(28 Maureen Glabman)* risk in a significant proportion of these areas can be mitigated through a holistic view of patient history and interactions with Healthcare systems. Here again the issue of data volume and information usage resurfaces. The question is, how much an individual can comprehend and remember long enough to make the right decision.

## The Top Ten Malpractice Claims

1. Medication errors
2. Diagnosis failures
3. Negligent supervision
4. Delayed treatment
5. Failure to obtain consent
6. Lack of proper credentialing or technical skill:
7. Unexpected death
8. Iatrogenic injury, nosocomial and wound infections, fractures
9. Pain and suffering, emotional distress
10. Lack of teamwork, communication

Extensive research has been conducted by means of white paper review, published and work in progress articles review, book review and interview into the cause of information overload through information growth and its effect i.e. the introduction of error. Sources used were as diverse as U.S. Central Intelligence Agency (CIA), Sandia National Laboratories, Dept of US Navy “Knowing: The Art of War 2000” and various Healthcare centered bodies such as California Health Foundation, American college of Surgeons (re patient safety) (**27 Christel Mottur-Pilson, PhD**), The New England Journal of Medicine, iHealthBeat publications from California HealthCare Foundation as well as interviews in St James Hospital Dublin.

In chapter 2 the current trends of data growth from a technology centric viewpoint will be presented illustrating the continuous growth pattern of data and the inevitability of exacerbating an already difficult situation of sifting through the

mountain of information. Examples of contributing factors and devices that are adding to this growing data mountain are presented.

In chapter 3 the possible root of the issue i.e. Human Cognitive/Physiological capabilities and limitations and how they effect decision making in a healthcare setting will be covered. This section draws from extensive work done for military purposes where similar problems are presented to a small number of people requiring near real-time decision making. The comparison between military and healthcare is relevant as these two apparently unrelated areas display similarities in the sense that large and sometimes confusing streams of data are being gathered from a myriad of sources.

In the remaining chapters 4-5 two areas are covered that could begin to address the chasm between the data avalanche and that of human cognitive and physiological shortfall i.e. Cognitive Systems (**24 Firsythe et al**) and Data Visualization.

To demonstrate how new technology can simplify and reduce the cost of current diagnostic equipment a simple device using mote technology has been developed to capture data representing the electrical activity of the heart. Alternative methods of display are explored which take account of cognitive and physiological needs. This data is then wirelessly transmitted to a receiver attached to a PC where the signal is represented on an oscilloscope application written in Visual basic 6.0. The Wave form is also represented in a waterfall plot to give an alternative view of the data. Further development will be discussed in order to demonstrate changes in the way in which raw data can be represented i.e. move from standard trace to multidimensional representation. This will be covered in chapter 6.

Finally in Chapter 7 the conclusions are presented.

## **1.2. Motivation**

Initially the primary thrust of this project was to develop an Electrocardiograph using miniaturized wireless devices and present how such devices could benefit caregivers in the provision of care. Based on research of current available devices mote technology was chosen as they had all the major components of a standard desktop PC albeit in a limited scale. These devices are easily modified to process sensory data collected by electrodes for example. When researching on data interpretation and presentation it became evident that while these devices can be beneficial they are also adding to the current problem of information overload.

Because of the growing pervasiveness of biometric devices as well as advances in other areas of data generation the potential exists for unprecedented levels of preventative and corrective actions that can be taken by care givers. This will have a major impact on successful treatment outcome, just as importantly though will be the challenge of using this data in an effective manner. To reap the benefit that these advances in technology can give, a thorough understanding of Cognitive and Physiological capabilities as well as limitations must be comprehended within the resulting information processing thereby allowing care givers focus their attention on the most relevant facts. Unless we address the way in which information is presented to caregivers they may be hopelessly overloaded from a sensory and cognitive perspective and thereby do more harm than good.



## CHAPTER 2. INFORMATION GROWTH AND INFORMATION OVERLOAD

The unrelenting progress being achieved in all areas of technology has generated exponential growth in information. People often ask, "How fast is information growing in our society?"

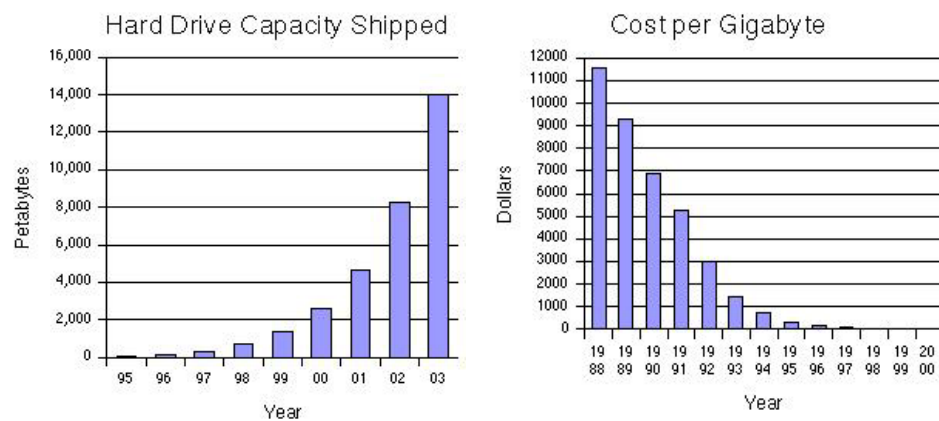
Hubert Murray (*18 Murray, Hubert, Jr.*) estimates that: - In every 24-hour period approximately 20,000,000 words of technical information are being recorded. A reader capable of reading 1,000 words per minute would require 1.5 months, reading 8 hours every day, to get through one day's technical output, and at the end of that period, he would have fallen 5.5 years behind in his reading.

Consider the fact that more new information has been produced within the last thirty years, than in the last five hundred years. Over 9,000 periodicals are published in the United States each year, and almost 1,000 books are published daily around the world. The November 13, 1987 issue of The New York Times numbered 1,612 pages, containing about 2,030,000 lines and over twelve million words. A report published in 2000 by Organization for Economic Co-operation and Development (OECD) shows secure web servers per million growing nearly six fold in as little as 3 years (ref figure 2-2). It is no wonder that the term "information explosion" has become so commonplace.

In a study (HOW MUCH INFORMATION 2003) (*34 Peter Lyman et al*), summary estimates show that the storage of new information has been growing at a rate of over 30% a year (upper estimate, uncompressed). There has been dramatic growth in storage of new information over the past two years in every storage medium except film. Of particular note is the growth in magnetic storage i.e. 117%. This is reflected in the volume of magnetic disk that has been shipped over the

period 1995 – 2000 with storage technology becoming a commodity priced item.

Ref figure 2-1



Source: How much information 2000

Figure 2-1 a) Worldwide PC hard drive capacity shipped. (1999 Winchester Disk Drive Market Forecast and Review) b) Hard drive cost per gigabyte. (IDC reports.)

Some examples of this growth are shown in Figures 2-2 to 2.4

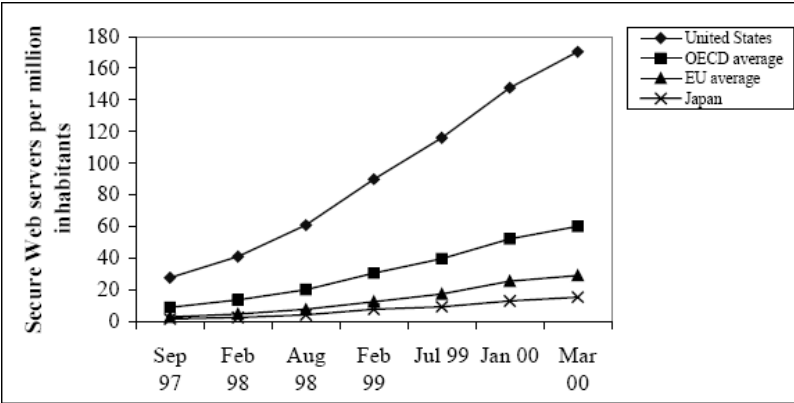


Figure 2-2 Growth of secure web servers storage technology becoming a commodity priced item.

Figure 2-3 shows information growth rates in PubMed and Patent Databases over the last 35 years.

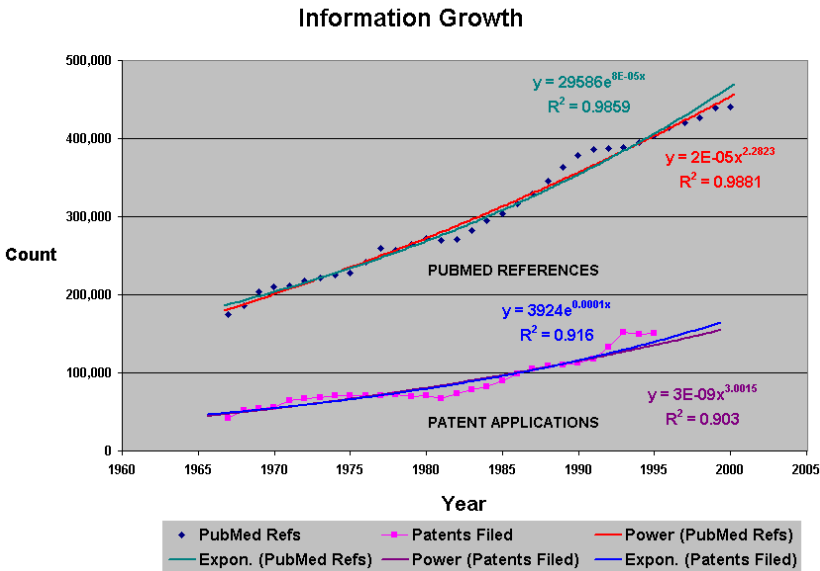


Figure 2-3 Information growth (source PubMed/US Patent office)

A further example of information growth in the field of medical science is in the area of DNA sequencing. Statistics from GenBank a comprehensive database that contains publicly available DNA sequences for more than 140000 named organisms shows startling growth from 1999 – 2004 ref figure 2-4

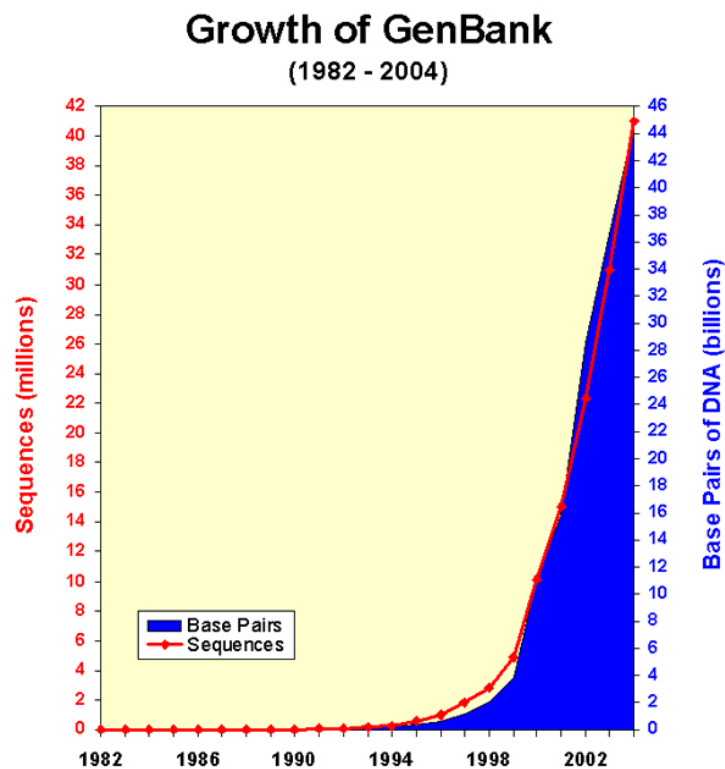


Figure 2-4 Genbank growth statistics Source  
National Center for Biomedical Information (U.S.)

Magnetic storage encompasses a wide range of media, from mini cassette tapes to terabyte-sized file servers and gives a good indication of growth storage requirements from 2000 to 2003.

Table 2-1 Comparison of production of original information for the major magnetic media types - 2000 sources vs. 2003 sources

Media Type	% change	Year	Unique Items per Year (World)	PB per Year (World)
Video tape (VHS and camcorder)	<b>-6%</b>	2000	355,000,000	1,420
		2003	220,000,000	1,340
Audio tape (analog)	<b>-30%</b>	2000	184,200,000	184.2
		2003	128,800,000	128.8
Digital tape [???	<b>0</b>	2000	5,000,000	250
		2003	5,000,000	250
Floppy disks	<b>-27%</b>	1999	75,000,000	0.11
		2003	55,000,000	0.08
Zip disks	<b>-68%</b>	2000	4,400,000	1.69
		2003	1,400,000	0.35
Flash memory		2000	N/A	N/A
		2003	43,000,000	1.2
Hard disk drives	<b>114%</b>	2000	39,918,000	926
		2003	43,928,000	1,986

Source: *How much information 2003*

## 2.1. Contributing Factors/Devices to this Growth scenario

Whether one is being treated in a physician's office, a hospital, or an emergency room, the advances in technology being applied in the provision of healthcare are nothing short of amazing these include in-vivo as well as in-vitro diagnostic and therapeutic devices, and implantable and disease-targeting drugs.

These breakthroughs are largely based on emerging micro technology and nanotechnology electronics. New tools with micro robotic grippers and tweezers

will offer surgeons the ability to operate on just about any part of the human body, no matter how small. Targeted drug delivery and analysis devices are also making great gains.

Examples extracted from Healthcare Information Management Systems Society (HIMSS) trends in healthcare and Healthcare Informatics top technology trends indicate areas where additional streams of data are currently being generated or soon will be:-

- Micro-array lab-on-a-chip
- Implantable Probes
- Reservoir Arrays
- Point-of-care diagnostics
- Biological Process imaging
- Nanomedicine
- Miniature Devices
- Micro-Micro Computing

## **2.2. Micro-array lab-on-a-chip**

Micro-array lab-on-a-chip products for point-of-care diagnostics are already at the clinical trial stage. A micro-array lab-on-a-chip is an array matrix that lets care givers instantaneously analyze fluids, cells, and even DNA structure right in the office. This high throughput analysis will be a boon to medical and pharmaceutical industries. The lab-on-a-chip promises high-speed fine-tuned identification of the protein sequences that make a difference in specific diseases. Many of these devices can be worn on the wrist or tucked under a belt.

Diagnostic chips for investigation of problems concerning vital organs such as the brain, heart, eyes, lungs, liver, and kidneys, are expected within five years. NASA researchers are developing complex, portable microarray diagnostic chips to test for all the genes and DNA responsible for determining the traits of a particular organism. **(67 Allan)**

### **2.3. Implantable brain probes**

The detailed study of neural activity using implantable brain probes is already possible. Currently "brain-on-a-chip" devices are under development; these "brain-on-a-chip" devices will allow care givers to view the simultaneous interactions occurring between brain neurons. The devices will enable diagnosis and treatment of various mental and other brain disorders. **(67 Allan)**

An example of such a device is the Center for Wireless Integrated MicroSystems WIMS cochlear prosthesis test bed, aimed at developing an implantable "button" capable of simultaneous multi-point recording, stimulation, and drug delivery at the cellular level. Figure 2.7 The first prototype of this prosthesis is aimed at recording signals from the motor cortex to provide closed-loop control of a robotic arm. The system is made up of a number of different components including the probes, flexible interconnects, interface electronics, a wireless link. **(69 Hetke)**

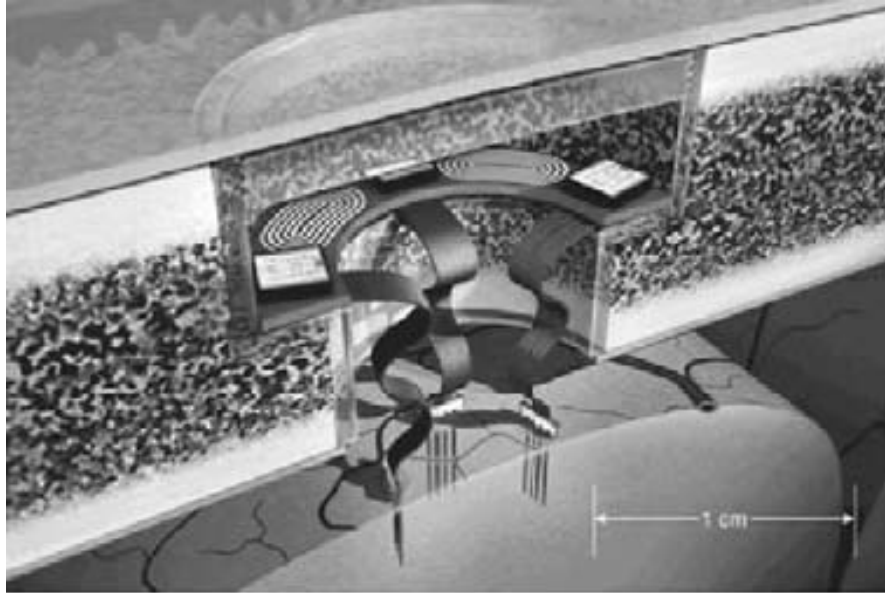


Figure 2-5 Microscale Intracortical Neural Interface.

