Computer, MD

by

Joshua Feblowitz

B.A., History & Literature (2009)

Harvard University

Submitted to the Program in Writing and Humanistic Studies
In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Science Writing

at the

Massachusetts Institute of Technology

September 2010

Signature of Author.....
Graduate Program in Science Writing
May 15, 2010

Signature of Author.....
Alan Lightman
Professor of Science Writing
Thesis Supervisor

Signature of Author.....
Thomas Levenson
Professor of Science Writing
Director, Graduate Program in Science Writing

Computer, MD

by

Joshua Feblowitz

Submitted to the Department of Writing and Humanistic Studies
on May 15, 2010 in Partial Fulfillment of the
Requirements for the Degree of Master of Science in
Science Writing

ABSTRACT

Clinical decision support is an emerging type of healthcare information technology that aims to actively guide doctors' decision-making processes. In its various forms, it can help physicians design treatment regimens, regulate dosage, avoid potentially harmful drug interactions and allergies, order preventative screenings, and even establish a diagnosis.

This project is a journalistic investigation of this new technology, its applications, and its effect on the medical profession. It examines two decision support systems, Partners Healthcare's clinical reminder system, and Logical Images' product VisualDx, in order to explore the potential for these technologies and how their use may change the practice of medicine. Through extensive interviews of experts in medicine, healthcare IT, and healthcare policy, it considers the major problems in implementing decision support, with emphasis on how the technology may affect doctors' autonomy, and how physicians' financial and professional incentives may influence how it is used.

Thesis Supervisor: Alan Lightman
Title Professor of Science Writing

I. Introduction

A few blocks from Harvard Medical School stands an unremarkable office building sandwiched between an ice cream shop and a grocery store. Down the street is the cluster of world-renowned hospitals that make up Boston's Longwood Medical Area. However, here at 1 Brigham Circle, there are no operating rooms and no laboratories. No MRI machines or CT scanners. Yet here, in a modest office on the third floor, Dr. Adam Wright sits at his computer, slowly reshaping the world of medicine.

Wright is a biomedical informaticist, a man who deals in the science of medical data; he spends each day working on the electronic medical record system used by several hospitals in Boston. A computer scientist by training, Wright works for the department of general medicine at Brigham & Women's Hospital.

On screen is an electronic medical record. The patient is a 75-year-old man with diabetes and a host of other ailments. The patient has missed a number of lab tests and screenings as well as his recommended pneumonia and flu vaccines. In all, the record paints a picture of a person at risk and in poor health.

Normally, this situation would raise red flags. The man's diabetes is unmanaged and his health is in danger. Fortunately, however, this chart does not represent a real person. This test patient, full name Mr. BHWLMR MapleTest10, is a figment of the computer's imagination, created by Wright to test the system. Among Wright's other fictitious patients are Frodo, Santa Claus and many less whimsically named.

Today, Wright is not interested in treating this patient. In fact, in order to demonstrate one of the safety features of his system, Wright is going to try to kill him.

"Let's try something fun!" Wright says with a chuckle. "Let's give him two things we definitely shouldn't. We'll give him Viagra and nitroglycerin." Both Viagra and nitroglycerin cause blood vessels to open, or dilate (albeit in different parts of the body). By themselves, each drug is quite safe, but together their effects increase dramatically, dropping blood pressure to dangerously low levels.

From the speed at which he completes the first order, it's clear that Wright is intimately familiar with the system. At twenty-eight, he has already published a wide array of articles on healthcare information technology. In 2007, he received the first PhD in biomedical informatics ever awarded by his graduate school, the Oregon Health & Science University. He is friendly and energetic with short brown hair, a broad smile and an infectious laugh. He gestures emphatically as he speaks, waving his arms or slapping his desk to punctuate each statement.

In no time, Wright has prescribed the first drug and added it to Mr. MapleTest10's medication list. Yet as soon as Wright tries to prescribe the second medication, a bright orange warning fills the entire screen, preventing him from going any further.

The computer has automatically recognized the dangerous drug combination, instantly alerting Wright to his life-threatening "mistake." The warning screen offers three possible choices: discontinue the first drug, cancel the order for the second drug, or override the alert and prescribe both medicines to the patient. However, if Wright chooses to ignore the computer's warning, he must also provide a specific reason for doing so.

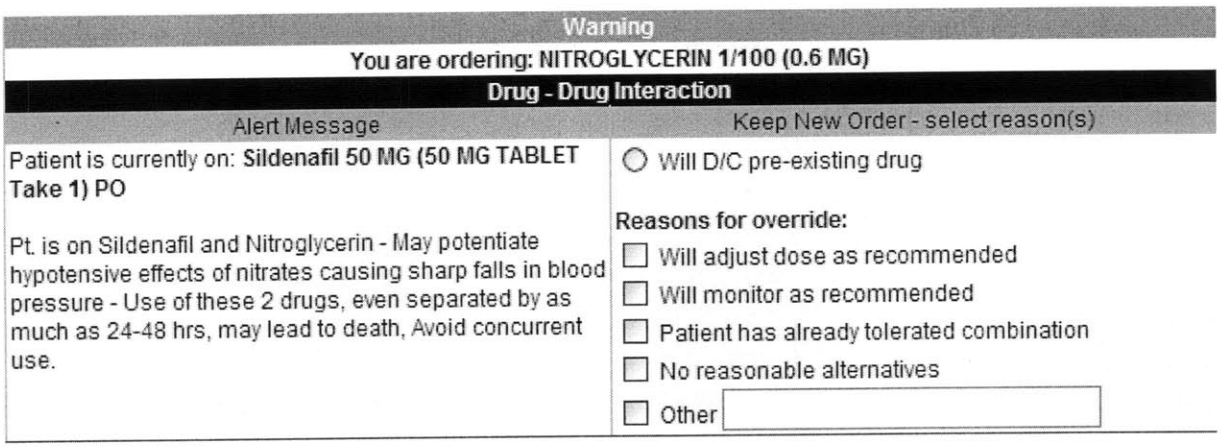

Figure 1: The drug-drug interaction alert for the combination of Viagra (Sildenafil) and Nitroglycerin.

This bright orange warning represents one of thousands of alerts that can be automatically and instantaneously triggered. As doctors enter information into each patient's medical record – allergies, illnesses, medications and test results – the computer cross-references this data with a vast set of rules and protocols compiled by Wright and his colleagues. A large staff of physicians, nurses and pharmacists work to update this content regularly, combing through the latest research to ensure that each warning reflects the best available medical evidence.

This simple warning system is one example of what is called clinical decision support, an emerging type of healthcare information technology that, some say, will change the practice of medicine and the delivery of healthcare.

Clinical decision support, often referred to simply as "CDS," is a type of computer system designed to assist physicians in the diagnosis and treatment of disease. Working in tandem with electronic medical records, decision support systems aim to reduce medical errors, shrink healthcare costs and ensure that all patients receive the best care possible.

Decision support is one kind of healthcare information technology and part of an industry that it is expected to top $54 billion by 2014. Recent years have seen dramatic growth in the

field, and the need for healthcare IT will only continue to expand as the population grows and ages. President Obama cites healthcare IT as a vital aspect of healthcare reform. Indeed, in a direct reference to these technologies, Obama pledged in his inauguration speech to help America "wield technology's wonders to raise health care's quality and lower its cost." Over the next several years, the stimulus bill, also known as the American Recovery & Reinvestment Act, will invest over $19 billion in healthcare IT through incentives given to physicians, clinics and hospitals. The US Department of Veterans Affairs already has one of the most sophisticated electronic systems in the country, and it has helped them to save $3 billion over the last decade.

Yet, healthcare information technology is still an industry in its infancy. Surveys show that only 20% of group physician practices use electronic health records. Only fifteen hospital systems in the entire country have been recognized by HIMSS, the Health Information Management Systems Society, for having fully integrated electronic medical records with decision support. Even Wright's employer, Partners Healthcare, a leader in many areas, hasn't achieved this level of technological integration. Overall, the United States lags significantly behind other countries in implementing healthcare IT and decision support, especially those with more integrated healthcare systems such as India and South Korea. However, over the next several years, the funding provided through the stimulus bill will likely increase the use of electronic records dramatically. Widespread use of these systems, often called EHRs, builds the foundation for more advanced applications of healthcare IT.

And that's where clinical decision support comes in.

Once health information is recorded and stored electronically, computers can begin to analyze this data in ways that are impossible when using paper charts. By pulling from the electronic databank, decision support works to bring key information to the forefront, prompting

physicians to order recommended tests and screenings and helping them to avoid mistakes. In its various forms, it can help doctors design treatment regimens, regulate dosage, and avoid potentially harmful drug interactions and allergies. It can remind them to order blood tests, X-rays and other screenings based on the patient's existing problems. It can even help them to establish a diagnosis.

The concept of clinical decision support is nothing new. Dr. Robert Ledley and Dr. Lee Lusted first presented the idea over fifty years ago in a paper in *Science*. In it, they propose a simple computer-based system for assisting physicians with diagnosis. Their version of decision support employed an analog card-sorting computer, with each individual card representing a diagnosis and a series of holes punched in the card to signify different symptoms. Using this system, physicians could match the patient's real-life symptoms to one or more cards in order to establish a diagnosis.

