History of Computing
CS 215
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1. American Computer Museum

Bozeman residents are fortunate to have an incredible historical resource available to them. The American Computer Museum, which is located on North 7th (north of I-90 opposite Murdoch's) has been the world's best computer museum since the closure of the Boston Computer Museum a few years ago. Over the years the museum has extended into more than just a computer museum, and so in addition to its computer holdings it has Babylonian Clay Tablets that are over 4000 years old, a page from a bible from the 13th century, original editions of books by Newton (*Principia*), Maxwell, Locke, Bacon, Darwin (*Origin of the Species*), and other great authors who changed the world (in many cases first editions), an original Volte pile, a western land grant signed by Jefferson, and so on.

The museum director, George Keremedjiev, is a world expert in metal forming, and he and his wife Barbara have done an amazing job with the museum. He also sponsors the Stibitz awards in Bozeman every year or so which recognize computer pioneers and invite them to Bozeman for talks at the schools and at MSU. We've had some great speakers out of this including the surviving members of the ENIAC team at Penn, Doug Engelbart with his original wooden mouse, Vint Cerf and Bob Kahn who initiated the Internet through a 300 baud cross-country link to BBN which cost $50K/month and subsequently were the designers of TCP/IP, Ted Hoff, Stan Mazor, and Frederico Faggin who built the first microprocessor (the Intel 4004), Jack Kirby of TI who invented the integrated circuit (the Stibitz was given shortly before he got his Nobel), and so on. My favorite year was when the three awardees were Tim Berners-Lee, who invented the Web, Steve "the Woz" Wozniak, the original technical brain behind Apple, and Ray Tomlinson, who invented email (and is most famous for selecting the @ in e-addresses). Shortly before that visit Berners-Lee had been selected by *The Times* as one of the ten most significant people of the 20th century, just behind Stalin and beating out Hitler. Wozniak has been a strong supporter of the Museum, including donating an Apple 1[1] and other objects.

[1] The Apple 1 was originally available as free plans, then could be purchased from Wozniak and Jobs for $666, but is now worth well over $50K to collectors.

In 2005, there were three new Stibitz awards given. The three awardees were Paul Baran, who first proposed a national distributed digital network for national security in 1962, which would later be developed as the Internet, Ross Perot, who founded EDS which made computing accessible for many more businesses (and later ran for the US Presidency), and John Blackenbaker who is credited with inventing the first PC. In 2007 there was a sole awardee, E. O. Wilson, the founder of Sociobiology.

See http://www.compustory.com/ for the museum Web page. In addition to the main museum on N. 7th, in 2006 a satellite display was added in Wilson Hall on campus.

2. History of Computing

None of us ever completely agree with each other on the credit that should be given for different inventions, so the history, below, represents my views of the most significant events that led to today's computers:

The first automatic[2] calculating machine that we know of was developed in 1623 by a German named Wilhelm Schickard whose "calculating clock" successfully added and subtracted six digit numbers, and even had an error handler (an alarm bell) if the addition overflowed or the subtraction was negative. Nineteen years later Blaise Pascal built and sold an adding machine which could add eight digit numbers. This was much less impressive than Schickard's machine, but it is much more famous. Twenty nine years after this, in 1671, Leibnitz built the first mechanical multiplier.

Charles Babbage designed two machines, the Difference Engine[3] and the Analytical Engine. The Difference Engine, first developed in 1822, was designed to solve fairly complicated polynomials using difference methods. The Analytical Engine, first developed in 1834, is often described as the first general purpose computer, although it was strictly mechanical as compared to today's electronic computers. It used punched cards for programming, and had the required capabilities for a modern computer including storage, looping, and conditional statements[4]. Babbage was a driven person, and appears to have been rather irascible. He managed to persuade the British government to put a lot of funding into the Difference Engine, but they finally gave up after many cost overruns and stopped supporting him. It turns out that he was limited by the construction techniques available at the time. Nearly two centuries later, in 1985, the Science Museum in London built a successful implementation of Babbage's second Difference Engine which they completed in 1991, in time for the 200th anniversary of Babbage's birth in 1792[5].