#### 2.4. Reservoirs Arrays

Subcutaneous implanted microchips are already proving their value in the area of drug delivery and monitoring. Implantable devices consisting of sealed arrays of reservoirs will be available for in-vivo and in-vitro drug analysis and delivery. These devices will be filled with drugs that can be released on demand and can check the efficacy of treatment released over long periods of time. (68 Healthcare Informatics)



## **2.5. Point-of-care diagnostics.**

Detectors of specific molecules will be developed and integrated into compact devices that can be used to provide real-time information about diseased cells or tissues, and thus can be used to determine targeted treatment options. Delivery and data collection mechanisms for these nano devices will be deployed throughout the healthcare delivery system, related devices would be implanted *in vivo* to provide real-time records for monitoring disease progression and therapeutic efficacy. **(68 Healthcare Informatics)**

## **2.6. Biological Process imaging**

Current imaging methods provide excellent information on the structure of molecules *in vitro* (e.g., X-ray diffraction) and high resolution of anatomical information *in vivo* (e.g. computed tomography). However, to understand dynamic living systems, and how they are affected by disease, we need to be able to image biological processes non-destructively *in vivo* in real time. GE Healthcare recently announced a 9.4-tesla magnetic resonance imaging (MRI) machine. With this level of power the MRI will enable researchers to detect signals from sodium, phosphorus, carbon, nitrogen, and oxygen -- the metabolic building blocks of brain function -- enabling them to look in detail at memory, vision and language. **(68 Healthcare Informatics)**

## **2.7. Nanomedicine**

Nanomedicine, defined as the monitoring, repair, construction and control of human biological systems at the molecular level, using engineered nanodevices and

nanostructures. Basic nanostructured materials, engineered enzymes, and the many products of biotechnology will be enormously useful in medical applications. **(70 Freitas)**

#### **2.7.1. Miniature Devices**

The rapid development of on-chip radio technology, with the ongoing evolution of miniature sensor technology, MEMS enables the creation of autonomous, integrated radio-sensor modules with powerful sensing and communications features. These wireless modules operate independently, sensing the environment and forwarding the collected information across a wide area, economically and efficiently. It is therefore no surprise that applications are flourishing. The cost target in volume quantities was less than \$50-100 per node in 2004 and is expected to decline to less than \$25 by 2008. In fact, many of the platform systems are already smaller and cheaper, depending on sensor type, range and power. **(68 Healthcare Informatics)**

#### **2.8. Micro-Micro computers**

##### **2.8.1. Mote Technology**

The "mote" concept creates a new way of thinking about computers, although the basic idea is pretty simple and incorporates many of the components commonly found in a standard Personal Computer.:

The core of a mote is a small, low-cost, low-power computer that monitors one or more sensors. E.g. electrical activity (ECG), blood pulse oximetry, temperature, pressure, humidity, etc. Not all mote applications require sensors, but sensing applications are very common. The computer connects to the outside world with a radio link in a similar way in which a laptop computer

connects to a wireless area network (WLAN). The most common radio links allow a mote to transmit at a distance of something like 10 to 200 feet (3 to 61 meters). Power consumption, size and cost are the barriers to longer distances. Since a fundamental concept with motes is tiny size (and associated tiny cost), small and low-power radios are normal.

In chapter 6 an example of mote technology will be used in the development of a basic Electrocardiograph (ECG or EKG) demonstrating its application.

## **2.9. Information Overload**

Information overload is the over abundant volume of information that must be examined, absorbed and comprehended. Often, large quantities of information must be digested just to locate the small piece that we need.

John Naisbitt (*17 Naisbitt, John*) writes, "Inundated with technical data, some scientists claim it takes less time to do an experiment than to find out whether or not it has been done before."

## **2.10. The Double edged sword**

Because of the pervasiveness of biometric devices and as a result, additional data collection there is the potential for a step change in quality of care. However with every new device there will be additional streams of data with a potential avalanche of data being thrust upon care givers each vying for attention. Appendix A shows the potential sources of information.

These devices will be interconnected and will act in a coordinated fashion as shown in figure 2.6. For example nanotech gene identifier allied with mems drug delivery

allied with biometric telemetry will require significant communication to act in concert, control of which could be governed by decision support systems and physicians. The data will need to be captured as part of the Electronic Health Record (EHR).

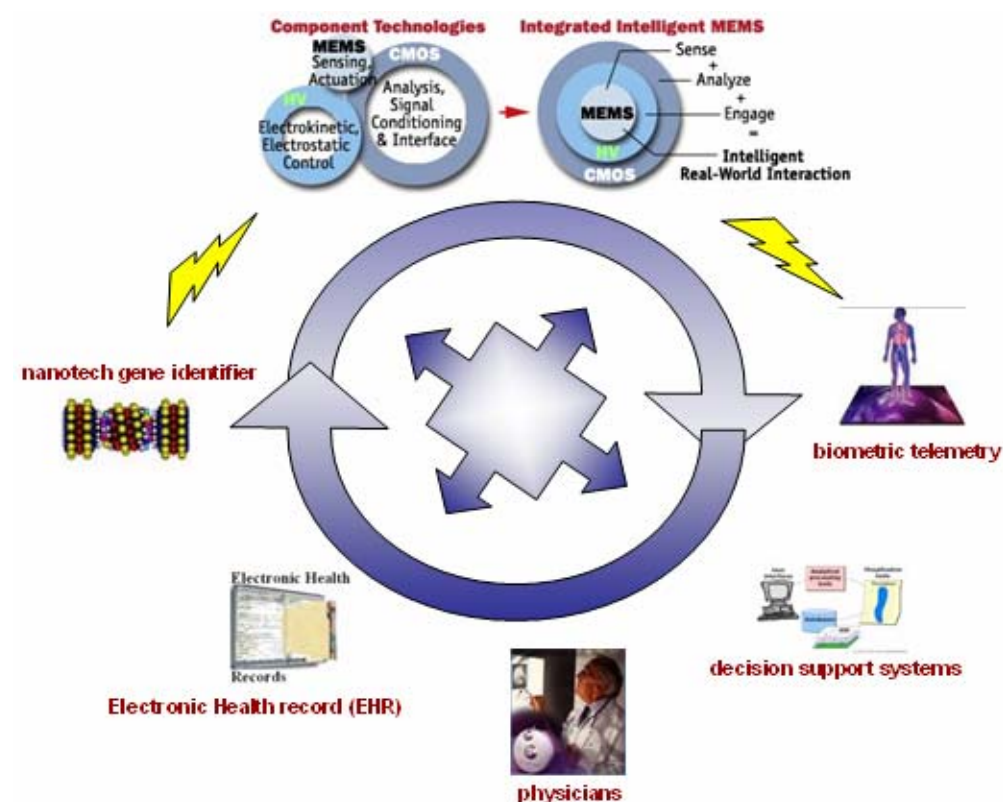


Figure 2-6 Nano to Micro devices coordinated to aid in the diagnosis and treatment of disease

Appendix A represents sources (department, specialties) of information within a healthcare setting. These areas will have many other data streams within their respective domains. Data from these sources can be continuous and real-time as in the ICU, ward or surgical setting or recent new data accumulated from nuclear medicine, laboratory, medication regimes, on-going review and patient interaction

as well as historical information derived from the electronic health record. Considering the complexity from a temporal and diverse data source that must be comprehended it is clear that care givers need help in the interpretation and presentation of these myriad of data points.

The challenge will be how to present all this data to care givers in a manner that is comprehensible, timely and useful while avoiding the downside effects of information overload. To understand the consequences of information overload a review of impact to patient safety is presented in 2.12.

**2.11. Situational Factors: - Impact on Patient Safety**

In J Williams (*14 Williams J*) report “A data-based method for assessing and reducing human errors to improve operational performance” Williams calls out a number of situational risk factors that can contribute adversely to patient safety, high in that list is information overload.

Situational Risk factors in decreasing order of magnitude:

- Unfamiliarity with the task                      x17
- Time shortage    x11
- **Information overload                                      x 6**
- Misperception of risk                                      x 4
- Inadequate checking                                      x 3

Only five situational factors are listed above, there are however more. Of particular significance is the fact that a combination of these areas is not cumulative i.e. Time Shortage + Information overload will not equal to a factor of 17, rather it will

increase almost exponentially. In Williams's estimation it is approx a factor of 50. Obviously a concern as care givers are rarely dealing with just one risk factor.

These factors were further discussed by the Society for Academic Emergency Medicine (SAEM) An SAEM task force was established and the findings published in a special issue of Academic Emergency Medicine in November 2000. The findings were similar to Williams and called out the following as contributing factors for errors in the emergency medicine setting. (*41 Croskerry et al*)

- High levels of diagnostic uncertainty
- **High Decision density**
- **High cognitive load**
- **High levels of activity**
- Inexperience of some care givers
- **Interruptions and distractions**
- Uneven and abbreviated care
- Shift work
- Compromised teamwork
- Poor feedback

Situational factors by themselves can promote the levels of error however no level of complexity has been discussed. If multiple steps are introduced the possibility of error is again increased relative to the number of steps that need to be executed for a given task to be completed.

## 2.12. Multiple Step Error Rates

The greater the complexity of the procedure the higher is the probability of error

- 1 step results in 5 percent chance of error
- 5 steps            in 33% chance
- 25 steps        in 72% chance
- 50 steps        in 92% chance

The error rate is directly related to the number of steps required, ranging from 5 percent for one step to 92 percent for 50 steps. *(15 Park H).*

One of the reasons medication errors are so frequent is based on this fact. Not only are multiple agents involved in the process but there are also multiple steps. This relationship between errors and steps is one of the reasons that simplification of a complex process is seen as a promising avenue to increase patient safety. It is not always possible to simplify a process by reducing the number of steps, More benefit may accrue from focusing on filtering the stream of information to caregivers thereby allowing them to concentrate on the truly critical facts. *(16 Nolan TW).*

## 2.13. Frequency of Medical Errors

The U.S. based Institute of Medicine (IOM) released a major report *(35 Kohn, Linda T)* on medical errors titled 'To Err is Human' in 2000. The report of which the major findings extrapolated statistically, highlighted medical errors may cause up to 98,000 deaths per year. That number would make death from medical error

the sixth largest cause of death in the U.S., according to the Centers for Disease Control (CDC).

The cost of these medical errors is enormous. Apart from the obvious human cost the report estimated the total cost of preventable medical errors could be as high as \$29 billion per year. Over half of that number represents healthcare costs or approx \$19 billion.

In 2004, HealthGrades released a report "HealthGrades Quality Study - Patient Safety in American Hospitals" (**36 Healthgrades**) which found that the IOM severely underestimated the number of deaths caused by medical errors each year. Its data suggest that the true number was closer to 195,000 deaths annually, nearly twice the number reported by the IOM. Also included in the report was some alarming statistics with regard to patient safety.

- 1.14 million or 3.08% of total patient-safety incidents occurred among the 37 million hospitalizations from 2000-2002.
- 1 in 4 patients that experienced a patient-safety incident died.
- Patient-safety incidents accounted for approximately \$2.85 billion annually in excess patient costs - nearly 3% of hospital inpatient budget.
- Extrapolated to the entire U.S., more than 575,000 preventable deaths occurred from 2000 to 2002, at a cost of approximately \$19 billion in excess medical expenses.
- If the Centers for Disease Control counted hospital errors as a cause of death, they would rank sixth, ahead of Diabetes, Influenza, Pneumonia and Alzheimer's disease.

If this is placed in an Irish context, based on figures reported by OECD 2004 for inpatient figures in Irish hospitals for 2000 (**38 Columbo et al**) extrapolated number of deaths in Irish health care facilities would be approximately four



thousand. The magnitude of scale is appreciable when compared to the number of road deaths in the same period (approx 350) ref Table 2-3.

Table 2-2 Hospital utilization by public and private patients

### Hospital utilization by public and private patients

	Public 2000	Private 2000	Total 2000
<b>Discharges (inpatients)</b>	<b>398492</b>	<b>124128</b>	<b>522620</b>
<b>Planned patients</b>	<b>103421</b>	<b>43929</b>	<b>147350</b>
<b>Emergency patients</b>	<b>295071</b>	<b>80199</b>	<b>375270</b>
<b>Discharges (Day patients)</b>	<b>209805</b>	<b>62883</b>	<b>272688</b>

Source OECD 2004

Table 2-3 Extrapolated percentage of patient safety incidents and projected resulting deaths based on IOM report using OECD data

### Extrapolated based on IOM study

	Public/Private 2000	
	Patient safety incidents @ 3.08%	1 in 4 Resulting in death
<b>Discharges (inpatients)</b>	<b>16097</b>	<b>4024</b>
<b>Planned patients</b>	<b>4538</b>	<b>1135</b>
<b>Emergency patients</b>	<b>11558</b>	<b>2890</b>
<b>Discharges (Day patients)</b>	<b>8399</b>	<b>2100</b>

There have been many reports and task force findings highlighting methods for reducing errors. Among them: evidence-based medicine, computerized physician order entry for medication orders, pharmaceutical bar coding and failure mode

effects analysis, which is used by the military, aerospace and automotive industries to predict bad outcomes.

So this then is the challenging landscape in which healthcare workers need to make critical decisions on a daily basis. Demand for services continue to grow, combating this technology growth marches on at an unrelenting pace. With this technology growth there is the possibility of outstanding capability as well as the possibility of overwhelming streams of information through which healthcare workers will need to navigate. In the following chapter a review of the factors influencing decision making in the healthcare setting with particular attention being placed on cognitive capabilities and limitations is carried out.

## CHAPTER 3. DECISION MAKING IN A HEALTHCARE SETTING

Decision making in the healthcare setting is influenced by two predominant factors

- The innate ability of human beings to absorb and comprehend information
- The context in which the events generating this information occurs.

Typically there will be limited control over both these factors, though they influence and shape many patient outcomes.

As a discipline, human information processing draws heavily on cognitive psychology covered in detail later on in this chapter. As we interact with our environment three areas, cognitive capacity, information processing, and human factors are influenced by our innate capacity to sense, select, store and process external stimuli.

Typically care givers are subject to time pressures imposed by the requirement to treat a prescribed number of patients a day with limited resources and unplanned/unforeseen events (emergencies etc) needing to be catered for. As highlighted in the previous chapter situational complexity leads to error. It is commonly accepted that time pressure adversely affects attention, perception and information processing. While under time pressure it is difficult to focus on the relevant detail necessary to determine the appropriate diagnosis, treatment regimen or provide quality care. The facts speak for themselves with 1.14 million patient safety incidents in the United States . **(36 Healthgrades)**

Situational factors such as resource constraints, inadequate facilities and overwhelming patient needs frequently present care givers with conflicting goals. Since the capacity for attention is limited, focusing on the problem at hand is impaired by confusion about which formulary to use, how to regain lost time etc. In circumstances like these the most pressing goals gets the attention of the care giver often to the detriment of other often more relevant detail or situation. Most individuals are unlikely to be able to deal with more than one complex situation requiring simultaneous attention and effective action.

Based on circumstance, attention can be strongly influenced by expectations or mindset. If, for example, a patient presents with the complaint of breathing difficulty as noted by the initial investigation (emergency room/paramedic interview), but also mentions pain in his/her leg, the physician may ignore the leg and focus exclusively on the breathing difficulty. In so doing the physician may fail to recognize the likely symptomatology of Deep Vein Thrombosis/PE (DVT) . *(37 Symptoms of DEEP VEIN THROMBOSIS)*

Selective attention is evident when a problem is so pressing that the individual becomes fixated on solving this overriding concern to the detriment of both understanding the underlying problem and appropriate solution. As Norman *(13 Norman, DA)* has recounted, divers, struggling to reach the surface of the water, frequently forget to release the weights on their belts which helped them stay down.

### **3.1. Perception and pattern recognition**

Depending on an individuals previous experience multiple stimuli are sorted into familiar patterns that help process them.

Since humans are constantly presented with a great variety of stimuli, we pay attention to those stimuli that we deem important. Consider the journey to work and try to recall even the detail between stoplights, only the most relevant events can be recalled. By recognizing their importance we draw on familiar patterns of experience (we remember due to episodic cuing) in which this stimuli or something similar to it occurred. Once a memory is cued a value judgment will be made as to what the pattern may signify. It is in this coupling of stimuli, perception and pattern, that understanding begins and, as a consequence, decision making.

Should the process of attending to a patient be interrupted, hurried, complicated by an overload of data or the care giver be distracted by other pressing needs, vitally important information can be lost or ignored. A well-known article written over 40 years ago, titled "The Magic Number Seven--Plus or Minus Two," contends that seven--plus or minus two--is the number of things people can keep in their head all at once **(57 Miller)**. That limitation on working memory is the source of many problems. Humans have difficulty grasping a problem in all its complexity and this in turn leads to indecision. For example, we think first about the arguments in favor, and then about the arguments against, and we can't keep all those pros and cons in our head at the same time to get an overview of how they balance off against each other. **(58 C.I.A.)**

The important point is that to recall memories or patterns it first has to be cued by facts perceived as relevant. Complex cases require time to access all situation-relevant information. Human tendency to simplify will lead to relevant facts being overlooked with resulting erroneous problem identification. Simplification is almost like a safety valve in situations where we have information overload.