Although computers have grown far more sophisticated since the days of analog punch cards, the essential design of decision support systems is the same today. The programming that underlies Wright's decision support is quite simple: the software is "rules-based," meaning that every relationship, every warning and drug interaction, is entered manually. Like the holes punched in Ledley and Lusted's cards, rules, or "best practices," have to be decided upon in advance, discussed and debated by experts in the field. "It's brute force," says Wright, pulling up the staggeringly large spreadsheets that display all of the system's rules.

In addition to the drug interaction alerts and test and screening reminders, the system also includes various drug dosage calculators, Pedios, Gerios, and Nephros that automatically calculate the recommended drug dose for children, the elderly and patients with reduced kidney function. Each of these calculators pulls relevant information from the patient's medical record,

providing instant recommendations based on age, weight and other factors. The computer automatically determines the best dose and sets this as the default choice on the next screen.

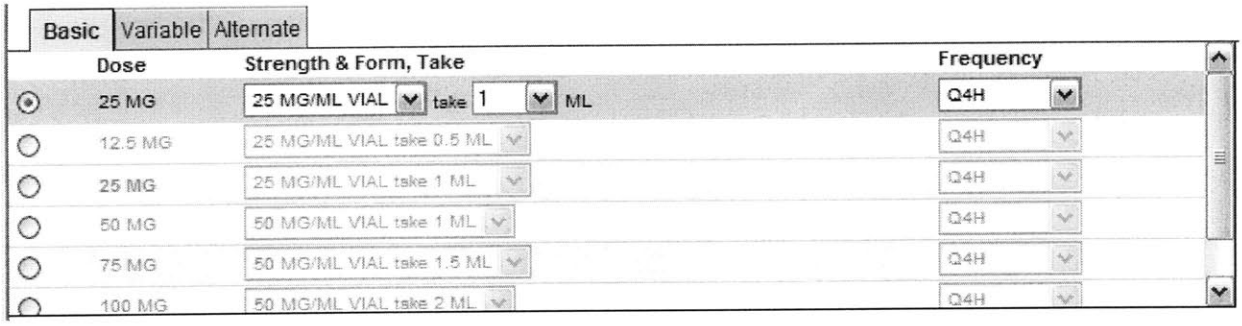

Figure 2: The basic drug dosage menu with the default dose highlighted at the top.

And the computer's talents don't stop there. The decision support software can check for drug allergies, recommend the best antibiotic and even choose drugs that will be more affordable for the patient. Instantaneously, the system scans through the patient's medical record, pulls out the relevant information and alerts the physician.

All this is part of the Partners' Longitudinal Medical Record or LMR. And all this happens with the click of a mouse, without the doctor needing to do anything.

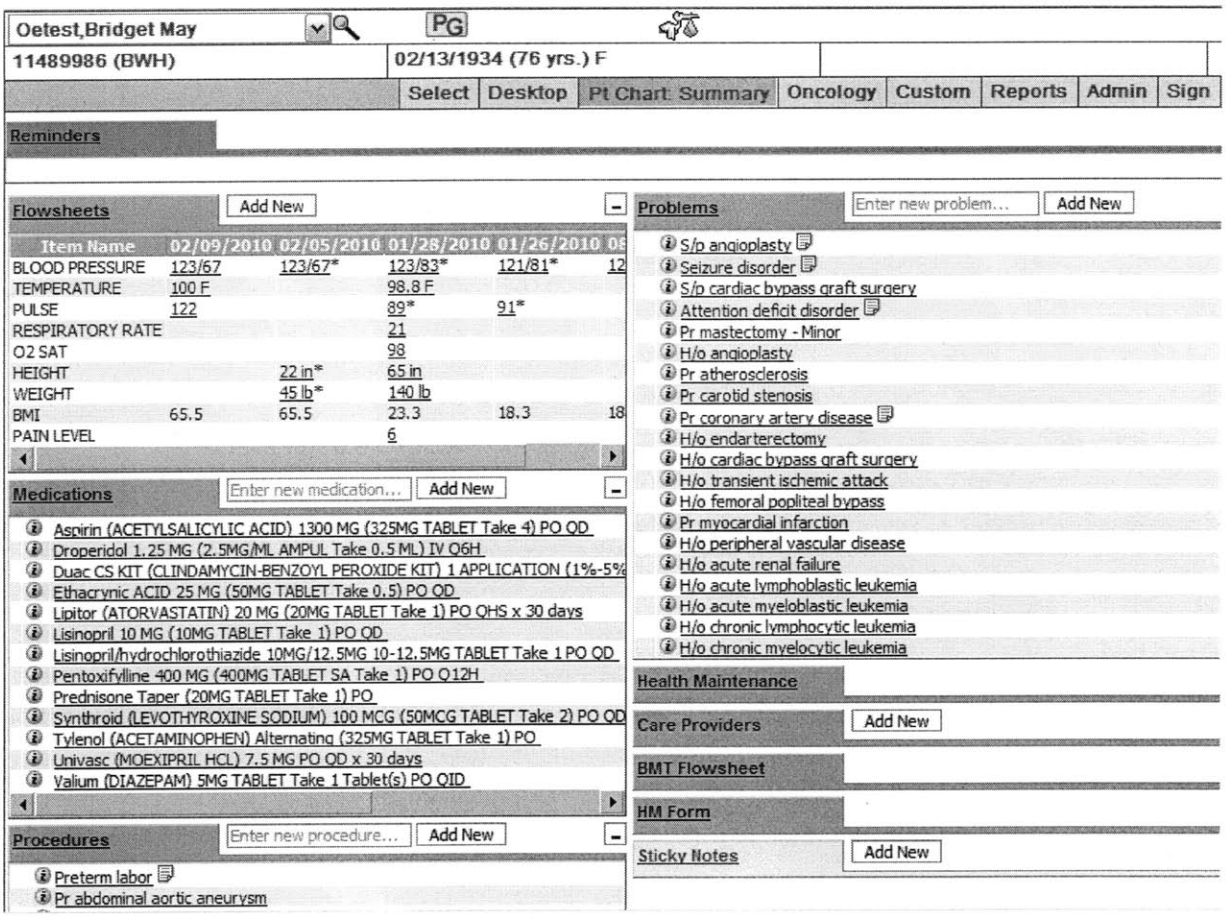

Figure 3: The Longitudinal Medical Record, LMR, with the patient's "problem list" on the right and reminder box at the top of the screen.

Often, these simple alerts can mean the difference between life and death. A missed drug allergy or interaction can result in an extended hospital stay and additional testing and treatment at great personal cost to the patient as well as significant financial cost to the healthcare system. In the landmark study, "To Err Is Human," published in 2000, the National Institute of Health found that as many as 98,000 patients die each year as the result of avoidable medical errors. Decision support, experts say, may prove effective in reducing the number of preventable errors each year.

Yet even more significant than the prevalence of medical errors is the simple fact that Americans aren't getting the care that they should be. Research has shown that, on average,

patients in the United States receive the best available care only about 50% of the time. In other words, much of currently available scientific knowledge is not being applied on a day-to-day basis. A study by the Commonwealth Fund found that inefficient or poor-quality medical care costs that nation $50-100 billion per year. For a variety of reasons, forgetfulness, out-of-date information, differences of opinion and insufficient time, doctors often fail to do what is best for their patients.

The most exciting aspect of decision support, says Wright, is it has the potential to reach a large number of physicians and provide them with new and better information, changing the very way that they practice. "Imagine you have an idea for how to treat a patient better and it's validated and you know it works," he says. "If you're just one doctor, really the best you can do is to treat your patients better. But this system gives you so much leverage. You can influence the behavior of hundreds or thousands of people in a way that could improve healthcare. That's what gets me out of bed in the morning. If I do a good job, I could help a lot of people, more than I could ever help one at a time. And that's really exciting."

Why, then, isn't everyone using clinical decision support?

II. Aye, There's the Rub

Of the more than 7,500 hospitals nationwide, only a handful has decision support systems as sophisticated as Wright's. "The number of patients that are treated where the providers are given reminders, where they have all the information, is vanishingly small, less than 2%," says Dr. Robert Kolodner, the Former National Coordinator for Healthcare IT under President Bush. This technology, it would seem, has incredible potential to save lives and save money. Yet, in the drive to make decision support more widely available, the roadblocks are numerous and, as a result, the technology hasn't yet taken off.

One major barrier to adoption is the fear that decision support is a vehicle for socialized medicine, that the protocols and reminders will be shaped not by medical experts but by bureaucrats interested in the bottom line. Conservatives have called clinical decision support "a euphemism for computers instructing doctors what to do," warning consumers that healthcare IT is simply a means of restricting care.

"Rationed care," healthcare services that are limited in availability based on cost, is a common charge levied against efforts to rein in healthcare spending. Patients understandably want the best medical care available and they, like their physicians, are wary of anything that seems to limit the availability of this care. Their concern is that decision support might be used to deny care, guiding physicians away from expensive treatments and restricting doctors' ability to provide the best care possible.

Wright argues that this view of decision support is a misperception, especially when it comes to the Partners system. "It's not the administration sitting in a room with their green eyeshades on, crunching numbers, coming up with clinical decision support," says Wright, who

works daily with physicians on his projects. At Partners Healthcare, doctors themselves determine content, and the informatics staff merely programs these rules into the computers. If a physician doesn't like a reminder or recommendation, chances are he or she knows the person responsible for implementing it, most often a leader in their field.