[2] As compared to, say, an abacus or a slide rule, where the operator does most of the work.
[3] A previous similar concept developed by Mueller in 1786 had been lost, and it appears that Babbage's design was independent.
[4] http://www.sciencemuseum.org.uk/on-line/babbage/page5.asp
[5] http://www.sciencemuseum.org.uk/on-line/babbage/index.asp

Ada Augusta[6], Countess of Lovelace, is usually given the title of "first programmer" because of her work with Babbage.

Ada Augusta, Countess of Lovelace, 1815-1852

Her programs for the Analytical Engine are impressive, and most agree that she deserves the title[7]. She was also remarkably prescient when she predicted that in the future computers would be used in areas like composing music and generating graphics. Her abilities were recognized by the other great minds of the time, and there is a wonderful book of her surviving letters to many of these people.[8]

The US Constitution requires that an "Enumeration shall be made within three Years after the first Meeting of the Congress of the United States, and within every subsequent Term of ten Years." Since the first census was held in 1790 this means that there is a constitutional requirement for a national census on every year that ends with a zero. This started to cause problems by 1880 when, because of the increase in population size and geographical distribution, the census was not completed until 1886, and it was recognized that the 1890 census probably wouldn't be completed until after the next one in 1900. To solve this problem the Census Department put out bids to create a better solution, and one of their former employees, Herman Hollerith, created a machine which could process data put onto 80 column punched cards[9]. Using this machine the Census Department was able to process the 1890 census is six weeks instead of the six years for the 1880 census. The solution was, however, twice as expensive as the 1880 census, which is a familiar problem now when many find that computing increases costs but also increases capabilities. Hollerith created a company which was later called the Tabulating Machine Company, which later merged with other companies to ultimately become International

[6] She was the poet Lord Byron's daughter.

[7] Some point out that Babbage and his sons must have written programs for the Engine before she did.

[8] Her husband destroyed the letters to her that she had kept; she was believed to be about to die and was told that she should confess her sins to her husband. After she did, he left her room and told the servants that they should no longer treat her as their mistress, destroyed her letters, and kept her in isolation until she died six months later (probably of uterine cancer) at age 36. This gives some credence to rumors that her relationships with Babbage and others were not completely platonic.

[9] These were the same cards as used by Babbage, and came from loom controllers.

Business Machines (IBM) in 1924. This became the most important company in computing, peaking at nearly 400,000 employees.[10]

The next major advances in computing occurred in the years leading up to the Second World War and then during the war.

In 1937 George Stibitz created a single binary adder in his kitchen based on telephone relays. He subsequently made a copy of the original adder which was donated to George Keremedjiev, who has it on display at the Computer Museum in Bozeman. A year later Claude Shannon published a paper on how to use relays to implement symbolic logic.

In 1938 a German named Konrad Zuse developed a mechanical calculating machine called the V1[11] that was based on Boolean logic. In 1939 his V2 improved significantly on the V1 by replacing the arithmetic unit with one based on relays. Zuse continued development of these systems during the war, which led to the V3 which handled floating point numbers with relatively high precision[12]. Zuse also developed an amazing programming language for the Z3 which he called Plankalkül, which unfortunately he never bothered to publish. If he had published it he would have dramatically changed the early days of computing. It included assignment statements, and even Boolean assignment statements (e.g. V1 + V2 => R and V1 = V2 => R), conditional statements, subprograms, loops, lists and list operations, arrays, exception handlers, and most features of fairly advanced languages apart from recursion.

In 1940 Williams and Stibitz created a complex number calculator which could be accessed (one at a time) using teletypes, and so provided the first example of remote computing. They demonstrated this by using the machine, which was located in New York, from New Hampshire.

In 1941 John Atanasoff and Clifford Berry built a machine to solve simultaneous equations called the ABC (Atanasoff-Berry Computer).

