

MEGA MINDS



How to
Create
and Invent
in the
Age of Google

Larry Kilham

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**How to Create and Invent in the
Age of Google**

By

Larry Kilham

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About the Author

Also by Larry Kilham

Great Idea to a Great Company:

Making Inventions Pay

For my uncle Jim Breese
who should have written this book.

About the Illustrations

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PART I

Creativity and Invention

Chapter 1

New Creativity for Renewed Prosperity

The era we are entering will be one of enormous social, political and economic change...

...things will have to change around here, and fast.

Thomas L. Friedman, *Hot, Flat, and Crowded*

On a recent flight to Orlando, home of Disney World and fantasy, I sat next to a really bright young entrepreneur. Working in the automobile parts supply business, he learned who the buyers are and who the sellers are, pricing, key trade shows to meet important contacts and so forth. He coupled this knowledge and his boundless inquisitiveness and energy with the new marketing medium of the Internet to start an “aftermarket” automobile accessories supplier mainly to the world of Toyota.

He has about 20 employees, is totally self-financed with no debt or government aid, has an adoring wife and great kids, and is generally enjoying the American Dream. He is less than half my age and, I thought, an ideal observer of the enterprise world coming upon us.

I asked him, “Are you developing any of your own products? Will you have some cool addition to the standard stuff everybody is making and selling?” He thought for a minute and replied, “There are extremely few, if any, new inventions anymore.”

You might think we will turn into the Internet marketing capital of the world and leave it to the rising class of Asian engineers who have found stimulating opportunities in their home countries to generate the products the whole world will need for today and tomorrow. Creativity will be reduced to thinking up new Corporate Goals statements and new luncheon theme ideas.

But Bette Nesmith Graham didn’t know this. A single mother and secretary in Dallas, she thought there would be a better way to cover up mistakes made in typing. She recalled her long ago artistic experience and looked for a liquid mixture to paint over the typing errors. The first formulations were made up in her kitchen blender.

In 1956 Ms. Graham founded the Mistake Out company, later well-known as Liquid Paper (figure 1a: <http://larrykilhambooks.com/M1a.aspx>) or “white out,” starting on the proverbial shoe string and working nights and weekends. By 1968 she had her own plant and 19 employees. She sold her company for \$47.5 million. Even if taxes and transaction expenses took over half of that, she cleared about \$1 million a year.

This is still possible at all levels from the kitchen chemistry lab to the killer app corporate development project or to the multinational research initiative. In 1993, I started my last company on the dining room table soldering parts together mostly purchased at the local Radio Shack. It grew into a small but leading gas detection instrument company which I sold in 2007 at many times my investment.

We are in new times and uncharted territory in the saga of enterprise. The United States and the rest of the western world are facing the possibility of no growth or at best very controlled growth for decades or longer. Major product ideas and resources are harder to find. The dollar is getting weaker, so we can't buy or outsource everything we need. We must create new solutions, products and services as a major component of future sales.

Entrepreneurs and managers must rediscover discovery. For the last few decades, the mantra in business schools and corporate training programs has been marketing. This was the way to the top. Information technology has also become an important fast track for rising managers. In most cases, product development and intellectual property accumulation has been a discretionary activity, seriously pursued when extra cash was in great supply.

This book focuses on the mindset and creative process involved to imagine, create and invent in the 21st century. This subject is not generally taught in schools and colleges, and it doesn't lend itself to a few simple rules for success, but we must tackle it if we're going to enjoy renewed prosperity any time soon.

While management of innovation has been a popular management development subject, the creative process itself is often not meaningfully addressed. This book will help you identify creative innovators, help you know what is a good creative environment, and help you understand what

knowledge resources innovators need to carry out the creative process. This information is equally valuable for the self-guided creator and entrepreneur. I will combine observations of historically creative and inventive people, new findings from cognitive science about the creative process, and ways to use the Internet and computer clouds to greatly enhance success in a creative project.

Whatever the era or product, the successful project or company starts with a creative visionary--somebody who is imaginative and persistent and who has a multifaceted mind.

Would an American corporation in the early 1800's (or now) hire as their chief designer a financially failing artist with radical political views and an itchy foot for world travel? There was such a person. He did not have a comfortable job, but he had a vision to develop a communication system that could send messages faster than the best steam trains and ships and unhindered by rain, sleet or snow. He was Samuel Finley Breese Morse, a distant relative, who invented the telegraph.

In 1832, while on a sea voyage back to America, Morse began to think about the concept of a telegraph system. He knew the basic principles of electro-magnetism, but not the practical aspect of engineering products and systems. Several European inventors were also working on telegraph systems, but apparently their efforts were unknown to him.

Morse used his creative abilities to see relationships and possibilities. His breakthrough was coding letters and numbers as groupings of binary digits. This allowed the simplicity of sending messages over one wire (the return circuit being ground) instead of several wires that would be required for simple or no coding schemes. The competing European designs required as many as 35 wires.

Public demonstrations of telegraphy happened about 12 years after Morse's first vision of it. What carried him through those wrenching times was perseverance, the ability to tinker and improvise, thinking about all aspects of the design such as the need for coding as well as transmission, and his ability to bring other people to help when design, manufacturing and other challenges required additional talents and facilities.

Both Bette Nesmith Graham and Samuel F. B. Morse were iconic American inventors who illustrate traits in common that

will be valuable to anyone interested in creating new designs and products:

- **Unleash your curiosity, quest for knowledge, and propensity for noticing things.** No lesser minds than Leonardo da Vinci and Albert Einstein were noted for being passionately curious, using their imagination as their prime lens to see ahead and their creativity to solve problems. Einstein wrote: “The important thing is not to stop questioning.” You should also notice all kinds of things, however unrelated to your quest they may seem. When Willis Carrier noticed the apparently odd behavior of water droplets in fog, he had stumbled into the basics of the novel technology of the Carrier Corporation, world leader in air conditioning.
- **Project your mind into imagination space, focusing on all the interrelated aspects of what you are creating or inventing.** To create your Eureka moment, you must forcefully move your mind beyond the existing thinking about the subject. You must move out of your conscious world and focus your mind in a new place occupied only by the new creation. This is your glorious imagination space. Some people, very few, keep this imaginative ability through adulthood. Their imaginings lead to inventions, art, designs and explorations of many frontiers never seen before. To start, try to be a child with the almost naïve capability of unfettered imagination. Emotion is part of this creative formula, and that has not been replicated in any advanced computer.
- **Bring in experts and specialists whenever and wherever appropriate.** A common mistake is to be overly protective about your novel idea. At the earliest possible time you should have your design or composition reviewed by an associate, faculty member, consultant or other trustworthy knowledgeable advisor. Usually you do not have to disclose important details to protect from copying, and very often a reviewer can give you surprisingly good guidance on design or composition improvement.

- **Focus on the practical, useful, needed and beautiful.** Very often inventions and other creations start out answering to a major need or a broad interest. Then the project morphs into a personal passion with little or no market value. Whether you're a garage tinkerer or Thomas Edison, ultimately your commercial success depends on developing something which economically fills a real need and which looks attractive to potential buyers. As you develop prototypes, theories or compositions, show them to people in the market for overall attractiveness feedback.
- **Be persistent. Don't give up!** In one famous incident, an associate found Thomas Edison at his lab bench surrounded by a sea of experimental storage battery test cells. 9,000 experiments had been carried out with no promising developments. His associate offered condolence, "Isn't it a shame that with the tremendous amount of work you have done, you haven't been able to get any results?" "Results!" Edison replied. "Why, man, I have gotten a lot of results. I know several thousand things that won't work!" For a major invention like the light bulb, this is what's involved. Even minor inventions seem to take more time than imagined to get to the production prototype stage.

These key parts of creative thinking will be explored in part I of this book.

Where the telegraph initiated the era of wired communications, the iPhone has started the era of the computer clouds (almost infinitely large bundles of data and services available by Internet) in the palm of your hand. The telephone is not obsolete, music radio won't go away, computers of all sizes will always be here, video games will always have their consoles, and data transmission will always be available through specialty equipment; but now all of these modalities are available together through a personal portable device.

Fast forward to 2005. Steve Jobs, the legendary leader at Apple®, is initiating a great leap forward (figure 1b: <http://larrykilhambooks.com/M1b.aspx>). He has directed about 200 of his best engineers to create what we now know as the iPhone TM. Like Morse, he is not the first with some version of

his product. And like Morse, Jobs can focus on a product vision that combines needs satisfaction, functionality, apparent simplicity, and, in addition, design beauty. The resultant product is a combination of invention, engineering, and aesthetic appeal. In short, it is a bold act of creativity.

The iPhones and similar smart phones are forever changing the way we use computers and communications. There are many competitors to the iPhone, but the design led by Jobs crystallized that this new communications and computing package was not a flash in the pan. It is a basic paradigm shift with benefits for everyone.

In retrospect, the design requirements seem obvious enough:

- Use a powerful operating system that doesn't hog memory (easier said than done).
- Develop reliable touch screen controls instead of typing keys (also no design job for amateurs).
- Enchant the prospective buyer with a beautiful design with no keys, shiny aluminum instead of black plastic and colorful icons.
- Offer a huge music and apps library.

Apple's sales of the iPhone have skyrocketed from nothing in early 2007 to 17% of the world market in late 2009. Steve Jobs commented in November, 2009, "We're making our most innovative products ever, and our customers are responding. We're thrilled to have sold of 5.2 million iPhones during the quarter, and users have downloaded more than 1.5 billion applications from our App Store in its first year."

Samuel F. B. Morse of course did not have the technology and resources available to Jobs for his design project. Most important for Apple is the role of computers in complex design. The several hundred engineers assigned to the project could not integrate all the subsystems of the iPhone such as the radio circuits, internal power supply, microprocessor, software, touch screen display and mechanical packaging without computerized integration of the subsystem designs. The search for components and design solutions would require intense use of the Internet.

Still, even in the Age of Google, a visionary leader is required, and Steve Jobs is reported to have mercilessly

driven his design group, never taking “no” for an answer. There were screaming matches in the hallways, doors slamming and completely burned out engineers.

The iPhone and many other recent developments from tiny pills to giant airlines call for the new tools for creativity, invention and design which we will explore in parts II and III of this book. A common thread among these tools is computer clouds and computer networks. They show up as:

- Use of large research teams in virtual labs defined by computer networks.
- Artificial intelligence (AI).
- Novel methods of analysis of massive data sets or “big data” including, notably, systems biology.
- Collective intelligence involving communities larger than research teams sharing private computer network wikis.
- Designing and inventing with Google and search engines using six basic steps.

These creative tools are required because the most creative challenges are much more complex compared to a century ago. The development of the iPhone requires thinking in a much more complex space than did the development of telegraphy even though both were hugely important in their time. The six steps for inventing and innovating that leverage Google’s comprehensiveness and speed can be found and will be discussed in detail in chapter 10 (figure 1c:

<http://larrykilhambooks.com/M1c.aspx>).

I will illustrate my story by references to thinkers and creators ranging from Leonardo de Vinci to Thomas Edison. We’ll see what Mozart and Einstein had in common. We’ll see what ordinary people can do to enjoy a more creative and prosperous life. There are many examples ranging from Bette Nesmith Graham to various enterprises in my own family to draw from.

We will go back to basics by reinventing the wheel; see how to design the world’s most successful bird feeder; discover that computers can design electronic circuits; see how Pfizer’s scientists collaborate on online shared research ideas; examine Boeing’s new design approach for the 787 Dreamliner; learn that an oil spill challenge was solved by a

concrete expert found by an inventor's outreach on the Internet; and see how MIT is approaching the climate change analysis problem by using an online "collaboratorium" of collective intelligence from many researchers in hundreds of fields.

Hopefully, somewhere in this stream of stories you will find something to enhance your creative life—maybe even make you insanely rich. Maybe there will be ideas here to help your children get launched in creative and remunerative careers. At the organization level the ideas in this book could benefit employees in order to achieve greater profitability for the company or productivity for the organization. There will also be a greater sense of purpose, feeling of satisfaction and improved self-esteem for the employees and other stakeholders.

This book is about the creative process, and how creativity and invention is enhanced by the availability and accessibility of information in the Internet age. This book will help you achieve your creative maximum using all of the Internet and other data resources available. Its observations apply to lone individuals, teams large enough to put a man on the moon, and everything in-between.

This book should also help you think about the education of today's kids and their kids. The Web mirrors life itself—it can be an opiate, trash pile, candy store or inexhaustible resource. An increasing amount of education should be teaching the new generations how to use it with discernment and how to question its results.

We will explore creativity and invention in this emerging era of Web-based collective intelligence with its almost infinite ability to connect to others and help us imagine and create in new ways. With limitless memory capacity, plain language instant communication, and software that parallels the natural thinking process, computer based systems including the Web, enable humanity to transcend each person's own educational and environmental constraints.

Recent years have seen an explosion in new understanding about the human brain. New reports are appearing weekly in scientific and lay media. Consequently, how the brain predicts and imagines is becoming clearer. At the same time, more sophisticated technologies are being developed to approximate human thought. Quite likely, any

discoveries will have ramifications in cyberspace and for our creativity and invention strategies.

This book will explore the key attributes of the creative mind. What special attributes did Mozart, Einstein and others have? What can we learn from them that can produce exciting thinking today? This takes us to a space apparently off-limits to computers: projecting the mind out of most all of its frame of references and rethinking a problem in the frame of reference of the problem itself. The mind is projected to a frame of reference most suitable for visualizing the invention or creation. This requires a bright mind, but also essential for outstanding performance are years of practice in conditioning the mind for this mode of thinking and aggressively gathering information for areas of continuing interest.

The gorilla in the room is the computer, and it may appear in many forms. Of particular concern, there are computers that think in a science fiction-like area called Artificial Intelligence (AI). Visions are revealed where AI will leapfrog human intelligence, and then little seems to happen. Still, progress lurches forward, and we examine AI as a threat or partner as the case may be.

More pervasive still—at least right now—are the almost infinitely large groupings of computers called computer clouds with libraries of trillions of pieces of data all of which are accessible by the click of a mouse. The clouds are everywhere. They are behind everything from online weather forecasts to harboring Facebook, Amazon and Google.

Advanced use of the computer clouds is for collective intelligence and data search for online inventing. The clouds support the research and creativity required for solving some of our greatest mysteries and problems, all of which seemed to be too complex to deal with before. This book will review these developments and help you develop your techniques for online creativity.

Chapter 2

Learning from the Masters

*People make a mistake who think my art has come easily to me.
Nobody has devoted so much time and thought to composition
as I. There is not a famous master whose music
I have not studied over and over.*
Wolfgang Amadeus Mozart

*I keep the subject of my inquiry constantly before me,
and wait till the first dawning opens gradually, little by little,
into a full and clear light.*
Isaac Newton

My father started instructing me in the dos and don'ts of creative design as soon as I could toddle into his workshop. While the other kids I knew thought I was a little weird, I stuck with the creative path because my father said it would always be remunerative and personally satisfying with a big emphasis on the latter. By the time I was in the world of engineering, creative design was second nature to me, and I couldn't understand why it didn't come as naturally to others.

We lived in the country, and when I was six or so I often passed the lazy summer days fishing. I noticed that the standard red and white striped lures the fishermen used didn't work as well as they should on a major local fish, pickerel. These lures were called spoons because they were metal and spoon-shaped minus the handle. The fish seemed to be intrigued with flashing gold things, so I experimentally produced gold spoons by hammering oval pieces of sheet brass on an anvil. I punched holes at both ends for the fishing line and the hook. There were a number of little production techniques to perfect, which was easy to do because my father had a machine shop on the property, and I wound up selling the lures for the equivalent of several dollars each in today's currency.

From that experience I learned that you're never too young to discover needs and to invent profitable solutions for them. It can lead to an interesting and remunerative entrepreneurial career.

In my early teens I became interested in electronics by making “crystal radios.” Using a coil wound on a toilet paper tube for tuning to a station, a safety pin called the cat whisker, a chunk of galena crystal ordered through the mail, headphones and a very long antenna you could listen to the local radio station (for a good description and illustrations of these early radios see Crystal Radio on Wikipedia).

Later, I found that a Gillette razor blade worked just as well as the purchased galena. In fact, I serendipitously discovered that with a second cat whisker and a battery you could amplify the radio signal. I was too young and naïve to understand that I may have discovered the transistor before it was invented!

This experimentation led to an interest in “ham radio” where with receivers, transmitters and an official license you could telegraph by Morse code or even talk by microphone all over the world. Eye popping stuff for a country boy. I eventually designed my own circuits drawing upon intuitive modifications of circuits found in radio ham magazines. Years later, I would learn how to design circuits using electrical engineering theory, but that was never as satisfying. However, it did lead to the basis for several instrumentation companies I started and sold.

If children are to be encouraged to pursue inventive or entrepreneurial careers, there should be an environment forcing intellectual inquiry and creative thinking and expression at an early age. Usually there is a parent, teacher or fellow student who is encouraging and mentoring the budding genius. This process often starts before 6 years of age. Finally, the genius-in-the-making must constantly be searching for knowledge, improvement and opportunities for outstanding intellectual achievements.

For major achievement by creative people, there is continuous and demanding intellectual work involved for most of a lifetime. This usually works best for self-starters and those who can maintain intense focus on their projects.

You or any adult can be a creator and inventor starting at any point in your life. For success, however, you must stick with your creative or inventive pursuit acknowledging that the inevitable downturns were opportunities that came along to learn something valuable for future success.

It has been no different for history’s well-known geniuses. They did not start composing great symphonies or invent light

bulbs by short bursts of creativity. The initial insight may have been similar to noticing something about the apple falling from the tree, but the execution to even a prototype production required lots of research and perfection—possibly years of ups and downs. This creative process is illustrated in figure 2: (<http://larrykilhambooks.com/M2.aspx>)

Wolfgang Mozart and Pablo Casals

Both Mozart and Casals had fathers who introduced them to their art long before most other children their age would be thinking seriously about getting involved in music. This syndrome appears with many other great artists, engineers, inventors and scientists. The father or mother who is comfortable and accomplished in a profession encourages their son or daughter to be a great achiever in that field--hopefully to be the best.

Wolfgang Amadeus Mozart (1756-1791) was born into a musical family in Salzburg, Austria, and at five years old he could read and write music. Wolfgang's father, Leopold, was a composer and teacher, and he wrote a violin textbook. When Wolfgang was four his father began teaching him music. He eventually home-schooled Mozart and his sister Nannerl fulltime. Wolfgang Mozart had a near photographic memory, and he learned a lot by mimicry. A famous example is his hearing Gregorio Allegri's *Miserere* once in the Sistine Chapel and later writing it down entirely from memory.

What was Mozart's genius contribution? According to the *Music Encyclopedia*:

To the neat and symmetrical periods of the Haydn symphony and sonata, with their fresh thematic treatment, Mozart added a tender grace and sweetness like the conceptions of a Raphael in painting. He was the apostle of melody. If he had never written, the art of music would have remained something quite different from what we know it. And wherever there are lovers of refined, noble melody, there will the music of Mozart be loved.

A somewhat similar life was led by the great cellist Pablo Casals (1876-1973). His father was an organist and choirmaster who instructed Casals in various instruments. At

four, Casals could play the violin, flute and piano, and at eleven he started his lifelong specialty of the Cello. A key trait of the genius mentality is illustrated when asked at the age of 94 why he still practiced every day, he answered “Because I think I detect signs of improvement.”

Leonardo da Vinci

If the parents aren't prepared to give the child a great intellectual or career start at a very early age, then he or she may still be given a fast start at a suitable school. Such a school might well be very vocationally oriented. This was the case for Leonardo da Vinci who is considered to be one of the greatest painters of all time and a brilliant scientist, engineer and inventor.

Born near Florence, Italy in 1452, Leonardo did not have a promising start, being the illegitimate son of a notary and a peasant woman. This social stigma prevented him from enrolling in an advanced classical academy, but at the age of 14 he was admitted to the workshop of Andrea del Verrocchio, probably the best place in Florence to be an apprentice under a craftsman. He would also have been influenced by his talented fellow students including Botticelli, Perugino, and Lorenzo di Credi.

Leonardo's father was encouraging and helpful in getting him this far. In 1472, at the age of 20, Leonardo was registered in the Florentine painters *Guild of St. Luke*. Shortly after that he completed his first solo painting, *The Annunciation*. Many more masterpieces followed including *The Last Supper* and *Mona Lisa*.

Leonardo's intellectual attributes included those in common with most other very creative people: intense curiosity, an insatiable quest for knowledge, a large memory, intense concentration, and continuous improvement of his knowledge and skills. He was always looking for ways to relate diverse categories of information and to search for novel patterns and insights.

Leonardo pursued parallel creative efforts in drawing, anatomy, science, optics, machinery and engineering. Leonardo saw no problem doing both “art” and “science” because to him these were complementary and mutually supportive skills. Art was the skill in doing something or in

mastering a field of study, such as the art of medicine; and science was the knowledge of living forms, their intrinsic nature and underlying principles.

Leonardo's imagination was tied to an understanding of nature. This gave him an aesthetic feeling of beauty and natural forms of design. This, in turn, gave him a reassuring feeling of correctness in his synthesis and analysis. In addition, Leonardo thought in terms of *fantasia*, the artist's creative imagination

Whether Leonardo would relate so much of his thinking to nature if he were living today, is an open question. Would he seize upon computers, the Internet, jet travel, and artificial environments as useful conveniences and aids to thinking, or would he think of these appurtenances mostly as needless destructors of nature?

I think Leonardo would embrace these modern technologies because he certainly made major efforts to improve life in his time through technology and engineering. For example, he designed artificial harbors and thought about the rerouting of rivers. Also, he is famous for his proposed designs of flying machines.

I also think Leonardo would agree, were he alive today, that with our Web incorporating billions of websites and trillions of pieces of information, with access to all by a laptop computer, that this data and computing cloud is closer to his hope for access to a nearly infinite universe than simply being able to see what can be observed from nature. Leonardo, however, would not give up observing nature. Everything would count.

While scientific instruments to aid in observing nature available in the Renaissance, they did not see down to the molecular level nor out to the galaxies scale. Routine observation of things and phenomena beyond direct human experience did not happen until the beginning of the twentieth century. These capabilities led to new basic branches of science including quantum mechanics, microbiology and astrophysics.