Beyond the issues of policy that decision support raises, acceptance within the medical community largely hinges on whether decision support can be made to fit into doctors' often-hectic professional lives. For all its potential, decision support, like other healthcare technologies, adds more tasks to the long list of physicians' responsibilities. For these systems to be effective, data must be input in the correct way, and this takes time.

Among those involved in decision support, one of the words you here almost constantly is "workflow." Workflow is the reason that you don't make pancakes and bacon on a weekday: you simply don't have the time. Instead you boil water for coffee, you pour yourself a bowl of Cheerios. These tasks fit more easily into a busy morning routine.

A physician's day is often chaotic. It involves frequent shifts in focus and changes of location as he or she visits patients, answers pages, makes phone calls, writes notes and fills out seemingly-endless paperwork. Just as only certain foods fit into your morning schedule, only certain technologies function well within a physician's workflow. If decision support is annoying, difficult to understand or complicated to use, in short, if it does not fit into the physician's workflow, it is useless. Informaticists spend day after day thinking about these issues and dreaming up new ways to make decision support as effortless as possible to use.

The way physicians are paid adds additional pressure to be efficient and productive, thus discouraging doctors from using any technology that takes up extra time. Today, the healthcare industry primarily uses a "fee-for-service" model, meaning that doctors get paid for what they

do, not how well they do it. Reimbursements are based on patient volume and procedures performed, not on the accuracy of diagnoses or the quality of care. Thus, there is always financial pressure for physicians to get through as many patients as possible, to *do* as much as possible. Likewise, patients have grown to equate better care with more care, since they don't pay for it directly and never know its true cost.

Yet, most physicians care deeply for their patients and take their professional responsibilities very seriously. They strive each day to deliver the best care possible and look out for the well being of their patients. Though this desire to help patients is a powerful factor, physicians must still earn a living and support their practices. As a result, they must often make fast and frugal decisions about how to care for their patients. These two conflicting motivations, financial versus professional, pull against one another constantly, complicating the decision-making process and making it harder to devote enough time to each patient.

Even if doctors were paid differently, even if decision support was made to fit seamlessly into their workflow, the most significant roadblock to adoption of decision support still lies within the medical profession itself, in which doctors must cede time and independence to this largely unproven technology and face questions that run to the core of their professional identity.

Doctors cherish their autonomy and they want to know that a computer won't be telling them how to go about their jobs as diagnosticians. They value flexibility and nuanced clinical judgment and are wary of anything that seems to replace these skills with a flowchart or checklist way of thinking. Dr. Jerome Groopman, author of *How Doctors Think*, has called clinical decision support and other protocol-based strategies "cookbook medicine" and has spoken vigorously against the push towards more standardized care. In an article in the Wall Street Journal, he writes:

> Medicine is an imperfect science, and its study is also imperfect. Information evolves and changes. Rather than rigidity, flexibility is appropriate in applying evidence from clinical trials. To that end, a good doctor exercises sound clinical judgment by consulting expert guidelines and assessing ongoing research, but then decides what is quality care for the individual patient. And what is best sometimes deviates from the norms.

Groopman's concern is that protocols, electronic or otherwise, will limit the role of the physician, allowing less of the flexibility that he sees as vitally important to the practice of good medicine. Moreover, some worry that the prevalence of computerized guidelines may make for less knowledgeable physicians, who rely on computerized systems for more and more of their clinical knowledge.

It would seem that for all the work put into these systems, the countless hours spent discussing rules, cataloguing them and programming each one, a larger question still looms: what will become of the art of medicine in the age of technology?

There are many skills that a computer cannot replicate, those of subtle observation, complex problem solving, and compassion, those that physicians strive over many years to master. The art of medicine requires attention to subtlety and tolerance of ambiguity, two things that computers aren't particularly good at. Yet, a computer can recall information with lightening speed and unfailing accuracy and it can provide support and instruction in times of uncertainty.

Can decision support be a partner without becoming a burden? Can it assist doctors without treading on their clinical judgment? For champions such as Wright, the answer is an unequivocal yes. For those currently practicing, however, the picture isn't quite as clear.

III. Because I'm the Doctor, And You're the Computer

"Medicine is itself an art," writes Dr. Therese Southgate in the *Journal of American Medicine*. "It is an art of doing, and if that is so it must employ the finest tools available – not just the finest in science and technology, but the finest in knowledge, skills and character of the physician." For most, the practice of medicine transcends hard science and textbook learning and enters into a realm of artistry and individual craftsmanship. How, then, could a computer program ever play a role in its practice?

Dr. Ann LaCasce is an Assistant Professor of Medicine at Harvard Medical School and a practicing hematologist-oncologist at Boston's Dana Farber Cancer Institute. She is a skilled teacher and a passionate advocate for her patients, most of whom suffer from forms of lymphoma and leukemia. On a daily basis, LaCasce uses the very same electronic medical record that Dr. Wright works on a few blocks away. But she uses it with caution and a certain amount of skepticism.

Like nearly all physicians, LaCasce has gone through the classic stages of training from medical school to residency to working professional. She began at Tufts Medical School, later completing a residency in Internal Medicine at Brigham and Women's Hospital before going on to fellowships in blood-borne cancers. These days, she works in the Gosman Infusion Clinic on the first floor of Dana Farber. She also supervises medical residents across the street at Brigham and Women's Hospital, where she helps them develop and hone their diagnostic skills.

Medicine, she says, is about generating a differential diagnosis, a list of all the possible diseases and disorders that could explain the patient's unique constellation of symptoms, physical findings and laboratory data. Once the doctor has a preliminary list, he or she goes

through every possibility, ruling them out one by one and prioritizing the most likely explanations.

Once a doctor enters the exam room, the formation of a differential diagnosis begins immediately. "One of the most important things that you learn," says LaCasce, "is, when you look at a patient as you walk in the room: are they sick or are they okay? And a computer program is not going to tell you that. You have to take a lot of different information and synthesize it and come up with your idea of whether they are really in trouble or not. And that is critical."

The differential begins with the patient's "chief complaint," the symptom that brought them to the doctor's in the first place. This might be something like chest pain or stomach cramps. Next comes the physical exam and history. The physician continues collecting information about the patient's problem through touch, sight, and sound while also listening to the patient's account of their illness, their "history." As this is going on, the physician is actively creating a mental list of possible diagnoses, refining it as he or she learns more. For example, an initial differential diagnosis for chest pain might include things like heart attack, heartburn, ulcers or a collapsed lung. This preliminary list then guides the doctor to ask additional questions and order relevant tests. The ability to rapidly collect and synthesize a wide array of clinical information is at the core of every physician's medical training.

But to think of the differential diagnosis as a puzzle to solve is somewhat misleading. Unlike those of television dramas, real-life medical mysteries do not wrap up neatly in the space of an hour. "A lot of people believe that medicine is very black and white," says LaCasce, "that it's about getting to an answer." In many cases, key information is missing or there are multiple

things going on at once, making it difficult or even impossible to come up with a unifying diagnosis.

This difficulty, says LaCasce, is one of the reasons that computers can only do so much. Medicine, she says, is not about crunching the numbers and coming up with a definitive solution; it's about making the patient better, which sometimes means acting on incomplete information and never knowing whether you made the best possible choice.

Alerts, protocols and guidelines, says LaCasce, are no substitute for the thoughtful, measured approach of the experienced physician. Whether using a computer with automated alerts or a simple paper set of clinical guidelines, LaCasce believes this rigid, flowchart-type approach falls short in providing the best quality care. With years of training and practice, doctors develop an intuitive sense of what information is relevant and an instinct for when and how to make difficult judgment calls. "I don't think you can replace the years of training and experience," says LaCasce. "You can't replace clinical judgment."

"You can tell I'm a bit of a skeptic," she says.

Despite these feelings about computer-aided treatment, LaCasce has no problem with the clinical reminders that often pop up on her computer screen. In fact, she can't imagine her day without the help of the LMR and its decision support. "There are so many great things embedded in this screen! I love it!" she says looking as if she might reach out and hug the computer monitor. "I think this enormously facilitates the care of the patient."

LaCasce, who has been practicing since 1996, uses the LMR every day to manage her patients' care. "To admit a patient back in the day," she says, "we'd have to wait for the paper chart to come up. Often times, you'd have to pour through document after document trying to

find the relevant information. Often times, parts were missing. Now, it's all in the computer. It is just so much more efficient."

LaCasce also knows that, regardless of the computer's recommendations, she always gets the final word on how to care for her patients. Almost all of the alerts in the LMR can be overridden, so the doctor remains in control of every decision. In fact, the only alerts in the system that cannot be bypassed are so-called "red alerts," level-I drug interactions that are so serious that the combinations should never be given. These kinds of "hard stops," as Wright calls them, are controversial. "Most places don't have any hard stops," says Wright. "Doctors are used to a lot of autonomy. It took a lot of convincing for doctors to let us put this hard stop in place. Essentially everything else can be overridden."

With the exception of these level-I alerts, doctors remain in the driver's seat. They can choose to ignore recommendations, dismiss alerts and proceed with whatever treatment they deem appropriate.