Many claim that the Colossus, developed at Bletchly Park in England in 1943, was the first complete electronic computer. It was built to break German messages encoded using their Enigma coding machine by a group that included Turing, Flowers, Newman, Michie, and Wynn-Williams and was covered by the British Official Secrets Act. Secrecy about the project stayed in effect until Don Michie published an account in the 1970's in defiance of the Act and despite threats of prosecution. Until Michie's paper there had always been comments on how rapidly the British computer industry had developed after the war. It is now known that the reason was that many people had been working on the Colossus project during the war and used the knowledge to jump start a number of developments after the war. This includes the work at Manchester which led

[10] As I write these notes on July 19, 2006, IBM has 329,373 employees. By comparison Microsoft has somewhat over 60,000 employees.
[11] Zuse's three machines, the V1, V2, and V3 were renamed the Z1, Z2, and Z3 after the war, presumably because the names V1 and V2 were also the names of German missiles developed by Lisserr and Zuse's friend Wernher von Braun that caused extensive damage in England throughout the latter parts of the war.
[12] A floating point multiply took just over 4 seconds.

to the creation of Ferranti. The Colossus was way ahead of its time, but all ten that were built[13] were destroyed at the end of the war under the secrecy edict[14].

For many years the ENIAC, developed at the University of Pennsylvania by Mauchly, Eckert, and others, claimed to be the first electronic computer. It was primarily designed to compute missile trajectories.

In the 50s a number of companies began to produce computers. These were at first almost all aimed at scientific computing, with programming moving from hard wiring programs by essentially connecting the needed components with wires, to machine language using the stored program concept developed by von Neumann and others, to assembly language which let programmers use mnemonic names (e.g., ADD) instead of binary machine codes. John Backus, who was working at IBM, proposed the development of a high level language that would be named FORTRAN[15] (FORmula TRANslator) that would let the programmer directly use variables and scientific expressions like `(x + y) * (a - b)`. Also the amazing Grace Hopper[16] led the development of a Cobol compiler (COmmon Business Oriented Language) which led to computers being used for business applications, McCarthy and others developed Lisp (LISt Processor) for artificial intelligence, and then to an explosion of hundreds of other languages, of which the most significant in terms of influencing future language designs was Algol60.

The development of languages to support non-scientific applications also led to the development of computers which were more appropriate for those applications. If one just looks at the two most important classes of applications, scientific and business, they put very different stresses on their computers. A typical scientific application reads in some numbers, crunches them for a while, and then outputs the result (e.g. 42). A typical business application has a large amount of information (e.g., payroll data) on external storage and is constantly reading in this information, usually doing fairly simple things on the cpu, and then outputting large files of manipulated information. So typical scientific applications are cpu-bound, which means that the power of the processor is more important, whereas typical business applications are I/O-bound which means that input/output speed is most important.

The first main family of computers was the IBM System/360 series, which all ran the same software, but with a wide range of computer sizes, and these computers dominated the field for several years. By then computers were using batch processing, and so instead of running one program, completing it, and then loading and starting the next, the user submitted their program into a queue, so that it could start as soon as the previous program finished. Later time sharing was introduced where computers had multiple

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[13] Nine Colossi Mark II's and one which was converted from a Colossus Mark I to a Colossus Mark II.
[14] Winston Churchill gave the order that all ten Colossi must be "broken up into pieces no larger than a man's hand."
[15] Later officially changed to Fortran.
[16] Grace Hopper was the first female admiral in the US Navy, and finally retired as a Rear Admiral. The guided missile destroyer, the USS Hopper (www.hopper.navy.mil), was named in her honor, and is known as "The Amazing Grace."

programs running simultaneously, with the operating system allocating slices of time to each program under some kind of priority queue allocation system. To each user it looked as though their program was running as soon as they submitted it[17]. Computers like the bigger IBM systems were called mainframes or, informally, big iron.

There were many other computers developed in the 1960s and early 1970s that greatly influenced future computing systems. E.g. the Manchester Atlas used virtual memory which was then abandoned by other systems for years[18]. Another significant occurrence was the introduction of minicomputers, in particular the PDP-8 and the PDP-11 family, which changed the model of how computing was done, and got computing down to a departmental or group level as compared to the centralized mainframe approach that was epitomized by the IBM 360 family.