To understand in more depth the process of comprehension that will govern an individual's ability to react and respond to external stimuli we must take a closer look at the cognitive capabilities / limitations that apply in the human context.

Many similarities exist in the environments of warfare and that of the frontline in the provision of care. The Department of Navy's work "Knowing, The Art of War" (**30 Bennet**) Bennet calls out two main areas in understanding human cognition i.e. Cognitive Capabilities and Cognitive processes. See Appendix B

### **3.2. Cognitive Capabilities**

Consider cognitive capacity as a set of building blocks. Each block has a function and is reliant on other blocks to both support it and provide some element of infrastructure to it. It in turn will do likewise for the blocks surrounding it. Highlighted in Figure 3-1 are the cognitive capabilities for observing, collecting and interpreting data and information, and building knowledge relative to a given situation.

There are five areas of note: (Covered in more detail sections 3.3 – 3.6.)

- Noticing
- Scanning
- Patterning
- Sensing
- Integrating

These areas are primary and the means by which we perceive the external world and begin to comprehend what is going on in it.

These five elements of observing represent the primary areas of cognitive capabilities needed to assist in creative and accurate situational awareness. They allow us to build a valid understanding of the facts presented. Supporting these cognitive capabilities are underlying processes that transform observations (the facts) and first-level knowledge (memory/experience) into a deeper level of comprehension and understanding.

Cognitive Capabilities/Processes

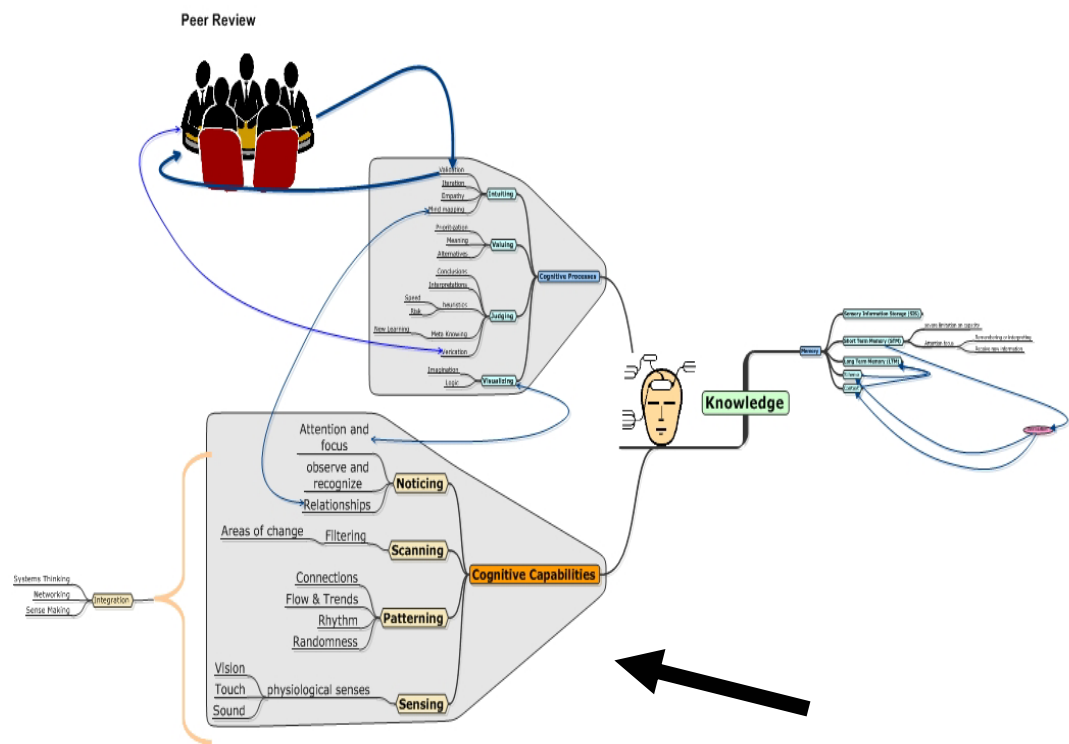


Figure 3-1 Cognitive Capabilities/Processes

### 3.3. Noticing

The first area of noticing represents the ability to observe and recognize (ref previous example of DVT), i.e., identify those things that are relevant to our immediate needs. A good example of the phenomenon of noticing takes place following the purchase of a new car, for the next six months the number of similar cars on the road seems to be significant. This is an example of a cognitive process in action of which we are frequently unaware. We notice those things that are recently in our memory or of emotional or intellectual importance to us. We miss many aspects of our environment if we are not focusing directly on them.



Figure 3-2 Noticing

An example of this phenomenon is represented in figure 3-2 and has been used in many children's puzzles. See if you can spot the difference in between the pictures in figure 3.2

Attention and focus are both important for noticing. We do not notice and will miss many aspects of our environment if we are not focusing directly on them even then we can miss data. We do not notice if we do not pay attention. People



are flooded with data, information and knowledge, for which in many situations it is impossible to allocate sufficient attention. Purveyors of data need to understand tradeoffs in the finite attention of its recipients. Recipients need to allocate attention to notice.

It is also easier for humans to notice if we understand how things are related, and if they are relevant to our immediate needs. Relevancy is subject to an individual's perspective and experience. The same thing may seem to be relevant to one individual, but not to another even though both individuals appear to be in exactly the same situation.

Noticing is knowing which areas of the environment are important and relevant at the moment, and focusing on those elements and the relationships among those elements.

Noticing may be considered the stage of building deep knowledge, fundamental to thorough understanding and context awareness.

### **3.4. Scanning**

The scanning building block refers to the ability to review a large amount of data or information and selectively identify or mark those areas that may be relevant or of interest. Scanning is employed as a filtering technique. Scanning is used to reduce data input and simplify complexity. While scanning humans filter out apparent irrelevant facts this irrelevant data can be considered noise. Through a system of environmental "speed reading," scanning can provide early indicators of change.

### **3.5. Patterning**

In any problem solving typically the first activity is to look for patterns. This activity demonstrates the ability to apply past experiences or learned knowledge to review, study and interpret large amounts of information and identify connections that may represent patterns. These patterns may be temporal or spatial and would include an understanding of rhythm and randomness, flow and trends. An obvious example would be in review of ECG traces in the diagnosis of issues pertaining to the heart.

#### **3.5.1. Characteristics of patterning include:**

##### **3.5.1.1. Connections**

By recognizing patterns we increase the ability to extrapolate outcome. Further, by building relationships between seemingly unrelated facts, events or situations patterns can be deduced. The ability to connect these situations to one another will facilitate prediction of possible outcomes that improve the ability to make situational decisions.

##### **3.5.1.2. Flow and Trends**

To discern and see in ones minds eye patterns and visualize ongoing developments.

##### **3.5.1.3. Rhythm**

Rhythm is intuitive it allows an individual to participate mentally at least in the ebb and flow of events. Rhythm is knowing when to stay steady, go faster, slower, higher, lower, more or less.

#### **3.5.1.4. Randomness**

An understanding that while patterns may have rhythm they can also have an element of randomness. Randomness should not be confused with unpredictability which is a related idea in ordinary usage. Some mathematically deterministic systems can be unpredictable in practice due to sensitive dependence on initial conditions. Many random phenomena exhibit organized features at some levels. For example, the increase of the world human population is quite predictable on average, but individual births and deaths cannot be accurately predicted with any precision in most cases. This small-scale randomness is found in almost all real-world systems.

#### **3.5.1.5. Sensing**

Finally sensing represents the human ability to absorb external stimuli via human physiological senses while translating that input into accurate models within an individual's comprehension. Human natural senses (ref 6.1 sensing limitations) are frequently augmented either visually or via acoustic enhancement. For example, we only see a very small part of the electromagnetic spectrum in terms of light, yet with technology we can tremendously expand the sensing capability. Ultrasound allows visual representation of a fetus in a womb.

While we often take our senses for granted they are highly sensitized, complex sensory systems that can cause immediate response without conscious thought (autonomic response).

### **3.6. Integration**

The last building block referred to in cognitive capabilities is integration. Integration is where it all comes together, where sense is made of the myriad

streams of data or information, where data is transformed into information. **(11 Weick, K. E)**. One of the most valuable cognitive capabilities in any situation is the ability to pull together the major aspects of a complex situation and create patterns that represent reality and facilitate decision making.

### **3.6.1. Characteristics of integration include:**

#### **3.6.1.1. Spatial ability**

Spatial ability may be defined as the ability to generate, retain, retrieve, and transform well-structured visual images. It is not a unitary construct. There are, in fact, several spatial abilities, each emphasizing different aspects of the process of image generation, storage, retrieval, and transformation. **(42 Lohman )**

#### **3.6.1.2. Systems thinking**

Systems' thinking focuses on how the thing being studied interacts with other constituents of the system – a set of elements that interact to produce a behavior – of which it is part. This means that instead of isolating smaller parts of the system being studied, systems thinking works by expanding views and taking into account larger numbers of interactions as an issue is being studied.

#### **3.6.1.3. Sense making**

Following the observation of a series of events, using past experiences the ability to select aspects or traits that can be correlated and presented in a comprehensible picture.

### **3.7. Cognitive Processes**

Figure 3.3 highlights four internal cognitive processes that support the capabilities discussed above. These four internal cognitive processes underpin the ability to understand the external world and to make maximum use of internal thinking capabilities, transforming observations into understanding. Cognitive processes are comprised of:-

- Visualizing
- Intuiting
- Valuing
- Judging

In summary, these four internal cognitive processes work in conjunction with the cognitive capabilities to process data and information and create knowledge within the immediate context and current situational factors. It must be remembered that individualism comes to play and knowledge created will be dependant on an individual's state of mind and experiences.

## Cognitive Capabilities/Processes

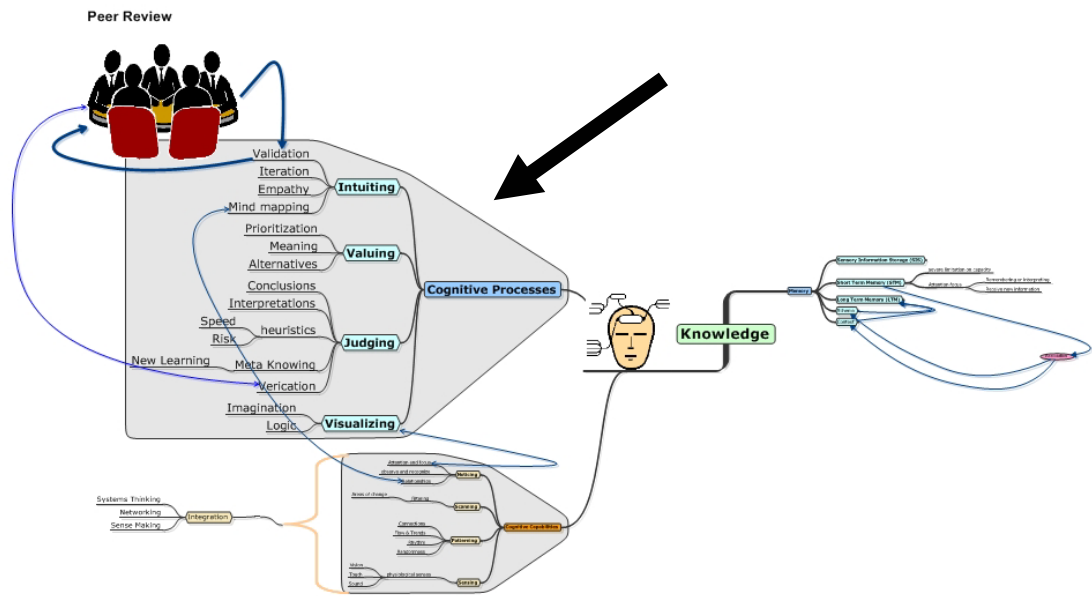


Figure 3-3 Cognitive Capabilities/Processes

### 3.7.1. Visualizing

When visualizing attention is focused on a given area or subject, Imagination and Logic is then used to create an internal vision, plan or scenario to address the task at hand. In developing this plan or vision, continuous polling of situational perspectives must be maintained. Through scenario playing a final set or single vision will be settled on. Creativity plays a more significant role than logic, intuition more than rationale. Brainstorming is a good example where this type of process works effectively at idea, scenario generation with possibilities challenged and eventually settled on. Visualizing may not always result in accurate representations of reality, however degrees of success can be achieved and further developed.

### **3.7.2. Intuiting**

Intuition will be influenced by experience, through that experience, iteration and a process of presentation and questioning. Intuiting is the skill of maximizing this experience and process. Intuition is typically understood as being the ability to access our non-conscious mind and thereby make effective use of its very large store of observations, experiences and knowledge. The dictionary definition of intuition is "quick and ready insight;" and "the act or process of coming to direct knowledge without reasoning or inferring." It is derived from the Latin word "intueri" which means "to see within." It is a way of knowing, of sensing the truth without explanations. Someone may not consider themselves to be particularly spiritual or metaphysically adept yet may be quite good at following their gut instincts.

Empathy is another aspect of intuition. Although commonly used as simply a synonym for sympathy, the term empathy means more than just one's identification with another's feelings. Instead, it refers to the imaginative projection of your own feelings into someone else. Thus, by starting out with your own feelings of happiness at some event, empathy allows you to abstract out the principle "such an event creates happiness" and then project that as a possible result in other people who experience a similar event. ... The ability of empathy allows one to translate our personal perspective into that of a patient and thereby understand their interpretation of the situation.

Mind mapping also plays a part in intuition. It is a tool to visually recognize relationships that may exist between pieces of information and data. Mind mapping may trigger ideas and allow further use of one's intuitive capability to bring out additional insights.

### 3.7.3. Valuing

Valuing is the capacity to observe situations, recognize and place a value on their various aspects while consciously taking into account one's values and beliefs. Valuing facilitates prioritization and focus on situations at hand. Through valuing, meaning may be derived. Possible outcomes may be extrapolated based on this meaning and therefore anticipated. Meaning may be influenced by goals and aspirations of the individual. It will also rely on the individual's experience and the context of the situation.

### 3.7.4. Judging

Judgments are conclusions and interpretations developed through the use of rules of thumb, facts, knowledge and experiences, and intuition. **Judgment** implies a balanced weighing up of evidence preparatory to making a decision. A formal process of evaluation applies. A judgment is expressed as a statement and is usually the outcome of an evaluation of alternatives. For example:

- There must be corroborating evidence.
- There must be no true contradicting statements.
- If there are contradicting statements, these must be outweighed by the corroborating evidence or contradicting statements must themselves have no corroborating evidence.
- Conclusion must also corroborate and be corroborated by the system of statements which are accepted as true.

Judgment utilizes heuristics, meta-knowing, and verification. Heuristics is a problem-solving technique that involves conceiving a hypothetical answer to a problem at the outset of an inquiry for purposes of giving guidance or direction



to the inquiry. Inherent in that approach there is power and danger. Danger is introduced in a changing situation or environment and this may invalidate past-proven heuristics and learning. The power of Heuristics is that they represent efficient and rapid ways of making decisions.

Meta-knowing is understanding the process of knowing. With this understanding comes the ability to learn and know new things in new situations as they evolve over time.

Verification improves the probability of appropriate judgments and working with others and using their experience and knowledge to validate and improve the level of judgmental effectiveness.

### **3.8. Cognitive/Sensing Limitations**

In sections 3.2 to 3.7 Human Cognitive capabilities were detailed, any deficit in these areas will severely limit the ability to absorb and comprehend external stimuli. Knowing where and on what to focus attention is compromised, resulting decisions are undermined and errors of omission or commission are made.

Some of the most obvious of these limitations are

- Human memory, both short and long term.
- Logical reasoning abilities
- Difficulty with coordinate transformations
- Ability to predict and anticipate states and actions
- Fusion of information from abstract sources

- Limitations of attention

Task analyses of cognitive tasks reveal requirements for cognitive capabilities that underlie performance. These requirements include, but are not limited to:

- A large amount of precise working memory
- Ability to integrate multiple information sources
- Logical reasoning in complex and abstract problem spaces
- Incorporating uncertainties and values
- Enumerating possibilities
- Predicting consequences and discounting future values appropriately
- Appropriate distribution rather than focused attention – for anticipation of problems

Human abilities and their limitations continue to be a subject of intense interest to psychologists. While the thrust of many experiments have been to discover the underlying cognitive and physiological mechanisms, the resulting data and models can also be used to understand cognitive limitations. Foremost of those limitations defined involves human abilities to incorporate uncertainty in their judgment and decision-making.