When prompted to provide a reason for overriding the alert, many physicians, says LaCasce, simply write, "will follow" (short for "will follow up") without any further explanation. "When I was an intern," she recalls, "one of my co-interns always used to write: 'because I'm the doctor and you're the computer.'"

Using Wright's decision support system, it would seem that doctors' professional autonomy remains intact. They can adapt treatment as they see fit, they can make judgment calls, they can retain the flexibility that Groopman values so highly. Yet as these systems become more sophisticated and their use more widespread, some physicians worry that decision support could dismantle the art of medicine, transforming it into a world of flowcharts and rigid protocols. LaCasce isn't concerned, so long as the systems still allow doctors the freedom to make their

own decisions. Yet underneath her colleague's sarcastic quip is an important assumption: the idea that doctors know best, that their clinical judgment is a genuine trump card over the recommendations of a computer.

However, as these systems begin to improve and spread and best practice guidelines become more standardized, this may not always be the case.

IV. Craft or Profession?

When you bake a batch of cookies, you might cook from a recipe or mix the batch from memory. In doing so, it's your prerogative to add, subtract and substitute ingredients as you see fit (chocolate chips, nuts, oatmeal, butter, margarine, oil, etc.). The only risk in experimentation is that you might end up with a bad batch.

When it comes to cookies, the stakes are low.

Yet in medicine, the stakes could not be higher. As a physician, the quality of care delivered can determine whether someone gets better or even if they live or die. So how closely must a physician follow each "recipe" for treatment? Who is responsible for formulating these guidelines? When is it right to play things by the book, and when is it right to make revisions based on clinical judgment?

These questions, says Wright, get at the core nature of medicine. "It's an issue that people have fought about academically for a long time, in theoretical terms," he says. "Decision support, however, is where the rubber meets the road because the computer can't as easily tolerate variation."

Clinical decision support is a type of evidence-based medicine. The concept behind evidence-based medicine is simple: all medical treatment, from diagnostic tests to preventative screenings to drug prescriptions, should be based on the newest and best available scientific data. As much as possible, experts should try to identify agreed-upon standards of care, the "best" way of treating a particular disease. Decision support is about bringing this best-practice knowledge to the forefront through reminders, warnings and other means. But what does this mean for the individual physicians, their clinical judgment and their professional autonomy?

"People talk sometimes about whether medicine is a craft or a profession," Wright continues. "A profession often has a particular style of dress; doctors wear lab coats and chefs wear hats. But one of the ideas of a profession versus a craft is substitutability. If you hire an electrician and then you fire that electrician and bring another one in, they would do roughly the same thing. As electricians, there's a way of doing things, although they may have their own flavor. Like all chefs agree that you should cook poultry to a 160 degrees but there may be some different way to spice it. I think with medicine we've often approached it as a craft. It's a free-for-all and people can do what they want. I think there's more and more thinking about it as a profession where there's some standard ways to approach it."

For example, says Wright, chronic gallstones are often treated by removing the gallbladder in a procedure known as a cholecystectomy. It's widely agreed upon that in most cases using a laparoscopic approach, in which surgery is done using tiny cameras and instruments inserted through very small incisions, is preferable to an open approach, which uses a much larger incision. Evidence has shown that a laparoscopic surgery leads to a much shorter recovery time and lower rates of complications. Given that fact, is it acceptable or even moral to allow a surgeon to perform open cholecystectomies out of preference? This is where evidence-based medicine comes into play.

It is this tension between best practices and clinical judgment that makes decision support controversial. "The care of patients is complex," writes Jerome Groopman in the *New York Review of Books*, "and choices about treatments involve difficult tradeoffs. That the uncertainties can be erased by mandates from experts is a misconceived panacea."

Furthermore, says Groopman, decision support systems don't solve the problem of improving the quality of care. "With these cookbook-type recipes for diagnosis and treatment,"

he says, "the risk is that it's garbage in, garbage out. They're only as good as the physician who is identifying what the key symptom or key finding is about that patient." In other words, it still takes a skilled, experienced clinician to input the data and interpret the information that decision support provides.

It is for this reason, says Dr. Blackford Middleton, the head of Partners Clinical Informatics Research & Development group and a colleague of Dr. Wright, that doctors should regard decision support as a helpful tool rather than a substitute for clinical judgment. "Just like the stethoscope augments our ability to listen to the heart and detect heart tones and murmurs," he says, "the idea with clinical decision support is that it's a cognitive aid and perhaps even cognitive augmentation. You're able to think and remember and synthesize things in a manner that you couldn't do with the unaided mind."

Middleton likens the role of decision support in medicine to that of the calculator in a math classroom. "The debate back then," he says, "was that kids shouldn't have calculators because they'll take away their ability to do arithmetic. Well, of course that's not true. And, furthermore, I think our experience shows at least with that simple technology that it allows kids to focus on the math rather than the arithmetic."

Despite their merits, decision support systems, in their current form, can't synthesize information in a way that even comes close to approaching sound clinical judgment. They cannot reason through ambiguous or confusing situations, they cannot make difficult judgment calls.

However, they can, as Middleton argues, augment physicians reasoning, calling their attention to important information and reminding them of all options and possibilities. Computers could never replace the physician, but they do have a spectacular memory. And that, experts say, is where decision support can help.

V. The Non-Perfectibility of Man

When Dr. Barry Chaiken gives a talk on decision support, he begins with a simple analogy.

"How many of you," he asks, "drive to work?"

Almost everyone in the audience usually raises his or her hand.

"Of all the times you've driven to work," he continues, "have you ever gotten off on the wrong exit on the highway?"

Many nod.

"You don't know where you work?" he says with a wry smile, "you don't know how to get there? Are you stupid?"

Of course not, says Chaiken, you're human and you get distracted. "There's no reason to expect that physicians are any different."

Decision support, says Chaiken, is a way to take the fallibility of human memory out of the equation. "If we can do something to remove that human element, particularly around recall, we can be better in treating patients. The average human being is terrible at recall. I don't want to rely on somebody's recall. We all have a bad day."

Dr. Barry Chaiken is the chair of the Health Information Management Systems Society, an organization of over 20,000 health and IT professionals from around the world, and Chief Medical Officer at DocsNetwork, Ltd, a healthcare consulting firm. He believes deeply in the potential of decision support to change modern healthcare, referring frequently to a fast-approaching "HIT revolution." Chaiken is a man of average height with sandy brown hair and a ruddy complexion. The force of his personality, however, makes him seem much more imposing. He is a man of great intensity in all aspects of his life: he loves wine, so he purchased a vineyard

in Argentina; he enjoys biking, so he completed the 193-mile Pan Mass Challenge twenty-five separate times to raise money for the Dana-Farber Cancer Institute. He has both a tremendous passion for the field of informatics and a pragmatic view of the hurdles that must be overcome.

Decision support, says Chaiken, will never replace doctors, but it does have the potential to shift the emphasis of medical training away from memorization. "Medical knowledge is so vast," says Chaiken, who trained as a physician before entering the healthcare IT industry, "it's a fool that thinks that a individual human being could know it all. It's impossible. What the individual physician has to do is be able to process the information that clinical decision support provides them and then make good choices. The skill is in the integration of the knowledge. The skill is not in the recall. The computer can recall."

Some have even suggested that decision support might allow some basic care to be handled by other health professionals, lightening physician caseload and using resources in a more efficient manner. "A lot of medicine still requires some superb diagnosticians, but an awful lot of it is becoming more routine," says Dr. Kolodner. "We understand it, we can predict it. We know what interventions will work." If done correctly, he says, much of this routine care can be assigned to nurses and physicians assistants or even performed by patients themselves.

Experts such as Chaiken believe decision support will allow doctors to shift their focus away from recall and towards diagnosis and treatment, integrating medical knowledge into their workflow far more fluidly that a textbook ever could.

But what if the idea could be taken even further? What if decision support actually helped physicians make diagnoses? Could it be effectively done and, even if it could, would physicians use these tools? These are questions that have been explored since the birth of decision support, ones that even the most brilliant informaticists continue to investigate to this day.

V. The Lone GP

"This is lupus!" Dr. Art Papier shouts, thrusting his iPhone out emphatically. "A picture's worth a thousand words."

On screen is a photograph of the butterfly-shaped rash often seen on the faces of patients with lupus erythematosus, an inflammatory autoimmune disease that can cause severe arthritis and a host of other problems. It took Papier only a few seconds to pull up the image.

Dr. Art Papier is an Associate Professor of Dermatology and Medical Informatics at the University of Rochester and co-founder and Chief Scientific Officer of Logical Images, the company that created this software. A dermatologist by training, he spends one day each week seeing patients in a university clinic and training residents and medical students. The rest of his week, however, is spent at his office, tucked away on the second floor of a shopping plaza outside the city, between Maynard's Electrical Supply Incorporated and Dell's House of Kitchens. Inside, the walls are decorated with stunning photographs, culled from Dr. Papier's massive collection of medical images.

At Logical Images, Papier and his staff work to design and market their flagship product, VisualDx, a dermatological decision support system. First released in 2001, the software is now licensed to over 1,000 different locations across the country including hospitals, government organizations, community health clinics, insurance companies and medical schools. The system logged over 10 million views last year alone. The goal at Logical Images, according to Papier, is nothing short of teaching physicians a new way of thinking.