There are thousands of specialty branches of science and together they interconnect to form a universe whose size and scope are beyond even what Leonardo could comprehend. Fritjof Capra, a leading historian of Leonardo noted:

The Scientific Revolution replaced the Aristotelian world view with the concept of the world as a machine. From then on the mechanistic approach--the study of matter, quantities, and constituents--dominated Western science. Only in the twentieth century did the limits of Newtonian science become fully apparent, and the mechanistic Cartesian worldview begin to give way to a holistic and ecological view not unlike that developed by Leonardo da Vinci. With the rise of systemic thinking and its emphasis on networks, complexity, and patterns of organization, we can now more fully appreciate the power of Leonardo's science and its relevance for the modern era.

It is true that the current world community dedicated to solving the remaining big problems have redefined the analytical methodologies and philosophies they work with. The remaining challenges are incredibly complex and include how living, replicating molecules evolved out of cold, lifeless chemistries; understanding the mechanisms of consciousness and free-will; and creating the ontology of really big thinking computers. Many have characterized this as a movement away from a strictly mechanistic, Cartesian view of the world to a holistic view involving boundless complexity and ecology.

The universe is not seen as neat separable systems to be described by exact mathematical models. Instead the universe is modeled as many interrelated systems whose behavior is modeled by active elements in those systems (often called "agents") and whose behavior is often described in probabilistic terms. A new science has emerged based on models of complexity and is the focus of the Santa Fe Institute in Santa Fe, NM, USA.

If Leonardo was resurrected and dusted off to help solve the mega problems we are struggling with today, how would he go about it? My guess is that Leonardo would be handed a laptop and told to log into Google to explore the vast data terrain. Leonardo would protest that he learned his skills in a *bottega* workshop where there was a constant exchange of ideas between fellow artisans, mechanics and inventors.

I don't know exactly what Leonardo would do except that because he would relish the challenge, he would pursue a solution with great energy. Would he act alone in classic hero fashion? Form a team of advisory experts? Be very plugged in

to the Web? We can't know exactly how he would react, but we can say that it would not be in his nature to subdue his curiosity nor to refuse to look at any information from any source. He would not seek the easy way out. Leonardo would want his solution to be original, responsive, and truthful.

With the intellectual playing field flattened by giving Leonardo the latest Web tools, can we assume that he would excel or even triumph with singular success in providing a creative solution using the computer clouds? The answer is he would do fine. Leonardo da Vinci and the computer clouds would be a hard combination to beat.

Albert Einstein

As I review the salient aspects of many acknowledged geniuses, the closest match in many ways to Leonardo da Vinci I can find is Albert Einstein. Their research and fields of interest were in different areas, but their points of view about life, science, creativity and other related areas are very similar.

Leonardo said:

The ambitious, who are not content
with the gifts of life and the beauty of the world,
are given the penitence of ruining
their own lives and never possessing the utility
and beauty of the world.

Einstein stated it this way:

The ideals that have lighted my way,
and time after time have given me new courage to face life
cheerfully, have been Kindness, Beauty and Truth....

The trite objects of human efforts--possessions,
outward success, luxury--have always seemed to me
contemptible.

Both men's developmental years were similar so we might expect similar outlooks in life. Albert Einstein was born in Ulm, Germany on March 14, 1879. His father was a salesman and engineer of electrical equipment. He probably began Einstein's learning process at home with talk about electro mechanical systems--maybe without Einstein being conscious of this--and

this thinking mode would be key to Einstein's visualization of multiple objects moving this way and that in space.

Einstein completed formal schooling in Switzerland with a degree in physics. He chafed at authority and regimen and felt that rote learning reduced creative thought. While he did well in math and physics, and felt that math was the best way to express nature's relationships, he was not considered a brilliant mathematician.

Both Leonardo and Einstein supported themselves by work relating to their education and interests, Leonardo as a contract artist and engineer, Einstein as a patent examiner. While both men had moments of engaging, outgoing personality, they both tended to retreat into intensely concentrated thought about the natural world as they saw it or a specific problem they were solving.

Both men avoided collaborative research, needless publishing, or joining collective science groups. Neither would be likely to be a part of sponsored team research prevalent today. Their genius flourished because of their intellectual self-sufficiency. The Leonardos and the Einsteins can't help their relentless pursuit of knowledge goals, anytime day or night, with or without associates, because they are passionately curious, using their imagination as their prime lens to see ahead and their creativity to solve problems, Einstein wrote:

The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity.

A professor of mine, Murray Eden, who studied at Princeton University when Einstein was there, tells the following story. One day he was at Einstein's office to pick up an employee and drive her home at the end of the day. Einstein seemed to be reflecting on a major unknown and asked what might be the unknowable: "Why is it that television antennas in America are all horizontal?" This genius who was a major contributor to electromagnetic theory had not considered that television broadcasting in America is set up for

horizontally polarized radiation, received best by horizontally oriented antennas. (In its beginning, television broadcasting could have been decided to be horizontally or vertically polarized but not both.)

For new inventors the message is: don't worry about not being an Einstein. If you know your area of specialty thoroughly, Einstein may have to get out of the way.

All descriptions of Einstein talk about his thought experiments. He asked what a light beam would look like if you could ride beside it. This was part of the inspiration of his special theory of relativity. In conceptualizing his general theory of relativity he imagined riding an elevator accelerating in space. In talking about gravity warping space and time, he describes billiard balls rolling down the surface of a trampoline deformed by a bowling ball.

Another factor in common among the classic geniuses from Leonardo to Einstein is intellectual honesty. First, you must be sure that your work is producing a true answer to what you seek. My father, who was a very prolific inventor with 19 patents, always counseled me, "Make sure you satisfy yourself first that your creation is true, original, and useful." Information offered on Internet searches seems to forget about the issue of intellectual honesty and truth.

Thomas Edison

The 1800-1950 period was a time span of extraordinary inventiveness. There were very smart, dedicated inventors who were lucky to find themselves in an embarrassment of newly emerging resources and know-how in electricity, chemistry, mechanical engineering. Theirs was an era of burgeoning economies wresting themselves from agriculture and colonialism as well as developing new equipment for industrialization and the wars. Investment money from wealthy individuals seems to have been relatively easy to find. It was a good time to be a practical inventor.

Rather than survey all the brilliant inventors of this period, I will focus on Thomas Alva Edison so that we can see in greater depth how such a person's mind works. Edison was born in 1847 and lived for 75 years. During that time he amassed 1,093 US patents and additional foreign patents. Edison's inventions were as diverse as communications, the

media, electrical machinery and systems, mining technology, and storage batteries.

Edison's only formal education lasted three months, and he described himself as fairly consistently at the foot of his class. While Edison was never proficient in math he was a natural experimenter. Isaac Newton, James Watt, inventor of the steam engine, and Sir Humphry Davy the eminent English chemist had similar unpromising beginnings.

Edison read constantly in such favorite subjects as astronomy, biology, mechanics, metaphysics, music, physics, electrical science, and political economy. In part to make up for his partial deafness, he became a speed reader and "read books faster than other people skimmed them....He seemed to read through the skin."

But in his diary, Edison said:

In trying to perfect a thing, I sometimes run straight up against a granite wall a hundred feet high. If, after trying and trying and trying again, I can't get over it, I turn to something else. Then, someday, it may be months or it may be years later, something is discovered by myself or someone else, or something happens in some part of the world, which I recognize may help me to scale at least part of that wall.

In one famous incident, an associate found Edison at his lab bench surrounded by a sea of experimental storage battery test cells. 9,000 experiments had been carried out with no promising developments. His associate offered condolence, "Isn't it a shame that with the tremendous amount of work you have done, you haven't been able to get any results?" "Results!" Edison replied. "Why, man, I have gotten a lot of results. I know several thousand things that won't work!"

This approach is not outdated nor only for the lab of the home-schooled experimenter. I met a high level researcher at a major pharmaceutical company who sent thousands of soil sample kits all over the world to see which hitherto unknown microbe returned in this quest would turn out to be the next penicillin.

With the advent of conducting project research using search engines such as Google, one can comb through millions of Web sites and thousands of data reports of possible

interest. Using these search results a trained Edison-like brain can sharpen the search inquiries, analyze the data to search for relevant patterns, or return to other techniques such as laboratory experiments.

Of course, if you ask the right question, you are more likely to get a relevant answer. As F. R. Upton said about Edison: "One of the main impressions left upon me after knowing Mr. Edison for many years is the marvelous accuracy of his guesses."

In his own non-flourishing way, Edison expressed his philosophy of life, and it seems quite similar to Einstein's:

Work. Bringing out the secrets of nature and applying them for the happiness of man. Looking on the brighter side of everything.

As for the value of Edison's genius mind, *The New York Times* of June 24, 1923 reported:

There is one human brain that has a hard cash market value today, in the business and industrial world, of \$15,000,000,000. Billions is correct, not millions. That is within 20 per cent of equaling the value of all gold dug from the mines of the earth since America was discovered.

The brain is that of Thomas Alva Edison, who many a time has said to his cronies, "Well, if worst comes to worst, I've got a good trade. I can always make \$75 a month as an expert telegraph operator and I can live comfortably on that."

The \$15,000,000,000 represents the present investment in America alone in industries which are entirely based on the inventions of Edison or which have been materially stimulated by his inventions. Several of the country's largest industries are included. Incidentally, that figure is \$189 billion in 2009 dollars.

Other Characteristics of Creative and Inventive Minds

There are other characteristics of genius minds applied to invention. Commonly cited is thinking in metaphors. In invention, this is the ability to relate two things that were not apparently related. Such an inventor has the tendency to

observe the world with a fresh eye. Aristotle wrote that mastery of metaphor “is a sign of genius, since a good metaphor implies an intuitive perception of the similarity in the dissimilar.”

My uncle James L. Breese, Jr., who was a gifted thermodynamic systems engineer, and whose father, James L. Breese received 136 basic patents in oil burners, wrote to me:

I have always felt that creativity and discovery arise largely from a talent for noticing odd things... Any number of people had seen swinging lamps and chandeliers before Galileo noticed that the period of swing was constant regardless of amplitude (within limits). How many researchers hunched over microscopes in that dusty London lab had impatiently cleaned pollen and fungus from their Petri dishes before Alexander Fleming noticed that fungus was devouring bacteria in the dish? After the discoveries of Faraday and Maxwell, everyone knew that moving a magnet near a wire produced the same effect as moving the wire near the magnet, but it took Einstein to see that this odd occurrence ruled out the notion of absolute motion. Willis Carrier, while waiting for a train to arrive on a foggy night noticed that water drops were forming where wisps of fog swept over rain puddles. He instantly had the counter-intuitive idea that moisture could be extracted from air by passing the air stream through a water spray that was below the dew point temperature of the air. He applied that to solving the problem of high humidity in printing plants and subsequently founding the modern air conditioning industry. Perhaps the greatest noticer of all time was Charles Darwin who saw important differences among plants and animals that countless observers before him had apparently never noticed.

Perhaps I can make the invention process less abstract by telling about my own invention experience for what eventually became a multimillion dollar product.

I was more or less happily plodding along as the partial owner and general manager of a plastics machinery company in New Jersey. I felt that I should develop a new product for quality control during plastics production. It was a gnawing feeling. I believed that there had to be a way to see the

impurities in plastics, called gels. They are in all plastic products, and they can cause a great deal of frustration by the damage they can cause, ranging from pinhole leaks in milk jugs to runs in stockings. I knew that the market for such an invention was potentially huge.

I knew that most plastics processing is done by machinery as part of the extruding or molding process. The logical place in the process to detect plastic gels would therefore be within this machinery. But knowing that I still didn't know how you would see the gels, even in fairly clear molten plastic, because of their small size and transparency. A gel is usually smaller than a pinhead and is floating around in a very hostile environment of high pressures and temperatures, strong chemicals and fumes, and other obstacles. It needed more thought on my part.

An optical approach seemed most promising. What I needed was some sort of very robust probe that would allow for a remote vision on a micro scale into molten plastic. What I was considering was like finding a way to use field glasses to look into a live volcano. It was a challenge, and I set out to solve it.

Then one of those little miracles of inspiration happened. While walking at dawn in the mountainous countryside in upstate New York, I chanced to see dew drops glittering on a spider's web. That's when it hit me. The light was sparkling from the dew drops like the sparkles of light from a chandelier. Sunlight shining from the other side of the tiny dew drops causes them to shine brilliantly as points of light even in the considerable early morning mist.

Furthermore, the vibration of the dew drops in the gentle morning breezes, made them shimmer and glitter, so that they stood out even more from their background. This "shimmering" insight would be the key to succeeding in the product development. As an engineer I saw that an electro-optical concept had presented itself.

I could now develop an instrument that would allow tiny impurities to be seen in murky molten plastic. It could not only detect gels but probably count them as well. I was elated by my discovery and anxious to get to work on it. I along with co-workers eventually received three patents on this and related process monitoring technologies.

Based on my experience, my list of things to do when you invent are:

- Put your mind in invention space (I will focus on this in the next chapter).
- Look at all system variables whether understood or not.
- Be on constant alert for the unexpected insight or analogy.
- Look for the connectedness of everything
- Look for a simple interrelated design solution.
- Do more experiments to improve your insights and understanding.
- Don't worry about what others think. Pursue the vision.

Edmund Fuller, who was a keen observer of American invention, wrote:

The spontaneous generation of an idea is a factor in mechanical invention as in all other creative processes. A concept which has not been present in the mind before simply appears. If the mind is unready or unreceptive, nothing happens (though possibly no authentic concept ever presents itself to such a mind). But if the mind is alert, the concept will set in motion a chain of events which we commonly think of as the processes of invention. Yet it is also true that in the active creative mind, the initial processes of logical reasoning may stimulate and arouse the unconscious resources. There is the real interaction.

Chapter 3

The Projected Mind: Your Key to Creativity

Imagination is more important than knowledge
Albert Einstein

“For three weeks, the Huygens probe had coasted, dormant, after detaching from the Cassini spacecraft and being sent on its way to Titan. Those of us watching anxiously felt a deep personal connection with the probe. Not only had we worked on the mission for a large part of our careers, but we had developed its systems and instrumentation by putting our minds in its place, to think through how it would function on an alien and largely unknown world.” So wrote Ralph Lorenz and Christophe Sotin in the *Scientific American* about their great space adventure.

These space scientists nailed it: to make new theories, new inventions, and other great creations, we have to do better than adjusting existing theories and designs. We must forcefully move our mind beyond the existing thinking about the subject. We must move out of our conscious world and focus our mind in a new place occupied only by the new creation.

Abstract Thinking and Refocusing the Mind

Reduced to its simplest elements, what you are required to do is solve a problem or construct a work of art without a complete set of instructions or without comprehensive data. In a creative process you are using your imagination to make an appealing or useful whole from a set of components that would not appear to be sufficient or adequate for the job. To do this you need to see beyond mere recollection or simple association. You are projecting the mind's eye to another point in space or time. You are putting your conscious being in an entirely different surrounding environment. One way of looking at this process is that you will be creating a new mind out of your regular mind.

Einstein placed himself in speeding trains, moving clocks and elevators in space. This was more than metaphorical

thinking; it was a mind transforming itself to another place. Einstein's strength came from his imagination and creativity. For the most part his mathematics is a precise description of the relationships he discovered rather than the way he arrived at those relationships.

My father invented a number of bird feeders that are the now familiar plastic tubing with metal perches. He started by imagining himself to be a bird on the perch. Then he envisioned the geometry that would be most accommodating to the bird. Only after the birds were satisfied did he select the materials and manufacturing processes to make an attractive and economical product.

He always included testing the feeder designs to see how happy the birds' chirping sounded! I venture to suggest that most would-be inventors or designers of bird feeders would start with an overall design, reduce it to acceptable cost, and finally test in an actual bird feeding situation. As a consequence, by not following the empirical route, they would probably not have an optimum design from the birds' point of view, which would undoubtedly put their product at a disadvantage once they came into competition with other feeders that were more compatible with the birds' needs.

I myself have three patents or co-patents relating to observing transparent particles and impurities in molten plastic flow and particles in paper pulp slurries. In each case during the inventing process I located myself as a microscopic observer in the chemical flow processes where I could see the relationships of particles in the liquid flow and under various illumination geometries. Of course it was necessary to apply chemical and mechanical engineering, knowledge of materials, and acquaintance with video processing to arrive at a useful design, but the insight came first.

When the inventor comes up with a truly novel idea, he or she has been exploring relationships, patterns, and associations until a productive interplay of ideas, images, and data of all kinds is found. That encouragement signals the brain that the chase is on. The mind is to be projected to a little world encompassed by this project. I call this world imagination space. I know this is what happens because I have done it many times myself. The creation of a successful commercial product using the projected mind is shown in figure 3: (<http://larrykilhambooks.com/M3.aspx>.)

I am projecting my mind into an external space somewhere outside of my head and my surroundings. This space could be invention space if I am creating new products. It could be a stage in artistic space if I am composing an opera. It could be inside a black hole if I am a physicist working on a new theory. In each case I am striving to be imaginative and creative by wholly implanting my mind's eye in the space immediately surrounding what's being analyzed and for endless periods of time. I analyze all the combinations of data and search for clues to the breakthrough I'm hoping for while unsociably avoiding distractions.

But none of this imagination is possible without referring to remembered or retrieved information and events. When we compare memorized and reference information with new information, through analogies we can invent solutions to a problem.

Creativity and Brain Structure

Jeff Hawkins has explored this area of memory and prediction in detail in his book *On Intelligence*. Hawkins is a computer engineer and founded the Redwood Neuroscience Institute. He proposes that our cognitive memory resides in the thin, shell-like neocortex on the top of the brain where it is estimated that there may be as many as one quadrillion synapses available for a lifetime of information storage.

His model is that all the brain knows is experiential patterns of sight, sound and smell. There are also temporal patterns showing pattern changes over time. The memories in the brain are stacked associatively. This means the separate events committed to memory are connected to each other by similar descriptive words or images. Such brain wiring is often called a semantic network.

Sequences of patterns are built that belong together by subject or by sequence of time. New information absorbed in life's journey is "pushed down" in its associated information stack resulting in a more detailed set of patterns. This collection of information is like an automatic filing cabinet.

Hawkins doesn't believe that creativity is some extraordinary quality that requires high intelligence and giftedness. He defines creativity as making predictions by analogy, and he proposes that it occurs in the entire range of

difficulty ranging from hearing a song in a new key to composing a symphony in a brand-new way. The problem with this latter extreme is that to make an entirely novel creation the inventor must think beyond the bounds of what he or she can recall from memory.

Hawkins' analysis is generally in the right direction, but I don't think he takes abstract thinking into sufficient account. Reasoning and abstract thinking are higher level thinking skills. These skills and abilities allow us to think in terms that are neither obvious nor readily referenced. Abstract thinking is a type of creative mind projection.

How the projection of the mind to a uniquely productive imagination space happens is a subject of a lot of current conjecture. One school of thought says that we store much more information in our unconscious mind than our conscious mind. In the intensive imagination and invention process, we search our unconscious memory for clues and ideas and promising ones are resurrected from time to time. One such time we all can relate to is thinking about an unsolved problem just before going to sleep and awaking with the idea in full sound and color. The mind had been rummaging around its archival memories overnight, probably while dreaming.

Freud's concept of the unconscious was proposed more than 100 years ago, but only recently has it received appreciably more scientific credibility by brain imaging studies. They confirm that there is indeed an unconscious memory that is referred to under some conditions. These studies however, revealed a potentially troubling fact: delays between when the unconscious responds and when the brain is outwardly conscious of a response are reported to be in the range of 1/10-1 second.

This caused Nobel Prize winning memory biologist Eric R. Kandel to ask "If the choice is determined in the brain before we decide to act, where is our free will?" My answer for the invention process is that free will was manifested in the instructions given to the brain's search engine before it dove into the unconscious.

It can also be argued that the human brain has a control element that can be subject to a random event within the mind. Thought patterns can be pursued that could not be previously foreseen if they can be switched randomly to new areas of inquiry or action. If the mind is deviated from a routine thought

sequence in the creative process, then it can be launched into highly creative imagination space by a random component to thought.

This aspect of brain activity is philosophical as well as scientific, and as of this writing, practical ways of introducing random elements into the creative thought process have not been conclusively determined. My suggestion is let your mind wander. This seems to happen when I'm hiking. My brain apparently is almost idling, but it seems to mysteriously come up with interesting ideas and solutions I have been seeking.

My feeling is that randomness is definitely involved in many creative discoveries although as Louis Pasteur famously observed "Chance favors the prepared mind." Pasteur also said, "Let me tell you the secret that has led me to my goal. My strength lies solely in my tenacity." One could interpret this as if you look for something long enough and diligently enough you won't need the providential intervention of chance.

Jeff Hawkins asked, "What's different about human intellect?" First, he notes that the human neocortex is larger than other mammals, so that we humans can make a more complex model of the world and make more complex predictions. We can create analytical worlds in an infinitude of specialties or in spaces beyond our surroundings far into the universe. Human intelligence can use thinking which is more detailed, more complex, and which can interrelate more parameters and data than can animals. This is one reason why we can fabricate imaginative visions of things that don't exist in everyday experience.

Cognition and Language

Hawkins says that the reason that our intelligence is much superior to animals is that we have language. While it is generally accepted that many animals recognize dozens of words, there is no evidence that they can learn expansive vocabularies or use grammars. In other words, animals cannot think in or communicate with language.

Hawkins summarizes: "Through language one human can invoke memories and create new juxtapositions of mental objects in another human. Language is pure analogy, and through it we can cause other humans to experience and learn about things they may never actually see."

Noam Chomsky, Professor of Linguistics at MIT, started this line of thought with his proposal that humans are born with a universal grammar. Grammars for spoken languages are quickly learned in early childhood because of the patterns already in the children's minds of the universal grammar. Chomsky speculates that humans fell into language and a universal grammar by a tipping point combining a specialized gene and maybe one or more small physical changes. In his lectures on *Language and Problems of Knowledge*, Chomsky broke some new additional ground:

Now for some speculation about human evolution. Perhaps at some time hundreds of thousands of years ago, some small change took place, some mutation took place in the cells of prehuman organisms. And for reasons of physics which are not understood, that lead to the representation in the mind/brain of the mechanism of discrete infinity, the basic concept of language and also of the number system. That made it possible to think, in our sense of thinking. *So now humans-- or prehumans-- could go beyond just reaching out to stimuli and could construct complex structures out of the world of their experience, and now, the world of their imagination.* Perhaps that was the origin of human language. (Emphasis mine)

Now the gene has been identified which is relevant to the human ability to develop language. It is identified as FOXP2. It was first isolated in studies of three generations of an English family who had extreme speech and language disorders and who did not have this gene. It is located on chromosome 7, and has also been identified in songbirds, mice, chimpanzees and gorillas and other animals.