Good-quality decisions are routinely made without issue. However decisions that require inclusion of 1 or more uncertainties and values prove to be very challenging. Incorrect conclusions are frequently made by even sophisticated and statistically trained individuals. Replicable errors in these situations have been

defined as “cognitive illusions” because individuals will continue to make these mistakes even if they know about their propensity to make them.

An example of a perceptual illusion of size is shown in Figure 3.4.

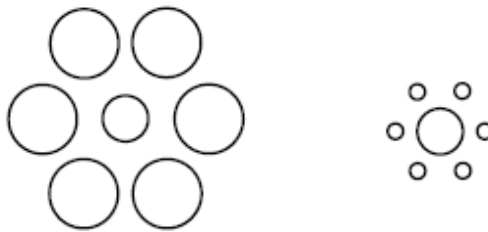


Figure 3-4 Example of a perceptual illusion. The two central circles are the same size. This illusion persists even if the viewer is aware of the physical reality.

A viewer can convince himself by a simple measurement that the two central circles are the same size, but the illusion persists even after performing a measurement of the circles. It is possible to design a perceptual aid that will “equalize” the perceived size of the central circles, but to do so require fairly deep knowledge of the perceptual processes that lead to the illusion. Similarly, by starting with an understanding of the underlying cognitive limitation that leads to particular errors, we can design cognitive aids to reduce performance errors. **(12 Misha Pavel).**

### 3.9. Limits of our Physiological senses

Our senses of vision, hearing, touch, smell, taste, temperature and balance are all limited. We may also have senses of electrical fields and magnetism, but they are so limited that we can't notice them

### **3.9.1. Limits of vision**

We can only see a certain range of colors. Also, we need the light to be bright enough to see things.

### **3.9.2. Range of colors**

We consider light to be the combination of colors we can see: red, orange, yellow, green, blue, indigo and violet. Visible light is just a small portion of the electromagnetic spectrum. There are animals that detect electromagnetic radiation beyond the limitations of the human eyes, and there are physical detectors that go even beyond what animals can see.

For example, moths and bees detect ultra-violet light, which humans cannot see. The ultra-violet or "black lights" used to make things glow give us just a glimpse of what things look like to these creatures. On the other end of the spectrum, animals that hunt at night are able to see infra-red light. We can use "night scopes" to see the infra-red.

Two broad areas have been highlighted as influential in the process of decision making in a healthcare setting i.e. Sight and Cognitive Capabilities. In the following chapters 4-5 methods for augmenting sight through data visualization and cognitive capabilities through cognitive systems will be covered.

## CHAPTER 4. DATA VISUALIZATION



Figure 4-1 Human ear presented in 3D Physicians wearing 3D glasses

### 4.1. Visualization

Visualization: - The use of computer-supported, interactive visual representations of data to amplify cognition. **(20 Card)** The main goal of information visualization can be summed up by: “the right information to the right person at the right time.”

Using images, it's much easier for individuals to see a concept than trying to explain it with words or numbers. Consider the difference between a written description of a person's face and a photograph of it, or the difference between a table of numbers containing a correlation and a scatter plot showing the same

information. Vision is the most important sense in our everyday lives. The brain perceives information more readily in a graphical way. **(50 Shneiderman)**

In earlier chapters human cognitive capabilities and limitations were covered, clearly the amount of information we can visually process at any one time is not infinite. Therefore, we require tools to assist us in developing a context to analyse data. With industry data sets now growing in excess of 100GB, these limitations are becoming more pertinent.

Visualization exploits the human brain's natural pattern recognition ability. Humans can scan, recognize, and recall images rapidly, and can detect changes in size, color, shape, movement, or texture. Vision can be classified as the superhighway of information flow with a bandwidth of information presentation higher than for media reaching the brain via any of the other senses. There are limitations though that must be overcome. The computer and its peripherals are acting as sensory augmentation to vision and going some way to addressing these limitations. As computers become evermore powerful the contribution they make in terms of visualizing data in a graphical manner is evidenced by the success of interactive user interfaces. Through information visualization the computer facilitates pattern recognition. It can highlight clusters, gaps, or outliers in statistical data.

In traditional analysis, maps are often used a visual representation of a 3d environment, but when we visualize an object in our mind, we do not have to build a contour map to understand it. Much information is lost or distorted when 3D objects are presented in 2D space. Some examples of this include size, perspective, context and aspect. What is underneath or beside an area of interest is often as important as what is on top. **(49 Christie)**

#### 4.2. Representation of data in 3D

True 3D means that multiple perspectives, usually more than two, are simultaneously presented to the human vision system from the display system. Approaches to true 3D include multiplexed 2D, volumetric, and holographic. See table 4-1 for descriptions. **(19 Darrel G. Hopper)**

3D representation is continuing to advance along three general approaches:

- (1) Multiplexed 2D;
- (2) Direct write volumetric
- (3) Electronic holographic.

Before true 3D, auto stereoscopic monitors with usable resolutions can be made available, challenges in device fabrication and materials will need to be addressed. A key advance here will be nanoelectronic silicon wafers for displaying pre-computed, high fidelity holograms. Table 4-1 describes various methods of display.

Table 4-1 Methods of Display

Method	Description
True 3D Electronic Display	True 3D means that multiple perspectives, usually more than two, are simultaneously presented to the human vision system from the electronic display system. Approaches to true 3D are multiplexed 2D, volumetric, and holographic. Pre-Recorded vs. Real-Time.
3D via Multiplexed 2D.	Multiplexed 2D has two general forms depending

Lateral Scene Sampling	on how the 3D scene is sampled: lateral or depth sampling. Each pupil intercepts a different perspective view. Left/right head motion causes each eye to intercept different views. Hence, depth cues derive from eye-brain processing of each instantaneous stereo pair.
3D via Multiplexed 2D. Depth Scene Sampling	In-depth segmentation, 2D image slices at each sample depth plane are generated on a 2D display device and reflected from an oscillating mirrored membrane whose motion is synchronized with the 2D display. Sparse, see-through scenes and symbol sets can be presented.
Volumetric	Volumetric displays generate points or continuous lines via direct- writing. The points or lines act as light sources. One version involves a rotating reflective/diffusive helical screen synchronized with a visible laser beam.
Holographic	Electronic holography with precomputed holograms played back as film strips is possible provided the scenes are very simple. Nanoelectronics fabrication techniques now being matured by the integrated circuit industry might one day enable fabrication of 25nm hologram pixels (h pixel) across 100 sq. in. of a 16in. wafer. The resulting sampled hologram (1014 h pixels) might correspond to a true 3-D resolution.
Holodeck	Full true 3D display technology is represented conceptually by the Holodeck of science fiction



	well into the future. The holy grail of 3D display, the Holodeck with ultrahigh resolution room-filling imagery with hidden lines removed plus haptic will not be available anytime soon.
--	---

*Source Reality and Surreality of 3-D Displays Air Force Research Laboratory 15 November 2000*

#### **4.3. 3D Data representation and visualization in healthcare.**

Data visualization in healthcare can take many forms from lab reports on blood cell count to complex imaging output from MRI systems. Clearly as humans are multidimensional, representation of any aspect of that form in as close as possible to its natural state i.e. multidimensional will facilitate cognitive capabilities. If that image or visualization is enhanced in a manner that facilitates pattern recognition or focuses attention on points of interest obvious benefits begin to be asserted.

An example of where 3D visualization can assist in the provision of healthcare is in the area of surgery. Typically when images are presently in a two-dimensional format the surgeon can see the surfaces of exposed tissues, but not internal structures. The surgeon must mentally map the 2D images seen on a computer screen to the 3D operating field.

Image-guided surgery provides augmented vision of what lies beyond the exposed surfaces, what types of tissue are seen, and through color coding may also indicate what functions the tissues serve. Different types of tissue may be difficult to distinguish with the eye alone, but appear markedly different on certain medical imaging scans.

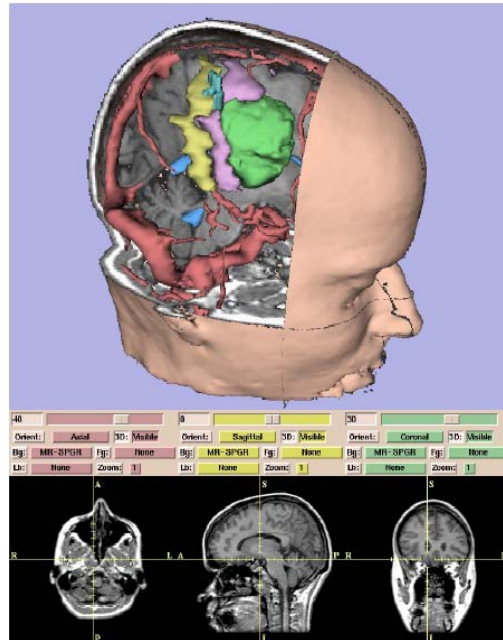


Figure 4-2 3D view where 2D slices are integrated with 3D surface models. The 2D slices are also shown in 2D image windows below the 3D view.

#### 4.4. 3D slicer

This application integrates several facets of image-guided medicine into a single environment. It allows medical scans containing anatomical or functional data to be automatically registered and semi-automatically segmented. 3D computer models of key structures such as skin, brain vessels etc can be generated and visualized in a 3D scene along with reformatted images. Multi-modal information is incorporated through automatic registration. The 3D Slicer features a computer graphics display that offers the flexibility to see the situation from viewpoints not physically possible with currently available image rotation through all axis. It has

the ability to fly through virtual data to facilitate the understanding of complex situations, and aid in avoiding damage to healthy tissue during surgery. (64 Gering)

Medical image interpretation is not straight forward and in general relies on human intervention for analysis. Identifying various anatomic structures and pathological findings requires mental effort. The task of interpreting medical images is complicated, involving simultaneous processes of searching, perception and decision-making. A crucial requirement for increasing effectiveness and accuracy of decision making is to reduce disruptions of analysis, particularly disruptions of visual search. To prevent this disruption, frequent tasks such as navigation and image manipulation and visualization should require little or no visual and cognitive resources.

Taking 3D a step further, while not quite the holodeck of science fiction a virtual reality simulation of the functional data could be presented to care givers allowing them a holistic view of the patient. Biometric data, imagery and ongoing treatment as well as charted progress could be presented in this environment.

An example of how this environment is being applied is the work being carried out at the U.S. Naval Research Lab in Washington D.C where scientists have developed what they call the GROTTTO (Graphical Room for Orientation, Training and Tactical Observation). The GROTTTO is an immersion room, 10 x 10 x 10 ft., where three of the walls and the floor have high-resolution stereo images projected on them. Right and left eye images are sequentially displayed by the graphics computer. Shutter glasses, synchronized with the computer by use of infrared emitters, block the right eye when the left image is shown and vice versa. A magnetic tracker detects the position and orientation of the user's head and

joystick. Head tracking is used to show the correct perspective according to the user's position, while the joystick is used to navigate in the virtual environment.

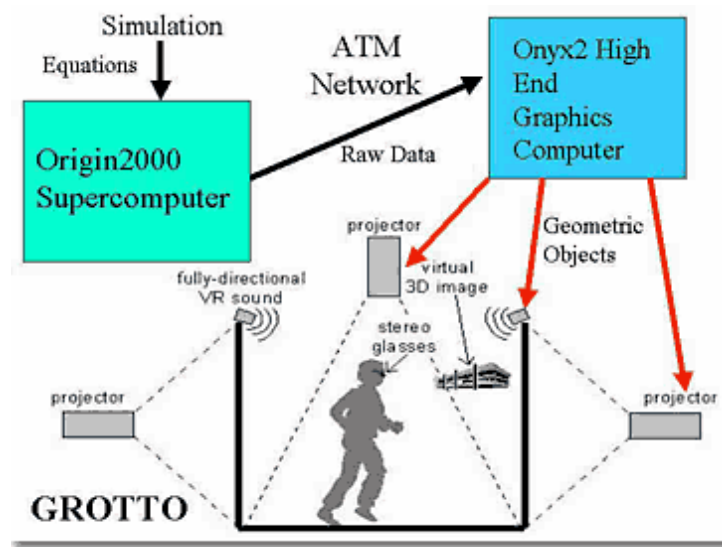


Figure 4-3 Basic configuration of the virtual reality setup.

The immersion room is like the holodeck on the Starship Enterprise in Star Trek. You go into the room and the graphical environment surrounds you. For instance scientists are placed in the middle of a molecule (Figure 4-4) so they can navigate inside it to look for important structures.



Figure 4-4 A scientist inside 1CRN-crambin

A scientist can explore and walk inside 1CRN-crambin, a small protein consisting of 327 atoms. The spheres represent the different atoms (carbon, oxygen, etc.) that make up the protein, while the tubes represent the bonds between the different atoms. **(65 Lanzagorta)**

## CHAPTER 5. 'COGNITIVE AIDE'

Within limits, humans are generally very good at assessing a complex array of data and recognizing meaningful patterns or events within that data *(26 Klein, G)*. However, as the number of data sources, and associated breadth and variety of data exceeds practical limits, humans are quickly faced with the common experience of “information overload.” Reference previous discussion on information overload and its effect on the provision of healthcare. The problem is exacerbated by the ever-expanding volumes of archival data. Consequently, people have coped by turning to a variety of automated alerting and data mining solutions.

In previous chapters Cognitive and physiological capabilities as well as limitations were introduced. Physiological senses, in particular vision have been augmented for many years. In the 16th century a desire to see objects smaller than the eye could see led to the development of a magnifier composed of a single convex lens, and this, in turn, led to the eventual development of the microscope. Over time we have added to the everyday tools that healthcare workers regularly use augmenting those physiological senses, for example Magnetic resonance machine MRI's, Xray etc. These augmented physiological senses are facilitated through data visualization tools and techniques already discussed. By their very nature cognitive capabilities are somewhat more difficult to augment, a review of literature will reveal how little is really known about the detailed working of the “thinking process”. There are however some commonalities and structures defined. Using defined constructs it is possible to attempt enhancement of cognitive capabilities through augmented models. Efforts underway in the Sandia Laboratory by Firsythe & Xaviour as well as McFarlane et al at Lockheed Martin advanced Technology Laboratories are attempting to define a cognitive system to

augment cognitive capabilities, while not focused on healthcare, similar conditions and scenarios exist in that environment. The 'Cognitive Aide' represents the major components referred to in this work and how this could be applied in the healthcare setting.

“A cognitive system refers to a variety of software products that utilize plausible computational models of human cognitive processes as a basis for human-machine interactions. The intent is to reproduce cognitive mechanisms responsible for the effectiveness of human-to-human interaction so that the human-machine interaction becomes more like an interaction between a human and a human-like cognitive entity. In short, a cognitive system consists of software that helps a machine interact with people in the way people interact with one another”. **(24 Firsythe et al)**

Some distinctions can be made when comparing artificial intelligence and cognitive systems i.e. Cognitive systems should be:-

- A dynamic system that responds gracefully to anomalous events and may easily adapt to changing circumstances, as opposed to the brittleness of rule-based expert systems.
- Capable of pattern recognition where knowledge is associative, as opposed to rule-based representations of knowledge and emphasis on logical operations.
- Machine interaction with human user based on adaptation to the unique knowledge and experience of individual with emphasis on systems that conform to the user, as opposed to one-size fits all approaches or customization based on statistical profiles.

Cognitive systems can:-

- Reflect on what goes wrong when an anomaly occurs and anticipate its occurrence in the future.

- Assist in their own debugging.
- Reconfigure themselves in response to environmental changes.
- Respond to naturally-expressed user directives to change behavior or increase functionality
- Be used, configured and maintained by non-experts

#### Rough Anatomy of a Cognitive System

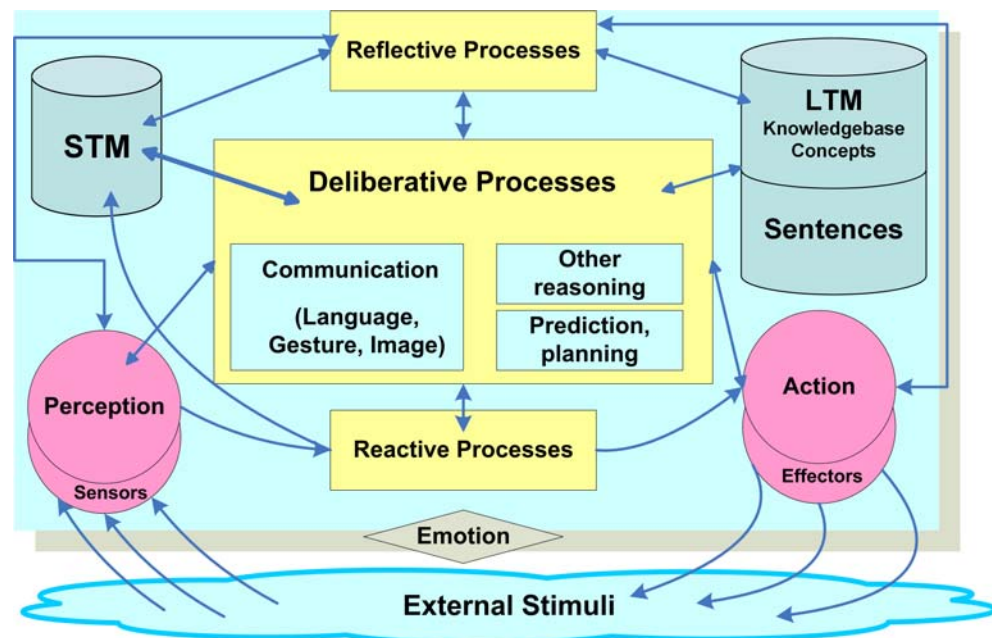


Figure 5-1 Rough Anatomy of a Cognitive System, Source A DARPA Information Processing Technology Renaissance: Developing Cognitive Systems

The paradigm of an ‘Aide’ “*someone who acts as assistant*” can be used to give an idea as to the roles and responsibilities of this system to augment cognitive capabilities. This ‘Aide’ knows where you are and where you are going, listens to every conversation to which you are a party, reads everything that you read, and remembers everything that you have done, how you have done it and outcome of



those actions. The 'Aide' will advise and assist in all day-to-day tasks. The major difference though will be the fact that this 'Aide' has unlimited storage and processing resources, it has access to and can recall every nuance and fact accumulated as a result of those interactions on a day to day basis.