If clinical decision support is about making medical information more readily accessible, then VisualDx Mobile fits the bill perfectly. The web-based decision support program can be installed on any iPhone or Droid and used by physicians without the hassle of sitting down at a

computer. Superficially, it looks similar to health information websites like WebMD. The underlying program, VisualDx can also be accessed through any web browser.

This system, however, is much different from Dr. Wright's LMR. VisualDx doesn't remind doctors to run tests, it doesn't alert them of allergies and drug interactions. Instead, VisualDx is designed to help them create a differential diagnosis, designed to supplement clinical judgment.

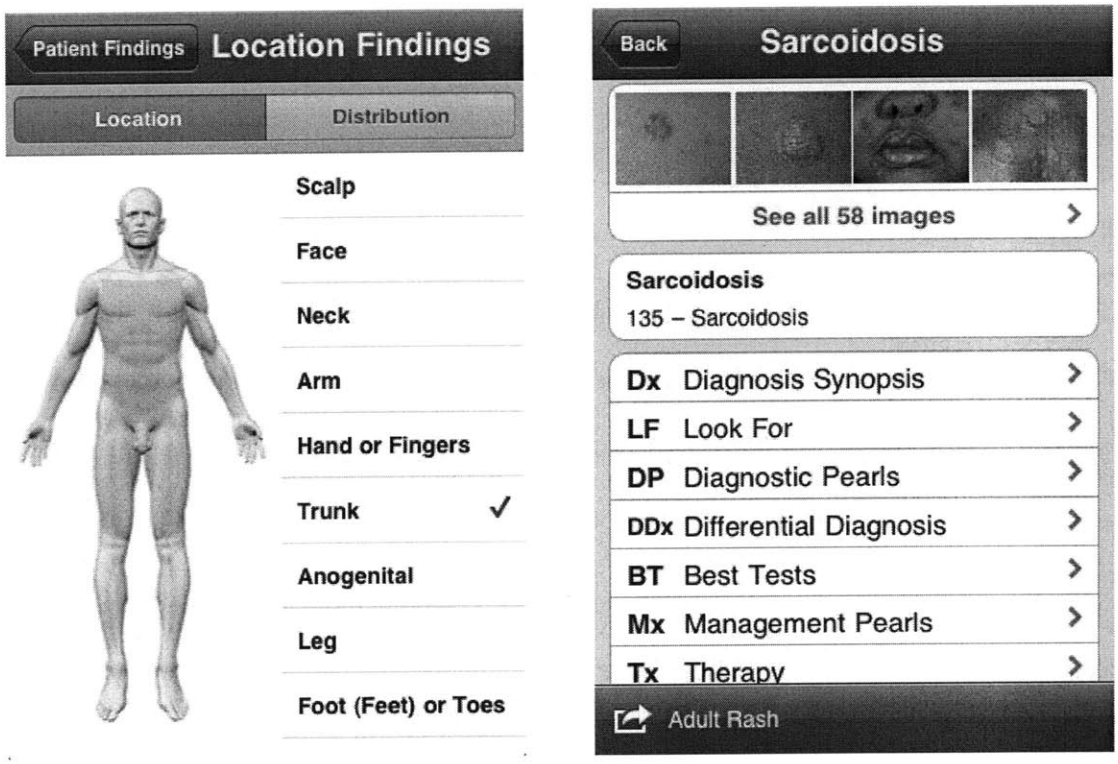

Figure 5: Screenshots of VisualDx mobile for iPhone and Droid.

The idea behind VisualDx has been around since the days of Ledley and Lusted. This particular category of CDS is known as *diagnostic* decision support, those systems that go beyond reminders and try to actively assist physicians as they form a differential diagnosis. Since the very first system in 1959, there have been numerous attempts to build a computer program that would be both accurate in identifying possible diagnoses and useful to the average

physician. One such software, DXplain was first developed at Massachusetts General Hospital in 1984 and is still in use today. Over the course of 18 years, doctors and computer scientists have revised and expanded the system to include over 2,300 diseases from every corner of internal medicine. Yet for some reason, these types of system have never caught on. DXplain is still sold today, yet the software is used infrequently where it is available and is often buried among all the other electronic resources available.

The reason, says Papier, that most diagnostic systems haven't been very successful is that doctors don't feel that they need them. "Everyone wants to perceive themselves as a great diagnostician." Polling has found that, by a large majority, physicians insist that they follow evidence-based guidelines most or all of the time, even as other research has revealed that patient's do not get the recommended treatment at least 50% of the time. "There's lots of variation in the willingness to admit uncertainty," agrees one of Papier's residents, Dr. Nananamibia Smith. In short, when it comes to diagnosis, doctors are bad at determining when they need help.

VisualDx, says Papier, is different because it addresses a particular problem that physicians have: the difficulty in accurately identifying the varied visual patterns that can appear on the skin. The program contains a database of dermatological images to help physicians diagnose rashes, reactions, and other disorders. The program is designed to replace other references, such as traditional textbooks and electronic atlases, instead mimicking the way doctors hone in on a differential diagnosis.

The VisualDx database is divided into several "modules," each covering a specific patient type or disease category. Physicians can input visual findings, body location and other relevant symptoms, and the VisualDx system provides them with a differential diagnosis as well

as full-color images, literature on the potential diagnoses and possible treatment options. The database contains over 18,000 digital images and covers over 1,000 medical diagnoses. The software is designed to help physicians make more accurate diagnoses, which, research has shown, are incorrect about 15-20% of the time.

Medicine, says Papier, must move towards incorporating computers into doctor's regular thought-process, not just as record keepers or even for clinical reminders. "Medical education," he says, "is based around the idea of getting students to learn prototypical or 'classic' cases and then to go out in the real world and generalize from those prototypical cases." Instead, Papier believes that physicians-in-training need a system that can accurately represent the incredible amount of variation that exists in human disease. Ultimately, medical students and residents should be tested, argues Papier, not on their ability to recall facts but on their ability to access information and use it to make appropriate care decisions.

"What we're really trying to do is change the entire paradigm."

For Papier, the most important elements of medicine are the common diagnoses that are often missed, the prevalent diseases that are mismanaged, or, as he calls them, "the boring stories."

In medicine, there is a common expression when it comes to diagnosing a patient: "when you hear hoof beats, think horses, not zebras," meaning that the simplest explanation is most often the correct one. Rare diagnoses, like those of *House, MD,* are, by definition, uncommon.

The challenge, says Papier, is not in brilliantly diagnosing rare disorders, but in consistently diagnosing common diseases that can appear differently based on sex, age, skin-tone or even just random variation. This natural variability, says Papier, is a normal part of human

disease, yet it makes diagnosis especially difficult for general practitioners, who have to treat every manner of disease and their variants on a tight schedule and often with limited resources.

"What happens when you have a generalist who has to know orthopedics, cardiology, psychiatry, dermatology, ophthalmology, a little bit of everything and they don't have experience seeing everything?" asks Papier, "They memorize the common things. They are taught the classic examples." This problem not only results in misdiagnosis, says Papier, it also means that general practitioners need to refer their patients to specialists, delaying diagnosis and treatment and costing the healthcare system money.

Far from diluting the physician's autonomy, Papier believes that diagnostic decision support will reinvigorate the practice of medicine. "Ironically, it's high technology only in the sense that you're using a computer," says Papier. "It's low technology in the sense that it's bringing back the art of medicine. It's bringing back the art of diagnosis."

The idea that decision support restricts the doctor's choices, says Papier, is a complete misperception. "Using these systems is not cookbook medicine and does not make your job easier, it makes it more difficult," argues Papier. "Instead of memorizing the most common diseases and then algorithmically, out of your brain, ordering what you know, it challenges you to make decisions about a broader differential diagnosis. Now you have to spend more time thinking."

Papier has a number of stories that he loves to tell about how VisualDx helped real general practitioners make a tricky diagnosis without the help of specialists. In Sioux Falls, South Dakota, he recounts, a patient came in one day to see Dr. Robin Meyers, a general practitioner, with an unusual itchy rash. The woman, who had emigrated from Africa, had been previously been evaluated and treated by two other primary care physicians and a dermatologist.

Doctors had prescribed various steroid creams to no avail. Yet Meyers is a general practitioner, not a dermatologist. How likely was it that she, given her already tight schedule, would be able to figure out what was wrong with the patient?

With very little time to meet with the woman, let alone to make a diagnosis, Meyers opened the VisualDx system on her office computer and entered the woman's primary symptom, a non-itchy rash, and also entered that the patient had recently traveled to Africa. In seconds, images matching these symptoms popped up onto the screen. At the top, along with psoriasis and dermatitis, was another diagnosis that even seasoned dermatologists hadn't considered: syphilis.

Using VisualDx, Meyers did some further reading on the disease and decided to order the necessary blood test. Sure enough, the patient's test came back positive for syphilis, a sexually transmitted disease that is many times more prevalent in Africa than in the United States. The woman's rash indicated that she was in the secondary stage of the disease.