However, the protein encoded by the gene found in humans is slightly different than the protein it encodes in other animals, and this may be why humans have unique and extensive language capabilities. The field of genetics and language is rapidly changing, and new developments and revisions of theories can be expected frequently.

Integral with the use of language in the world of imagination, is the dialoging process, often with one's self. Arthur Koestler described this process as, "Creative activity could be described as a type of learning process where

teacher and pupil are in the same individual.” Einstein said: “The important thing is not to stop questioning.” This is an important tie-in between language and extreme creativity and innovation. Only man asks questions. His imagination poses potential answers.

When I am inventing, I am in a constant dialog with myself:

Well, let me see. If I want a support for this wide, thick plank, moving it forward, I will need something flat that keeps the plank off the ground.

Hmm. How about some sort of disk?

Seems promising...How does it hitch to the plank?

Put a hole through the center and have a big spike fix it to the side of the plank.

Well, wouldn't it be easier to put two on the plank--one on each side--and push the plank with a handle on the rear edge?

Or better still, how about two pairs of rotary support disks on the plank? It would be more stable.

I built the first prototype using stock wood from the shop and a few tools. It squeaks when pushed. The disks wobble uncontrollably, and the contraption is generally unsatisfying. So it's back to the drawing board:

Couldn't we design a cylindrical fitting...how about a cup shape?...With a big round hole in the center...it could slide over a round support rod with grease between them. This fitting could be press fitted into the disk.

Hallelujah! I just invented the wheel, hub, and axle. Of course I could have done this without language, but for me the process would have been much more tedious.

I go through an interactive development process like the one above when I am interacting with Google in a search for ideas and components to support a possible invention. Google is just a passive recipient of queries in this dialog. Someday,

Google or other search engines will ask questions in response to inquiries in order to speed up and sharpen the development process.

Recently, while at the shop, I received a visit from two bright kids about 12 years old. Out of curiosity, and to gain insights about the invention process, I decided to conduct a little experiment. I showed them the workbench where there was an assortment of small empty bottled water bottles and screw on caps, empty soft drink cans, various sizes of rings, rods, and fittings. I asked them to develop the wheel and without a lot of conversation about it as they experimented. I was surprised at how long they struggled with fitting parts together and trying to evolve a wheel. Not using language or dialoging was clearly a great handicap to their creative process.

When I asked the kids what they would do next if they had more time, one replied that he would do further experimentation after searching around for more experimental parts, and the other said he would research ideas on the Web.

There is much debate about whether the creative process starts with images or language. Antonio Damasio in the classic analysis of cognitive thinking, *Descartes' Error*, says:

It is often said that thought is made of much more than just images, that it is made also of words and abstract symbols...In this regard it is interesting to observe that some insightful mathematicians and physicists describe their thinking as dominated by images.

While language is a common way for creative people to force their minds into creative spaces that normal thinking wouldn't bring them to, and it will become more important as research is done using the Internet, there are other ways to do this.

Temple Grandin says, "I think in pictures." She is autistic, a lifelong student of the learning process, and an equipment designer for the livestock industry. Grandin received a bachelor's degree in psychology and master's and doctor's degrees in animal science. She is professor of animal science at Colorado State University, a bestselling author and consultant to the livestock industry.

Grandin writes, "When I invent things, I do not use language. Some other people think in vividly detailed pictures, but most think in a combination of words and vague, generalized pictures." She describes her visualization abilities projecting her mind as follows:

Early in my career I used a camera to help give me the animals' perspective as they walked through a chute for their veterinary treatment. I would kneel down and take pictures through the chute from the cow's eye level...They helped me figure out why the animals refused to go in one chute but willingly walked through another.

On the other hand, my thinking is non-stop verbal dialog. I think Grandin would accept this to be logical because even though I am trained as an engineer, I have always been verbal. I was the features editor of the college newspaper in my sophomore year, and I scored higher in the verbal scholastic aptitude tests than the mathematical abilities tests.

My father on the other hand, dropped out of Harvard in his senior year and became a successful inventor and small business entrepreneur. He was never very verbal. He liked to think through mechanical ideas with me by talking in terms a stream of drawings he would produce on a sequence of 3 X 5 cards. They showed parts coming together and pulling apart with occasional labels, dimensions, and notes.

He would always project himself into the invention space at the beginning of these thought sessions with me by saying something like: "Imagine you are a gear on this shaft and you engage with another gear located over there..."

The Emotion Factor

Emotion is very important in high level thinking, but its exact relationship to the thinking process has not been defined or detailed exactly.

Marvin Minsky, Professor of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology and cofounder of the MIT Artificial Intelligence Laboratory, in his book *The Emotion Machine*, explores emotion as an outcome of several states of mind. Our various

emotional states result from turning certain mental resources on and off.

Minsky writes that we are programmed from birth with responses to anger, hunger, fear and thirst. As we learn and grow, we add mental states of a more intellectual nature starting with learned reactions, progressing to deliberative thinking, reflective thinking, self-reflective thinking and winding up at self-conscious emotions.

On the other hand, a heightened emotional environment may cause the thinking person to switch into a higher or lower level of mental activity instead of the other way around. This may be particularly true for the creative thinker. Again, Antonio Damasio writes:

The cognitive mode which accompanies a feeling of elation permits the rapid generation of multiple images such that the associative process is richer and associations are made to a larger variety of cues available in the images under scrutiny. The images are not intended for long. The ensuing wealth promotes ease of inference, which may become overinclusive. This cognitive mode is accompanied by enhancement of motor efficiency and even distribution, as well as increase in appetite and exploratory behaviors. The extreme of this cognitive mode can be found in manic states.

One emotional influence is the socioeconomic pressures of a given era. Times of tension and danger often seem to foster creative and inventive efforts. The great artists of the warring states of the Renaissance and the incredible scientific developments made during World War II are classic examples. Was the creativity enhanced because there was a top-down pressure on creative thinkers to work even more diligently on their projects?

Was it because the pressure of the times somehow modified the brain chemistry of the creative people forcing them into an involuntary manic mode much of the time? The influence of chemicals ranging from alcohol to narcotics to imbalances of neurochemicals such as serotonin to dopamine has been noted and discussed from ancient Greek times to the present. Many creative people such as writers feel that immensely creative states of mind are reached when the mind

is not in a normal equilibrium state. Everybody has heard of the swings from writer's block to great bursts of creativity.

The *Wall Street Journal* reported that Ritalin and other drugs for attention-deficit hyperactivity disorder (ADHD) have helped many children improve their focus and behavior but their creativity and drive may be dulled. Among the very creative people thought to have ADHD include Thomas Edison, Albert Einstein, Salvador Dali, and Winston Churchill. Ritalin's generic name is methylphenidate, and how it affects ADHD patients is not well understood. One theory is that ADHD is caused by a dopamine imbalance in the brain, and that this increase is partially blocked by the methylphenidate.

It has also been reported that artistic brilliance and a dazzling memory are related to autism and other developmental disorders. Temple Grandin puts it this way:

It is likely that genius is an abnormality. If the genes that cause autism and other disorders such as manic-depression were eliminated, the world might be left to boring conformists with few creative ideas. The interacting cluster of genes that causes autism, manic depression, and schizophrenia probably has a beneficial effect in small doses.

Then Grandin explores another emotional element that is very intriguing:

Similarly, being childlike may have helped me be creative. In his book *Creating Minds*, Howard Gardner outlined the creative lives of seven great twentieth-century thinkers, including Einstein, Picasso, and T.S. Eliot. One common denominator was a childlike quality. Gardner describes Einstein as returning to the conceptual world of the child, and says he was not hampered by the conventional paradigm of physics.

I think as we get older almost all of us yearn for the carefree times of childhood. Despite the many problems that hemmed in almost every child, the child still has the almost naïve capability of unfettered imagination. Some people, very few, keep this imaginative ability through adulthood. Their imaginings leads to inventions, art, designs and explorations of

many frontiers never seen before. Emotion is part of this creative formula, and perhaps the emotional element is what is hardest to reconcile in equating the human mind to an advanced computer or an artificial intelligence machine. Did you ever see a computer cry?

Imagination gets us beyond the here and now. It gives us the ability to ask questions in a new spirit of discovery. It facilitates seeing ahead and exploring the best way to go. This is an essential step to go from imagination to creativity to invention. This puts us in a class distinct from very smart animals and super intelligent computers.

Chapter 4

Teams, Collectives, and the Clouds

The open society, the unrestricted access to knowledge, the unplanned and uninhibited association of men for its furtherance-- these are what may make a vast, complex, ever growing, ever changing, ever more specialized and expert technological world, nevertheless a world of human community.

J. Robert Oppenheimer

As I was leaving childhood it was the 50's and 60's. That was a carefree time bridging the national self-confidence after World War II with the hope coming out of the labs--big cars with tail fins, "Atoms for Peace," Miracle Drugs, Electronics. The world was not ready to think about the big ecological picture except for some strange voices like Rachael Carson who wrote stirringly about impending ecological crises.

I recall the excitement when computers became useful in the early 60's. As an engineering student, I learned to program those huge machines full of glowing tubes. A coffee pot was kept warm on an equipment rack. Replacing burned out tubes was as routine as sweeping the floor. Transistors were just being invented and circuit chips were a figment of someone's imagination. Data was fed into and out of the machines by punched paper tape and later by the familiar IBM Cards with the rows of rectangular holes. The most advanced machines, accessible only by pedigreed top researchers, had less computer power than today's personal computers.

At MIT I was an assistant to Professor Franco Modigliani who later received a Nobel Prize for his Life Cycle Theory of Savings. This theory maintains that the level of savings depends on the age of consumers rather than on the level of family income. The very young and the aged draw down on family savings while the working age members produce the savings.

He would call me anytime, day or night, "Larry, it's time to run some more data!" This always seemed to happen on Saturday night, and my date would help sort punch cards into decks to feed the hungry computer. The next day, Sunday, there would be printouts to review with the professor.

Modigliani would review the correlations, modify his model, and I would head for the patient computer to do another run. The world at that time was ready for econometric-based economic theory but not major complexity.

A few years later, I graduated and took my first real job with a Cambridge, Mass. think tank called Arthur D. Little, Inc. One of my projects was working with an antisubmarine warfare team. We designed long-range sonar for tracking Russian submarines, and we also devised mathematical scenarios for predicting how the Russian submariners would try to traverse the oceans to the US. "He thinks that we don't know that he knows a special route free of sonar..." The thought gaming simulations were entered by a clackety-clack teletype to a time-shared sort-of-super computer far away. A laptop would probably better handle this analysis today. On at least one occasion, when the scenario became too huge or complex for computer analysis, it was simply assumed that the captain wouldn't choose to take that route!

I had found myself in the early stages of the analysis of large scale, complex problems which today has engendered its own scientific discipline called complexity. Solving these problems has led to big team research.

Creative Teams Led by a Charismatic Technical Leader

World War II produced a host of challenges and eventually products that involved complexity on a scale unimaginable in the inventive times of the 19th century. The atomic bomb immediately comes to mind, but there were plenty of other big challenges. Important new technologies included antibiotics, plastics, heavy-duty aircraft, rockets, and radar. While the initial idea or discovery could have been done by one man or woman, completely characterizing the invention, analyzing a practical version as a system, and developing testing and manufacturing methods inevitably and quickly lead to the formation of a team.

The team quickly became known as "The Lab"--a convenient term for an affiliation of engineers and scientists collaborating to solve a specific problem. MIT pioneered this with the Radiation Lab which was responsible for much of the radar development during the World War II. As an electrical engineer I found their lab notes published in the "Radiation

Lab Series" still useful, for example, in the derivation of optimum filters.

Another MIT mission-oriented lab was the Instrumentation Lab which developed servo systems and inertial guidance systems so critical for the important national efforts of the cold war ranging from guided missiles to lunar probes. And there was the Manhattan Project to develop the atomic bomb at Los Alamos National Labs.

A key part of the MIT lab formula, as I will call it, was having a collection of people working on the problem, starting with a charismatic scientific leader such as J. Robert Oppenheimer. He would have a prestigious board that could include a university president, scientists, industrialists, academics and military representatives. Staffing was often ad-hoc with scientists and engineers grabbed from almost anywhere handy. Shirtsleeves experimentation always was important. Attributes of the team leader are shown in figure 4a: (<http://larrykilhambooks.com/M4a.aspx>.)

This same pattern was in the submarine tracking program I mentioned earlier. Our designs were successful, and the Navy deployed a worldwide system to detect, identify and track enemy submarines. The project, code named SOSUS, was first publicly mentioned in the book and movie *Red October*. Like the World War II development projects, we had a scientist leader, an eclectic collection of support engineers and scientists, and a high ferment creative environment.

Anyone, however lowly, could volunteer an idea. People would dash off tennis courts to scribble down concepts. The really important classified stuff wasn't determined by the ominous degree-of-secrecy labels on your filing cabinets; it was determined by an informal almost secret society of intellectual buddies. As the project became institutionalized, with a management bureaucracy taking over, the old gang including myself drifted off to seek new challenges.

It seemed that the bureaucracy evolved from fostering innovative solutions for research goals to preserving the status quo and raising more financial support. While researchers understand the need for stability and funding, they also seek leaders who are creative themselves.

We had a study group researching how to most effectively manage innovation. An interesting finding was that the probability of coming up with a major breakthrough was

directly proportional to the proximity among the team's researchers, engineers and technicians. Everyone located on the same floor of one building lead to the best results. Chances of success declined as the project occupied two floors of a building, two buildings even less, and least of all, two sites a day's or more travel apart. The conclusion was that innovation is fostered by informal communications, and these are encouraged by many informal "what if?" and "let me show you something" discussions (figure 4b: <http://larrykilhambooks.com/M4b.aspx>).

The restraints of working on the same floor or in the same building seem to be relieved by Wikis (common interest Internet discussion groups). Web-based development collaboratives, mobile phone hookups and the like are all attempts to foster group creativity and informal communications.

The lab development organization carried over to US and other countries' corporate development projects largely for non-defense products. IBM, Xerox, and Bell Labs were among the industrial companies that produced troves of valuable patents which were critical to industrial growth and consumer well-being in the latter half of the 20th century.

One indicator of the continuing trend towards large group research is the ever larger number of names listed as authors on research papers. In the old days 3-5 might have been considered a typical research team. Nowadays it is not uncommon to see over a dozen names and some reports have listed over 100 or even 1,000 authors.

The major development opportunities and priorities now are molecular biology, computer and software systems, energy and ecology. All of those areas typically require research efforts with at least dozens if not hundreds or thousands of scientists and engineers per project.

The ideas these teams work on must start with seeds planted by inventors. These turn into green shoots if they're encourage by the team. If success continues, management and investors take control, hoping for a big harvest.

*A new way of inventing is in order:
The emergence of connected intelligence via the Web*

When it seemed that much important technology development would be confined to research parks in known creative places like the Boston area, the Bay Area and the Research Triangle, the emergence of the Internet made physical location a much more flexible option for many participants. A leading scientist might work out of his home office in the Great Smokey Mountains teleconferencing daily to his labs in San Diego and Cambridge.

It is important to note that all communications media can be used. It's no longer just emails, although they are still important. Video conferencing is simple and low cost. Laboratory experiments can be read and controlled from anywhere (figure 4c: <http://larrykilhambooks.com/M4c.aspx>).

Perhaps most important, the remote scientist can access all the world's libraries through the computer clouds using Google and other search engines. He or she could also access their employer's library and wiki through a secure high speed data connection.

All of this began inauspiciously when Larry Page and Sergey Brin met as students at Stanford in 1995. Brin was assigned to show Page around campus. In 1996 these two computer science grad students collaborated on a search engine called *BackRub* run on Stanford computers. The following year they changed the name to *Google* based on the mathematical term googol meaning 1 followed by 100 zeros. This inspired term represented their goal to organize an almost infinite amount of information on the Web.

In 1998 they incorporated their venture which was operating out of a garage in Menlo Park, California with \$100,000 of a friend's investment. The number of URLs (websites) that were indexed by Google grew exponentially from about a billion in 2001 to about a trillion in 2008.

Early in 2008 Google came out with its Cloud Strategy as it is called in Google land. The concept is to deliver to students, researchers, and entrepreneurs all the power of Google computing using a cloud of Google and other computers. The cloud is maybe a million, maybe more, small computers like ordinary PCs. They are connected as a web and answer billions of requests in fractions of a second.

The energy consumption of all these computers is so significant that Google has researched and designed a new computer basing approach. The computers will be put in a ship

at sea where the ocean currents will provide energy for generators and water for cooling. A patent was issued to Google for this interesting idea.

Massive (essentially infinite) computing power becomes an essential resource in this emerging era of connected intelligence and the collectivization of information. Software for accessing and working with the information is also of critical importance. Google corrects spelling and translates languages with a program that fits on one sheet of paper. This is important because that same program must be used millions of times a day delivering information to users in a fraction of a second.

The verb “to Google” has entered the common vernacular as the preferred term to do a Web search. In the rest of this book I will often refer to Google, and about using Google, as generic terms to this search methodology and data base when it is to be understood that various other search engines could serve as well. However it is accessed, the World Wide Web has put most of the world’s published knowledge at your fingertips.

Is HAL on the Way? Computer Intelligence

At this time, however, computers or computer clouds are not ready for consciousness and free will. Working by themselves, they can’t do artistic expression to evoke emotion, invention of complex products using several scientific disciplines, or just unrestricted wanderlust into the joys of poetry.

Arthur C. Clarke in his 1968 science fiction epic film *2001: A Space Odyssey* has his super computer HAL ask the space ship commander: “By the way, do you mind if I ask you a personal question?...I’ve wondered whether you might be having some second thoughts about the mission.” In this case fiction, written by a scientist, proposes that a computer can think like a person.

According to the Turing Test which is the standard of comparison for computer intelligence, HAL the computer was most probably as intelligent as a human because the blindfolded observer would not be able to decide which speaker was the computer and which was the human. In the popular mind, the genie was out of the bottle.

Technology futurist Ray Kurzweil asserts that strong artificial intelligence (AI) and nanotechnology will be able to create any product, any situation, any environment that we can imagine at will. And this will be before the end of this century. Computer expert and intelligence theorist Jeff Hawkins disagrees. He states that “AI suffers from a fundamental flaw in that it fails to adequately address what intelligence is or what it means to understand something.”

My Experiments with Internet Design

My first brush with the Internet and creativity came in the late 1980's when I asked my Chinese immigrant engineer his solution to solve a particular aspect of a major product development problem. His answer was unexpected and unsettling: “I will find it on the Internet!” I was shocked and dismayed that its solution might be found somewhere in cyberspace. I didn't realize the extent of the information available on the Internet in those early days, and my self-image as the all-knowing inventor was crumbling.

My engineer looked like a kicked dog after he sensed my reaction. I thought the Chinese had inscrutable ways of problem solving combining centuries of invention with a lot of training in our universities, but I never expected this mode of problem solving.

Anyway, the product was developed based on its innovative key component, and I built a profitable business based on it.

Recently I tried reinventing the product I was discussing with my Chinese engineer. I put gave Google search combinations of terms relating to my invention such as gels, particles, polymer stream, seeing transparent particles, fiber optics, process windows and so forth. The searches did turn up some abstruse technical papers in a somewhat related field, infrared analysis, which could give clues to what I was trying to invent. An English product also turned up which incorporated part of my invention but which wasn't on the market when I introduced my product. Figure 4d: (<http://larrykilhambooks.com/M4d.aspx>) shows locating your product among similar ideas in cyberspace.

What I found was that I could not “invent” the product in terms of Google presenting me with an “aha!” insight. What

Google did do was greatly speed up “what if” searches for engineering and production solutions to building a feasible prototype. This is important because if I could not find an apparent product construction that worked, I might normally abandon the project. The search encouraged me to think that I had a potentially valuable invention and that I should press forward.

I had saved myself hours or days of time of literature search, phone calls, correspondence and so forth. Having established that the basic product concept could probably be converted to a working product, I could pour renewed energy into thinking about everything from the concept to detailed engineering. Also helpful was that the web searches gratuitously turned up some patent applications and issued patents in related areas.

Buoyed by the encouraging results with a Web search engine, I tried using Google to reinvent the wheel. The process was inefficient and strained. Google works better with complex inventions where some law of large numbers allows it to dig out and relate many data. It isn't well-suited to conceptualizing a few basic relationships like a wheel, hub and axle.

Development success using a search engine is unlikely to happen unless you know the right questions to pose to the search engine. These insights come from experience in many technical fields and probably some trial and error experimentation to define the research approach. I think Leonardo da Vinci would agree.

PART II

Models of the Mind

Chapter 5

Artificial Intelligence: Can it do Our Inventing for Us?

*The non biological intelligence created in that year (2045)
will be one billion times more powerful than all
the human intelligence today.*

Ray Kurzweil, Futurist

As the world cruises towards seemingly intractable problems such as overpopulation, depleted resources, and global warming, we will increasingly need breakthroughs of the kind that have been produced by ingenuity and insight. How can artificial intelligence contribute to solving these daunting problems and what are its advantages over human-based thinking?

There have been many statements to the effect that artificial intelligence will greatly exceed human intelligence in just a few decades. There may be little doubt that this will be the case for applications mostly requiring massive and repetitive computing, but is not so certain for projects requiring significant imagination and creativity. One project experimenting with human-like robots is MIT's Kismet shown in figure 5: (<http://larrykilhambooks.com/M5.aspx>) They can be used in detailed multidimensional design. They can manage vast projects. There are even computer programs to invent new devices which are modest advances over those currently used. There is talk of nano (very tiny) computer-like robots that can circulate around in your body. But as far as I am aware, no computer independently came up with the general theory of relativity.

Really Simple AI

Since the explosion of electronics beginning roughly during WW II, there has been ever increasing interest in thinking machines. This field is now generally known as artificial intelligence (AI) and is used to mean almost anything from a smart light switch to the Google clouds. I use the term to mean the ability of a computer, machine or device to perform those activities that are normally thought to require intelligence. Artificial intelligence devices range from bug-like robots that

can find their way around a terrain to mega-computers that someday may be more intelligent than humans.