These characteristics of the perfect 'Aide' are aspects required in a cognitive system:

- The 'Aide' knows what you know and don't know and is aware of the underlying structure of your knowledge.
- The 'Aide' knows what you do, how you do it, and why you do it that way.
- The 'Aide' not only has access to past experiences but can also place those experiences within the context in which they were derived.
- The 'Aide' can apply your unique knowledge and experiences to interpret events in a familiar manner.
- The 'Aide' recognizes when it is learning and how this learning has influenced perception of the world.
- The 'Aide' knows the consequences of past experiences and can anticipate reactions to future situations.

### **5.1. Cognitive Systems applied in a healthcare setting**

In addition to an individual's experiences and knowledge the 'Aide' has full access to a fully digital record of not only interactions with a patient that include circumstantial, diagnostic investigation, clinical pathways applied, ECG waveform analysis, medication administered and full knowledge base of known diseases and symptoms. The 'Aide' would assist the care-giver in decision making, would not be susceptible to interruption, would be aware of conflicting treatment regimens,

can offer guidance on alternatives and can ensure multi-step procedures can be carried out through audit thereby increasing the quality of care.

As an alternative to current methods used in monitoring and data mining, a cognitive model may serve the same function. In such systems, various data streams are assigned as input to the cognitive model. These streams will be generated automatically via diagnostic or monitoring devices or observations entered by Healthcare providers. Intermediate methods are used to synthesize and convert data so that it is consistent with the concepts or cues utilized by the cognitive model. The cognitive model is armed with various contexts that it recognizes i.e. clinical pathways, disease symptoms, patient history etc. These may be contexts that span the range from extremely brief (i.e., milliseconds) to extremely long (i.e., years) temporal intervals. In addition to the recognition of contexts by which it will provide feedback, cognitive models may also use a comparator as a mechanism to detect and alert users to anomalous events (e.g., deviant behavior i.e. Step error or conflict in drug allocation).

While full comprehension of situational awareness with regard to an individual's knowledge and experience may be some time away a more realizable goal may be to limit this awareness to the patient record, clinical pathways, investigative output, disease information etc. Further layers of granularity could be applied limiting the 'Aides' scope of coverage.

## CHAPTER 6. CASE STUDY OF ECG ON A MOTE

### 6.1. Electrocardiogram, one data point

The electrocardiogram (ECG) is a recording of the electrical forces produced by the heart. It is the most frequently monitored physiologic signal in the intensive care unit (ICU) environment.

*(32 J. Willis Hurst)* An ECG is performed by placing electrodes referred to as leads at certain specific locations on the body. (Figure 7-1) They only record the heart's electrical activity. They do not produce any electricity of their own. The test does not hurt and has no known side effects. It does not require any preparation (except for possibly shaving chest hair to get a better recording). The recording itself takes only a few seconds.

### 6.2. History of ECG

**1901** Einthoven invents a new galvanometer for producing electrocardiograms using a fine quartz string coated in silver based on ideas by Deprez and d'Arsonval (who used a wire coil). His "string galvanometer" weighs 600 pounds. Einthoven acknowledged the similar system by Ader but later (1909) calculated that his galvanometer was in fact many thousands of times more sensitive. *(10 Einthoven W.)*

**1908** Edward Schafer of the University of Edinburgh is the first to buy a string galvanometer for clinical use.

**1912** Einthoven addresses the Chelsea Clinical Society in London and describes an equilateral triangle formed by his standard leads I, II and III later called

'Einthoven's triangle'. This is the first reference in an English article I have seen to the abbreviation 'EKG'. (9 *Einthoven W.*)

**1928** Ernstine and Levine report the use of vacuum-tubes to amplify the electrocardiogram instead of the mechanical amplification of the string galvanometer. (8 *Ernstine AC*)

**1928** Frank Sanborn's company (founded 1917 and acquired by Hewlett-Packard in 1961 and since 1999, Philips Medical Systems) converts their table model electrocardiogram machine into their first portable version weighing 50 pounds and powered by a 6-volt automobile battery.

**1932** Charles Wolferth and Francis Wood describe the clinical use of chest leads. (7 *Wolferth CC*),

**1934** By joining the wires from the right arm, left arm and left foot with 5000 Ohm resistors Frank Wilson defines an 'indifferent electrode' later called the 'Wilson Central Terminal'. The combined lead acts as an earth and is attached to the negative terminal of the ECG. An electrode attached to the positive terminal then becomes 'unipolar' and can be placed anywhere on the body. Wilson defines the unipolar limb leads VR, VL and VF where 'V' stands for voltage (the voltage seen at the site of the unipolar electrode). (6 *Wilson NF*)

**1938** American Heart Association and the Cardiac Society of Great Britain define the standard positions, and wiring, of the chest leads V1 - V6. The 'V' stands for voltage. (5 *Barnes AR*)

**1942** Emanuel Goldberger increases the voltage of Wilson's unipolar leads by 50% and creates the augmented limb leads aVR, aVL and aVF. When added to

Einthoven's three limb leads and the six chest leads we arrive at the 12-lead electrocardiogram that is used today.

**1949** Montana physician Norman Jeff Holter develops a 75 pound backpack that can record the ECG of the wearer and transmit the signal. His system, the Holter Monitor, is later greatly reduced in size, combined with tape / digital recording and used to record ambulatory ECGs. **(4 Holter NJ)**

**1963 Baule** and McFee are the first to detect the magneto cardiogram which is the electromagnetic field produced by the electrical activity of the heart. It is a method that can detect the ECG without the use of skin electrodes. Although potentially a useful technique it has never gained clinical acceptance, partly because of its greater expense. **(3 Baule GM)**

**1968** Henry Marriott introduces the Modified Chest Lead 1 (MCL1) for monitoring patients in Coronary Care.

1992 Cohen and He describe a new non-invasive approach to accurately map cardiac electrical activity by using the surface Laplacian map of the body surface electrical potentials. **(2 He B)**

**1993** Robert Zalenski, Professor of Emergency Medicine, Wayne State University Detroit, and colleagues publish an influential article on the clinical use of the 15-lead ECG which routinely uses V4R, V8 and V9 in the diagnosis of acute coronary syndromes. Like the addition of the 6 standardized unipolar chest leads in 1938 these additional leads increase the sensitivity of the electrocardiogram in detecting myocardial infarction. **(1, Zalenski)**

**2005** ECG on a mote. Byrne TJ develops simple ECG device using mote technology.

### 6.3. How and Why and Electrocardiograph (ECG, EKG) works

The body acts as a giant conductor of electrical currents. Any two points on the body may be connected by electrical "leads" (see Figure 6-1) to register an ECG or to monitor the rhythm of the heart. The tracing recorded from the electrical activity of the heart forms a series of waves and complexes that have been arbitrarily labeled (in alphabetical order) the P wave, the QRS complex, the T wave and the U wave. The waves or deflections are separated in most patients by regularly occurring intervals.

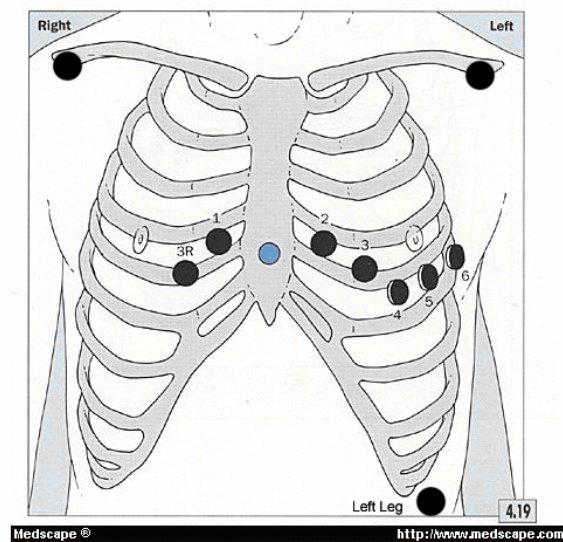


Figure 6-1 9 Electrodes in total (10 for children and sometimes adults) laid out as shown.

Depolarization of the atria produces the P wave; depolarization of the ventricles produces the QRS complex. Repolarization of the ventricles causes the T wave. The significance of the U wave is uncertain, but it may be due to Repolarization of the Purkinje system. It appears at a time when many ectopic (premature)

ventricular complexes (PVCs) occur and is affected by a variety of factors, such as digitalis and electrolytes.

The PR interval extends from the beginning of the P wave (the beginning of atrial depolarization) to the onset of the QRS complex (the beginning of ventricular depolarization). It should not exceed 0.20 second as measured on ECG graph paper, where each small square represents 0.04 second. The QRS complex represents the electrical depolarization of the ventricles. The upper limit of normal duration of the QRS is less than 0.12 second. A QRS duration of less than 0.12 second means that the impulse was initiated from the AV node region or above (supraventricular). A wide QRS ( $> 0.12$  second) may signify conduction that either arises from the ventricle or comes from supraventricular tissue. Prolonged conduction through the ventricle produces a widened QRS. (71 Yanowitz)

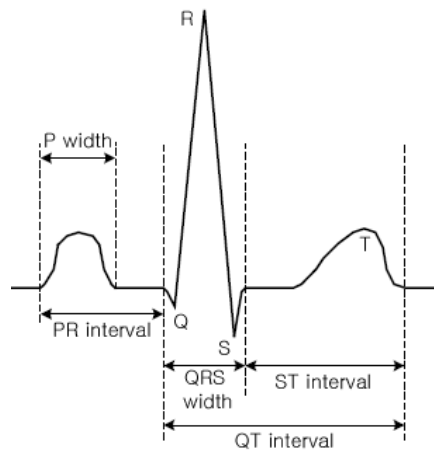


Figure 6-2 Normal ECG signal

Normally, ECGs are recorded at a rate of 25 mm/s and the ECG paper is printed with thin vertical lines 1 mm apart and thick vertical lines 5 mm apart (Fig. 6-3). The interval between the thin lines represents 0.04 s and that between two thick lines 0.20 s. If the heart rhythm is regular, the rate can be counted by dividing the number of small squares between two consecutive R waves into 1500 or large squares into 300. There are also thin horizontal lines at 1-mm intervals and thick horizontal lines at 5-mm intervals. An ECG recording is standardized so that 1 mV gives a deflection of 10 mm on the paper. The height of a deflection therefore indicates its voltage.

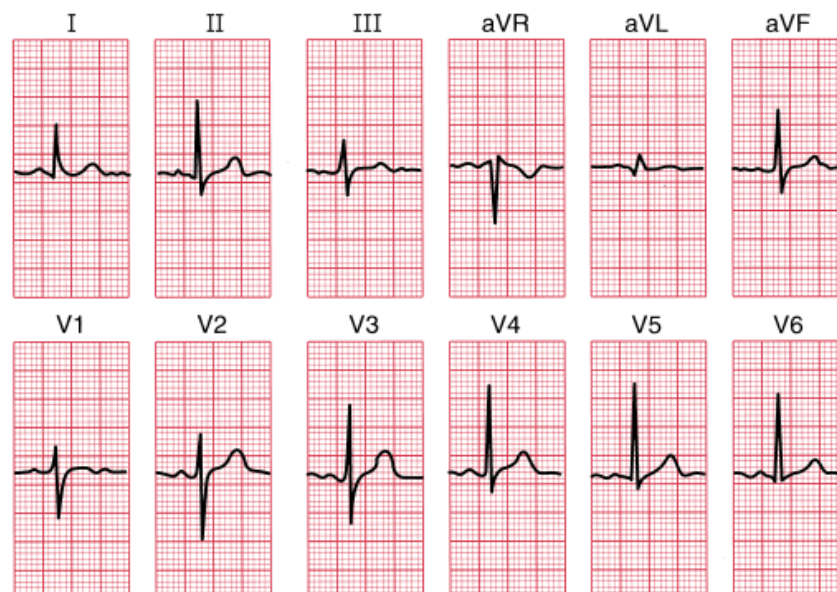


Figure 6-3 Normal 12-lead electrocardiogram. Note the progression in the upright deflection from 'r' over the right ventricle (V1) to an 'R' over the left ventricle (V6)



These “Leads” or sums of electrode readings are then printed out like the picture below (Figure 6.4), being recorded 3 at a time. (The fourth, continuous strip is called the rhythm strip and is usually taken from Lead II). **(32 J.Willis Hurst)**

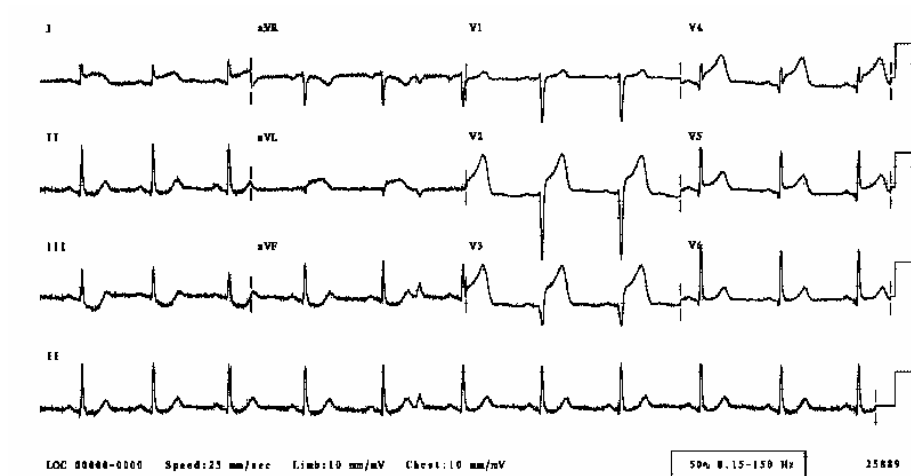


Figure 6-4 Printout from ECG source **(32 J.Willis Hurst)**

#### 6.4. Problems with interpretation

Interpretation of an ECG is no simple matter. Presently in rare cases difficulty in interpretation occurs due to:

- There are hundreds of patterns to recognize.
- It may be impossible to tell how long an abnormality has been present.
- This issue becomes crucial in an emergency situation when a person has symptoms consistent with a heart problem and an abnormal ECG.

Some or all of the abnormalities may have been caused by an event long in the past and unrelated to the current situation.

- Some people are even born with ECG abnormalities.
- This can make it difficult to identify which problems require urgent treatment.
- This is the equivalent of examining a car that has been in both a recent car accident and accidents in the past. Which dents were caused by which accident?

Given the experience of the reviewer there are obvious patterns that can be recognized with little difficulty however the key point here refers to the number of patterns that need to be interpreted and this is where assistance can be provided with wave for analysis and referenced.