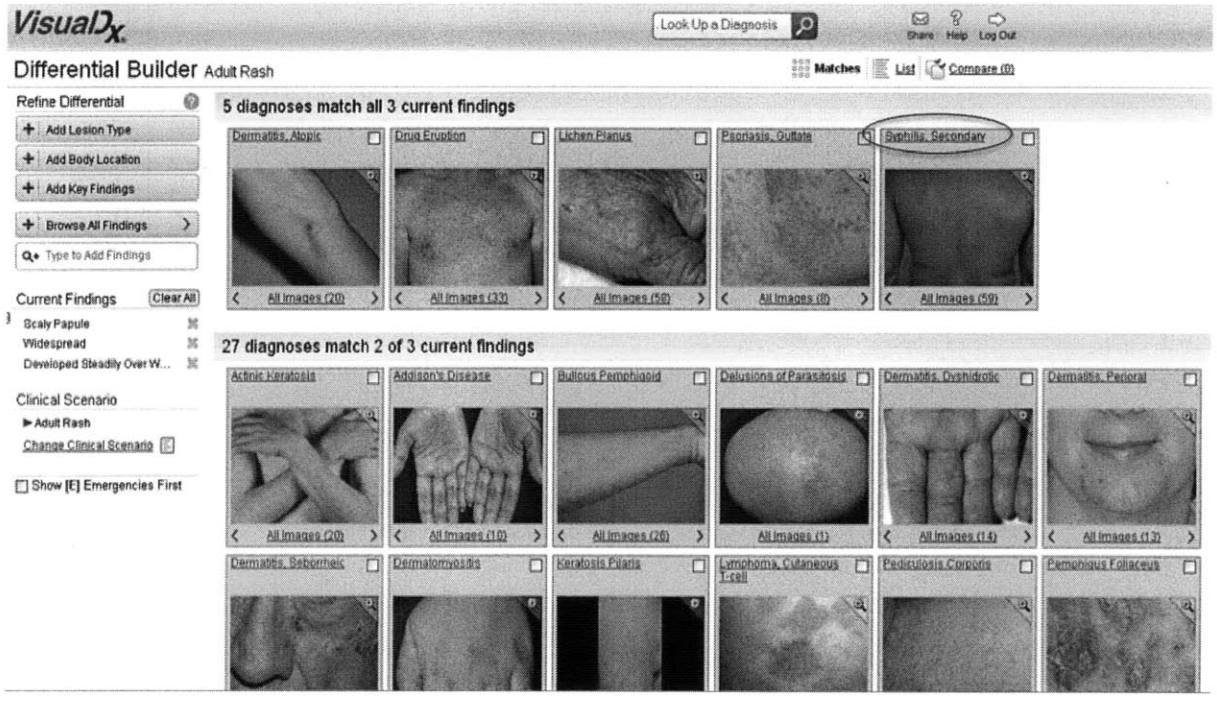

Figure 5: The VisualDx "differential diagnosis" function showing secondary syphilis as a possible diagnosis.

Although she almost never sees advanced cases of syphilis, Meyers was able to quickly and accurately diagnose the woman's illness, notify the Health Department and begin treatment. Without the software, Meyers would have likely referred the woman back to a dermatologist; instead, she uncovered a serious condition and prescribed the necessary antibiotics to cure her patient.

Meyers' story is a dramatic and satisfying one. A doctor was helped through a difficult problem, a patient was saved further illness, uncertainty and expense. But how often does this actually occur?

Even with all the effort to make VisualDx user-friendly and fast, many physicians still treat it as a traditional reference, rather than using the sophisticated differential diagnosis tool to solve a case. Moreover, stories like Meyers' are relatively rare; it's not often that VisualDx is responsible for a dramatic "aha!" moment of diagnosis. One reason is that diagnostic decision support systems like Papier's are even rarer than Wright's clinical reminders. Like Wright's system, diagnostic decision support software is expensive to build and maintain. Another reason for this, however, stems from the way physicians tend to use Papier's decision support, how they integrate it into their workflow.

At the nearby Highland Hospital in Rochester, Dr. Bilal Ahmed uses VisualDx to teach students and for assistance with some cases. Ahmed is a skilled and experienced physician and has no qualms about using new technology. He can often be seen searching for medical photographs on Google Images in order to corroborate a diagnosis. Yet he also believes very strongly in the value of a detailed patient history, of making the diagnosis not through myriad lab tests but through a careful physical examination and thoughtfully constructed differential diagnosis.

During rounds one morning at the hospital, Ahmed discusses a case of stasis dermatitis with his residents. Stasis dermatitis is a condition that develops when blood backs up in leg veins due to faulty vein valves. This, in turn, causes inflammation and an ugly-looking rash, which Ahmed points out on the patient's lower legs. General practitioners and emergency room doctors often mistake stasis dermatitis for cellulitis, he says, a much more serious condition that requires hospitalization and intravenous antibiotics. Thus, it is important, both for the patient and for cost savings, to make an accurate distinction between the two conditions.

In the exam room, Ahmed pulls up VisualDx on the computer screen, inviting a resident to step forward and use the software. The doctor who uses it seems unsure of himself, like he's never seen it before. He punches the diagnosis into the reference side of the program, rather than using the differential diagnosis function.

After reviewing pictures of stasis dermatitis, Ahmed attempts to demonstrate the differential diagnosis function for his residents. However, there are nine doctors in the crowded room, all impatient to get on with their duties. The Internet is slow. As a result, when Ahmed tries to launch the diagnosis application, nothing happens. So he snaps the computer shut and ends rounds for the day.

Ahmed has twenty patients to see today. He has only seen two and it is noon already.

Ahmed doesn't often use VisualDx for assistance with diagnosis and the truth is, most of the time, he doesn't need it. In almost all cases that he does employ the software, Ahmed admits that he uses it primarily to "confirm what I already know." He sees its value more as a teaching tool, something that experienced physicians don't need to rely on. The reality is that there was little time in this busy hospital to use even the most streamlined of software to assist with the diagnosis.

There was only time for the quick impression, the rapid and skillful assessment that physicians develop over many years of training. That skill that lies somewhere between art and science.

Even if VisualDx fit seamlessly into Ahmed's workflow, even if was perfectly easy to use, accurate and fast, could it truly augment his diagnostic skills? For all Papier's ingenuity, the programming behind VisualDx is quite simple. Like Wright's clinical reminders, VisualDx relies on the same rules-based reasoning. The program takes all of the symptoms that have been entered and displays a list of possible diagnosis that contains the maximum number of matching symptoms. The computer is not reasoning, it is not weighing probabilities, it is not crafting its assessment on anything other than the physician's inputs.

To be sure, VisualDx is a valuable tool, one that forces doctors to consider new possibilities and helps them refine their differential diagnosis. However, it's questionable whether decision support could ever do more than that, could ever begin to approach the way a physician thinks. The reason for this lies in the incredible complexity of medical diagnosis. As more variables are built into diagnostic decision support, the problem rapidly becomes more and more difficult for the computer to solve. Of those who program diagnostic decision support, software, some believe that diagnostic decision-making belongs to a category of problems known in the computer sciences as "NP-complete," ones that are difficult or even impossible to solve in a reasonable amount of time using any known computer algorithms. Even if you had the fastest computer available, it still might take more than a human lifetime to find a solution.

Decision support systems can also be fooled. One situation in which this can happen, explains Dr. Mitchell Feldman, is when a patient suffers from more than one disease. Feldman, a pediatrician at Massachusetts General Hospital, is one of the physicians who works on DXplain,

a diagnostic decision support system created there in 1984. In many patients, especially older adults, says Feldman, it is not uncommon to have multiple problems going on at once, or "overlapping syndromes."

For example, says Feldman, in a patient with hepatitis, a disease of the liver, and hypothyroidism, a condition that affects the thyroid, the system misses the correct diagnosis. Pulling up the web-based DXplain system, Feldman plugs in a mix of symptoms that point to both diseases: right upper quadrant abdominal pain, weakness, joint pain, lethargy, fatigue, low blood pressure, high fever and jaundice.

Feldman knows the likelihood of these two conditions occurring together, but DXplain can't navigate the situation, can't tease out two sets of symptoms the way a physician would. Instead, what happens is "all the hepatitis diagnoses come way up on the list, because some of those terms are very important for hepatitis and are strongly suggestive of hepatitis," says Feldman. "But, interestingly, the weakness, the joint pain, the tiredness, the fatigue, the low blood pressure, all of those are supportive of hypothyroidism. Despite all those findings being known to be part of hypothyroidism, it still is the 93rd disease out of the top 100."

These systems, says Feldman, are reliant on the information that physicians input. "All computer programming is made-made. There aren't computer programs yet that can correct themselves," he says. If a physician doesn't understand the significance of the information he or she is entering, then the system can do them little good. An example of this, says Feldman, is how DXplain can fail to properly identify cases of dengue fever, a virus that occurs in tropical regions of the world. The condition causes a high fever, headache, joint pain, and a rash. Yet, all of these symptoms are very non-specific, meaning that they are associated with all sorts of different diseases like the flu and the common cold. One of the most significant findings,

however, is whether a patient has recently traveled to a tropical area. If a physician doesn't think to enter this information, then dengue fever doesn't even come up in the top 100 possibilities.

"Of course you can't expect a system to be a mind-reader," says Feldman. "Physicians are always going to know more about the patient than a computer system is going to be able to figure out, nuanced things." The irony of decision support is that the software can only reason from the information that the physician inputs; if some important findings are missed by the physician, then they are likewise missed by the computer system, or, as Groopman puts it: "it's garbage in, garbage out."