AI started with conventional electronic circuits wired to achieve an intelligent task. These circuits were built on “if...then...” logic. For example, “if the temperature is below 72 degrees, then turn on the heating; otherwise, leave the furnace off.” In other words, the traditional home thermostat is a simple AI device. Simple electronic control circuits are the key to many successful industrial machines and consumer appliances today.

Increasingly, the electronic logic circuits have been replaced by tiny single purpose computers called microprocessors or embedded systems. These can introduce more intelligence into the control system. Now we take for granted the availability of home controls that not only control temperature, but manage the outdoor lights, water the lawn, and remind you to walk the dog.

The AI field started during World War II with much of the activity in the northeastern universities and centered at MIT which had many projects, formal and informal, to develop innovative electronic systems to support the war effort. These projects were very sophisticated such as “fire control” systems to optimally aim anti-aircraft guns aiming at fast moving aircraft. The special purpose projects evolved into large laboratories that took on their own identities through the 1940’s-1960’s—including the Instrumentation Laboratory for developing the electromechanical guidance systems for aircraft, rockets and projectiles; and the Radiation Laboratory for developing radar and signal processing.

Warren McCulloch and Walter Pitts, mathematicians with strong interest in neuroscience, were AI pioneers. In 1943 they published their path-breaking paper, “A logical calculus of the ideas immanent in nervous activity.” McCulloch and Pitts formalized the concept of neural networks that replicated the brain’s neural networks. This work led to a mathematical basis for computer logic design and “connectionist” models of language and cognition. The theory is that mental processes can be simulated by the brain modeled as a network of computer circuits with predictable responses for defined stimuli.

Important additions to the McCulloch and Pitts model were made by D.O. Hebbian who in 1949 proposed a variable

strength of connection between the input and output nodes of a neuron in a process where the connection strength increased each time there was activity through that synapse. Something analogous to this process is observed in living organism memory where repeated sensitization causes neurons to grow the connections necessary for long-term memory.

The work of McCulloch, Pitts and Hebbian did not lead to a major AI industry when they were active, but their theories and constructs have been widely referred to ever since in describing the neural mechanisms of the brain.

The penetration of simple AI is pervasive. Just as there are many times more insects than higher mammals, there are many simpler artificial intelligence devices than complex thinking computers. Cars, airplanes, boats, and space vehicles utilize countless simple AI control devices. These devices have an IQ of less than an ant's, but the technology has been perfected to a high degree of confidence, reliability and low cost.

Major opportunities to be creative in developing really simple AI inventions today are in the nanotechnology arena. This is where the mechanical parts and circuits have been reduced in size down to almost molecular scale. Applications range from smart phone controls to nano robots cast adrift in the body to do presumably good things such as manipulate genes and proteins.

Complex AI

If artificial intelligence could solve more complex problems and do large-scale useful jobs, this would be a payoff for humanity. These challenges could range from operating giant crawlers to remove trash from ocean bottoms to translating all the hundreds of disappearing indigenous languages. I call this complex AI because computers and sophisticated sensors are involved. Complex AI is also referred to as narrow AI and weak AI, to differentiate it from strong AI which specifically refers to the intelligence of a machine that can successfully perform any intellectual task a human can.

The development of advanced computers greatly assisted the assault of complex AI on what had formerly been intractable problems. The first computer with memory, stored

programs and arithmetic functions was the EDVAC developed in 1945 by the immigrant Hungarian mathematician John von Neumann.

While this computer never solved any major problems, it started the genealogy of computers which lead up to the present day. Following it came the ENIAC (Electronic Numerical Integrator and Calculator) developed at the University of Pennsylvania in the mid-1940's. It was used by the Los Alamos national laboratory to carry out physical modeling problems and bomb design calculations. In one case in 1945, a half-million punched cards were shipped from Los Alamos to the University of Pennsylvania in Philadelphia to carry out the high precision calculations. Then the Los Alamos Laboratory contracted for its own computer, the MANIAC (Mathematical Analyzer, Numerical Integrator and Computer) to be completed in 1952 when it was used for hydrogen bomb calculations.

Eventually, out of this progression came the IBM STRETCH super computer. Next came IBM's Deep Blue supercomputer which in 1997 defeated Grandmaster Gary Kasparov in chess. Deep Blue's per circuit processing speeds are many fold faster than Kasparov's neuron processing speeds so that Deep Blue could faultlessly examine more possible plays and scenarios.

Now IBM has an even faster supercomputer, Blue Gene. It is being used to model and simulate the brain. We are at an interesting crossroads where the computer created by human brains is now being used to research the brain's structure and operation.

In 2005 the project was initiated at the Brain Mind Institute of the Ecole Polytechnique Fédérale de Lausanne in Switzerland. The computer can do up to 22.8 *trillion* operations per second. Each of its microprocessor chips simulates a single neuron which is the basic go-no go logic unit in the brain. Each human brain has billions of them which makes it too big even for Blue Gene to simulate so Henry Markram, the project's director, decided to simulate a rat's brain.

The computer simulates the neocortical column of a two week old rat which is merely 2 mm X .5 mm, but computationally it represents 10,000 neurons and about 30,000 synaptic connections. This would to be an enormous computing facility, but it is only a tiny part of the rat's brain

which in turn is nowhere near as intelligent as the human brain.

Actual simulations were run in mid-2008. The computer simulation produced behavior like a real neuron. Various cells did what they were supposed to do and in the proper sequences. The microprocessors were hooking themselves together and evolving into a cognitive mechanism similar to the core part of the mind. Blue Brain appears to demonstrate that the research team's neurological model of the neocortex is correct.

However, scaling the model up to human brain size, where trillions of synapses are involved, would require about 500 petabytes of data (equivalent to 200 times Google's current total system wide computing capacity) and megawatts of electrical supply. What this means, at least for the present, is that current simulations of the human brain have come to a capacity limitation even for a super computer.

Ray Kurtzweil, who is an optimistic and prominent futurist for AI, says that "Ultimately, organizing computation with massive parallel processing, as is done with the human brain, will not by itself be sufficient to keep energy levels and resulting thermal dissipation at reasonable levels." In other words, the computer will overheat unless a fix is found. With respect to whether there are inherent limits to the capacity of matter and energy to support computational processes, "This is an important issue...but we won't approach those limits until late in this century."

So, one trade-off might be stated as: Even though the computer may be an more infallible machine in terms of accuracy in storing and processing data, the human brain of similar capacity is much more energy efficient.

A more down to earth but little recognized application of complex AI is in video games. These are programmed to make the computer behave similarly to a human. When the video game encounters a situation entered by a player, it searches its repository of rules that apply to the situation. This is what a human would do. If there are many rules to deal with hundreds of situations, the game becomes extremely challenging. This complex and intelligent behavior by the game may explain why video games become addictive, particularly to adolescents who do not have a lot of stimulating intellectual contact with other humans.

An emerging application of complex AI to be discussed in greater detail in later chapters is called machine learning. It is used where thousands or millions of data samples are recorded from an experiment and the goal is to find a mathematical model to describe what is happening in the experiment. The application arises most commonly in biological and pharmaceutical research. There are hundreds or thousands of interactions in the chemical components of a biological cell, and it is usually impossible to analyze and model these interactions beforehand. A computer however can notice patterns of interrelations among the thousands of data sets, and then it can postulate an empirical model in terms of biochemical reactions.

Inventing with AI

Inventing by use of an AI program has succeeded in a number of cases where the product to be invented involves one discipline such as mechanics or electronics and does not involve too many component parts. This emergent field has taken on the terms genetic algorithms or evolutionary algorithms because the design approach is evolutionary, seeking optimal success as various mutations are introduced.

While genetic or evolutionary algorithms are usually best suited for the design of simple devices where one discipline is involved such as an electronic circuit of a few components, or the shape design for scissors, their use has been reported for the design on dams, bridges, gyroscopes and wind turbines.

Ed Ramsden, writing on “evolutionary computation” to develop optimum signal processing circuits for sensors, calls this “Just add parts and shake.” He wrote that the following steps are involved in designing an optimum circuit such as a filter (A filter is a circuit to separate a desired electronic signal such as music from the unwanted signal or background noise) using just computer simulation:

- 1 – Define the basic circuit in terms of the how the components are connected to each other and the component values. It will be optimized by trying out variations of its design.
- 2 – Define a criterion of optimum circuit performance. Maximization of results based on this criterion indicates when to stop trying design variations.

- 3 – Start with a circuit design using electronic component values chosen arbitrarily.
- 4 – Simulate operation of the circuit, change component values and their placement in the circuit, and record circuit performance at each step.
- 5 – Rank circuit performance in terms of design changes. Eliminate all but the front runners. Select the best circuit from the final candidates.

You could do the same steps in perfecting a chocolate chip cookie recipe—baking cookies many times and changing ingredient proportions, baking temperatures and times, etc., until the cookies were delicious beyond description. This process would be very difficult to adapt to artificial intelligence because it would be difficult if not almost impossible to design a machine-readable measurement for the “most delicious cookie.”

Designing robots is a common application of this approach, and there are many reports about self-improving robots. Some of these are self-designed—especially their control circuitry and programming—based on trial-and-error results of the robot’s performance while it is doing typical tasks.

You start with a collection of shafts, wheels, sensors, structural kit parts and so forth and build a robot as a starting genotype as described for circuit design above. Then the robot is powered around its typical environment, with changes introduced to its design from reaction with its environment (such as too much bumping into things) or experimental random changes in the design to see what the change in performance will be. Developers of these kinds of robots claim that their experiments produce sophisticated robots that work as well as the old fashioned human design approach. Many examples and reports can be found by an Internet search.

Perhaps the most ambitious enterprise so far doing evolutionary computation to use computers to invent is Genetic Programming, Inc. headed by John R. Koza. They employ mutation, recombination and natural selection to achieve machine intelligence. Genetic programming has been claimed to produce 36 inventions that can be categorized as competitive with what knowledgeable developers in the fields of application could do. Fifteen of the evolutionary technique

duplicated patented inventions indicating that the genetic programming approach does have creativity.

The inventions are in computer programs and algorithms and electronic circuits for very specific applications. These are generally parts of much larger products and so cannot be cited here as individual recognizable products. For example, the genetic AI methodology could be expected to design a more efficient cell phone battery charging circuit, but not invent a cell phone. So this process typically is not inventing breakthroughs. It is potentially making the invention process more efficient.

It should be said that these applications avoid having to deal with mechanical engineering, materials, fittings, etc., whose selection and optimization is the hard work of many inventions. This backs up my own experience with three patented inventions that involve chemical engineering, mechanical engineering and electronics all blended together.

The Genetic Programming, Inc. procedure essentially follows the six steps described above with some additional refinement of evolution and mutation. Their computer produced up to hundreds of thousands of genotypes that evolved over hundreds of generations. It can take a laptop computer a week or more to do the computations. Genetic Programming, Inc. expects that using 50 gigahertz workstations (very powerful computers tied to an online central computer), the evolutionary computation approach will be very acceptable for producing useful inventions.

The fundamental weakness of the AI invention process using genetic or self-improving algorithms is that it only works within a closed system. The program is given a list of components to interconnect and optimize, but it does not allow inquiry into other methods or improvements to better achieve the invention's goals. It does not allow intellectual inquiry into all the resources, methods, and prior art found in the computer clouds.

What Went Wrong with AI and Where Next

So where do we stand with artificial intelligence? As of 2008, the *Financial Times* in a survey report about AI concluded that, having never lived up to the promises made for it, its development now focuses on probability and pattern

recognition. Human thinking is flexible and accommodates ambiguity, so strong artificial intelligence must include probability in its conception. It must look for patterns in masses of data. This development approach leads to structuring artificial intelligence based on biological models, like the human brain. We have been hobbled by our attempt to create intelligent computers which operate by traditional step-by-step analytical logic.

If you are looking for a repetitive solution to a defined problem, you might want to consider artificial intelligence. Genetic improvement programs may help you design simple devices. But artificial intelligence has not reached the goal as an intellectual equal to the human. During the rush of enthusiasm for this new science a few decades ago, achieving parity with humans was proclaimed to be just over the horizon.

Artificial intelligence presently works for smaller problems with more achievable goals. Successful applications include medical diagnostics, stock market trading, optimal vehicle control, mineral prospecting and home appliances. At best, there are AI controlled machines that can automatically do limited tasks such as vacuuming a floor or guiding a rocket.

The AI computers and systems up to this point have generally been judged to be disappointing in terms of the concept of devices that would mimic human thought and intelligence. It became clear that artificial intelligence programs were limited in scope because they incorporated step-by-step computational algorithms based on reductionist conceptions of how to solve problems. The models could not reach out and incorporate new variables or data that the model itself thought might be useful.

Further the models usually did not assume random changes in the situation from time to time could change the behavior of the system being modeled. For example, if we have a model of sunlight affecting an insect, we must assume that on some days there is no sunlight and on some days the insect does apparently random acts of non obedience to the model.

In other words, we will have to deal with the real world where almost any situation of interest for resolution by very intelligent machines will have hundreds or thousands of variables. These variables do not have static relationships. Their interrelationships are constantly changing with time.

It's like looking at the morning TV newscast showing a live video of traffic seen from a helicopter. While the flow of cars is basically the same from day to day at commuter hour, we observe that the flow volumes on given roads change depending on accidents, weather, special public events, etc. To model this traffic flow so that it can flow more efficiently when controlled by an AI computer gets more and more complicated as we peel back the layers and find ever more variables.

The human brain gets around a lot of this complexity problem by storing many patterns for future reference. In the traffic analysis example, the experienced helicopter pilot would have stored thousands of patterns and the associated information about weather and the many other variables. Without doing the time-consuming exact computations that a computer would do, the pilot would project his thoughts based on analogies with historical patterns. This is an example of associative inference where the brain thinks in terms of patterns (not variables) stored associatively (related patterns are stored together) in the neocortex.

So far, though, we really haven't confronted thought head-on, whether it's done in a brain or a computer. David Gelernter, professor of computer science at Yale University, writes:

AI has no comprehensive view of thought: it tends to ignore some thought modes (such as free association and dreaming), is uncertain how to integrate emotion and thought, and has made strikingly little progress in understanding analogies—which seem to underlie creativity.

Gelernter goes on to say:

Computers don't know or care what instructions they are executing. Switching applications changes the output, but those changes only have meanings to humans. *Consciousness*, however, doesn't depend on how anyone else interprets your actions; it depends on what *you yourself* are aware of.

One of Gelernter's constructs is the *cognitive continuum* where all information you receive and remember is cognitively connected to all other information you receive and store. It connects such reasoning as analytical thought, analogical thought, free association and creativity. These thought processes all are part of mental focus or concentration. Without this cognitive continuum, he says that AI has no comprehensive view of thought.

These statements about thought and reasoning seem very abstract unless we have a look at the inner workings of the brain. This is a fascinating and rapidly emerging science which can help us understand how to create and invent using the great advantages of computers and the Internet.

Chapter 6

The Amazing Brain: How It Works in the Creative Process

*We are not who we are simply because we think.
We are who we are because we can remember
what we thought about.*

Larry Squire and Eric Kandel
Memory: From Mind to Molecules

Thinking about thinking has always fascinated me. It started when I was in graduate school at MIT in the mid-60's where I did some original analysis of artificial intelligence. I focused on the idea that the mind assimilates information by association with similar information it already has. By projecting from a sequence of correlated patterns, the mind decides what to do next. I called this associative inference. It is a simple idea but was not widely discussed at the time.

Evolution has brought us to the point where we can remember what we thought about and with our present mental equipment we can also imagine, create and invent. Will we humans continue to dominate the creative process or will super computers assume this function? It is worthwhile looking at the thinking part of the brain to see where we fit in comparison to the evolution of computers.

The Basics of the Thinking Brain

Developing the brain to its current level of sophistication in human beings has taken billions of years beginning with the advent of life itself. The earliest organisms that were around over a billion years ago came preprogrammed by the software called DNA. This produced genetically inherited information which changed and improved from generation to generation. Some genes in the DNA contained the instructions for manufacturing the organism, and some gave it automatic direction to follow up on clues about food, presence of light, temperature and the other environmental essentials of micro life.

Fish, birds and other non-mammalian creeping, swimming and flapping creatures were packaged with a memory-based

improvement to deal with moment-by-moment changes in their environment. This was the allocortex, which allowed simple responses to various observed situations, but not cognitive intelligence at the level of, say, a dog or cat.

A big step in the development of the brain was the emergence of mammals. The timing of their very beginnings is fuzzy, but they diversified quickly and flourished after the extinction of the dinosaurs 65 million years ago. The mammal brain includes an addition to the allocortex called the neocortex. It is the outer layer of the upper hemisphere of the brain and consists of six layers. Its functions include sensory perception, the ability to learn with behavioral flexibility, motor commands, conscious thought and, in humans, language. In humans, the neocortex is 90% of the cerebral cortex up from a very minor percentage in simple mammals.

Another important part of the brain which makes it a superb thinking machine is the prefrontal cortex behind the forehead. It relates current perceptions to memories of past experiences in order to provide an executive and planning function for judging priorities and future planning. It plays a critical role in the regulation of emotion, and it is the storage area for short-term memory. The prefrontal cortex is involved with decision making, problem solving and integration of ideas. Other mammals, particularly primates such as monkeys, have prefrontal cortices but not as developed.

Also important is the hippocampus, a small component in the lower central brain, which manages information flow to the long-term memory. It also is important for spatial navigation such as finding your way around the room.

The fundamental component of information storage in the neocortex is the neuron, a biological cell. The neurons have information gates to connect to other neurons called synapses. The neocortex nodes are the intersection of billions of interconnected synapses resulting in a virtually solid mass of ultra fine wiring. Francis Crick, co-discoverer of DNA hypothesized that these brain cells represent the mind in the cognitive sense, no more or less. Spread around in that gooey mass are all your memories, skills and the pathways interconnecting them.

How big is this cerebral mass in modern computer terms? The neocortex has about 100 billion (1×10^{11}) neurons which are about the same as the 100 billion bytes (100 gigabytes) of

a typical recent model personal computer. Not encouraging so far in view of the fact that many PC memories have to have their storage capacity increased. Now look at the synapses, the interconnections between neurons. Estimates here vary widely, but a middle ground estimate could be 5,000 (5×10^3) synaptic connections per neuron. This totals half a quadrillion (5×10^{14}) synapses. This is about half a billion synapses per cubic millimeter.

The number of synapses is the most important number because it is a rough approximation of the brain's information recognition capacity. The bottom line is that the human brain has enough memory capacity to accommodate most reasoning and cognitive tasks.

An interesting indicator of total brain activity is that the brain accounts for about 20% of the body's energy consumption while it only accounts for about 2% of body weight. It consumes about 15 watts of power which is much less than a computer that would be processing the equivalent data input but not doing complex intelligence computations.

Much of the rest of this chapter will be devoted to teasing out a schema of the mind by which we can visualize and describe intelligence. We will explore how information is stored and retrieved in those 100 billion neurons and over one quadrillion synapses. This is still a very lively area of current research, and the interested reader is advised to stay current by following publications that report on cognitive science. The general facts and figures are mapped out in figure 6: (<http://larrykilhambooks.com/M6.aspx>).

DNA programming is done both by "nature" and by "nurture." The nature part is incorporated within the philosophy of nativism, which argues that certain abilities are included in the brain at birth. These abilities would be included in the genes and modified by altering the DNA from generation to generation. For example, the ability to acquire and use spoken language easily is critical to the unique human intellectual capability.

The nurture part, also referred to as the *tabula rasa* or blank slate, is concerned with the absorption of information and abilities into the human brain over a lifetime.

Eric Kandel revealed that synaptic connections are weakened or strengthened with experience and that the neurons are not altered. Genes alter the long term memory

stored data by responding to information forwarded from the short term memory. Input from gene activation proteins called CREB-1 are balanced against the input from gene suppression proteins called CREB-2. This is one reason why you do not remember everything you have learned. He has pointed out that “memory reinvents itself. Every time you remember something, you modify it a little bit.” He adds that memory is always a mixture of images, feelings, words, and other percepts.

From Day One when you are born and first see light, your brain is an almost completely empty filing cabinet. With each event, you enter information into the filing cabinet where it is filed and indexed by some process unknown to you. The logical thing for your brain to do is file by subject with reference notations so that the contents in any one file can be referenced to the contents in all other files.

The connection from one to another is by a fine fiber extension called an axon. It connects to the synapse connection at another neuron. With about 7,000 synaptic connections per neuron, this is sufficient connection options to other neurons to totally thoroughly describe the subject in such as size, shape, color, sound, odor, taste, name, and relationships with beings and places.

The first perception you will have after birth probably is your mother. With further sensory input the “mother” file is connected to files such as sounds associated with her (spoken name, etc.), visual (appearance, etc.), places where she is found, other people she knows, and so on. You develop a similar grouping of files for “father” interconnected by common files such as “family” and “our house.” You are the central connection point to all those files, and you can add to them or read from them at will. In similar fashion you add Fido, the family dog, your neighborhood, the weather and other important things in your life.

Piece by piece, you are building your personal cross-referenced file which in the aggregate describes your environment and accumulated experiences. As the days, weeks, months, years, and decades pass, you keep adding files which accumulate additional information as your horizons constantly widen: new family in your house and living elsewhere; friends and groups of friends; towns, cities, states, countries; objects described by color, sound, location and so

on. Your nearly instant access to this unique universe of files to give you a here-and-now picture of you in your environment represents a key part of your consciousness.

In the brain, we go from detail, to aspect, to percept by going from neurons to nodes to networks of nodes. Virtually all neurons are interconnected to other neurons in the brain by the synapses. When we compare percepts, such as your dog to another dog, your mind does a cognitive matching process that could be called associative inference.

Notice that with the neurons cross referenced by thousands of links per neuron, you can do a search by any topics or topics, and pull up any or all of your stored information related to the inquiry. Friends who have brown hair: this sets off a Google-like search using “brown”, “hair”, and “friends” as related file linkages. You bring a new person into your memory who you’re not sure is a friend, but they have brown hair and could be matched up with all other related information in your memory. Then they are wired in as a friend with brown hair or possibly a stranger initially mistaken as a friend with brown hair. This associative inference process is also referred to as thinking in analogies and pattern matching. As part of the creative process, you can make predictions by analogies comparing patterns or comparing the same pattern with itself from an earlier time.

In order to put the whole picture together, we have to see what is known about how the brain projects into the future based on stored information from past experience. Daniel Schacter, Professor of Psychology at Harvard University, and collaborators in 2008 did important research where they found a cognitive process they called “simulation” which allows us to imagine, plan for, and predict possible future events. They found that we can place ourselves in a hypothetical scenario and explore possible outcomes. This ability does not appear to be present in animals or computers.