#### **6.5. ECG developed using mote technology**

The overall objective of this section of the thesis is to design and implement a simple ECG system using mote technology. In so doing it should be possible to demonstrate data volumes and also present possible areas for changing the way in which this data can be viewed. I.e. Waterfall diagrams as well as discussing future development i.e. 3 dimensional representation. (figure 6-5)

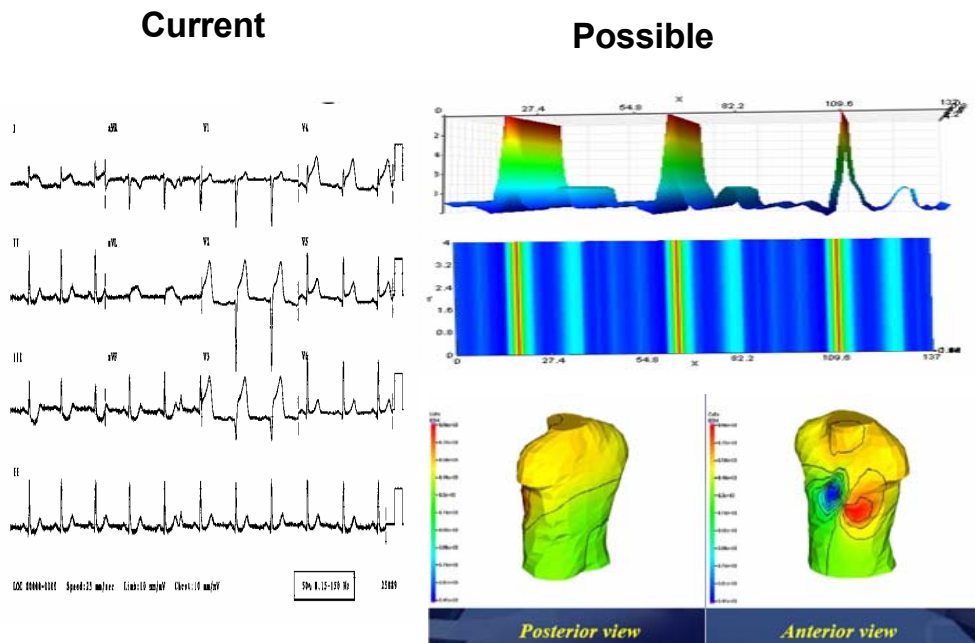


Figure 6-5 Representation of a before and after view of ECG readings displaying the data in standard paper trace as well as potential 3D and Waterfall viewing

This ECG Mote will acquire and digitize the hearts electrical signals, package and transmit to a receiving PC where through a visual basic program the data will be reconstructed and displayed. Further graphical representations (waterfall diagrams) are made using Graphis software.

Analogue electronics are used to obtain the signal and to filter noise, while PC based software (Visual Basic 6.0, Graphis Analytical software) is used to display the results.

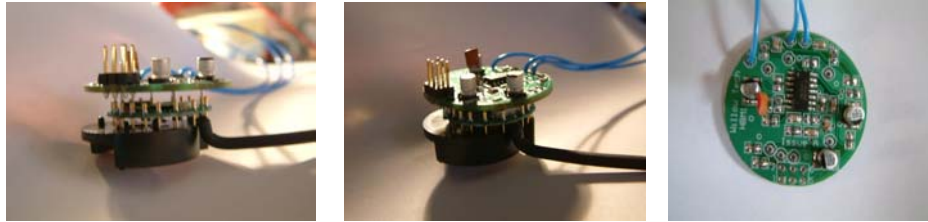


Figure 6-6 Graphic show mote with ADC, Leads and Battery

Sensor printed circuit boards (pcbs) were constructed to measure heartbeat via standard ECG recording electrodes, or "leads". These sensor pcbs are double-sided, Mica2dot (Figure 6.6) sized which plug directly into the standard Crossbow Mica2dot radio pcbs (part ref MPR510CA). Measurements of mVolts, a time stamp & mote id are transmitted via the MPR510CA at a target rate of 1 packet every 0.5secs. Sample rate of the mV can be at higher rate than this and there is the ability to store data so that upon the next transmission several samples may be sent to maintain the overall trace picture at the desired rate.

## 6.6. MICA2DOT

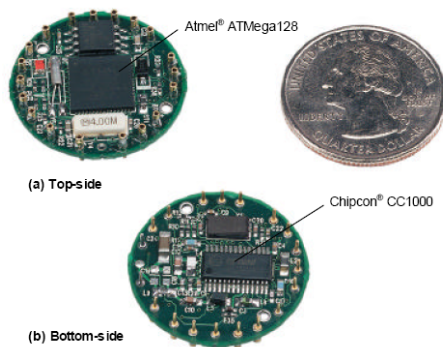


Figure 6-7 Photos of the MICA2DOT shown next to a US quarter: a) Top-side

The MICA2DOT Mote is a third generation mote module used for enabling low-power, wireless sensor networks. The MICA2DOT is similar to the MICA2, except for its quarter-sized (25mm) form factor and reduced input/output channels.

#### **6.6.1. Processor and Radio Platform (MPR500CA):**

The MPR500CA is based on the Atmel ATmega 128L. The ATmega 128L is a low-power microcontroller which runs Tiny Operating System (TOS) from its internal flash memory. Using TOS, a single processor board can be configured to run sensor application processing and the network radio communications stack simultaneously. The MICA2DOT features 18 solder less expansion pins for connecting 6 Analog Inputs, Digital I/O, and a serial communication or Universal Asynchronous Receiver/Transmitter (UART) interface. These interfaces make it easy to connect to a wide variety of external peripherals.

The core of the unit is an ATMEL reduced instruction set computer (RISC) micro controller, running at 8MHz. This device has onboard 10bit ADCs, RAM, FLASH memory. The radio section is generated by a Chipcon CC1000 which is fully Programmable over the frequency range (300-1000 MHz). The radio frequency (RF) output power is 5mW, the receiver sensitivity is (-110 dBm) which Complies with EN 300220 and FCC CFR 47, part 15. The CC1000 does all the data modulation and de modulation onboard releasing the processor from this demanding task. The data is encoded using Bi-phase or sometimes called Manchester encoding. The modulated data rate is 38.4 kBaud, which gives a user data rate of 19K2 kBaud.

### **6.7. ECG Mote mode of operation**

From power up the software sets up the processor peripherals and does the initial configuration of the radio. The internal Analogue to Digital Converter (ADC) is set to interrupt every 415uS and the 10 bit value is stored in an internal register. An internal timer is setup with in the processor and interrupts every 5mS, when this interrupts takes the last ADC value and stores it in a data buffer. This data buffer can store 200 readings. When this data buffer is full i.e. 200 5mS ADC readings, it sets a flag, the radio task sees this flag, and starts to process the radio function.

First the radio checks to see if it is in transmit mode, if it is not the CC1000 is configured for transmit. The CC1000 synthesizer is setup and checked that it has locked onto the correct frequency, if it has not an internal calibration takes place. Once the CC1000 is locked and calibrated, the Radio Frequency (RF) power is increased. It is done in this order so that if the CC1000 is off frequency you don't start sending out RF on undesired frequencies.

Once the CC1000 is setup and generating RF, data is feed into the CC1000. The CC1000 generates a clock, and the processor clocks data serially into the CC1000 on the rising edge. The first part of the packet is called preamble, basically just one's and zeros, this is used so the radio receiver can lock onto the incoming signal. Next we have to tell the receiver software that our data is just about to arrive so we send a sync byte, now both the transmitter and receiver who where they are in the radio transmission. Next are just some general overhead like node identification (ID), packet number and size of the data payload. The data payload is then sent (200 ADC readings) followed by a carriage return (CRC). All this takes a matter of mS. Once all 200 readings have been sent, software flags are

cleared and the 5mS timer interrupt starts filling the 200 reading data buffer again.

The receiver works the same way apart from it receives the data packet and after performing a CRC check outputs the data packet as an 8bit hexadecimal value over a serial port.

Figure 6.8 shows the first successful trace to an oscilloscope; all major elements of the standard wave format are present.



Figure 6-8 First trace to oscilloscope

## 6.8. Operating Environment

The ECG mote will enable standard connection cables to be attached to both the ECG mote and the electrode; these cables should be reusable following contact with patient.

Reconstruction of the data captured by the ECG Mote will be on a standard Personal Computer/Laptop running a Visual Basic application specifically developed to represent the data. Statistical analysis will also be carried out on the

data captured with representation in the form of waterfall diagrams using 'Graphis software'

### **6.9. Heartmonitor Application**

The heart monitor application is written in Visual Basic 6.0. The application mimics an oscilloscope presenting the data captured from the serial port. The heartbeat (pulse) is also displayed, this is calculated based on a preset threshold of maximum voltage. The application is continually monitoring comm. Port 1 for input. As the mote is bursting data to the radio transmitter some buffering takes place before display. Some rudimentary filtering takes place with out of spec values i.e. values generated as a result of radio interference etc, being ignored before writing to the buffer.

While the primary display area displays the advancing trace the secondary display area displays the same trace in a rudimentary waterfall diagram with the trace shown from above. Figure 6.9 shows a simulated trace of a pattern that may be interpreted as hyperkalemic. Figure 6.10 depicts data captured via standard electrodes in a 3 lead configuration.



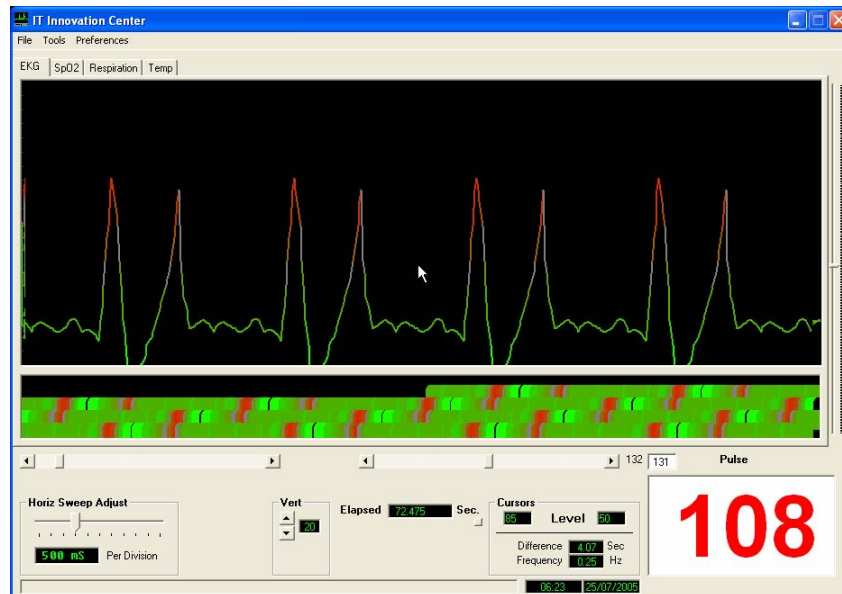


Figure 6-9 Simulated trace of Hyperkalemia

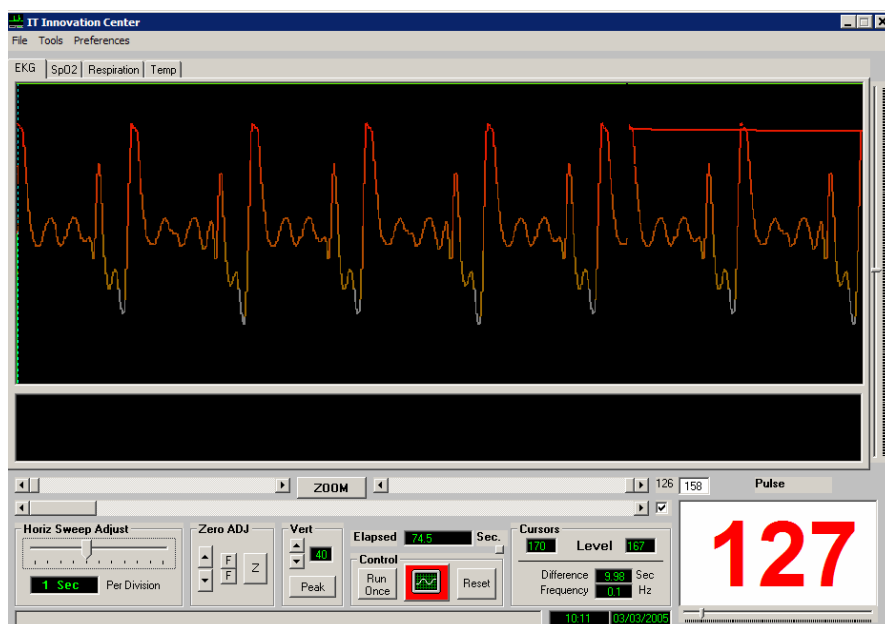


Figure 6-10 Heart Monitor (visual Basic Application)

On display the trace line is color coded based on value. This was done as a first step to a display in the format of waterfall plot (ref figure 6.9). No wave form analysis is done and the representation is wrapped around when end of line is met, additional work is required to identify start and end of the complete ECG cycle.

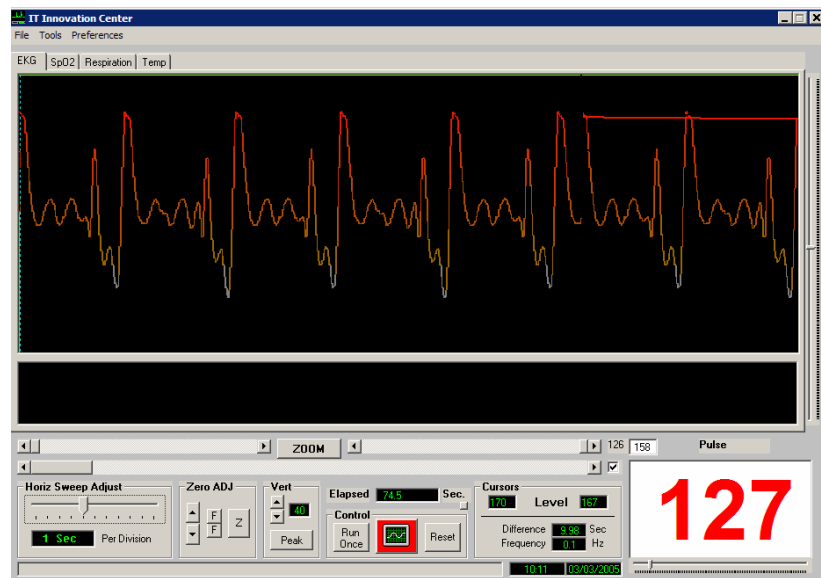


Figure 6-11 Heart Monitor (visual Basic Application)

The application is comprised of 3 major sections, interaction between these areas are initiated primarily by timed events.

#### 1. Initialization

In this section the application paints all visible components of the application including primary and secondary display areas as well as control keys and buttons. All initialization of counters takes place at this stage.

## 2. Port monitor

In this section of code the application monitors communications port 1 of the PC on which the application is running. Using dynamic link libraries the application accepts data received at comm. Port 1. On receipt the application completes some rudimentary filtering, ignoring major out of spec data. Accepted data is written to a multidimensional buffer.

## 3. Display

Once the data buffers are filled (approx 5000) readings the applications paints the trace to the primary display area in the form of a standard trace, the pitch and speed can be controlled by through the user interface. By changing the pitch and speed the user can effectively zoom in on the trace.

### **6.10. Graphis visualization and data analysis program.**

Graphis contain 2D and 12 3D plot types, allowing analytical or tabular input to be plotted in Cartesian, polar, cylindrical or parametric coordinates.

Graphis has been designed to make the generation of Scientific, Engineering and Business graphs as simple as possible, while retaining the flexibility required making a graph look exactly as you want. Whether you are creating a 2D graph or a 3D graph and whether your graph is based on analytical or tabular input, Graphis will use initial default settings to allow you to get a view of the data with the minimum of effort. Because care has been taken to ensure a consistency of approach in producing the various graph types and in modifying graph parameters such as axis ranges, labels, colors etc., tailoring a graph can also be done in an intuitive and user-friendly way.

### 6.11. The Waterfall Plot

A waterfall is a presentation of both frequency domain and time domain data on a single graph. Time domain data is voltage or pressure as a function of time, usually in the form of a measured impulse response (origination from a pulse or MLS measurement), which covers all time.

Figure 6.12 uses data captured via the ECG mote and input to the Graphis application. With this application the data can be viewed in two temporal dimensions, i.e. from left to right as well as back to front. By doing so patterns of activity become clearer. If the graph is viewed top down these patterns are more obvious. Ref 6.13. With further development this visualization could be incorporated in to the Heartmonitor application.