Despite these limitations, diagnostic decision support could be a very valuable resource, if doctors can learn when and how to use it best. Though computers may never be able to accurately replicate the complex reasoning that goes on in a physician's mind, Papier and Feldman hope to prove that they can offer a helping hand that goes beyond simple reminders. Systems like Visual DX and DXplain face the same hurdles as any other decision support software with the added challenging of convincing physicians of the necessity of a program that aids in diagnosis. Moreover, the barriers to widespread use of decision support are substantial and before this technology can do anything significant for society, these problems must first be addressed.

VI. Stumbling Blocks

"To be sure, we need innovation to expand our knowledge and therapies," writes Atul Gawande in his book *Better: A Surgeon's Notes on Performance*, "But we have not effectively used the abilities science has already given us. And we have not made remotely adequate efforts to change that."

Decision support is one way to work towards this goal, one way to ensure that the best available medical knowledge is used as much as possible.

There is a great deal of debate over how to fix American healthcare, but there is little doubt that the country is on an unsustainable path. By 2025, healthcare costs will reach 25% of the national gross domestic product. And, despite the incredible expense of modern healthcare, outcomes are not improving. The United States continues to rank near the bottom of industrialized countries in life expectancy, adult and infant mortality and preventable deaths.

There are many, including the likes of Wright, Papier and Chaiken, who believe very strongly in the power of healthcare information technology to alter this path. As David Blumenthal, the current National Coordinator for Healthcare IT, writes, "Information is the lifeblood of modern medicine. Health information technology is destined to be its circulatory system."

Decision support, experts say, holds great promise in terms of improving both the cost and quality of healthcare. "If we are able to embrace clinical decision support," says Chaiken, "we can ensure that people are getting the best care, that procedures and tests are not being repeated or being given that are unnecessary, wasteful or unhelpful, and the treatments that we decide to give to people are the best possible."

Decision supports will enable us, he says, to work towards improving outcomes, reducing illness and death, and increasing efficiency, which are all tied together. "Good quality care isn't expensive," says Chaiken. "Good quality care is getting value for the resources you are expending to achieve that outcome. What's expensive is poor quality care."

However, identifying the potential of these technologies and actually realizing their widespread use are two very different tasks. One of the biggest challenges beyond developing decision support, say experts, is getting it to the right places, rural areas and small practices where specialists aren't immediately available, and where general practitioners are overburdened and can't possible remain up-to-date on all the diseases that they treat.

Decision support, especially diagnostic decision support, is most useful for those physicians with less specialized training, a lesser ability to refer to specialists, or fewer colleagues with whom to consult. In short, decision support is most beneficial for general practitioners working alone or in small-group practices who are trying to treat every manner of medical issue on a tight schedule.

However, the ability to provide these physicians with decision support technologies remains much more elusive.

The problem in delivering these tools is two-fold. For private companies, such as Logical Images, who make and market decision support for a profit, it is only natural that they seek out higher paying clients such as hospitals. Indeed, despite Papier's desire to reach out to small-practice general practitioners, approximately 80% of the over 1,000 VisualDx licenses are purchased by hospitals. It is simply easier and more profitable to sell to large multi-specialty institutions where the products aren't needed as much.

Decision support developed by hospitals themselves poses the same problem, albeit for different reasons. Only at well-funded urban teaching hospitals is it feasible to construct these types of systems. Massive rules-based decision support requires substantial resources and a staff of trained informaticists, as is the case at Partners Healthcare. However, the average practice in Massachusetts, for example, has only three physicians. There's hardly room in their budgets for a brand new computer, let alone a staff of IT personnel.

Perhaps the biggest problem of all, however, is that doctors won't reap significant benefits from installing these decision support systems, which are often expensive to implement and maintain. Even if decision support helps physicians to increase efficiency and improve outcomes, these benefits go to the patient and the insurance company in the form of better health and lower healthcare costs. To be sure, most physicians want to do everything possible to deliver quality care to their patients, but for many, especially those running their own practices, there are few incentives to purchase these systems other than this desire to help their patients.

The current "fee-for-service" model is hardly a strategy that will encourage measured deliberation and the acceptance of new tasks into the doctor's workflow. It is doubtful that clinical decision support will have a dramatic impact if doctors don't have additional motivation to focus on the quality of care and diagnostic accuracy. "Right now the payment system pays for doing things," says Kolodner. "It's absolutely natural for those who are providing care to have a tendency to do more things because they get more payments. Unless you change that incentive system, you're still not going to solve the problem."

Even if these roadblocks can be removed, issues remain that run to the core of doctors' professional identity. In order for decision support to be effective, experts agree that we will have to accept a new way of thinking about the practice of medicine. We have come to a place

where it's no longer possible for a single human mind to keep pace with the field of medicine, a place where it would be irresponsible to build healthcare on the foundation of imperfect human memory. We must, they argue, shift away from a system that relies heavily on human recall to ensure best practices are used. We must adjust the way in which we train physicians. We must trust computers to remember things for us.

With renewed focus on healthcare reform and the substantial funding made available through the American Recovery and Reinvestment Act, decision support will likely become much more widespread over the next decade, and these issues will become more and more prominent. At this point, even experts are unsure what the result will be. Decision support is still a field in its infancy, yet one that has great potential to improve healthcare in America and around the world. The Clinical Informatics Research and Development group at Partners has estimated that universal electronic medical records with decision support could potentially save the country over $44 billion per year.

"I am so curious what's going to happen," says Wright. "I can see it being anywhere from a panacea, we've achieved so much to we spent all $19 billion and everybody has a computer but they are mad about it, they're not using it, they turn all the decision support off, and it's just kind of a doorstop."

In large part, the success or failure of decision support depends on whether it can become a part of doctors' day-to-day care of their patients. Only thoughtfully designed and highly streamlined systems can ever find a place in doctor's busy schedules, let alone begin to enhance the quality of care that they deliver. Only those systems that contain the best-available research will be accepted by physicians. And only through careful study, trial-and-error and the ingenuity

of experts such as Wright, Papier and Chaiken will decision support be able to realize its full potential and transform American healthcare.

"It's an exciting time to be in this field," says Wright, "because those in the field have some obligation to try and steer the ship in the right direction."

Yet as we move towards more standardized care, difficult questions remain. Will decision support take something away from doctors or will it make them something more? How will the profession evolve to incorporate computers into the practice of medicine, into the very heart of medical decision-making? How can we give physicians incentive to do better diagnosis, rather than just more diagnosis?

What will become of the art of medicine?

Many miles apart, Dr. Adam Wright and Dr. Art Papier sit at their computers each day working to craft a new era of healthcare, striving for a solution to the daunting crisis that we face. The way they see it, there is no choice but to change.

Interviews

Ahmed, Bilal. Associate Professor of Clinical Medicine – University of Rochester. In-person interview. January 15, 2010.

Burill, Rory. Director of Consumer Health – Logical Images. In-person interview. January 15, 2010.

Chaiken, Barry. Chair of the Health Information Management Systems Society. In-person interview. December 17, 2009.

Cohn, Jeffery, MD. Chief Quality Officer – Albert Einstein Healthcare Network. Phone interview. December 31, 2009.

Datena, Stephen. President of Lifecom Systems. Phone interview. November 12, 2009.

Feldman, Mitchell, MD. Clinical Instructor in Pediatrics – Harvard Medical School. Phone interview. December 23, 2009.

Feldman, Mitchell, MD (2nd interview). Clinical Instructor in Pediatrics – Harvard Medical School. In-person interview. January 13, 2010.

Feldman, Mitchell, MD (3rd interview). Clinical Instructor in Pediatrics – Harvard Medical School. Phone interview. April 28, 2010.

Halton, Heidi. Image Archivist – Logical Images. In-person interview. January 15, 2010.

Herron, Keith. Clinical Content Manager – Patient Care Technology Systems. Phone Interview. November 4, 2009.

Herron, Keith (2nd Interview). Clinical Content Manager – Patient Care Technology Systems. Phone Interview. December 3, 2009.

Hoberman, Brian, MD. Inpatient Physician Leader – Kaiser Permanente. Phone Interview. December 16, 2009.

Kibort, Phillip, MD. Chief Medical Officer – Children's Hospitals and Clinics of Minnesota. Phone interview. January 11, 2010.

Kolodner, Robert, MD. Former National Coordinator for Healthcare IT. Phone interview. November 24, 2009.

LaCasce, Ann, MD. Oncologist – Dana Farber Cancer Institute. In-person interview. December 16, 2009.

LaCasce, Ann, MD. Oncologist – Dana Farber Cancer Institute. Phone interview. April 27, 2010.

Messina, Dino, MD. Associate Program Director, Internal Medicine Program – Danbury Hospital. Phone Interview. December 22, 2009.

Middleton, Blackford, MD. Corporate Director of Clinical Informatics Research & Development. Phone interview. December 21, 2009.

Papier, Art. President and Founder of Logical Images. Phone interview. December 18, 2009.

Papier, Art (2nd interview). President and Founder of Logical Images. In-person interviews. January 14, 2010 and January 15, 2010.