The hippocampus which I cited earlier for its role in managing information flow to and from the long term memory also seems to be crucial to the reintegration of details in order to recollect a past event and to recombine details into a simulation of a specific future event. Current research supports the role of the hippocampus in supporting relational memory processes.

Incidentally, it is interesting to speculate about how animals think. Schacter reports that there are compelling experimental demonstrations that cast doubt on the claim for human uniqueness. He cites studies of jays and rats which exhibit strong planning-like behavior in such areas as storing and retrieving food. Anyone who has a pet dog is likely to agree. However Schacter is not certain if the debates about mental time travel in animals will ever be settled because we have not found a way to communicate with animals about their thoughts!

fMRI Brain Scanning

The studies by Schacter and others drew from a combination of neuroimaging, neuropsychological, and cognitive studies to arrive at models of thought processes. Neuroimaging, especially functional magnetic resonance imaging (fMRI), has led to a continuing stream of breakthrough studies to better understand what's going on in the brain. Its colorful images of the inner workings of the brain are beginning to appear in television science shows and popular magazines.

fMRI is a specialized application of magnetic resonance imaging (MRI) which has been used for some time in clinical studies of patients' organs and structures. In MRI studies, the patient is placed in a powerful cylindrical magnet the size of a small room. This magnet creates a field roughly 10,000 times stronger than the earth's magnetic field. Also, radio waves are imposed in the area of analysis. The combination of the radio waves and the magnetic field causes atoms and molecules to emit weak signals.

These faint signals can be detected by sophisticated equipment indicating chemical differences in cross sections of the brain tissue. The whole area of analysis is scanned in thousands of small steps and the resultant complex mass of data is analyzed by computer to look for patterns. Hydrogen atoms which are part of the molecules of water, carbohydrates, proteins and sugars show strong signals and thus give clear images. Therefore fatty tissue which has many hydrogen atoms looks bright and bone which has few hydrogen atoms looks dark.

fMRI focuses on the neural activity in the brain to see which parts of the brain are active at any time. It detects releases of oxygen to the activated neurons. While at first glance, fMRI's basic limitations might look overwhelming--such as a resolution of several millimeters versus the fractional millimeter size of neurons themselves, and the response time of several seconds versus the fraction of a second response time of neurons--using chemical enhancement techniques, statistical analysis, and various computerized models very useable data can be collected and displayed. Still, the number of studies is limited, due in part to the very high cost of the fMRI equipment, computer systems, and specialists involved and because of the tedious experience endured by the human "subjects" that are required.

A path-breaking study using fMRI of how the brain represents conceptual knowledge entitled "Predicting Human Brain Activity Associated with the Meanings of Nouns" was done by Tom Mitchell, Professor of AI and Machine Learning at Carnegie Mellon University, and associates. Their study was conceived to build upon brain imaging studies that have shown different patterns of neural activation are associated with thinking about different categories of pictures and words such as tools, buildings and animals. fMRI measured neuronal activity for volunteers who were asked to think about nouns such as "celery" and verbs such as "eat" and "taste" (related to celery) and "ride" (not related to celery).

Responses for sets of words that are related and for sets of words that are not related were detected as bright areas in the brain by fMRI scans. These were compared to linguistic data bank statistics of the probability of co-occurrences of different words to be found together in thousands of texts. In simplified terms, it has been found by fMRI that you think of "chew" with a greater degree of association with "celery" than when you think of "celery" and "ride." The degree of association of "celery" and "chew" corresponds semiquantitatively to the degree of association between "celery" and "chew" computed after reading millions of texts where those words occurred.

Back to Google

The word text data bank with frequency of co-occurrences referenced in Mitchell's experiment was developed by Google, Inc. and made available to researchers through the University of Pennsylvania. Approximately a trillion words were involved. This pattern development becomes much more statistically valid when these unimaginably large numbers are used and will become an important concept later in this book as pattern recognition in on-line searches is discussed.

Mitchell and his collaborators summarize:

These results establish a direct, predictive relationship between the statistics of word co-occurrence in text and the neural activation associated with thinking about word meaning...This is a natural progression as the field moves from pretheoretical cataloging of data toward development of computational models and the beginnings of a theory of neural representations.

They conclude that while more research is required in predicting fMRI neural activity, they are on their way to understanding the neural representations of meaning.

Their computer model has been tweaked to interpret sentences. It shows similar brain scan patterns for a bilingual person thinking of a noun in either language. Google has used similar analytical techniques involving word co-occurrences as part of their on-the-fly spell-checker and in their language translator.

Here we see an emerging paradigm of the human mind: apparently using associative inference to search for analogies between the brain's stored information and incoming information. This process is similar to pursuing ideas developed using on-line search programs and community data programs using queries and locators based on associative inference. This will be an important consideration as we try to see how the creative human mind can work most effectively with the computer cloud.

It should be evident by now that we can't really think about an idea for which the brain has no significant related reference information. This is a basic reason why geniuses cannot produce really great ideas or creations simply because they have a very high IQ. Through years of study and piecing

together bits of information, they accumulate a cache of information which is necessary to find a solution to a problem. To see a relationship as yet unseen by other researchers, the genius thinker must project his or her mind to a space that has a perspective which uniquely encloses and defines the problem unfettered by conventional thinking about the topic.

Consciousness and Creativity

It could be argued that consciousness at this moment is the node where you are now connected by synaptic links to all other description terms of your immense associative memory. This includes all stored data (long term memory) plus current sensory inputs (short term memory and incoming information). As Eric Kandel succinctly put it, "You are your synapses." In non-neuronal terms, consciousness could be described as where you are, what you are doing and, in a particular sense, who you are; seeking additional information to improve what you are doing; and being able to relate all the information you have received about everything (and remember) to give you a sense of being, place, and strategy going forward.

If consciousness was the only achievement of an advanced mammalian memory, then we humans would only be the equals of dogs or elephants among all the creatures competing to survive. What really sets humans apart from animals is our thinking and reasoning capability, and this is most facilitated by language and abstract thinking.

Some of the language relationships in the human brain were described in the Mitchell study noted earlier. Dialoging with one's self, or self-talking, allows us to expand our inputs from information stored in our own memory as well as in the surrounding environment by searching questioning:

- Why is the sky blue?
- How big is that house?
- How far is it from Chicago to New York?
- Why can't I see electrons flowing through the wire?

Furthermore, it is generally acknowledged that there is an emotional element to creativity. Increased emotion can elevate the mind to higher levels of thought. Emotion is released after

the eureka discovery moment. Computers of any kind, as far as we know, don't experience this emotion or any other.

From this starting point we can arrive at the three modes of the intellectually stimulated mind: imagination, creativity and invention. With imagination we can see beyond mere recollection or simple association. It gets us beyond the here and now. The mind's eye is projected to another point in space or time. A mental picture or vision is created without complete data or information.

Creativity moves forward from imagination to solving a problem or creating a work of art without a complete set of instructions or recipe. Creativity uses imagination to make an appealing or useful whole from a set of components that would not appear to be useful for the job. Invention carries this process forward still farther. It cycles through imagination, creativity, and experimentation powered by persistence to develop a new product or process.

PART III

Massive Data and New Solutions

Chapter 7

Finding Solutions in Oceans of Data

...in the era of big data, more isn't just more. More is different.

Chris Anderson, *Wired Magazine*

"There is such a thing as everything" is what I overheard while passing a boy of about seven playing with some friends on a hiking trail. They were looking at flowers, trees and some butterflies, and were awed about the whole ever-changing scene. For a youngster who has not confronted the practical limitations of computing, this seemed like a perfectly reasonable thing to say. And I think Leonardo da Vinci would have happily endorsed the boy's point of view.

But for us, the older and wiser laborers in the vineyards of knowledge, the idea of looking at something based on all we know about the whole world in order to understand and model a part of it seems at best to be a kid's fantasy and, at any rate, of little practical value over existing modeling techniques. Even super computers haven't reached the point where we can use them to model the whole universe.

However with new information technology, the holistic all-encompassing view has several positive points in its favor:

1 – *The almost infinite search engine data base.* The enormous, ever growing, and instantly accessible knowledge base accessed through Google, Microsoft, Yahoo, Amazon and others, or what are known as computer clouds, is so fast and comprehensive that it is a new resource and not just an electronic library. It has information that is required to refocus and refine the individual's thinking and thereby multiplying their mental powers manifold times. Sitting all by themselves, the computer clouds won't invent anything, and sitting all alone, the individual won't realize their full potential as an inventor. But the combination of both can produce an invention of immense scope and importance.

2 – *Relationships derived from massive sets of data.* Peter Norvig, Director of Research at Google, implemented and popularized an interesting and important discovery. He confirmed that using a corpus of millions of words indicating

the probability of their co-occurrences (the probability of any two, three, four or five given words occurring together in a sentence), he could predict the correct word from a misspelled word with a prediction accuracy considerably better than chance. This program is part of the familiar Google spell checker and fits on one page. Norvig also implemented the program that translates the texts from one language to another using the co-occurrence corpuses for words of both languages.

In mathematical terms we can say that Norvig's revelation was that the data teaches us the algorithm if there is deep enough inherent structure and if there are indeed relationships between sets of data. In general, if we work with massive data sets we can often use different and relatively simple computational algorithms whose computational results are not exact answers but are good enough.

The traditional scientific approach has been to use exact computational equations or algorithms and assume that only a fixed number of well-defined variables are involved. This is the classical analytical approach and is often referred to as reductionist. It is the general algorithmic approach used in many classic artificial intelligence programs.

Machine Learning: The Computer Develops Its Own Model from the Data

Analysis using multi-million cell data sets is ever more important because many of the world's most important research and development challenges are problems involving dozens to thousands of variables and thousands to millions of data points. Analysis of many data sets produces likely candidates for variables in a system model. The model building uses inductive reasoning where relationships suggest themselves based on observations that statistically seem likely. These problems are likely to be solved empirically where the computer searches for a best fit model in a process called "machine learning."

An interesting example of machine learning is its use to analyze complex biological systems. In the development of a model to determine how an organism's genes behave under various conditions, Chris Wiggins at Columbia University is using machine learning to see which pairings of sets of DNA

most influence the activity of the yeast's 6,200 genes. As pairings are changed in the model, called MEDUSA, effects are observed such as if RNA production is increased or decreased. Using a statistical approach, the behavior of the organism's gene regulatory networks can be determined. Of course, any given statistical prediction is not 100% certain, but certainty is only relative anyway in biology where no two organisms, though theoretically identical, are likely to be so in fact. In any case, the emerging model for yeast has been helpful to biologists in determining the collection of proteins that relate to a cell's features. Wiggins points out that "machine learning lets the data decide what's worth looking at."

Storing of Billions of Data Sets by the Brain

The human brain, on the other hand, rather than storing a huge pile of impersonal data and then finding patterns in it, stores all input information flow from the outset as patterns. Everything we see, hear, smell, and read is received somewhere in our brain and stored as patterns or additions to existing patterns. The information is connected by activated synapses to previously stored information as interconnected associations of similar percepts (color, person, city, time, etc.) as discussed in chapter 6. Information storage can be in the trillions of bits. By the time you are six years old you are considered independently intelligent (you must start grade school then), and one reason is that your number of stored precepts, concepts, events, etc. must total in the millions. By the time you reach old age, if that be the case, those remembrances probably total in the billions or trillions. This is important to have some statistical certainty in your thinking process.

A great feature of the human brain is that it doesn't require complete information about a given pattern to use that pattern in its thinking. It "fills in" the missing information so as to be able to continue thinking without delay. The brain remembers the important information as a priority over remembering all the details.

Human intelligence really is not meaningful as a static model. It reveals itself as a process where new information flowing in is integrated into a greater whole. The manager

(you) is aware of what the on-going assembly looks like, consciousness if you will, and can use that as a data base for referencing new incoming data. Changes noted in the pattern comparisons give the brain a basis for predicting future changes in the patterns.

Comparing the Computer with the Brain

As we review what has been said so far in this chapter about massive computer data bases and machine learning, and by comparison the pattern learning of the human brain, I propose that a fundamental difference persists: we probably can't build and program a digital computer that totally emulates the mind nor can we force the mind to do all the things the computer can do. At first glance, the emulation of one by the other looks easy, but there are irreconcilable differences:

Data Formats. The mind can do digital computations like a very simple digital computer ($1 + 1 = 2$, and so on) but it is by far more suited for verbal, aural and visual information processing. These are precisely the data formats that computers struggle to use. I myself have engineered computer systems to notice and analyze changes in a video scene. It can be done, but the electronics and software are daunting indeed compared to what even a mouse (the animal) can do in this context! On the other hand, the human brain cannot compute the square root of two to the high precision and in the short time achievable by even a \$20 pocket calculator, let alone do the simplest tasks achievable by any laptop computer.

Open sourcing and indefinite expandability of information. The mind is programmed to salt away information for all kinds of eventualities. This is a major driver for "natural curiosity." Even dogs, for example, have this as can be seen when they investigate any new space for food, doors, friends, threats and places to sleep. Humans have the higher calling of the continuous expansion of the mind's library of knowledge. Computers, on the other hand, have no survival-based instinct for continually expanding their information wherever such information ingestion may lead. They simply absorb whatever information is supplied to them if it fits their data formats and storage capacities.

Processing speeds and capacities. Traditionally, in artificial intelligence discussions, the idea of computers replicating the human brain and indeed exceeding its capacities was brought up and agreed upon as a theoretical possibility but not likely in the foreseeable future. Ray Kurzweil, inventor and artificial intelligence optimist, created a stir in his book *The Singularity is Near* by saying that by 2030 that computer capacity will be achieved which is equal to the human brain. The “Singularity” he refers to is when computers will attain a profound expansion of our intelligence, and this “profound and disruptive transformation in human capability” will happen in 2045. However, Kurzweil reassures us that “Despite the clear predominance of nonbiological intelligence in the mid-2040s, ours will still be a human civilization. We will transcend biology but not our humanity.”

Limitations of Computers

There are at least two problems with this vision of the future. One is whether computer capacities continue to climb rapidly, and the other is if the computers of the future will be able to incorporate such apparently essential human thought attributes as consciousness.

Kurzweil bases his technology projections on a number of data plots that compound as straight lines on a logarithmic scale. The best-known of these is Moore’s Law named after Gordon Moore, a famous inventor of the early integrated circuits, who later was chairman of Intel. Moore observed that the number of transistors, a basic element in computer logic circuits, in an integrated circuit doubles about every two years. Tying this to several other technical considerations, Kurzweil arrives at a projection that computer price-performance doubles every year.

Recent publications by computer scientists and engineers cast some doubt on this prognostication by pointing out that even if computer designs incorporate quantum spin technology --thereby reducing what was the transistor to an atom--that other limitations come to the fore perhaps most importantly heat dissipation. Some large, fast computers today are water cooled and some emerging designs will be cryogenically cooled.

As more and faster computation cycles are crammed into shrinking volumes, something has to give way and that appears to be heat dissipation. I started my electronics career at the end of the vacuum tube era, and at that time saw transistors take over, and later integrated circuits--millions of transistors on a chip--so I intuitively feel that within a few decades there will be technical breakthroughs which enable computers of human brain capacity.

The bigger problem standing in the way of Kurzweil's vision is the human brain algorithm--how it thinks and its ongoing process of deciding what to think and what to do. As described in the preceding two chapters, the brain combines all its stored and incoming sensed patterns in as many ways and combinations as possible. It constantly is alert to new information to improve its understanding of its environment or of a goal it has set for itself.

Association and abstract thinking become important. Through consciousness the brain reviews all the foregoing in a dialog with itself and then moves forward with the next course of action. Someday, a super mega computer, or an infinitely expansive computer cloud, may be able to do all this at brain speed while incorporating the brain's stored information volume, but the chances are remote at least in this century that such a computer will be commonplace and available to everyone as a laptop is today.

Search Engines

What will be available to anyone with any kind of personal computer are the ever-growing, practically infinite computer clouds of information accessed by search engines. If access to virtually any kind of publicly accessible information is required to develop a great idea, this capability already exists in the computer clouds. The iterative interplay between the creative human thinker and the computer cloud resource for major problem solving should be the equal of Kurzweil's super mega computer for the foreseeable future.

One such productive information interplay in progress now is at Google where they are trying to make us more productive as thinkers. One of their founders, Larry Page, told a convention, "The ultimate search engine is something as smart as people--or smarter." At a more recent convention he

proclaimed that Google is “really trying to build artificial intelligence and to do it on a large scale.”

Undoubtedly we will greatly benefit from the information resources available to us through the computer clouds. Inventors must use resources beyond the traditional workshop and laboratory. Major technical discoveries and developments are now being done as laboratory projects by science and engineering teams. Now major developments in such complex areas as alternate energy sources, drug development, and large aircraft design require not only the classical talents of inventors, scientists and engineers, but also the combined resources of libraries, laboratories, field studies and all kinds of computer and software resources. The focused thinking of the creative human brain and the human guiding of Internet search is potentially more intellectually productive than either developmental method alone.

Examples from Drug Research and Development

The first practical example I heard about this was on National Public Radio, May 8, 2008. It is simple but illustrative of the process. A family’s doctor, Hal Dietz at Johns Hopkins University who specializes in Marfan syndrome was looking for new treatments that would not require surgery. Marfan syndrome is a genetic disorder of the connective tissue resulting in defective heart valves, aorta and other organs. It affects about .02% of the US population so it has not received the drug discovery research efforts dedicated to major diseases.

Dr. Dietz knew that a protein called TGF-beta seemed to be active in people with Marfan syndrome. The aorta in mice with TGF-beta blocked developed normally. Where could he find a TGF beta-blocking drug? Typing “TGF beta-blocking drug” into a Google search turned up references to a drug called Losartan used as a blood pressure medication but also known to be an effective TGF-beta blocker. Additionally, Losartan had been used to treat tens of millions of patients with high blood pressure and is noted to be extremely safe and well-tolerated.

Because Losartan already is in pharmacies and has been tested for safety in humans, Dr. Dietz can write prescriptions for it. While Dr. Dietz’s story represents a very elementary

example of discovery using Google search, it does represent an approach which can be used on a much larger scale for inventive research.

One example of a new technique for drug discovery that could be used on a very large scale for drug discovery is “systems biology.” The data bases are so large and rapidly changing that some data storage and search mechanism like Google will have to be used. Systems biology is a holistic approach to incorporate all elements of a biosystem--typically a cell--and to model the interaction of each element with all other elements. The disciplines include biology, chemistry, physics, math and computer science; and the biological elements include genes, proteins and enzymes.

“The models that will come out of biological systems will be the most complicated models that have ever been built” states Dr. Peter Sorger of MIT’s Computational and Systems Biology Initiative. “It’s going to be the development of fundamentally new paradigms and approaches to modeling that we’ve never seen before.”

The website of the Harvard Medical School Fontana Laboratory, which is focused on systems biology, notes:

Empirical knowledge about protein-protein interaction is rapidly evolving, while being scattered across different research communities. Models and the facts they rest upon must therefore become self-documenting. They need to be embedded in an “operating environment” designed to help biologists cope with incomplete, inconsistent, and continually changing information. Modeling in biology is also a process for inventorizing knowledge.

One project for centralizing knowledge on cellular biochemistry and the modeling networks of cell signaling is called Cellucidate. Professor Walter Fontana, Professor at Harvard Medical School’s Department of Systems Biology and at the Santa Fe Institute, calls this “A Facebook for researchers that deal with proteins.” He adds, “People are very skeptical about modeling. They say we can’t model because we don’t know everything yet. But this is precisely why we need to model.” For the complexity involved in a model for the signaling in a single cell, see figure 7: (<http://larrykilhambooks.com/M7.aspx>).

To get the feeling for the scope of a drug screening project, consider that it would not be unusual to put a million different molecules through a screening to detect a target response. Systems biology seeks to replace this random testing approach with a more informed approach to discovery and development.

The computer clouds that could incorporate the ever-growing data base for drug discovery using systems biology can be “public” or “private” or both combined. Drug giant Pfizer has created a collaborative Internet website operating a combination of resource library, chat room, blog and bulletin board--a wiki--that combines a general map of research going on throughout the company with hypertext links to detailed research. By 2007 it was receiving 12,000 hits per month by 13,000 individual users from all Pfizer operations worldwide. Its community calls it the Pfizerpedia. Most of the world’s “public” knowledge can be accessed by the Pfizer researchers through Google and other search engines. For any particular researcher, results from Google and Pfizerpedia searches can be combined in a dynamic data base in their own computer or work station.

Aircraft Design

Boeing’s aircraft products represent a different but no smaller challenge. In this case for very complex, highly optimized large aircraft, the challenge is not to make sense of millions of pieces of data, as in the search for a drug solution; the challenge is to design thousands of parts or subsystems that will integrate as an optimum total system. Boeing is home to 165,000 employees so designing an aircraft is not like the movies that often show an entrepreneur, a pilot, an engineer and some mechanics in a drafty hanger producing drawings in weeks and a plane in a year.

The basic airliner of our times--the 737--has 367,000 parts, not counting bolts, rivets and other fasteners. The 747 whose economy section is 150 feet (45 meters) long or about the length of the Wright brothers’ first flight at Kitty Hawk, NC, has about 10 times the number of parts as the 737. An engineer designing a given part must consider its effect--such as weight, resistance to stress, etc.--in relation to all its

neighbors. The sum total of all parts characteristics, such as weight, must satisfy the design goals for the whole aircraft.

Boeing has moved from paper drawings to computer aided design (CAD) drawings which are stored as a master set in one computer and instantly available to Boeing people worldwide in what could be called the Boeing cloud. The computer software program, called CATIA, allows three-dimensional graphics for all parts to assure utmost precision and fit. From the very beginning of the design process, each designer and engineering team must react with the Boeing cloud as well as the public Google cloud to deal with the design goals effectively and economically.

The point of all the foregoing is to make the design of something as complex as a new drug or new aircraft as simple and meaningful as, say, designing a hammer. The designer or inventor can't afford to overlook the heaps of information that is available for any aspect of the project. This survey of the clouds can energize the inventor so that he or she can completely project their mind into the appropriate invention space. They can force themselves into a unique intellectual position where the solution will occur to them and quite possibly no one else. Once found and accepted as feasible, the solution can be optimized and crafted into a practical design, again using the resources of public and private data clouds.