Supercomputers, which were incredibly powerful number crunchers, were first developed by Seymour Cray with his Cray 1 in 1976. It had to be cooled with Freon because otherwise the heat from the circuits would have led to self destruction. Some of the original applications for supercomputers are now run on networks of smaller computers (e.g., PCs), and so supercomputers are now used only in very specialized highly computational applications like weather forecasting. Supercomputers are also built out of very large numbers of tightly connected simple processors. E.g. the Connection Machine could be ordered with up to 2^{16} (65,536) processors. The fastest current supercomputer (August 2006) is the MDGrape-3 at Riken in Yokohama, Japan, which was clocked in July 2006 at one quadrillion floating point calculations per second, which was the first to have what is called petaflops speed (1000 trillion floating point operations per second), about four quadrillion times faster than Zuse's Z3.

It wasn't until the mid 60's that computers became cheap enough to be considered at the departmental level as compared to the corporate level. Time sharing had been developed, and to some extent virtual memory had been reinvented, so efficiency had improved, but the boxes were still ridiculously expensive. Then in 1965 DEC came out with the PDP-8, for only $18,500 for a minimal configuration. This, and the huge PDP-11 family which began in 1970 and cost $10,800 at minimal configuration, revolutionalized how we did computing. There were many other PDP models, from the PDP-1 to the PDP-16[19], but the 8 and the 11 were the most influential. After the PDP families of computers DEC continued down the same path with their VAX families. Other vendors also developed minicomputers, including Data General, which was the subject of Tracy Kidder's classic book *The Soul of a New Machine*, which should be in every computer book collection

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[17] This led to a theoretical slight drop in throughput, although it also opened up the possibility of multiple users interacting with the computer over some kind of terminal, which was much better than submitting a job and then coming back a few hours later when it made it to the front of the queue. When I went to Penn for my PhD in 1968 the had just received two IBM 360/67s, which were like the 65s but with time sharing. Because of concerns about throughout the Computing Center removed the time sharing and ran them as dull 65s.

[18] When I went to Penn in 1968 for graduate studies they has just received one of the first IBM

[19] The PDP-2 existed only on paper, there wasn't a PDP-13 because of the bad luck connotations, and apparently other PDP-N names were used by people who extended PDPs. E.g., the Australian Atomic Energy Commission upgraded a PDP-7 by adding a PDP-15 slave and named the combination the PDP-22.

Over the last 20-30 years changes have been dominated by networks and by personal computers.

Beginning in 1967 Vint Cerf, Bob Kahn, and others began work on what would become the ARPANET, the predecessor of the Internet. Cerf and Kahn later developed TCP/IP, the communications glue that holds the Internet together. Many people think of the Internet and the Web as being the same thing, but the Web is just one of many applications that runs on the Internet. (Email is another, and predates the Web by many years.)

Then came the next big change, the development of personal computers. They were made possible by the development of the microprocessor. The first microprocessor was the Intel 4004 developed by Hoff, Mazor, and Faggin.

John Blankenbaker is credited with creating the first PC, but his KENBAK computer was not commercially successful. Steve Wozniak ("the Woz") and Steve Jobs at the Homebrew Computer Club in California designed and distributed plans for the Apple 1 computer which they ultimately sold for $666 leading to Apple Computer[20] Corporation. Initially these personal computers were often home built, with virtually no I/O devices (imagine using 16 toggle switches to put in a program one 16-bit machine instruction code at a time – I've done that on an 11/05), then came the idea of hooking one up to a keyboard and a TV, and later a tape drive. Software was still minimal. Then Bill Gates built a Basic compiler for the Altair PC and asked his employer[21], to pay him $10/hour instead of royalties because everyone would steal it and so he claimed that nobody could make any money from selling software, VisiCalc came out and caused a storm in industry because it changed how accounting was done, CP/M was the operating system of the future, until they asked for too much from IBM, who did a deal with Microsoft instead[22], WordStar gave us word processing that was dramatically nicer than the Unix nroff, and almost accidentally computing had moved from being the domain of a few to being the domain of all.