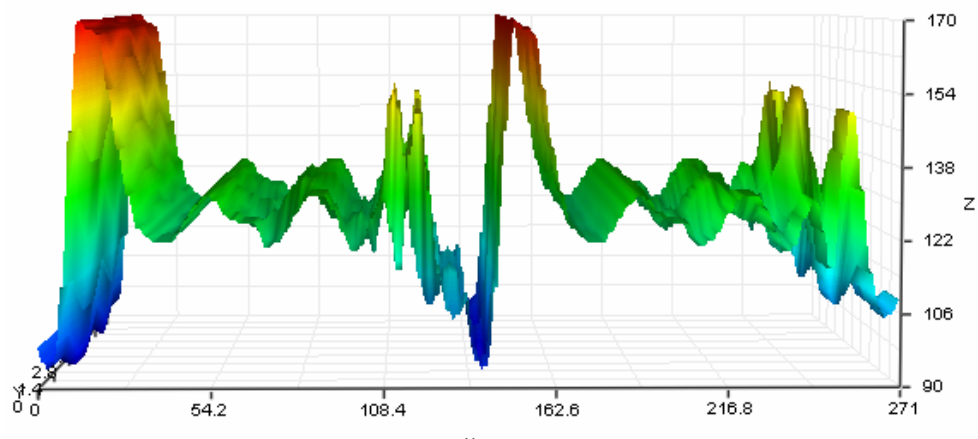


Figure 6-12 Data displayed as a waterfall plot using Graphis analytical software package

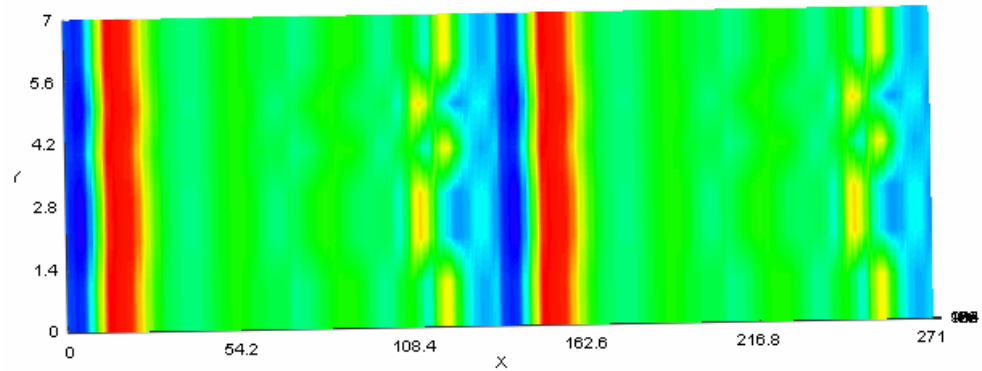


Figure 6-13 Data from hear monitor application viewed as top down

## 6.12. Examples of ECG traces Current paper trace V 3D waterfall plot.

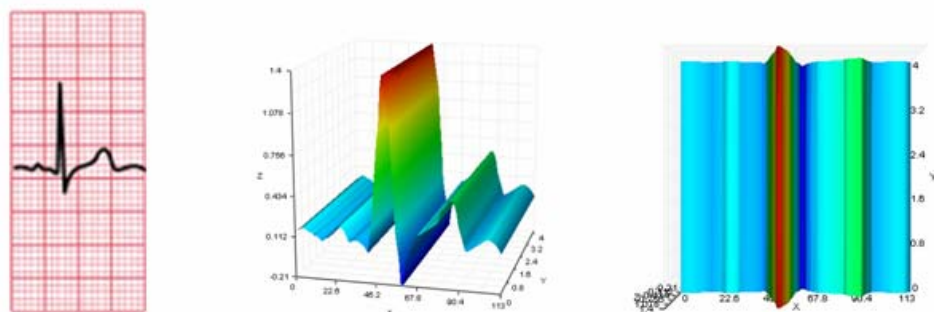


Figure 6-14 Standard trace with P-U elements evident on the left with 3D waterfall plot Middle and top down view Right

### Hyperkalemia

Potassium (K) is one of the 2 ions that make up the bulk of the ion-based membrane potential of cardiac cells (both myocytes and conduction cells). An imbalance of potassium can create a life threatening situation which must be corrected immediately. The most prominent feature of an ECG of a hyperkalemic

patient is the peaked-T wave. The other feature of the hyperkalemic ECG is a stretching of entire waveform.

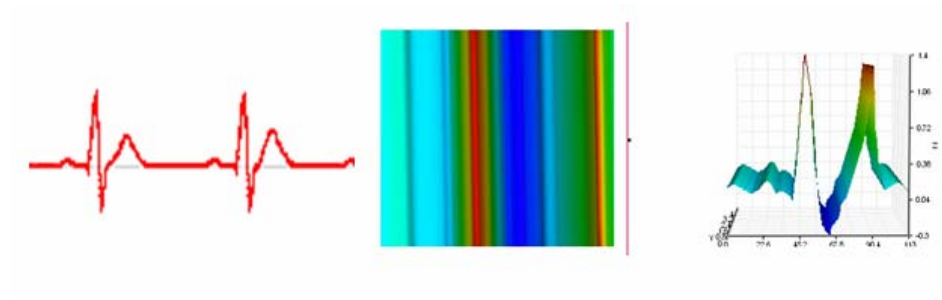


Figure 6-15 Simulated trace on left exhibiting characteristics of Hyperkalemia, Middle and Right in Top down and waterfall respectively

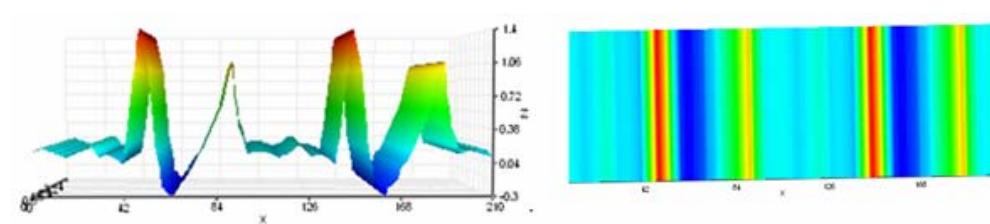


Figure 6-16 Simulated trace exhibiting characteristics of Hyperkalemia and right Top down view of Stylized trace exhibiting characteristics of Hyperkalemia

Using the waterfall graphing patterns of color can be recognized, as this data is simulated there is uniformity in presentation, however as deviations occur those deviations are highlighted and easily recognized.

### **6.13. Development of the mote and application to use Ultra-low-noise electrical-potential probes**

So far we have looked at conventional approaches to the rendering of data collected via standard electrodes placed on the skin. The readings from these probes we then, in the case of standard ECG plot on paper and in the case of the mote displayed via a PC application with rudimentary color coding. Output from the mote was also rendered via a graphics package (Graphis) with the output again color coded and displayed in a waterfall plot (side on as well as top down). In one respect these approaches are entirely similar i.e. they are two dimensional. The waterfall plot adds the Z plane but this is only used to represent multiple slices of the trace and allows easier comparison to previous cycles.

With the development of ultra low noise electrical-potential probes (UNEP) the standard electrode probes can be replaced. These UNEP's operate on displacement, not real charge or current eliminating the need to make direct electrical contact with the body. Probes can be positioned off the body at a distance of 3 mm.

By configuring many of these UNEP's to act in unison it should be possible to add that third dimension and represent entire electrical information during the cycle of a heart beat.

#### **6.13.1. Ultra-low-noise electrical-potential probe for human-body scanning**

Body surface maps, when obtained from electrocardiograms recorded from the entire surface of the torso, with a sufficient number of probes, contain the entire electrical information that can be captured from body surface measurements. Studies have shown that Body Surface Maps (BSM's), in their different formats,

have higher diagnostic value than the 12-lead ECG. There are issues using BSM's they can be difficult to interpret and need to be supported by additional information and computer processing. (40 Taccardi et al)

#### 6.14. Body surface maps (BSM)

In the 1950s and 1960s, more advanced mapping techniques revealed that the potential distributions generated by human and animal hearts were much more complex than those produced by a single dipole. This work suggested that important diagnostic information might be obtained from BSM's. Maps were recorded in thousands of patients with congenital and acquired heart diseases: coronary heart disease. Maps were interpreted using visual inspection, pattern recognition, statistical analysis (significant departure from normal patterns), principal component analysis and pace mapping. (40 Taccardi et al).

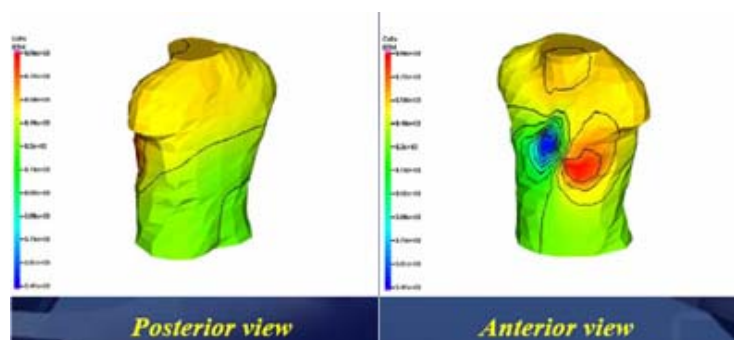


Figure 6-17 3D view of electrical activity measured by non contact probes

In the great majority of heart conditions, BSM's have demonstrated a higher diagnostic power than the 12-lead ECG. In many cases, significant features, such as abnormal potential minima or maxima, signaling myocardial ischemia or infarction, were found in chest areas that are not sampled by the 12-lead system.



In those cases, the classical 12-lead ECG was normal and overlooked the pathological features. (40 *Taccardi et al*)

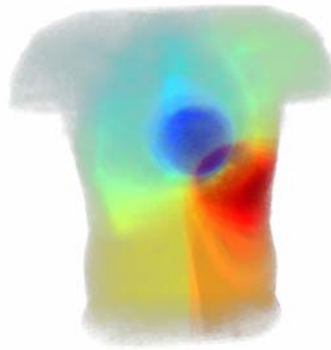


Figure 6-18 A hardware accelerated volume rendering showing the propagation of electrical potentials from the heart simulated

#### 6.15. Limitations of body surface maps

Despite their demonstrated diagnostic power, BSM's have not become a routine clinical method. This is due to a number of difficulties: necessity of recording a high number of leads (32 to 219); multiplicity of lead systems used by different laboratories; difficulty of memorizing hundreds of patterns (usually one for every msec during the P-QRST interval) that vary in different heart diseases. The most serious obstacle, however, is the difficulty of interpreting the various features of a map (number, location, amplitude and time-course of maxima, minima, saddles etc.) in terms of intracardiac events. Most of the other imaging methods provide a direct representation of cardiac anatomy and function that is easily recognizable by cardiologists. Conversely, BSM's do not show an image of the heart, but an attenuated, smoothed and distorted reflection of the intracardiac electrical events, as projected on the body surface. Thus, many important features of the electrical

activity of the heart are not recognizable through visual inspection of the maps.  
*(40 Taccardiet al).*

## CHAPTER 7. CONCLUSIONS

The initial thrust of this dissertation was the development of an alternative method of collecting and displaying ECG signals using mote technology and graphical software to display collected data in waterfall diagrams. It became obvious however that these devices may not only be of benefit to the provision of healthcare but also add to a situation whereby healthcare providers are being overwhelmed by the amount of information being presented to them. A number of published reports based on U.S. data, point to alarming rates of error resulting in varying degrees of negative outcomes for patients. While there are a number of contributory factors, information overload plays a significant role in the commission of those negative outcomes.

Without exception we are limited in both our sensory and cognitive capabilities, ignoring these limitations will further endanger patients and undermine the quality of care and the outcome of that care. Best case scenario this will result in added cost, worst case error will result in death.

The unrelenting pace of technological development in the area of sensors and diagnostics will no doubt add to speedier and more accurate disease identification, the proliferation of these devices however will contribute to the mountain of information that healthcare providers already need to assimilate in order to make decisions. Examples of some of the major areas of development and how these devices are contributing to the problem of information overload have been called out in chapter 2.

Information overload figures highly both as a cause and as a multiplier in the commission of error. As the pace of technological development continues so too

will the issue of interpretation of data produced by those developments. Decision making will become more difficult for healthcare workers.

While not definitive, there are models of the human cognitive processes. Major components of these cognitive processes and capabilities have been presented. With cognitive capability come limitations and with those limitations the potential for misinterpretation, interrupted attention, lack of focus or misdirected focus can be exacerbated. While not solely responsible for the 1.4 million incidents highlighted in the 2004 Healthgrades report **(36 Healthgrades)** cognitive capability would appear to be a common thread in the areas highlighted as a contributor to error. *(41 Croskerry et al), (14 Williams J)*

With the development of the ECG mote it has been possible to demonstrate alternative methods of data presentation, while no computer analysis or pattern recognition is done, simply representing the data on two time dimensions X and Z allows the reviewer to view a) a larger dataset and b) present patterns that can focus attention on areas of interest.

## **7.1. Challenges**

### **7.1.1. Data Visualization**

Although the computer contributes to the information explosion, it is potentially the savior for finding, sorting, filtering, and presenting the relevant items. Search in complex structured documents, graphics, images, sound, or video presents grand opportunities for the design of user interfaces and search engines to find the needle in the haystack.

### 7.1.2. Cognitive capabilities

Extensive psychology research has revealed that people have surprisingly stubborn limitations on their ability to carry out multiple tasks at the same time. Refer to chapter 2 re introduction of error when multi-step actions need to be taken. When a cognitive bottleneck is tied up by one task, the second task has to wait until the bottleneck is released. (66 Jiang et al)

In the design and development of new healthcare application consideration must be given to:-

**User Interface:** To dynamically balance multimedia cueing to match operators cognitive needs (flashing, alarm sounds, color and spatial layout)

**Cognitive System Component:** DSS engineering to manage alerts (negotiation-based task management; interactive visualization; automatic trend inference; context recovery support)

**Alert Generation:** Systems engineering to generate alerts to support tactical action (hard real-time computing; operations; tactical role modeling)

**Audit:** If decisions are to be made based on a cognitive system the ability to review why a particular course was chosen is critical, this would need to be supported by a snapshot of the data on which decisions were made.

### 7.1.3. Information Overload

There is a threshold for people's ability to handle the myriad of external stimuli and interruption without support, and when this threshold is exceeded, situational awareness fails and decision quality drops resulting in accidents, errors, misdiagnosis, adverse drug reaction etc.

Successful provision of healthcare depends on high quality decision-making. However, this is not possible without more appropriate application of decision making and alerting technology.

It must be recognized that while motivation, training and experience levels are at high levels within the healthcare professions the problem of information overload will not only persist but become an evermore prevalent issue.

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The U.S. Census Bureau - Social, Economic, and Demographic Information  
<http://www.census.gov/>

The U.S. Census Bureau - United States Census 2000 (detailed census data)  
<http://www.census.gov/main/www/cen2000.html>

UCLA Center for Health Policy Research - Information on California's Medically Uninsured Population <http://www.healthpolicy.ucla.edu/>

Medi-Cal Policy Institute - Independent Medi-Cal News and Analysis  
<http://www.chcf.org/topics/medi-cal/index.cfm>

The Medi-Cal Website - Information for Medi-Cal Providers- <http://www.medi-cal.ca.gov/>

## GLOSSARY

<b>ECG</b>	An electrocardiogram (ECG / EKG) is an electrical recording of the heart and is used in the investigation of heart disease.
<b>mote</b>	There are currently several versions of the mote, and even more in the works. There are two versions with which you need to be familiar: Renee and Dot. They will be described separately below. As in the Running Man project, it helps to first look at the basic description of the mote as a component. In the most simplified description, a mote is nothing more than a wireless receiver/transmitter. The mote itself does not have any sensors built-in. It should also be mentioned that the motes have super low power consumption. The consumption is significantly lower than anything currently available, including Bluetooth stuff. Both motes run on a 3.0 V supply.
<b>Ventilation:</b>	Artificial breathing for a patient who is not breathing.
<b>TinyOS</b>	TinyOS is an open-source operating system designed for wireless embedded sensor networks. It features a component-based architecture which enables rapid innovation and implementation while minimizing code size as required by the severe memory constraints inherent in sensor networks. TinyOS's component library includes network protocols, distributed services, sensor drivers, and data acquisition tools – all of which can be used as-is or be further refined for a custom application. TinyOS's event-driven execution model enables fine-grained power management yet allows the scheduling flexibility made necessary by the unpredictable nature of wireless communication and physical world interfaces.
<b>Kilobyte (KB)</b>	1,000 bytes OR 103bytes 2 Kilobytes: A Typewritten page.

	100 Kilobytes: A low-resolution photograph.
<b>Megabyte (MB)</b>	<p>1,000,000 bytes OR <math>10^6</math> bytes</p> <p>1 Megabyte: A small novel OR a 3.5 inch floppy disk.</p> <p>2 Megabytes: A high-resolution photograph.</p> <p>5 Megabytes: The complete works of Shakespeare.</p> <p>10 Megabytes: A minute of high-fidelity sound.</p> <p>100 Megabytes: 1 meter of shelved books.</p> <p>500 Megabytes: A CD-ROM.</p>
<b>Gigabyte (GB)</b>	<p>1,000,000,000 bytes OR <math>10^9</math> bytes</p> <p>1 Gigabyte: a pickup truck filled with books.</p> <p>20 Gigabytes: A good collection of the works of Beethoven. 100 Gigabytes: A library floor of academic journals.</p>
<b>Terabyte (TB)</b>	<p>1,000,000,000,000 bytes OR <math>10^{12}</math> bytes</p> <p>1 Terabyte: 50000 trees made into paper and printed.</p> <p>2 Terabytes: An academic research library.</p> <p>10 Terabytes: The print collections of the U.S. Library of Congress. 400 Terabytes: National Climactic Data Center (NOAA) database.</p>
<b>Petabyte (PB)</b>	<p>1,000,000,000,000,000 bytes OR <math>10^{15}</math> bytes</p> <p>1 Petabyte: 3 years of EOS data (2001).</p> <p>2 Petabyte: All U.S. academic research libraries.</p> <p>20 Petabyte: Production of hard-disk drives in 1995.</p> <p>200 Petabyte: All printed material.</p>
<b>Exabyte (EB)</b>	<p>1,000,000,000,000,000,000 bytes OR <math>10^{18}</math> bytes</p> <p>2 Exabyte: Total volume of information generated in 1999. 5 Exabyte: All words ever spoken by human beings.</p>
<b>Nanotechnology</b>	Research and technology development at the atomic, molecular and macromolecular levels in the length scale of approximately 1 – 100 nanometer range.
<b>Voxel</b>	The voxel is an volume element $v(x,y,z, \Delta x, \Delta y, \Delta z)$ located at a point $p(x,y,z)$ with dimensions $\Delta x, \Delta y, \Delta z$ .