I should confess that, although I try to be a scientist, I am by training an engineer. We engineers are looked upon suspiciously by scientists as grasping at solutions without regard to whether there is solid science behind them. The success of low brow empirical language translation programs at Google, or the models developed for machine learning for drug discovery, often can help us get somewhere until we figure out the theory. The process is going back and forth between hypothesizing and proving a model and finding empirical data to confirm or reject the hypothesis. In addition to designing and carrying out experiments, researching the vast resources of the Web may hasten confirmation of the model.

It would be interesting to see how aspirin could be developed from scratch today and how long it would take to approve it for general over-the-counter sales. By sorting through various folk remedies in the 5th century B.C., Hippocrates discovered that the bark of the willow tree treated

fevers and pain. He had empirically discovered salicylates without a pain chemistry model. In 1897 Felix Hoffmann, a chemist working for Bayer, devised a milder formulation, acetylsalicylic acid now known as aspirin which he used to treat his father's rheumatoid arthritis. It wasn't until 1971 that a British Pharmacologist, John Vane, found that aspirin controls prostaglandins which control body compounds involved with the maladies treatable by aspirin.

Chapter 8

How to Catalog Knowledge and Find What You're Looking For

I do not fear computers. I fear the lack of them.
Isaac Asimov

Historians have always benchmarked ancient civilizations by their achievements in collecting, cataloging and archiving knowledge. The library in Alexandria, Egypt was once the Wikipedia of the known world. Destroyed about 2,000 years ago, it housed one-half million to a million scrolls. On the other hand, this vast collection was not available to anybody but only the literate few with time to browse; and it certainly wasn't available on home computers. It was also hard to find what you were looking for.

1,400 or so years later Johannes Gutenberg invented movable type and began commercial printing which quickly spread across Europe becoming the vital catalyst which ushered in the Renaissance and scientific revolution. This was somewhat like inventing the minicomputer in that it was an enabling mechanism for information processing at the local level and making it rapidly available everywhere else

Recently such basic commercial products as Intel chips, Microsoft software and the Google search engine have enabled the modern equivalent of the library at Alexandria to be instantly accessible on the laptop and Blackberry of every man, woman and child in much of the world. Proclamations about the death of the book are premature, but printed encyclopedias have almost been wiped out by the on-line communal encyclopedia, Wikipedia whose contents probably surpass all print encyclopedias combined. The age of Google has ushered in resultant fear and misunderstanding about the new paradigm, much like Gutenberg must have experienced.

Information Flows among You, Your Collective and the Computer Clouds

What has happened with the Web and computer clouds is that the information flow between you and the computer clouds

and you and your collective intelligence groups has speeded up by factors of billions. Mankind progressed from counting on fingers, to the abacus, to the slide rule and mechanical calculating machines, to faster and faster and larger computers. For research and design, this increasing of computation speed, volume and accuracy were needed just to keep up with the exponentially increasing volume of reference information as shown in figure 8a: (<http://larrykilhambooks.com/M8a.aspx>).

Figure 8b: (<http://larrykilhambooks.com/M8b.aspx>) shows how information and knowledge has been partitioned and stored at various times in human intellectual development. The earliest model of information and knowledge storage and use probably would fit in the era from pre-history to the early Bronze Age. You and your clan or village did not have libraries or in most cases not even the written word to any great extent, but you did have a great knowledge source through tradition, oral histories, and all kinds of know-how passed down from generation to generation.

It is probably impossible to even make a good guess at how much traditional information was guarded by tradition—let alone in a modern metric like bytes—but it was probably a lot more than the typical person of those times carried around in his head. In other words, compared to what he needed to know for daily living, the knowledge in the “tradition cloud” was much more extensive than he would ever need. He knew that chiefs, priests, and clan leaders would have the additional information required for special occasions.

From the Bronze Age to late in the twentieth century, the focus of information and knowledge was the library. The traditional stories and new knowledge of any kind were written down and stored in a central repository. Response to information queries was still rudimentary by Google standards, and it was done through such familiar means as index cards and dedicated librarians.

The 1900's saw the emergence of the laboratory as a local information development and processing resource. It was an important development starting with the major research projects of World War II. At major research institutions the project “lab” has taken on the meaning as a collective intelligence group. Its resources include a traditional experimental lab but also include a library, meeting areas, and computer facilities—in short, a complete intellectual unit.

Now, in the 21st century, your laptop computer can be the port to all of the world's knowledge. You can locate yourself wherever you feel most creative. Anywhere you can log in to the various computer clouds of interest, you are an active part of the world intellectual community. With petabytes (quadrillions of information chunks) of information at your disposal in fractions of a second and cross indexed in limitless ways, your creative quests can gather about all of the world's apparently relevant information to structure your thinking.

You will undoubtedly learn about potentially mutually helpful people in your Internet explorations. These Other Minds become a collective intelligence community, especially if they are organized through an association, Web chats, meetings or as an Internet group called a Wiki.

The flow of information from the computer clouds, other minds, and your mind converges at a thought vortex which almost has a state of being and mind of its own. This is shown in figure 8c: (<http://larrykilhambooks.com/M8c.aspx>). This web of information sources and users will underlie the solution of most very complex problems.

The Age of Google

Google is at the point of storing all of the world's open literature, papers, documents and website contents. This was bound to happen once the software algorithms and computing hardware became available and commercially feasible.

The Google search algorithm, called PageRank, was developed by Google founders Larry Page and Sergey Brin when they were at Stanford University. They started work in 1995 and had a prototype named Google in 1998. A patent was issued and assigned to Stanford. Google received exclusive rights to the patent in exchange for 1.8 million shares which the university sold in 2005 for \$336 million.

PageRank ranks a page by the number of other pages linked to it and by the ranking of those pages. So a page with three links to it is ranked higher than a page with one link, assuming the other pages connected by those links have equal rankings. If the other pages' rankings increase, so does the ranking of the pages they are linked to. There are other undisclosed adjustments to the PageRank algorithm to prevent manipulation and other problems better known to Google.

The major plus for the Google PageRank algorithm is that it works well for rapid searches and with a relative minimum of user computer capacity required. Further, it does not require humans to adjust the page rankings directly within the Google data base itself. The rankings are adjusted automatically whenever a person links one page to another.

The rankings for all pages in the Google memory change continuously much like the human brain continuously changes the degree of importance connections between subjects based on the continuing inflow of new information. For example, your brain has some relationship established linking “dogs” and “fleas.” The negative for Google’s PageRank is that PageRank doesn’t know what dogs or fleas are or the relationship between the two. It will display ranked pages talking about dogs and fleas if you tell it that both are important in a single search by typing in the search space “dogs fleas”.

Searching for pages by functional relationships among a set of search terms is the basis of the semantic web, an alternative to the PageRank search method, to be described later in this chapter. So far Google’s search engine is the optimum for most applications for finding information using sets of search terms that often are unrelated to each other. The emerging semantic web algorithm, on the other hand, may be better for very focused search using search terms which are related to each other.

All of the Google indexing and search tools would be of little practical use except that computer technology now allows storing and accessing just about all the information in the world. This is not a sales pitch. Let’s look at some facts and figures. The big development was realizing that huge supercomputers are not the optimum way to handle the job. Small computers, not too different from a home PC, are networked together in any number and in many locations to collectively do whatever very high volume computing is required. These are called servers, and as of early 2008, Google had 450,000 servers which collectively consume over 20 megawatts for an electric bill of over a \$2 million a month.

As for throughput and storage capacity, Google processes about 20 petabytes per day where one byte is about equal to the information in one keystroke (letter, number, space, etc.) and peta means one quadrillion (10^{15}) bytes. It is estimated that this computer cloud collectively stores about 150

petabytes of data. Everything is programmed and arranged so that the elapsed time from your query to the result is within .2 of a second.

What can you do with that storage capacity? They have indexed and can instantly access over a trillion URLs (websites) and this pile of data grows at the rate of several billion pages per day. There is a copy of the entire Internet within the Google computer complex so that it can find and analyze information faster. Now Google is copying all the world's books to which it has been given access--which is probably the large majority--and it is three dimensionally mapping all the earth's surface to better than one meter resolution. This fits within the scope and spirit of the company's mission "to organize the world's information and make it universally accessible and useful."

It appears that the Google cloud is basically in place and from here must grow to accommodate the ever-increasing pile of information building up all over the world. According to an interview Peter Norvig, director of research at Google, gave to *Technology Review* magazine, Google search development is heading towards all kinds of content and interface modes. This can be seen now with the user-controllable view of almost any part of earth through Google Earth and with viewing of video documents stored in Google, such as the familiar YouTube.

These visual media have in turn multiplied the information storage requirements of the Google cloud by what Norvig estimates to be a thousand times. Not only is "a picture worth a thousand words," but compared to alphanumeric data the requirements for transmission capacity through wires, fiber optics and satellites is very much greater.

New Media and More Dimensions

Users of Web search and download are accessing the Web from more than just a workstation at work or a personal computer or laptop at home. The smart phones such as Blackberry, iPhone or Google's own G1 phone are allowing Web access from virtually anywhere. Norvig points out that the tiny screens and awkward keyboards of those phones drive the development of other interface methods such as speech recognition.

Marissa Mayer, Vice President of Search Products and User Experience at Google, in an interview with *Webpronews* said that “search needs to be mobile. It should be available and easy to use in cell phones and in cars and on handheld wearable devices that we don’t even have yet.” In this context Mayer refers to *Universal Search* that retrieves results as sites, images, video, books and maps. The company has already launched an early version of this rich media retrieval package.

Video games have probably been the inspirational factor behind another Web projection and search network. This is to project “the world” into 3-D so that instead of terrain maps such as seen on Google Earth you see a 3-D vision of the terrain you’re interested in as if you were flying down through it in a helicopter. Various names have been used for this new Net space including Second Life (a commercial product), World Wide Sim, Second Earth, and Metaverse. You and other people can project yourselves into the Metaverse as “avatars”-figures who can converse with each other, carry on transactions, explore through doorways, etc.

This vast three dimensional computer generated information space should fit well with the creative projected mind which is looking for new ways of visualizing things such as depicting a three dimensional space capable of representing the key elements of the invention in progress. For example, with this spatial reconstruction of reality, the inventor can see how the gears would engage in an automobile gear box. He or she could create a dynamic, working gearbox in the Metaverse that could be used for visualization and experimentation.

The trouble so far with computerized three dimensional projections is that the lack of realistic detail is off-putting and the movement of figures or objects within the scene is erratic and not smooth and lifelike. While not essential to the invention process, the cleanup of these distractions would free the creative mind for its real pursuit of creating something new.

There are various approaches to help the creative person envision objects and spaces better. One of these is “hands-on computing” using multi-touch screens as a way for one or many participants to receive and enter data from a common data base. Apple’s iPhone is the most familiar multi-touch screen. By moving fingers apart and together, and moving

them around, various commands are instantly conveyed to the iPhone.

For serious work, however, such as for corporate research, the screens range in size from a TV screen to an entire wall. The user can retrieve an image from a private data base, a local camera, or the Internet and then move other images, data tables or effects over that image. In the case of the gear box we just looked at, the gears could be moved around to different positions in a series of “what if” experiments.

Several departments of a company can each have their screen connected to a common data base so that many participants in several locations can participate in the process visualization and in changes to the mechanisms. Microsoft is commercializing this kind of system in a package it calls Surface Computers with the trade name of Surface.

The Semantic Web

For the more verbally oriented users of the new (Web-based) media, there is at least one other basic way to schematize information indexing and search on the Web and that is generally known as the “Semantic Web.” This addition was unveiled in the May, 2001 *Scientific American* by Tim Berners-Lee, James Hendler and Ora Lassila. They envisioned data that could be easily accessed by PCs and hand held devices like smart phones. Intelligent software agents would seek out customized answers to practical questions without sifting through copious intermediate results. Tim Berners-Lee invented the World Wide Web and leads the World Wide Web Consortium at MIT.

The primary software language for the Semantic Web is the Resource Description Framework, or RDF, which sits on top of the HTML language now so common on the Web. RDF encodes data through “triples” which are sets of subject, verb and object. These triples, tell the computer what the object is (for example a car), descriptions of it (price, location, etc.) and what should be done (seek such a car for purchase).

In a subsequent Berners-Lee article with Nigel Shadbolt, they show you how to find a used Toyota in Lenox, Massachusetts that costs \$7,500 using a Semantic Web search. In other words, a major purpose of the Semantic Web

is to simplify and make more productive searches involving new relationships or correlations.

Search engines generally do not think the way humans think when humans are looking for additional information. Search engines use key words and not associations of search term words with other words. Your thinking process is more like the Semantic Web in that you can instantly make associations in your mind by any set of associations that present themselves: different people you know, places you know about, or people and places. In technical research you can fix in your memory observed situations and observed outcomes. You can relate what you are doing to what other people have published about the same research topic.

This process is associative inference, and it allows us to think about any combination of things we have in memory compared to new information flowing into our memory. Continuing our earlier analogy, if you never had a dog, and it didn't have fleas, or thought about this relationship much, your associative retrieval of dog and fleas would be weak or even forgetful. But if you have a dog and it has been plagued by flea problems, the association between dog and fleas in your mind would be very high.

The Semantic Web can be more powerful than an individual human brain or a Google search for a particular search topic area if many humans have entered search terms interrelationship data so that the Semantic search engine is already well-informed in your area of search. If you have many terms in your search, the Semantic Web engine will construct a network of all the known relationships among those terms and using this perspective give you the best knowledge-based response to your query.

The Semantic Web is an enhancement of the World Wide Web and is not a replacement for it. It requires a lot of time and effort to enter enough data to have an area of Semantic Web search that is clearly more useful than Google. For this reason, the Semantic Web has found its users among specific application groups, often in private networks of computer clouds which are not a part of the Web. These groups have the interest knowledge and budgets to encode the thousand of word combinations suitable for their field of use.

Examples are users who have common interest in such diverse areas as genetic research or in dog breeding. Among

the companies which are using Semantic Web languages and technologies are British Telecom, Boeing and Chevron. As of late 2007, a summary of Semantic Web languages, engines and applications is reported by Lee Feigenbaum and others in the Scientific American.

One interesting effort at applying Semantic Web approaches to Web search is DBpedia. This is a project to greatly enhance the usefulness of Web search of Wikipedia, the on-line encyclopedia with free access and to which almost anyone can contribute. Despite Wikipedia being the largest encyclopedia that has ever existed, it only supports one search term. You can query it about Paterson and receive an article about Paterson, New Jersey, but you cannot ask it for all the cities in New Jersey with more than 100,000 inhabitants.

If you use a search engine like Google in research for a new invention, more often than not, it will turn up a Wikipedia article but unfortunately not one that really answers your objective. As of early 2009, however, DBpedia's knowledge base was only about 2.6 million "things" so it is not yet generically useful. Its base would have to be millions of times larger.

The Search for Patterns in Big Data

Another effort is oriented towards experimenting with the effectiveness of analyzing massive amounts of data to search for patterns. This is the Cluster Exploratory (CluE), a National Science Foundation program using Google and IBM computing platforms and tested in conjunction with six pilot universities. The cluster will consist of 1,600 processors, several terabytes of memory and hundreds of terabytes (hundreds of trillions of bytes) of storage along with the software including Google File System, IBM's Tivoli, and Google's MapReduce. Early projects are in the biological sciences and include analyses of the brain and nervous system.

Besides the CluE project, IBM has recently announced a new software package to find trends in large data sets. It rapidly analyzes huge volumes of data to find trends. Finance, health care and space research are among the applications IBM sees as good candidates for its new software. This

software is the key offering of a new IBM division called Analytics.

As of late 2009 it has 4,000 “consultants” with a target of settling at 10,000-15,000 consultants. IBM Analytics has its own massive supercomputers. Its first target market is “Smart Cities” where IBM will help clients find ways to save energy such by better management of automobile traffic. In an October 2, 2009 interview with CNBC’s Maria Bartiromo, Sam Palmisano, CEO of IBM, said that Analytics could help the world avoid a financial crash like the recent catastrophic one by instantaneous analysis of data streams coming in from various financial institutions, primarily in New York.

The Swedish Institute of Space Physics has been testing an early version of the CluE program to relate gas clouds and particles cast off by the sun to disruptions of communications on earth. Bo Thidé at that institute emphasizes that, to be useful, any system used must give immediate answers.

If the cluster exploratory approach works, where are we headed from here? Stephen Baker in *Business Week* writes:

What will research clouds look like? Tony Hey, vice-president for external research at Microsoft, says they’ll function as huge laboratories with a new generation of librarians—some of them human—“curating” troves of data, opening them to researchers with the right credentials. Authorized users, he says, will build new tools, haul in data, and share it with far-flung colleagues. In these new labs, he predicts, “you may win the Nobel prize by analyzing data assembled by someone else.” Mark Dean, head of IBM’s research operation in Almaden, Calif., says that the mixture of business and science will lead, in a few short years, to networks of clouds that will tax our imagination. “Compared to this,” he says, “the Web is tiny. We will be laughing at how small the Web is.” And yet, if this “tiny” Web was big enough to spawn Google and its empire, there’s no telling what opportunities could open up in the giant clouds.

What of the Scientific Method?

Some people say that the era of big data and development of patterns by correlation of data sets will make the scientific method obsolete. Chris Anderson of *Wired Magazine* wrote:

“All models are wrong, but some are useful.” So proclaimed statistician George Box 30 years ago, and he was right. But what choice do we have? Only models, from cosmological equations to theories of human behavior, seemed to be able to consistently, if imperfectly, explain the world around us. Until now. Today companies like Google, which have grown up in an era of massively abundant data, don’t have to settle for wrong models. Indeed, they don’t have to settle for models at all...The big target here is...science. The scientific method is built around testable hypotheses. These models, for the most part, are systems visualized in the minds of scientists. The models are then tested, and experiments confirm or falsify theoretical models of how the world works. This is the way science has worked for hundreds of years.

It might appear that the scientific method has become a charming anachronism like the Dodo or the slide rule, but it is not a question of “either” or “or.” It is a combination of “both.” Pattern analysis in massive amounts of data should not be thought of to produce a final model for scientific purposes. It should be used to produce a working hypothesis based upon which an analytical model is developed. It is like producing sketches before composing a painting.

Implications for Inventors

Despite the easy use of the computer clouds and the proliferation of communications devices to connect with them, creation and invention have not been automated. Successful creation of major inventions requires as much as a lifetime’s pursuit of relevant knowledge, full use of the Web, experimenting with possible solutions in a hands-on laboratory, informally tossing ideas around with real people in one place, and a lot of solitary thinking. That’s why there will always be room for the Edisons and the Leonardos.

My friend Dr. Joseph R. Stetter, a chemist with more than 25 patents and many awards for creativity, offers this interesting perspective as we enter the Age of Google:

There was a time when I spent time each month in the reading room in the chemistry library browsing my favorite journals. There was a time when I visited the library on the spur of the moment whenever I had an idea to elaborate, or a problem to solve, or any issue for which I needed added information. There was a time when I took and later taught courses in the organization and searching of the literature of science and engineering.

In brief, invention is “building a better mousetrap” and innovation is “doing something different with the invention for social impact.” Of course my career *modus operandi* in science and engineering would have evolved in any case and in many areas of the scientific endeavor since progress in scientific instrumentation as well as knowledge has evolved rapidly and significantly.

But, in the aspect of scientific invention and innovation, no greater impact has been observed than that of the internet and allied technology (search engines, content providers, etc.). No longer do I need to go to the library to find information. And while this sounds simple, it is an immense transformation.

A good research group or research university was judged in part by how good the library was. Now stature in research capability is judged by how good your search engine might be. I still love libraries but it is a nostalgic love and not a love from need. I love the atmosphere of a library and the feel of a book. However, I now have at my fingertips, still for a subscription fee of course, multiple libraries that grow in quantity of information with unbelievable rapidity.

My challenge now is to understand the search engines, so I am not misled to what the provider wants me to see and to the best information to understand my issue. Operationally, I now first go to my computer when I need information rather than the library. The course I last taught in chemistry literature was not so much an emphasis on library literature and libraries but about distinguishing the quality of information from anecdotal web page postings to the highest quality refereed

journal articles and the ongoing scientific discussion that improves our theories and knowledge base.

Finally, I absolutely enjoy having information from technical to social immediately available to solve a problem and find it enabling of invention and innovation on many fronts. The ideas that I have come to me at odd times, and often can only gel if they can be incubated quickly. This is now realized and I look forward to the day when every piece of literature in every language is available immediately to every person on earth on their cell phone! What a transformation of thought, operating style, and creative stimulus we have seen in less than a single lifetime.

Chapter 9

Collective Intelligence: Managing Large-Scale Research and Innovation

We as a species have entered a new phase of evolution with the appearance of the World Wide Web. You can find out almost anything you want to know at the click of a button, and this happened suddenly, nobody predicted it. This is a collectivization of human information.

Once you start to act with other people, you can do things you couldn't do as an individual. You become a connected intelligence and just like joining computers together, that increases your effectiveness and power... For scientists, it means the world is now one giant research group.

John Barrow, *The Infinite Book*

A fundamental mechanism of human intelligence is combining known and unknown data. This is a process of increasing your knowledge and often increasing the knowledge of other like-minded people as well. This goes back to the cavemen who sat around the campfire and shared ideas about which spear head worked best on the hunt. This seems to be the case with more elementary creatures as well. Adjacent members of a species are generally aware of each other's presence and will share concerns if they can. This is known among biologists as "quorum sensing."

With the advent of Internet forums, wikis, affinity groups, blogospheres and so on we humans are into quorum sensing with a vengeance. This learning and group communication mode is becoming known as "collective intelligence." See figure 9: (<http://larrykilhambooks.com/M9.aspx>). In its most general form, it is determining the consensus of many minds to find a response to a complex challenge. For example, collective intelligence could be used to find solutions for many problems engendered by climate change.

Examples of Collective Intelligence

The MIT Center for Collective Intelligence has been shepherding the development of an online forum called the

Climate Collaboratorium. It will be a constantly evolving computer model of the Earth's atmosphere and human systems with inputs from online scientific chat rooms. All the variables and factors that can be imagined relating to climate, the environment, interactions with human beings, and ecology will be included in the evolving model.

Professor Thomas W. Malone, the center's founding director and MIT Professor of Management, compares the Collaboratorium to the Manhattan Project which developed the atomic bomb during World War II. "The difference between the Climate Collaboratorium and the Manhattan Project is that this is a problem everyone in the world needs to solve, but because of new technologies like the Internet, it's possible to enlist far more people than during World War II."