IBM's entry into the PC market, on August 12, 1981, exactly 25 years ago as I write this, led to the acceptance of PCs into the business world. Until then personal computers had been thought of as machines for hobbyists. Amazingly IBM decided to go with an open architecture, which let clone manufacturers build copies of their PC. Initially they maintained a dominance of the PC market, and quickly obliterated the sales of Apple who had a closed architecture, but soon the clones, led ultimately by a wide range of companies that included HP, Compaq, Gateway, and Dell, were producing high quality equivalent systems that were cheaper than the IBM PCs, and so IBM lost a lot of their market share. Looking back it is clear that their big mistake was to underestimate the importance of the software that would run on not only their systems but also on all of the clones that came out. To get a feel for how critical this was, on January 10, 2005,

[20] Named by Jobs to honor the Beatles, who had founded the Apple Corps collection of companies. Subsequently this decision led to many trademark lawsuits, which are still continuing.
[21] Ed Roberts, who was another Stibitz awardee.
[22] Microsoft based their DOS products on a system that they purchased called Q-DOS, for Quick and Dirty Operating System.

China's Lenovo Group bought IBM's PC division for $1.75 billion, whereas the current (August 2005) value of Microsoft is around $250 billion.

There were many major event both preceding and intertwined with this which influenced developments. One of the most visionary events was given by Doug Engelbart, who in 1968 at the Fall Joint Computer Conference (FJCC) gave what is known as the mother of all demos which included the introduction of a mouse in a multiple windows environment, as well as video-conferencing and many other features of a modern computer system. This was years ahead of anything that anyone else was working on at the time and was apparently greeted with disbelief at FJCC. When he received his Stibitz award in Bozeman Engelbart brought his original wooden mouse with him.

The other big change, of course, was the Web, and how it has changed the way in which we access information. In the mid-1990s the Web was new, and there were less than a million pages, world-wide. One of the early pages, in 1994, was Condom Country with Prophylactic Pete and his faithful horse Latex, which was the first site that I saw where someone used the Web to sell their product. This site gave us our first hint that the Web could be far more than we had been expecting, positive, negative, and possibly weird.

3. My Personal Computing History

On a personal note, my first programming was from January through August 1965. I'd been accepted at Oxford University starting in the fall of 1965, so saw no reason to finish my last two terms at school, dropped out, and took a job at the Royal Aircraft Establishment (RAE), Britain's large government research organization in aircraft research and development. This was the period of enterprise computing with mainframes, and the RAE's only computer was a Mercury made by ICL and programmed using Mercury Autocode[23]. I've included a photo of the Mercury, below on page 9.

Note the beautiful parquet flooring – we treated our computers with respect then. Also note all of the cabinets, many of which were used for the computer's memory, which would be considered laughably small now. I'll let you guess the memory size in class.

In many ways the Mercury was also a personal computer, because it had been designed before timesharing, and so a programmer would sign up for, say, 10:00 – 10:30 a.m. one day, bring in their program on five-hole paper tape, put it into the Mercury, get a tape back with the executable punched on it[24], and give that back to the computer, which would run it. Careful programming was important because it was difficult to reserve

[23] An interesting language, and the only one that I have used that used adjacency for multiplication instead of having a multiplication operator, so if you wanted the expression ab+cd, you typed ab+cd instead of typing a*b+c*d. This meant that there were severe restrictions on possible variable names and that function calls had to be preceded by a φ, as in φlog(x). If you forgot the φ, in this case you got l*o*g(x). It also significantly restricted potential variable names to only one character.

[24] The computer didn't have enough memory to store the executable program internally.

Mercury time more than once every couple of days. We also did production runs on the Manchester Atlas with weekly turnaround through the British postal service.

ICL Mercury computer, c. 1965

When I came to graduate school in the US three years later in 1968, Penn had an IBM 360 system with IBM 026 BCD card punches (the computer museum has an 029 EBCDIC card punch – the later model). Moving from tape to cards was the greatest single improvement in computing technology that I have gone through, although we still had only daily batch turnaround. Algol was the language that we used most at that time.

Since then I've gone through a wide range of technologies, of which the most important were the IBM 370 family, PDP-11 minis and VAX super-minis, and then the whole personal computer and networking revolutions, which included the concept of making computing available to everyone.