Reinhart, Donna. Vice President of Sales – Logical Images. Phone Interview. November 19, 2009.

Reinhart, Donna (2nd interview). Vice President of Sales – Logical Images. Phone Interview. January 15, 2010.

Robinson, Roy. Chief Software Architect – Logical Images. In-person interview. January 15, 2010.

Throumoulos, Kristy. Marketing & Communications Manager – Logical Images. In-person interview. January 15, 2010.

Wright, Adam, PhD. Instructor in Medicine - Brigham and Women's Hospital Boston. In-person interview. December 2, 2009.

Wright, Adam, PhD (2nd Interview). Instructor in Medicine - Brigham and Women's Hospital Boston. In-person interview. December 15, 2009.

Wright, Adam, PhD (3rd Interview). Instructor in Medicine – Brigham and Women's Hospital Boston. In-person interview. January 21, 2010.

Books and Journal Articles

Amarasingham, R., Plantinga, L., Diener-West, M., Gaskin, D. J., & Powe, N. R. (2009, January 26). "Clinical information technologies and inpatient outcomes: A multiple hospital study." *Archives of Internal Medicine, 169*(2), 108–114.

"Amelior ED Brochure." Patient Care Technology Systems. http://www.pcts.com/. Accessed October 10, 2009.

Anderson, Howard. "Supporting Clinical Decisions in the Physician's Office." *Health Data Management,* October 2009.

Bates DW, Kuperman GJ, Wang S, et al. Ten commandments for effective clinical decision support: making the practice of evidence-based medicine a reality. *J Am Med Inform Assoc.* 2003;10(6):523-530.

Blumenthal, David. "Launching HITECH." *New England Journal of Medicine.* Volume 362, Issue 5. February 4, 2010. Pgs. 382-385.

Chaiken, Barry. "Keynote Address." HIMSS 2010 Annual Conference. Georgia World Congress Center, Atlanta, GA. March 1, 2010.

Chaiken, Barry. "Leverage Clinical Decision Support." *Managed Healthcare Executive,* June 1, 2009.

Chaiken, Barry. "State of the Art in Diagnostic Clinical Decision Support." *Patient Safety and Quality Healthcare,* July/August 2009.

"Collaboration for Clinical Decision Support: An International Movement Toward Clinical Transformation." *Inside Edge,* Scotsdale Institute, November/December 2008.

Conn, Joseph. "IT's the Money; Funding to Expand EHR Initiatives Nationwide." *Modern Healthcare,* February 23, 2009.

Consuelo, David et al. "The Accuracy of Diagnosis of Cellulitis Among Hospitalized Patients." Presented at the SHM Diagnostic Error in Medicine National Conference. October 21, 2009.

Danbury Hospital Development Fund, Inc. "Report to Donors: 2008."

Friedman, Charles et al. "Enhancement of Clinicians' Diagnostic Reasoning by Computer-Based Consultation: A Multisite Study of 2 Systems." *Journal of the American Medical Association.* November 17, 1999. Volume 282, Number 19: 1851-1856.

Gawande, Atul. "For Performance." *Better: A Surgeon's Notes on Performance.* New York: Metropolitan Books, 2007, pg. 232.

"Global Healthcare Information Technology Report Reveals, the Healthcare IT Market is Estimated to be $53.8 billion by 2014." *Business Wire,* October 6, 2009.

Groopman, Jerome. "Health Care: Who Knows Best?" *The New York Review of Books*. February 11, 2010. Volume 57, Number 2. http://www.nybooks.com/articles/23590. Accessed April 1, 2010.

Groopman, Jerome and Pamela Hartzband. "Why 'Quality' Care is Dangerous." *Wall Street Journal.* April 8, 2009. http://online.wsj.com/article/SB123914878625199185.html. Accessed April 16, 2010.

Heselmans, Annemie et al. "Effectiveness of Electronic Guideline-Based Implementation Systems in Ambulatory Care Settings – A Systematic Review." *Implementation Science.* Volume 4. December 30, 2009.

Himmelstein, David, Adam Wright & Steffie Woolhandler. "Hospital Computing and the Costs and Quality of Care: A National Study." *American Journal of Medicine.* Volume 123, Issue 1. January 2010. Pg. 40-46.

Hunt, Derick et al. "Effects of Computer-Based Clinical Decision Support Systems on Physician Performance and Patient Outcomes: A Systematic Review. *Journal of the American Medical Association.* October 21, 1998. Volume 280, Number 15: 1339-1346.

Institutes of Medicine – Committee on Quality of Health Care in America. *Crossing the Quality Chasm: A New Health System for the 21st Century.* Washington, DC: National Academy Press, 2001.

Johnston, Mary et al. "Effects of Computer-based Clinical Decision Support Systems on Clinician Performance and Patient Outcome." *Annals of Internal Medicine.* January 15, 1994. Volume 120, Number 2: pg. 135-142.

Kaplan, Bonnie. "Evaluating Informatics Applications – Clinical Decision Support Systems Literature Review." *International Journal of Medical Informatics*. Volume 64, Issue 1. November 2001. Pg. 15-37.

Kaushal R, Shojania KG, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. *Arch Intern Med.* 2003;163(12):1409-1416.

Koppel, Ross et al. "Role of Computerized Physician Order Entry Systems in Facilitating Medication Error." Journal of the American Medical Association. Volume 293, Issue 10. March 9, 2005. Pg. 1197-1203.

Ledley, RS and LB Lusted. "Reasoning foundations of medical diagnosis; symbolic logic, probability, and value theory aid our understanding of how physicians reason." *Science* 130 (3366), (1959), pp. 9–21.

Leonhardt, David. "In Medicine, The Power of No." *The New York Times*. April 6, 2010. http://www.nytimes.com/2010/04/07/business/economy/07leonhardt.html. Accessed April 7, 2010.

McCaughy, Betsy. "The Attack on Doctor's Hippocratic Oaths." *Investor's Business Daily*, April 30, 2009.

McDonald CJ. Protocol-based computer reminders, the quality of care and the non-perfectibility of man. N Engl J Med 1976;295:1351-5.

McGlynn, El., et al. (2003). "The quality of health care delivered to adults in the United States." *The New England Journal of Medicine*. Volume 348, Issue 26. Pg. 2635-2645. At http://content.nejm.org/cgi/content/abstract/348/26/2635.

McKenny, Maureen. "Decision Support for Docs." *Hospitals & Health Networks.* 2009. Volume 83, Issue 12. Pg. 42-43.

Medscape.com. "Medicine & Art." http://www.medscape.com/viewarticle/561511. October 20, 2009.

"New Computer Program Helps Danbury Doctors." *Connecticut Post Online*, July 28, 2009.

Newman-Toker, David and Peter Pronovost. "Diagnostic Errors – The Next Frontier for Patient Safety." JAMA. March 11, 2009. Volume 301, Number 10.

Osheroff, Jerome A. et al. "A Roadmap for National Action on Clinical Decision Support. June 13, 2006.

Rosenbloom, S. Trent, Doug Talbert and Dominik Aronsky. "Clinicians' Perceptions of Clinical Decision Support Integrated Into Computerized Provider Order Entry." *International Journal of Medical Informatics.* Volume 73, Issue 5. June 15, 2004. Pg. 433-441.

Sanders, Lisa. *Every Patient Tells a Story*. New York: Broadway Books, 2009.

Sittig, Dean, Adam Wright, Jerome Osheroff, Blackford Middleton and Jonathan Teich. "Grand Challenges in Clinical Decision Support." Journal of Biomedical Informatics. Volume 41, Issue 2. April 2008. Pgs. 387-392.

Sittig, Dean, Adam Wright, et al. "The State of the Art in Clinical Knowledge Management: An Inventory of Tools and Techniques." International Journal of Medical Informatics. Volume 79. 2010. Pg. 44-57.

Sucher, Joseph et al. "Performance of a Computerized Protocol for Trauma Shock Resusitation." *World Journal of Surgery.* Volume 34, Issue 2. February, 2010. Pg. 216-222.

Visual DX Brochure. "Hospital Challenge: The cost-and-quality call to action." Logical Images. http://www.visualdx.com.

Weaver, Christopher. "Administration Faces Tough Sell on Healthcare Information Technology." *The Monitor* (McAllen, TX), July 19, 2009.

Wensing M, Wollersheim H, Grol R. Organizational interventions to implement improvements in patient care: a structured review of reviews. *Implement Sci.* 2006;1:2 http://www.implementationscience.com/content/1/1/2. Accessed January 24, 2010.

WhiteHouse.gov. "Vice President Biden Announces Availability of Nearly $1.2 Billion in Grants to Help Hospitals and Doctors Use Electronic Health Records." http://www.whitehouse.gov/the_press_office/Vice-President-Biden-Announces-Availability-of-Nearly-12-Billion-in-Grants-to-Help-Hospitals-and-Doctors-Use-Electronic-Health-Records/, October 14, 2009.

Wright, Adam and Dean F. Sittig. "A Four-Phase Model of the Evolution of Clinical Decision Support Architecture." *International Journal of Medical Informatics*. Volume 77, Issue 10. October 2008, pgs. 641-649.

Wright Adam et al. "Clinical Decision Support Capabilities of Commercially-Available Clinical Information Systems." Journal of the American Medical Informatics Association. June 30, 2009.