There are of course many examples in history of collective intelligence that has gone wrong. Contrary to the then prevailing wisdom we now know that the world is not flat and it is not at the center of the solar system. Wars have been started by propaganda whose content is skewed or falsified so as to inflame emotion.

There are however plenty of examples that could be cited to show the amazing accuracy possible with collective intelligence. Malone and his associates at the MIT Center for Collective Intelligence report:

- *Kasparov v. the World* was a chess match held in 1999, when world champion Gary Kasparov played against "the world," with the world's moves determined by majority vote over the Internet of anyone who wanted to participate. Kasparov eventually won, but he said it was the hardest game he ever played (at least until he met IBM's "Big Blue" super computer and lost).
- *NASA Clickworkers*. In 2001-02, NASA let anyone look at photos of the surface of Mars on the Internet and identify features they thought were craters. Crater locations were designated by sets of coordinates in two dimensional space. When the coordinates contributed by amateurs were averaged, they were found to be just as accurate as the classifications made by experts.

The most common example of successful collective intelligence is the Google search engine. Its search for the ranked results of any inquiry is based on the collective intelligence drawn from all Internet searches to the present. The collective intelligence is the number and locations of linkages between websites that were developed in prior searches. These were remembered by Google. It does not know the expertise of the people who made those prior searches. Some people argue that this is a weakness of the Google algorithm and others argue it is a strength.

Malone and colleagues divide organizational goals of collective intelligence groups into:

Create. The participants create something such as an entry in Wikipedia, more software code for Linux, or a poem in honor of a member.

Decide. The participants evaluate and select alternatives such as estimating climate change effects next year or deciding whether to delete a Wikipedia article.

Because we are concerned with innovation and creativity, I will focus on the “create” aspect of collective intelligence. First, we should agree that the inventor or creator when researching a particular subject sooner or later must engage collective intelligence. In the old days, a corporate researcher might consult the books, journals and papers in the company library and exchange ideas with his or her colleagues in the company cafeteria.

This procedure has been replaced or at least augmented by searches for relevant information in the Internet, searches in the company’s own computerized data base and its wiki if it has one, and idea sharing with colleagues by email, blogs, the company wiki, etc. The volume of source information is orders of magnitude more than the old days, the speed and flexibility of access is unimaginably higher, and the number and distance of people who can be involved in the creative process is no longer limited.

The Boeing 787 Project

An appropriate case in point is Boeing. For commercial jet aircraft, this company is noted for many innovations such as

the first enduring airliner, the 707; the largest aircraft in the world, the 747; and the most purchased model, the 737. In 1995 Boeing started shipping the 777 a long-range, wide body jet and the largest twinjet in the world. For the design of this plane, Boeing worked with its long-time software partner Dassault Systèmes to model each of the plane's 10,000 parts in 3D on the computer instead of building physical prototypes.

The 787 which followed the 777 moved collective intelligence design into mid-stream. "We had over a thousand of our partners' engineering personnel here to jointly define the airplane," said Mike Bair, head of the 787 program for Boeing. "That way we get the best ideas from everybody, as opposed to just ours."

The 787 Dreamliner, currently in final test stages before first deliveries, in many ways has been a visionary great leap forward. It was organized to use the 777 virtual design approach and to exploit the advantages of using composite materials for approximately 50% of the primary structure instead of aluminum. The composites are carbon fiber reinforced plastics. The features that are to be realized from the use of the composite materials include:

- 20% less fuel consumption due to lower weight.
- Better cabin air quality because the higher strength of the composites allow greater pressurization (the equivalent of 6,000 feet altitude instead of the normal 8,000 foot equivalent pressurization) and higher humidity because the composites will not corrode from humidity condensation like conventional aluminum.
- Fewer parts, such as 50,000 less fasteners, due to larger one-piece fabrications replacing smaller plates fastened together.
- Less assembly time.

In order to accelerate the design at lowest cost for this innovative plane, Boeing decided to shift much of the design to its supplier partners. Previously, Boeing designed 70% of the aircraft. Now its 43 top-tier suppliers and many more sub-tier contractors from 24 countries would work at 135 partner sites. Key to project progress was getting these design-partner suppliers to give up their individually favored computer aided

design (CAD) systems for the common language and format of Boeing's Catia V5 system.

All members of the 787 design team are networked by the Global Collaborative Environment (GCE). In addition to the Catia CAD design program used by all design members, the Dassault suite of program management tools include Delmia for digital manufacturing and Envoia to inventory all information on the 787.

Once this was done, the supplier could design many of the parts or assemblies from more general specifications supplied by Boeing. The communication between the supplier and Boeing was enhanced and standardized using the same engineering design and data communication programs. As a result, specification to a supplier dropped from 2,500 pages to 20 pages. Mike Bair explained, "We've realized that it's more effective when the people who are building the parts also do the engineering. They know better than us how their factories run, and to think that we can design a part that not only serves our needs but is also the most efficient for them to produce would be pure guesswork on our part."

While using vendors in a pool of collective intelligence to help design your product through customization of their designs for you is not a new idea--I have used this approach as a central focus in several of my technology companies--what I can attest to from hard experience is that doing it is much harder than describing it. What makes this approach possible to a much greater extent today is massive data base and networking computer technology and the new generation of engineers' positive attitudes towards the use of collective intelligence.

It could be said that the Boeing team design approach is more collaborative than collective. The collective approach might assume more open-ended outside contributors and more freedom of ideas on their part than simply finishing up designs whose general guidelines came from the project's management.

There are at least three reasons why Boeing's approach is less than fully collective. One is that once a collaborative effort is launched the company is not looking for fresh, new designs. The basic designs and parameters have already been determined for each part or subassembly.

Also, the company keeps new ideas, concepts and designs proprietary. All intellectual property belongs to Boeing or its collaborators. Enforcing control of intellectual property is much more difficult when contributors can come and go at will. Eventually controversy would develop about who owns which ideas.

Finally, collaborative intelligence such as can be attained through a wiki makes proprietary and secret information impossible to control. I know of a national government laboratory where the scientists are very frustrated about the lack of a computer-based bulletin board or chat group through which to post data and exchange ideas. The challenge hasn't been solved about how to prevent the escape of national secrets.

Solutions from Internet Challenges

Another approach to innovation and design using the flexibility and outreach of the Web is to broadcast a request for an invention or design to anyone who cares to rise to the challenge. There is a reward to the winner of the challenge--usually in the 10's of \$1,000s. A leader in offering this type of service is InnoCentive based in Waltham, Mass. It is a global Web community enabling scientists, engineers and others to collaborate to deliver breakthrough solutions for innovative R&D-driven organizations. Since 2001 their clients have included Procter & Gamble, Eli Lilly, The Rockefeller Foundation, government agencies and non-profits.

As of early 2009, 814 challenges had been posted (a "challenge" is a request for an innovative solution), for which 12,529 solutions have been proposed, and 391 were accepted and received cash awards. Among the challenge solutions InnoCentive feels are of broad significance are:

- *Oil Spill Recovery.* In 2007 the Oil Spill Recovery Institute posted 3 challenges dealing with oil spill recovery. One of these was solved later that year by a researcher who proposed a solution based on his expertise in the concrete industry. Insights can be found unpredictably in unrelated applications.
- *Towards eradication of tuberculosis.* Also in 2007 the TB Alliance, a not-for-profit development partnership

dedicated to accelerating the discovery and development of drugs to treat TB posted a challenge on the InnoCentive web site to simplify the manufacturing process of a current drug. Solutions were provided by solvers, one of whose mother was a victim of the disease.

- *Clean water in Africa.* A water filtration system has been developed in response to a change which uses carbonized coconut shells to filter out large particles and heavy metals. The water is then sterilized by an ultraviolet LED powered by a solar panel.

Considerations When Using Collective Intelligence

Collective intelligence is better for idea generation than idea evaluation according to Eric Bonabeau writing in the MIT Sloan Management Review. He points out that management decisions today must be made more rapidly in the face of much more data and opportunities than was the case of our ancestors. Our limitations as individuals may not be sufficient for today's decision making, and perhaps we should rely more on others to find solutions. Outreach is needed to obtain diversity of stimuli, assumptions and solutions.

For many problems a solution can be found outside of the company, so tools need to be developed for tapping into helpful outside sources. Understanding must be used to balance between diversity vs. expertise and decentralized vs. distributed decision making. Care must be taken to tap the crowd's wisdom and not its madness.

Now the question arises: where would the visionary thinker, the Thomas Edison, fit into this entire comforting new world of collective intelligence? Edison did the best he could without the benefit of Web-based collaborative intelligence, Google or wikis. He achieved much the same thing by surrounding himself with an army of engineers and technicians, and by maintaining his own large technical library. He also gained venturesome technical insights from his social associations with such industrial entrepreneurs as Henry Ford and Harvey Firestone.

Many people would consider all of this prohibitively expensive and time-consuming to do today. They would reach for their laptops and see if solutions could be found there.

Leonardo da Vinci, were he alive today, would join Internet chat groups and log into the computer clouds and addition to keeping a close circle of friends at his workshop. He would eagerly pick from the nearly infinite number of creative challenges that could be presented to him today. Leonardo would agree that with our Web incorporating billions of websites and quadrillions of pieces of information, with access to all by a laptop computer, that this data and computing cloud is closer to his infinite universe than simply being able to see the outer limits of the actual universe.

Leonardo's practical nature would appreciate that the use of modern communications technology and the Internet is more efficient, and he would not waste time on inventions that already exist.

Google and the other computer clouds are a new paradigm of creative thinking. The complex and critical problems confronting civilization today are demanding solutions at a much less leisurely pace than in the past. Darwin could arrive at his theory of evolution over a lifetime with no contrary consequences of his slow, methodical progress. Today, however, problems including global warming, food and water, and the tightly coupled national economies require genius-level insights in a short time. For a particular problem, if the right solution is not agreed upon and enacted in time, the world system may have crossed the Tipping Point beyond which the system cannot recover.

As the predominance of the lone inventor gives way to highly computerized research labs and teams, concern mounts about data management. There has been recognition that stewardship of data in the era of big data is a major priority. In January, 2009 the White House National Science & Technology Council issued a study, "Harnessing the Power of Digital Data for Science & Society" which noted that "preservation of digital data is both a government and private sector responsibility and benefits society as a whole."

Chapter 10

How to Invent With Google

The Ultimate Search Engine is as smart as people—or smarter.

Larry Page, Google Cofounder

How do you know when to start creating with Google and how to go about it? It's much easier when you have an actual creative design challenge. It helps greatly to have the motivation of getting useful information tied to a real goal.

This happened to me when I decided to make a simple instrument to detect common household fumes known technically as volatile organic compounds. I started with a cheap Japanese sensor designed to detect patients' bad breath in dental offices. It worked in my application, but sales were not exciting. One day a customer reported that it worked well for detecting ozone from photocopier machines and that a huge market awaited for photocopier machine repairmen who install ozone filters.

Meantime, however, the Japanese supplier discontinued the product because his dental market fizzled. I had to scurry to find a new sensor and hastily searched the recently-established Internet for a new manufacturer of the same kind of sensor (heated semiconductor) used in my design. I found a startup company in Switzerland that probably could only have been found on the Internet. I also had to research circuit design sites on the Internet to find a way to use this sensor for ozone instead of household fumes. The integrated circuit (IC) chip manufacturers' Web sites had the circuit design guidance required.

From there it was a question of making prototypes, having customers try them, redesigning based on their feedback, and eventually finishing up with a design ready for manufacturing and sales. While I never sought to patent the design because of the cost involved for only a two person startup, my fledgling company grew every year with little competition, and I wound up selling it successfully to a larger company in its industry.

While I could have done all the component search and product design without cruising around in Google or similar

information clouds, the time to production could have taken years, not months.

The immensity of the computer clouds offers us all kinds of creative opportunities and resources. The question is how best to optimize human and artificial intelligence in the Age of Google. What do I do best? What does the collective intelligence do best? What do the computer clouds do best? And how can I make the most effective use of their combination?

Beginning the Searching and Inventing Process

There probably is no one way to be imaginative and produce a great innovation or creation. Like any other project in life, it's most effective to have a general plan in mind just as if you were setting about to build a house or travel to a distant city. First spot the need your invention will satisfy. Next determine what product or service needs to be invented to satisfy that need. Then identify the obstacles to the product's proper functioning or in offering a service.

The vision and invention process starts in your mind, and when it is in a state that can be discussed, you generally should engage other minds when you feel that there is no danger of giving away the whole recipe. This could be a group of friends or professional associates, or perhaps a special affinity group wiki. They add to your vision and list of things to do. They point out probable dead avenues in your approach.

In creating and inventing, you are trying to control the information flow to your advantage, so if possible you should always have an off-line model to experiment with, free of computer communications to the clouds. This would include your notes and drawings, an engineering prototype, circuit boards, chemical formulations and so forth which collectively contain more of the essence of the ideas than your Internet correspondents can reverse engineer.

A key part of the creative and imaginative thinking process is "persistent thinking." This is reflecting on your present design solution and comparing it to everything you recall from memory; with what your support group advises you; what you have read and heard; and what you can find out from the search engines. This is a repetitive process, constantly

comparing the model of the invention in your mind with proposed design variations that you can imagine.

You would compare the information found above and through analogy and associative inference produce a conceptual solution to the problem. As time passed, you would cycle through the process above mining for new information, experimenting with physical models of the latest concept, comparing ideas with other people, etc. You would be alert for unexpected clues to understanding the phenomenon or solving the problem. Eventually an optimal or at least suitable solution would present itself.

Throughout this long and often lonely journey you should never lose your imagination and curiosity. You should not lose the creative person's enthusiasm, sense of purpose, propensity to ask profound questions and resolution to think boldly. This is what the masters like Einstein and Edison taught us.

Don't get discouraged or overly distracted. You're entering the phase of the mad inventor, and there's nothing anyone can do but put up with it. When your mind starts to wander, either make a new effort to focus your thinking or, failing that, reboot. Go for a long walk. Give your mind an opportunity to reset its programming. Suddenly a new answer may come because your mind has been working on the problem subliminally all along. Write down the insights before they disappear!

Inevitably, your emotional ups of creativity will be offset by emotional downs that can even lead to depression. You must stoke your ego and keep thinking about what fascinates you. When I am in a mental block, often I will cruise the Internet in my general area of interest and see if I meet my cyber muse. New ideas and insights may spring forth.

Bringing in the Search Engines

Indeed, a good search engine such as Google can make creativity and invention much more efficient and insightful: Often its use leads to serendipitous results for first-time users trying to find solutions to new problems.

Enter a few search terms and the requested package of knowledge is plunked in front of you. Apparent success (a "Google solution") has probably stalled many promising searches for a required innovation because the person

searching using Google did not know when they had reached a viable solution or when they should change their search strategy. One thing that will help the new generation is classroom education to include critical use of search engines just as critical reading of literature has been taught.

Many people tell me that they can't find the important and novel solutions they are seeking by Google searches. This happens if searches are done superficially. To get where you want to go in Google, you must devote considerable thought to what terms (places, things, people and other references) will link you in to the sites that you will want to visit.

My searches may cycle through over dozens of iterations as I try to garner clues from one search about what key words to use on the next one. After trying various combinations of key words and reading selected content of prior searches, suddenly the mother lode will appear. Each search will produce a dozen or more pages with 10 or so suggested sites per page.

I find that usually the first two or three pages are by far the most productive. Your most effective searches will build upon key words and ideas learned earlier. Searches will keep building upon prior searches.

Relevance and perspective are often gained from Wikipedia sites referenced as the source of search engine suggested sites. Wikipedia often has provided unexpectedly important insights and data for my development projects.

Google is often considered to be just a very convenient infinitely large and very up-to-date reference library. In the classical sense it is, but for the imaginative, curious thinker, it can be much more. That is because a very fast stream of data, information, references, and concepts are being exposed to the searcher. If he or she is motivated, curious, imaginative and seeking solutions, new associations and references will occur to the searcher that never would have happened were they just plodding through libraries.

The Google searcher is flying through a time warp universe defined by all the works of all time that might be relevant to the search and journey. Some people will sleep through this journey and others will absorb all the potentially relevant information along the way.

The Six Steps for Innovating and Inventing Using Google

What is the optimum way to make use of Google's comprehensiveness and speed? In addition to following the basics of any well-designed search project, there are at least six important steps as described below. They are derived from project flow diagram shown in figure 10: (<http://larrykilhambooks.com/M10.aspx>).

1 – Narrow the search and find prior art and solutions.

This is the time to vent your naïve enthusiasm and surf all around in Google and other web sources. Get a sense of the lay of the land. Which direction do you want to be headed? Has somebody already invented what you were seeking to invent? If not, why not? Have some obstacles unforeseen by you been discovered by others? Can you still envision a solution, not yet offered on the Web, which is worth pursuing? What are the key technical or design problems that need to be overcome? Can they successfully be addressed by your resources and ingenuity?

Also, if you are interested in patent issues at an early stage in your project, Google:

(http://www.google.com/advanced_patent_search) and other Web services offer efficient patent searches.

2 – Postulate a design or system solution. From what you have now learned from the Web, can you make sketches of your imagined creation? For example if it's mostly mechanical design, can you envision the placement of motors, gears, shafts, controls and so on? If it's electronic, can you draw a block diagram and logic flow chart for which specific circuits, IC chips and software can be dropped in later?

3 – Look for design elements on the Web. Check the Web and other sources for suppliers and parts and ingredients for your creation. Sometimes seeing different parts or ingredients than you originally had in mind will cause you to improve your design. It never hurts to order some key parts and start physical experimentation, if for no other reason than to further focus your mind on the essence of the solution.

4 – Design and redesign. Perfecting the smooth response of a mechanical mechanism, rewriting computer code, or experimenting with electrical circuit variations can be done and redone almost infinitely. This is part of perpetual creation and invention. This is also part of the relentless quest for full

understanding of the process and perfection in action. When inventing interactively with Google, iterate back and forth keeping in mind both the big picture and the details. This is the dual focus between you and the computer clouds for greatest creativity.

You can tweak your design too much or too little. It is important to know when to stop tweaking your invention. Most people tend to err on the side of premature product introduction. I have found with my inventions that in retrospect it would have been better to not worry so much about being first to market and better to have worried about reliable product performance.

Preproduction prototypes can be shown to critical observers in your shop or lab, and if those reviews go well, preproduction prototypes can be tried out by trusted customers. The revised US patent law gives US inventors a year to technically evaluate and get market response to their invention in a public setting before the final application is filed. There are similar provisions in many other countries.

5 – Find other people, companies and projects with similar interests with whom you can communicate. This partially refers to the collective intelligence groups and wikis discussed in the previous chapter. These groups are not always helpful in the nuts and bolts design process, but they can be helpful in giving feedback about a market application you have in mind, offering novel suggestions about different ways to look at your project, or having some very specialized data that would only be known to a very specialized collaboration group. Much of this work is definitely best done on the Web.

It often happens that you will have chance encounters in cyberspace as well as individual people ferreted out on the Web who may be of special interest to you such as professors, writers, skilled tradesmen, software writers and the like. Of course not all of your new acquaintances may turn out to be as friendly or useful as they first appear--some may well turn out to be jealous or competitive—but I think it's best to get involved with other people at this point and weed out the undesirable ones as you go along.

6 – Organize notes and source material. In the past, note taking, indexing and filing consumed disproportionate amounts of project time. While this essentially manual process will

never be eliminated completely, Web services such as Google, plus similar information access technology for use on data stored in your computer make it easier to manage a data base. I find Microsoft Windows Desktop Search easy and efficient to use.

By noting search terms that work particularly responsively in Google, in effect I have defined my personal space in Google search. By knowing what wiki or blog is closest to my interests, I have defined a link to groups of collective intelligence. By using a search engine to find things in the impossibly large and growing data base in my personal computer, such as Windows Desktop Search or Google Desktop Search, my personal data base is more responsive to queries and, hopefully, no data or insights are lost. Particularly important is that crucial data such as pages from Wikipedia can be “migrated” to my home computer data base.

In addition to gathering information, Google can also channel the creative mind into the unique imagination space that could not be found by simple day dreaming. Seeing what potential suppliers of parts and services do, and seeing the features of similar product designs, can give you new ideas where to fine tune your focus. If this tack is not productive, give your mind free rein to wander again. This is stepping back and searching anew for the way forward.

A Design Example

In the pre-Google days, you had to start with parts something like you would be designing. Let's say you wanted to design a super high-strength rivet for aircraft. You would find or buy a dozen different rivets, set them out on the work bench, roll them around, examine them, make some sketches of a design concept on your pad, and then set up the machine tools to make a first design prototype of your design.

Now, with Google, you might type in the search terms “design of aircraft rivets” and (as of this writing) in less than a second Google would offer a number of candidate pages. The very top one, <http://www.nationalrivet.com/custom-engineered-fasteners.htm> will bring you to a very informative rivet design Web site featuring drawings of all kinds of rivets. You could study these rivet designs to get your mind programmed to think about designing your own rivet.

But you might say, “What’s so difficult about visualizing rivets?” It gets a lot deeper from here. I tried Googling “riveting in space” and only found space photos that were riveting (attention-getting). I tried “riveting from the space shuttle” thinking there might be some interesting photos of astronauts doing riveting repairs in space. This turned up in the 19th ranked entry: *Friction welding as a rivet replacement technology, patent no. 6779707*.

To see what that patent is all about, I go to the Google patent search site and type in 6779707: http://www.google.com/patents?id=UrAQAAAAEBAJ&printsec=abstract&zoom=4&source=gbs_overview_r&cad=0#v=onepage&q&f=false in the information search bar and up pops a 23 page patent. I go there, and look at the drawings (“figures”) in the patent. It appears that this sophisticated process for joining aluminum alloy panels such as used in aircraft would not be easily visualized by just looking at conventional rivets. A frictionally heated tool is pulled along to continuously weld two panels together, replacing the conventional rivet process. Inventing this process would require conceiving the welding process as seen by the welding tool as well as understanding many things about aerospace materials and fabrication processes.

Key Points in Using Google and the Clouds

Google can be extremely helpful in helping you find your way in some of the stages of your new creation or invention. Google, however, will not do your abstract thinking for you. Google compares data sets exactly as they appear. It does not do abstractions of the data sets. The human mind, by comparison, has powerful imagination in part because it can do abstract thinking stimulated by the data sets. Abstract thinking and reasoning belong to a set of cognitive skills that are reserved for higher level thinking not yet found in the computer clouds. These abstract thinking skills are required for original and creative thinking.