4. Changing Attitudes to Computing

When I was working at the RAE the programmers were gods. Even computers like the Mercury cost millions, and we were the only people who could use these ridiculously expensive devices. There were very few computers in the world, and they were all owned by government organizations or huge companies, and all computing had to be performed at the machine – there was no networking.

Visionaries who accurately described the future were ignored or laughed at.

- When Paul Baran proposed in 1966 that by the year 2000 people would go online onto a computer to go shopping he was derided. He'd just developed the concepts of breaking a message up into packets and doing what he called hot-potato switching[25] and gave a paper at the American Marketing Association called *Marketing in the Year 2000* where he described push-and-pull communications and how we will do our shopping via a television set and a virtual department store. He said "If you want to buy a drill, you click on *Hardware* and that shows *Tools* and you click on that and go deeper. In the end, if you have two drills you're interested in, then you hit your Consumers Union button, and their evaluation goes up on the screen." In a recent interview in *Wired* Magazine Baran said "Some in the audience were furious. They said, 'People don't go shopping to buy things. They go there because of the enjoyment. You don't understand women'."
- Even when in the early 90's Tim Berners-Lee proposed the initial World Wide Web, his proposal was rejected by the CERN administration and sat on a shelf for a year until his manager found a project that he could try the idea out on.
- Earlier I described Doug Engelbart's "mother of all demos" at the FJCC, where "it was claimed that he was treating a computer as if it were for his personal use."

There were also many leaders, usually believed, who made much less optimistic predictions about the future of computing. Some classic examples:

- "I think that there is a world market for maybe five computers." Thomas Watson, IBM, 1943.
- "Computers in the future may weigh no more than 1.5 Tons." Popular Mechanics, 1949.
- "There is no reason anyone would want a computer in their home." Ken Olson, President Digital Equipment Corporation, 1977 (the year that the Apple 1 was introduced).
- "Nobody will ever need more than 640K RAM." Attributed to Bill Gates, Chairman of Microsoft, in 1981 although he denies making this statement or similar statements that are attributed to him.

5. The Future of Computing

[25] Unfortunately the name *packet switching*, although much less descriptive and also much less interesting than *hot-potato switching*, became the standard name.

I've always been very poor at predicting what the future will hold. Moore's law that computer power and speed will double every 18 months[26] has been remarkably stable[27]. Now people feel that the law is threatened because of limitations of the underlying physics. Many low level components are now measured in a small number of atoms, and so there is a physical limit to how much they can be shrunk. In the past there have been many papers showing how Moore's Law must soon be broken because of physical limits (in particular the speed of light which limits communications to one foot per nanosecond and also heat considerations) and every time changes in technology blew right by the proposed theoretical limits. So we can confidently predict that computers will continue to get much faster, and that they will have constantly increasing internal and external storage capabilities. More important is that the Internet will continue to go faster and faster, and that the Web will continue to grow and become more and more important to our lives. On mundane matters, household appliances will become much more intelligent. (E.g. prototype networked fridges already exist that can order more milk when you are running low.)

A couple of hints on where things might go: Vint Cerf was working on the design of an intergalactic Internet when he received his Stibitz Award in Bozeman (the transmission delay times cause interesting problems)[28]. In 2001 IBM announced that they had successfully implemented a seven qubit[29] quantum computer in a test tube, and had used Shor's quantum factorization algorithm to factor 15 into 5 times 3. This might not sound like much, but if they can ever implement a large quantum computer a whole new kind of programming will come into existence, based on quantum effects, and current encryption systems will be useless. Fortunately I think that I will retire before quantum programming will become a requirement for computer scientists.

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[26] He claims that he said 24 months, but the number that is usually used for the Law is 18 months.

[27] Moore's Law originally only predicted increases in component density on circuit boards, but it has been informally extended as a goal throughout the industry. I commented earlier that the new MDGrape-3 system will be about 4 quadrillion times faster than Zuse's Z3 from the early 1940s. Since 4 quadrillion is about 2^{52}, we should have expected that this speedup would take about 78 years, which is pretty close.

[28] I don't know whether he is still doing this, since he now runs the ICANN Corporation which assigns Internet names and numbers.

[29] A qubit is a quantum bit.