<b>iatrogenic</b>	Induced in a patient by a physician's activity. The word originally meant a condition induced by the physician's examination, manner, or discussion but the term is now applied to any adverse condition resulting from treatment by a physician or surgeon, especially an infection or other complication of treatment.
<b>Data</b>	Data on its own has no meaning. Only when interpreted by some kind of data processing system does data take on meaning and become information.
<b>Information</b>	The meaning that a human assigns to data by means of the known conventions used in their representation.
<b>UART</b>	The Universal Asynchronous Receiver/Transmitter (UART) controller is the key component of the serial communications subsystem of a computer. The UART takes bytes of data and transmits the individual bits in a sequential fashion. At the destination, a second UART re-assembles the bits into complete bytes.



## ABBREVIATIONS

<b>CPOE</b>	Computerised Physician Order Entry
<b>TOS</b>	Tiny Operating System
<b>BSM</b>	Body Surface Maps
<b>ICU:</b>	Intensive Care Unit
<b>WLAN</b>	Wireless area network.
<b>DVT</b>	Deep Vein Thrombosis/PE (DVT)
<b>OECD</b>	Organization for Economic Co-operation and Development
<b>EHR</b>	Electronic Health Record.
<b>UNEP</b>	ultra low noise electrical-potential probes (UNEP)
<b>FDA</b>	Food & Drug Administration
<b>MRI</b>	magnetic resonance imaging
<b>pVT</b>	Pulseless VT.
<b>PDA</b>	Personal Digital assistant
<b>PEA</b>	Pulseless Electrical Activity. Electrical activity is present on the cardiac monitor, no pulse is present.
<b>VF</b>	Ventricular Fibrillation. Rapid, disordered, ventricular electrical activity.
<b>VT</b>	Ventricular Tachycardia. Rapid, regular, ventricular electrical activity.
<b>SAEM</b>	Society for Academic Emergency Medicine
<b>PCB</b>	printed circuit board

<b>ADC</b>	Analogue to Digital converter
<b>HIMSS</b>	Healthcare Information Management Systems Society
<b>LTM</b>	Long Term Memory
<b>STM</b>	Short Term Memory
<b>UART</b>	Universal Asynchronous Receiver/Transmitter
<b>RF</b>	Radio Frequency
<b>RAM</b>	Random Access Memory

## APPENDIX A SOURCES OF DATA

### Appendix A Possible sources of data

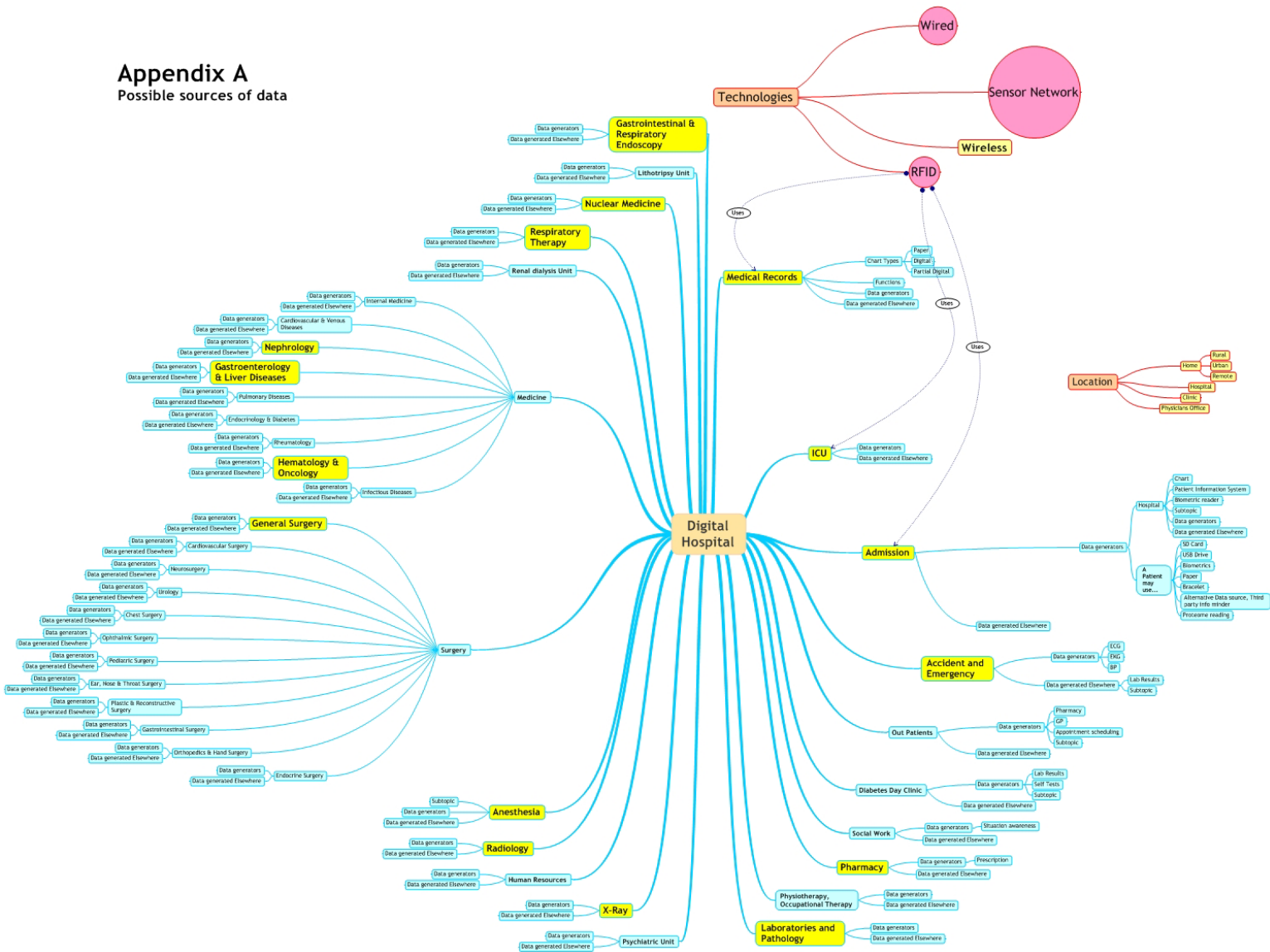
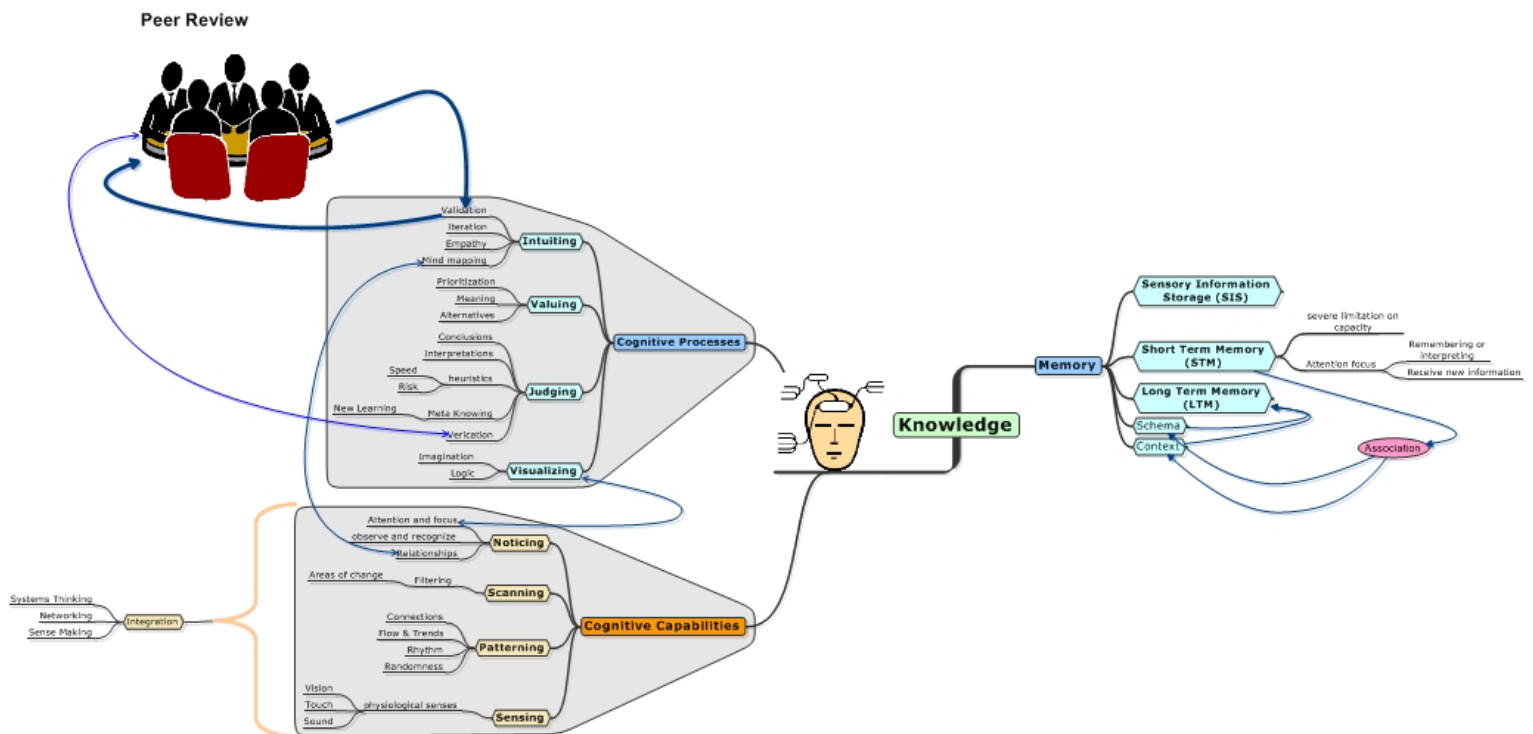


Figure 0-1 Hospital Departments

## APPENDIX B COGNITIVE CAPABILITIES/PROCESSES

### Appendix B Cognitive Capabilities/Processes



## APPENDIX C GRAPIS DATA FROM MOTE

Table 0-1 Output from ECG Heart Graphis  
waterfall diagram

Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5	Data Set 6
112	112	103	103	112	103
112	112	103	103	112	103
129	129	119	119	129	119
146	146	137	137	146	137
160	160	155	155	160	155
170	170	167	167	170	167
169	169	170	170	169	170
168	168	169	169	168	169
168	168	169	169	168	169
168	168	168	168	168	168
167	167	168	168	167	168
163	163	167	167	163	167
155	155	161	161	155	161
155	155	161	161	155	161
148	148	153	153	148	153
142	142	146	146	142	146
142	142	146	146	142	146
136	136	140	140	136	140
132	132	135	135	132	135
132	132	135	135	132	135
128	128	130	130	128	130
125	125	127	127	125	127
125	125	127	127	125	127
124	124	124	124	124	124
123	123	123	123	123	123
123	123	123	123	123	123
122	122	122	122	122	122
122	122	121	121	122	121
122	122	121	121	122	121
122	122	121	121	122	121
122	122	121	121	122	121
122	122	122	122	122	122

124	124	123	123	124	123
124	124	123	123	124	123
125	125	125	125	125	125
127	127	127	127	127	127
127	127	127	127	127	127
129	129	129	129	129	129
130	130	130	130	130	130
130	130	130	130	130	130
131	131	131	131	131	131
132	132	132	132	132	132
132	132	132	132	132	132
132	132	132	132	132	132
131	131	132	132	131	132
131	131	132	132	131	132
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128	128	130	130	128	130
127	127	128	128	127	128
127	127	125	125	127	125
127	127	125	125	127	125
126	126	123	123	126	123
126	126	122	122	126	122
126	126	122	122	126	122
126	126	121	121	126	121
126	126	122	122	126	122
126	126	122	122	126	122
125	125	123	123	125	123
123	123	125	125	123	125
121	121	124	124	121	124
121	121	125	125	121	125
121	121	125	125	121	125
122	122	128	128	122	128
122	122	128	128	122	128
122	122	130	130	122	130
124	124	130	130	124	130
124	124	131	131	124	131
126	126	132	132	126	132
128	128	132	132	128	132
128	128	133	133	128	133
129	129	132	132	129	132
131	131	132	132	131	132
131	131	132	132	131	132
132	132	130	130	132	130

132	132	130	130	132	130
132	132	127	127	132	127
132	132	127	127	132	127
132	132	126	126	132	126
132	132	124	124	132	124
131	131	124	124	131	124
129	129	124	124	129	124
129	129	123	123	129	123
127	127	123	123	127	123
124	124	123	123	124	123
124	124	123	123	124	123
122	122	124	124	122	124
120	120	124	124	120	124
120	120	124	124	120	124
120	120	125	125	120	125
121	121	123	123	121	123
121	121	123	123	121	123
124	124	119	119	124	119
127	127	116	116	127	116
127	127	116	116	127	116
129	129	124	124	129	124
131	131	124	124	131	124
131	131	138	138	131	138
130	130	150	150	130	150
124	124	150	150	124	150
124	124	154	154	124	154
116	116	149	149	116	149
116	116	149	149	116	149
116	116	138	138	116	138
127	127	138	138	127	138
141	141	126	126	141	126
141	141	117	117	141	117
150	150	117	117	150	117
150	150	110	110	150	110
150	150	110	110	150	110
143	143	106	106	143	106
133	133	104	104	133	104
133	133	104	104	133	104
123	123	104	104	123	104
115	115	106	106	115	106
115	115	106	106	115	106
110	110	109	109	110	109
107	107	111	111	107	111

107	107	111	111	107	111
106	106	111	111	106	111
106	106	111	111	106	111
107	107	108	108	107	108
109	109	104	104	109	104
109	109	104	104	109	104



## APPENDIX D PUBMED/US PATENT DATA

Table 0-1 Growth of information based on published documents and patent filing source PUBMED/US Patent office

Growth of Databases								
Year	PubMed References	KFINDER Counts	PATENTS (application date)	PATENTS (priority date)	Aging References	GENBANK	Genbank (Human)	UNIGENE
12/31/1956								
12/31/1957								
12/31/1958			72					
12/31/1959		3	96	12				
12/31/1960		5	129	30				
12/31/1961		1	139	64				
12/31/1962	21	21	188	74				
12/31/1963	1,179	1,179	214	110				
12/31/1964	7,581	7,581	340	260				
12/31/1965	99,779	99,835	520	551				
12/31/1966	174,530	174,553	908	1,332				
12/31/1967	186,343	186,430	2,832	4,734				
12/31/1968	203,375	203,520	15,994	10,770				
12/31/1969	210,327	210,448	42,006	12,697				
12/31/1970	211,642	211,644	52,520	13,918				
12/31/1971	217,091	217,166	54,243	15,524				
12/31/1972	221,226	221,303	55,745	19,676				
12/31/1973	224,802	224,855	64,600	20,483				
12/31/1974	228,184	227,932	66,999	19,358				
12/31/1975	242,322	240,555	68,867	21,057				
12/31/1976	259,307	245,616	70,817	22,233				
12/31/1977	256,938	249,293	71,370	23,135				
12/31/1978	264,954	256,115	71,032	24,491				
12/31/1979	272,690	265,241	71,117	25,865				
12/31/1980	269,344	263,281	72,109	25,878				
12/31/1981	271,003	265,383	69,171	27,002				
12/31/1982	282,024	275,325	70,751	27,376				
12/31/1983	295,557	287,635	67,627	30,664				
12/31/1984	304,232	297,292	73,665	34,281				
12/31/1985	316,119	307,587	78,611	36,031				
12/31/1986	328,808	320,501	82,177	38,169				

12/31/1987	345,772	337,113	89,269	42,922				
12/31/1988	362,873	354,106	98,377	44,893				
12/31/1989	378,432	369,345	104,590	46,039				
12/31/1990	386,293	376,549	108,603	45,393				
12/31/1991	386,936	375,605	109,507	44,818				
12/31/1992	388,978	377,028	112,980	45,361		10,682	4,830	
12/31/1993	395,393	381,186	117,291	47,546		149,562	41,668	
12/31/1994	403,807	381,672	132,797	47,653		88,017	27,478	
12/31/1995	413,664	353,568	151,952	48,049		414,649	316,991	
12/31/1996	420,387	285,102	149,615	39,840		473,554	265,292	
12/31/1997	426,009		151,165	20,885		825,625	413,229	
12/31/1998	438,885		81,961	4,748		870,444	466,868	40,348
12/31/1999	440,212		16,916	350				
12/31/2000								
Total:	10,537,019	8,851,574	2,649,882	934,272	0	2,832,533	1,536,356	40,348

## APPENDIX E WATERFALL PLOTS OF STANDARD ECG'S

Table 0-1 Examples from Table of Normal 12-lead electrocardiogram. Traces are represented with Waterfall plot and topdown view.