When you think of a bright idea that you want to research further, you want to do it now. Your neurochemicals are flowing. Your neurons are alertly looking for new connections.

Your brain is stepped up to an emotional high. While it is there, avoid procrastination! Keep moving while you can see

all of the project's interrelationships. While fear of failure is undoubtedly present, on balance you will feel better about yourself if you pursue the emerging development while your mind is in high gear.

While you may not get a new insight out of Google right now, by entering its search cloud with your new project in mind, you have that exciting feeling that the development project has been inexorably launched.

If information about a package of related issues gets processed in this extended information blender causing your creative consciousness to be significantly raised, then you are making progress. This should lead to raising your enthusiasm, curiosity, sense of purpose, propensity to ask profound questions, and bold creative thinking.

You should not overlook using Google or other search engines and Web resources to research the early history of your field of interest. This history notably would include the pioneering big thinkers in the field. It can be very revealing to see what they thought about the important issues. The original thinkers in various areas were, by nature, very curious and often expressed themselves in a frank and wondrous manner. While their naïveté in hindsight may seem laughable, on the other hand they often spoke in straightforward terms that paid no attention to offending colleagues or to political correctness. They noticed things that might be worth reexamining.

Conclusion

Chapter 11

The Future of Megaminds

The problems of the world cannot possibly be solved by skeptics or cynics whose horizons are limited by the obvious realities. We need men who can dream of things that never were.

John F. Kennedy

Planet earth is spinning towards a new intellectual ecology. Due to massive low-cost computer clouds and nearly limitless communications networks connecting everyone, culture will irreversibly change and will change the way everyone lives. The brain that made man special over all the other creatures has created a networked brain about whose magnitude and consequences we can only speculate.

This growing Internet brain will offer any kind of instant data and apparent solutions to problems. But for humans to maintain their independence, and personal programs of achievement, education must emphasize that truth is the important goal of the searches and not feel-good satisfaction. Creativity and invention will follow.

A pioneering proponent of the world view was Pierre Teilhard de Chardin (1881-1955), a visionary French philosopher and Jesuit priest. He was trained as a paleontologist and geologist and was involved in the discovery of Peking Man. Teilhard de Chardin saw a sheath of consciousness surrounding the earth which he called the Noosphere (from the Greek, literally “the Mind Sphere,” or the sphere of human thought). This was a “planetary thinking network” of interlinked consciousness and information. Awareness of it would increase with ever more complex social networks. Key outcomes would be a global network of self-awareness, rapid feedback, and communication. While Teilhard de Chardin did not live to know the Internet, in view of his imaginative ideas, he must have sensed that something like it was coming. He felt that with the emergence of the Noosphere, the age of nations will pass and The Nation will be replaced by The Earth.

As time passed, the sense of euphoria about the Planetary Thinking Network has turned to a colder sense of impending

reality. Susan Greenfield, a neuroscientist at Oxford University wrote in *The Guardian* on February 10, 2005:

You're just a consumer, living at the moment, having an experience, pressing buttons but not having a life narrative anymore. You're not defined by your family, or by what you know, or by specific events in the real world, because most of your time is spent in cyberspace. So what are you? Could it be that we just become nodes on a much larger collective thought machine? (such as seen in figure 11a: <http://larrykilhambooks.com/M11a.aspx>)

It is easy to settle into being a cyber traveler, but the journey can get you ever farther from the focus on truth. In order to make useful sense out of the masses of the data in the computer clouds, you should constantly check the accuracy the answers you receive and the models you build.

There is a need for a new kind of thinking in the face of the recently available mountains of data—data instantly accessed and conveniently packaged like a supermarket consumer product. In order to break loose from a steady diet of package information figure 11b: (<http://larrykilhambooks.com/M11b.aspx>) you must fire up your imagination and embrace new ideas. From that start, creativity and innovation leads to new frontiers, and education is the basic force for insuring productive change from generation to generation.

If we don't refine our paradigm thinking, our ineptitude in managing with science will get us in the end. As a child growing up on a bucolic farm, I always liked to say without a lot of thought, "Nature always gets the upper hand." Its meaning really sinks in today. To avoid that fate, we must avoid dogmatic thinking and authoritarianism.

The Individual, the Internet, and the Truth

The creative person seeks something more than being part of a computer cloud-based social affinity group. He or she increasingly will have to balance plugging into the computer clouds and collective wikis on one hand and continuing the search for unexpected that may not be in the clouds on the other (figure 11c: <http://larrykilhambooks.com/M11c.aspx>) There is the balance between the insightful mind and the collective

intelligence. There are the different worlds of the instant Other Reality on the Internet versus the very long private intellectual quest. There is the abstract thinking mind versus the ever-improving machine learning.

Therefore, the creative person seeking new truths and models must constantly try to sort out the relevance of the computer clouds information versus what he or she thinks independently. People immersed in information analysis must increasingly be on guard that rumor and invective may be outpacing the seeking of truth.

The industrial revolution has given way to the knowledge revolution. The evolving mind of man may be overwhelmed by the computer clouds. The combination of peoples' minds and clouds' minds can be thought of as a super mind. A growing problem however will be that our thinking may not be so focused towards complete analysis and the best analytical methods. Holistic solutions to problems perceived in mega-data sets can lead us to new insights but they can also lull us into overlooking reductionist analyses and model building typical of the classical scientific method.

Noted MIT computer scientist Joseph Weizenbaum (1923-2008) was not impressed by the Internet and was troubled by the fact that it was easy for people to mistake pattern matching for true understanding. For the individual human trying to make the most of the Internet, maintaining perspective about the apparent truth emerging from the data analysis will be very difficult. One way to do this is by seeking perspective through original research.

All over the world people are sensing that knowledge and information have become a common resource and tool, and that has led to whole new Web services, "social media" such as Facebook and Twitter, and Web-based mega companies such as Google and eBay. Collective thinking, however, can lead to mantras based on questionable science. People can all start thinking that honeybees are dying because of insecticides; and when reinforced by Internet chatter and talk shows, the group diagnosis becomes the Truth.

Therefore, anyone finding newly discovered "scientific" revelations and discoveries on the Internet should be skeptical. Scientific detachment would indicate wait for some time to pass, seek other opinions, and search for probing questions to test the new and often popular theory. Use the

Internet and other resources to find opposite points of view or broader perspectives about the issue.

Imagination and creativity, integrity, a sense of wonder and truth, persistence of inquiry--these keep us above the turmoil and herd mentality of the Internet. They allow us to profit from the inexhaustible information resource of the Internet if we keep our sense of perspective and good judgment.

A New Awareness and Education

Everyone should know that we are in a paradigm shift with respect to knowledge acquisition and understand that there are serious consequences for sloppy data interpretation. Otherwise, we could be in for an era of increasingly misunderstood big science and misapplied analytical technology and methods at the enterprise level.

I woke up to this emerging reality recently when judging an elementary school science fair. This school was serving the poorest part of town with many of the students being the children of undocumented Mexican immigrants. Nevertheless, they were bright eyed and anxious to show their exhibits of such things as the way plants grow with different nutrients and demonstrations of gravity and motion.

As I talked to the kids, it dawned on me that they were getting a lot of their project ideas and help from the Internet (figure 11d: <http://larrykilhambooks.com/M11d.aspx>). Some kids were getting their project designs from Web-based services catering to science fair students, and my unscientific survey estimated this at 20% of those in grade 2 and 80% in grade 6. There is a warning sign here that the unconditional use of the Internet packages may have proliferated due to an emphasis on right answers and attractive demonstrations with a disregard of the science involved. On the positive side, maybe the Internet set the kids' minds in motion, and perhaps they will embark on fruitful scientific careers.

About that time, I saw an article by Monica Hesse in the Washington Post where she asked, "For the Google Generation, what happens to the concepts of truth and knowledge in a user-generated world of information saturation?" She reports on a college freshman who never checked out a book from the university library but who was overwhelmed about all the Internet information. The student

remarked, "The idea of having an original thought terrified me." Once she realized how much information was out there, the idea of productively using it seemed impossible. Part of ignorance is not knowing how to filter out irrelevant information.

We must inculcate the value and methods of good research in our student population. As they enter the enterprise world, be it public or private, profit or non-profit, they must have and maintain a critical attitude towards information, knowledge, truth, creative ideas, invention, flights of fancy and imagination. They must realize that the pursuit of new scientific insights must include focusing on finding truth among all the information and not just processing the information itself. Without the sense of importance of empirical truth, the relevance of reality is lost and progress is stalled.

Education's Role

Again my father has something important to say. He was willing to give education a chance, but became discouraged. In 1933 he wrote:

Now let us look at schools and see what the future of the country may be. Are people made like machines, in quantity and to a set standard? Or is education a means of developing the individual? In the main I think we shall find schools to be factories of the more expensive variety. Of course there is at present a very strong trend in teaching towards broader and more individual education, but in general what have we? Classes of numbers of pupils, I believe, all of whom are graded in a series of numbers that do not relate to any of them. Classes in which the book is the thing, not the pupil. Classes where memory ranks high, imagination low. Classes where every subject is divided into parts instead of classes where the parts are combined to show the whole. Self-sufficiency demands a broad general education put to use according to the need. Schools give a pigeonholed education almost totally removed from use. They tell us it is "mind training" but the memory is only part of the mind.

I couldn't agree more. It was the same in my education 20 years later.

Formal education is very important for entrepreneurs, but as has always been the case, many of those with creative minds tend to be impatient and often drop out of school before they complete their formal education. They become frustrated with the formality and rigid structure they perceive to be endemic to classroom education. There is a tension between the accumulation of facts and nurturing creativity. There doesn't seem to be any room left for the mind to wander, catch a glimpse of a new vision, or pursue it wherever it may lead.

In the 21st century, information is growing so rapidly that it is impossible to select what should be taught to students as The Knowledge that they will need in the future. Besides teaching the basics, schools will have to focus on providing students with the skills they need to solve problems and questions that can't even be asked yet, let alone answered.

Correspondence schools and community colleges traditionally have been a source of second start education for those who grew to realize that they didn't learn enough to achieve some aspiration. Today's correspondence courses and some community education courses are offered with the convenience and appealing media of online transmission. Some universities including MIT are offering their courses free online to anyone who logs in to them. This is a definite second chance for some self-directed individuals. Where possible in such cases however it would be very helpful to have a coach or tutor critique and guide the otherwise self-guided student as they try to sort out this stream of knowledge.

With highly interactive computer clouds offering multimedia education in a reality-based dialogue method, the students could find themselves in a virtual classroom with personal attention.

When students become employees in industry or government, they often will find more interest in new ideas than seemed to be the case in schools, especially if they are employed in technical areas such as engineering. However, deficiency of essential formal education often shows up as lack of essential technical knowledge or communication skills.

I have encountered many entrepreneurial technicians and engineers who hit a brick wall because they didn't know the physics or chemistry involved in their inventions. It is very

difficult to catch up in deep technical areas later in life. They should have studied more science and math in schools and universities. The areas of significant technical invention today usually are much more complex than in Edison's day, so prospects are much dimmer for the essentially self-taught entrepreneurs.

Equally a stumbling block is the lack of communication abilities on the part of these entrepreneurial hopefuls. They can't seem to explain in understandable language what they are thinking or proposing. They can't read published information that is required to support their project. They can't write down their findings and notes for their associates and followers.

Our schools apparently have the reference resources students need in terms of both technical education and communication skills, but this knowledge often doesn't seem to be getting through to the students. Three things need to be done:

- 1 – Get children interested in creative accomplishment at an early age and keep them focused on this throughout their lifetimes. This requires teachers who love what they are doing. Teachers who are on fire. Teachers who love science and really want their students to absorb it.

- 2 – Make sure that the fundamental knowledge needed has been presented and learned. If teachers do not know their course material, replace them with ones who do.

- 3 – See that the students who are interested in innovation, invention and entrepreneurship don't drop out of school prematurely, foregoing the additional technical education and communications skills that they will need.

We will need many graduates who are hooked by the challenge of the unknown. They will be captivated by the wonder of unknown and the goal of making a unique contribution to its understanding.

This motivational process starts at the top—with the President of the United States—and carries through political and business leaders, parents, clergy, educators and many others. When Russia launched the first orbiting satellite, there was frenzy in the United States not to fall behind in the technological race. We put our man on the moon first, and this goal has faded out. Now the world is faced with larger and sometimes irreversible problems of environment, climate, food,

water and energy, and a new sense of mission must be developed.

Towards the New Frontier

Times of insight and creativity come and go with the ebb and flow of unexploited knowledge and with society's sense of urgency for new solutions. The industrial revolution and World War II were eras that saw surges of insights, creativity and invention. Now the world is benefitting from a combination of bright new minds coming up through the educational systems, well-equipped laboratories and shops, and the new information sources of the computer clouds; but there is an apocalyptic sense of the world running out of time. Also, many people feel a sense of "Why bother?" because it appears that the world has run out of possibilities.

People must see that the whole universe is available to them and that creativity has never been more important than now. Children should realize that there is an infinite future for them. Society's failure is failure to give them hope and encouragement.

Now is the time for the men and women who dream of things that never were. Their dreams are the starting points in great creations. The positive emotions of the challenge will cause the complexity and depth of the world's problems to fade away. The one catch is that their dreams will have to answer to unmet realities.

It is time to turn America into a nation of creators and inventors again and for the whole world to work together to deal with the many challenges and opportunities that are upon us. From garage inventors to multinational corporations we must make a fresh effort at creativity and innovation including using the vast new resources of the Internet and the computer clouds. America needs to become more creative in all endeavors.

In the waning months of his life, I was with my father in his combination shop and office. He was looking through his company's yearly financial reports, noting profitability increases every year, and looking at me for a response. I didn't know what to say or how to respond. They were just sheets of paper with numbers on them being shown by a great

inventor. He didn't refer to his inventions, models or artwork. We fell silent and then slowly left for the kitchen.

Over the years I have been haunted by this scene. The same questions have kept plaguing me: What was his purpose? Did he want me to take over the business? Was he disappointed in the way his life turned out—thinking of himself as becoming merely a shopkeeper? Did he think that the financial statements were all that I, a business school graduate and corporate manager, could understand? Was I incapable of understanding him?

As I write this book, the answer comes. The financial figures were the distillation of truth. It had taken a lifetime, but the world at last had come to accept his creations and was willing to pay for them. Not only had he had created useful and beautiful things of lasting value, but they were valued in the market place. Things he could be proud of.

Unknown to me, he knew this conversation would be about our last. He was saying, "Be guided by the truth, and the rewards will come."

Glossary

The following are my definition of key terms used in this book written in lay language and defined in the context in which they are generally found in this book. More authoritative definitions can be found in standard references.

Algorithm A step-by-step procedure for solving a problem often written as one or more mathematical equations or as a small computer subprogram or program.

Artificial Intelligence (AI) The ability of a computer or other machine to perform those activities that are normally thought to require intelligence. Artificial intelligence devices range from bug-like robots that can find their way around a terrain to mega-computers that someday may be more intelligent than humans. The term artificial intelligence is used in a variety of ways ranging from an engineering and scientific discipline to a specific computer, program or device.

Associative Inference Calculating or inferring the strength of the connection between two words or data points in a knowledge network such as a computer data base or a network of neurons. While all points are almost always connected to each other, the strength of any given relationship is determined by the sum of the strengths of the direct and indirect connections between the two data points. Example: “dog” and “ice” would not be likely to have a strong connection, but “dog” and “fur” would have a very strong connection based on direct and indirect (multi-linkage) connections.

Autism A brain development disorder characterized by limited social interaction and communication. Autistic people seem to think more in terms of pictures and numbers than in verbal communication. Many autistic people have nearly perfect memory in both detail and the amount of information that can be remembered. Autism may provide some clues about the ways the brain thinks and imagines. The causes and treatments of the condition are still not well understood.

Bipolar Disorder A psychiatric disorder characterized by periods of mania alternating with periods of depression. There is a theory that very creative people are all to a certain extent bipolar.

Bytes One byte represents the memory capacity in a computer to store a letter, digit, character or space. A **kilobyte** (1,000 bytes) is about the storage requirement for a page of text. A **megabyte** (1,000 kilobytes) is about the storage capacity required for a medium resolution photograph. A **gigabyte** (1,000 megabytes) is about the storage capacity of a CD disk. 100 gigabytes or more is the storage capacity in a PC or laptop. A **terabyte** (1,000 gigabytes) is the size range of very large storage in corporate and government computer systems. A **petabytes** (1,000 terabytes) is a suitable dimensional unit for a computer cloud. The Google cloud represents well over 100 petabytes.

Cartesian Often referring to Descartes, and his mathematical methods and philosophies. More generally, usually means emphasis on logical analysis and its mechanistic interpretation of physical nature.

Clouds, Computer Clouds An evolving term referring to computer services accessed in the Internet, especially where there are extremely large capacities of programs and data storage. The user generally does not need to know about the technology of the computers, software or data handling.

Collaborative Intelligence People working together to solve a problem, accomplish a design, or other action generally too complex for a lone individual. The working environment may be in a room, by way of the Internet or through a wiki. For collaborative intelligence the people involved know each other as associates, contractors or through other relationships.

Collective Intelligence Similar to collaborative intelligence above except that many of the people involved do not know each other. People can join the group and leave so that the composition of the group may be changing all the time.

Connectionism A construct in artificial intelligence modeling the mind as functional modules and nodes wired together. It is also used in cognitive and neural sciences to model the thinking process as the flow of information between interconnected units. The network nodes are identified in numerical terms. In contrast, *semantic* networks have nodes identified by names or words.

Consciousness Conscious is a very widely used word that, depending on the observer or situation, may have several meanings. Therefore, it will be forever difficult to define to everybody's satisfaction what consciousness is. Your consciousness could be said to be everything you yourself are aware of. This awareness is a synthesis of your past and present taking into account all your senses and memories. Since you are aware of yourself, conscious includes self-awareness but it is not of itself intelligence.

Cryogenic Relating to the production of very low temperatures.

Cybernetics The science of control systems for living beings and machinery. Derived from the Greek word *kubernētē*, governor, cybernetic means the control of the organism or machine from a self-correcting point of view. It was a precursor to artificial intelligence but today it is not generally considered a central construct of artificial intelligence.

Data Base A collection of data, usually stored in a computer, that intends to have its elements interrelated by one or more themes or relationships.

Data Sets Data stored so that rows and columns represent particular variables. As the term is used in this book, data sets usually means meaningful data relations, hitherto often unknown, which can be found in massive data bases.

Determinism The philosophy that all actions are the consequence of prior actions and that these relationships between current and prior actions can be described analytically.

Dopamine A neurotransmitter involved in regulating movement and emotion. Some think that an excess level of dopamine causes both attention deficit hyperactivity disorder (ADHD) and creativity. Geniuses may have high levels of dopamine.

fMRI Electromagnetic imaging brain scan used to plot the locations of mental activity in the brain under various experimental conditions.

Hippocampus A small structure found deep in the brain that is a key manager of the memory process. While the hippocampus is not unique to humans, it is considered helpful in advanced thinking processes such as sorting out what is novel. It is also a key brain component for managing spatial navigation.

Holism The idea that the system cannot be determined by its parts alone. The term is often used to mean approaching a complex problem from the top down--looking for patterns in all of the data and then developing an analytical model. *Reductionism* is posed as the opposite to holism and it maintains that a system can be determined by its component parts.

Intelligence Like consciousness, intelligence is a word that has no single definition and its meaning is often more fully defined by the context in which it is used. In this book, I use intelligence to mean the mental powers to learn, reason and act and, most importantly, to grasp relationships and meanings and to think abstractly.

Manic-depression Older term for what is today usually called bipolar disorder.

Neocortex an addition to the cortex called the neocortex. It is the outer layer of the upper hemisphere of the brain and consists of six layers. Its functions include sensory perception, the ability to learn with behavioral flexibility, motor commands, conscious thought and, in humans, language. In humans, the neocortex is 90% of the cerebral cortex up from a very minor percentage in simple mammals.

Neural Networks Used to describe brains and artificial minds in terms of wiring or neurons connecting various data or information nodes. See *connectionism* above.

Neuron A biological cell that is the fundamental storage and interconnection unit of the nervous system and brain. Neurons connect very rapidly with another with great precision through interconnection elements call synapses. The human brain has about 100 billion neurons and over a thousand synapses per neuron.

Prefrontal Cortex Located in the front of the brain, the prefrontal cortex is especially prominent in humans and is associated with planning, decision making, and higher level cognition.

Reductionism A philosophical position that a complex system is the sum of its parts. It is the basis of classical analytical science. The opposite of reductionism could be said to be *holism* described above.

Schizophrenia A psychotic disorder characterized by withdrawal from reality, illogical patterns of thinking, delusions, and hallucinations, and accompanied by other emotional, behavioral, or intellectual disturbances. Schizophrenia may be caused in part by dopamine imbalances in the brain. There has been conjectures of schizophrenia being a possible component of genius behavior.

Semantic Web Used in artificial intelligence theory, data base design, and search engine strategies. Connection nodes or words in networks or data bases are identified as words or other non-numerical descriptors. It is proposed to making the thinking and information search process more logical and efficient. See *connectionism* above.

Serotonin A neurotransmitter chemical in the brain involved with the regulation of mood states including depression, anxiety, perception and transmission of impulses between neurons. It has been speculated that serotonin has a role in creative thinking.

Social Media Media and tools for people to share information primarily by the Internet. Currently popular examples are Facebook and Twitter.

Turing Test A proposed test of the mathematician Alan Turing to demonstrate that a machine is intelligent. If a human cannot tell which responses from a human and from a machine to common inquiries and conversation are from the human or the machine, then the machine has passed the test and can be described as intelligent. This controversial test is widely encountered in artificial intelligence discussions.

Synapse Neurons connect very rapidly with another with great precision through interconnection elements call synapses. The human brain has about 100 billion neurons and over a thousand synapses per neuron. Synapses could be thought of like electrical relays or transistors, and their mechanism are chemical and electronic.

Wiki A collaborative website used as the basis for much collaborative intelligence and collective intelligence. The content on the wiki site can be added to or edited by anyone who has access to it much like an electronic community bulletin board. Wikis are usually focused on a particular topic such as pharmaceutical research and they can be public (accessible by anyone with access to the Internet) or private (limited to members of a company, agency or association).

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