LA-UR-17-24329
Approved for public release; distribution is unlimited.

Title: Seventy Years of Computing in the Nuclear Weapons Program

Author(s): Archer, Billy Joe

Intended for: Parallel Computing Summer Research Interns lecture

Issued: 2017-05-30

Seventy Years of Computing in the Nuclear Weapons Program

LA-UR-

Parallel Computing Summer Research Interns

June 30, 2017

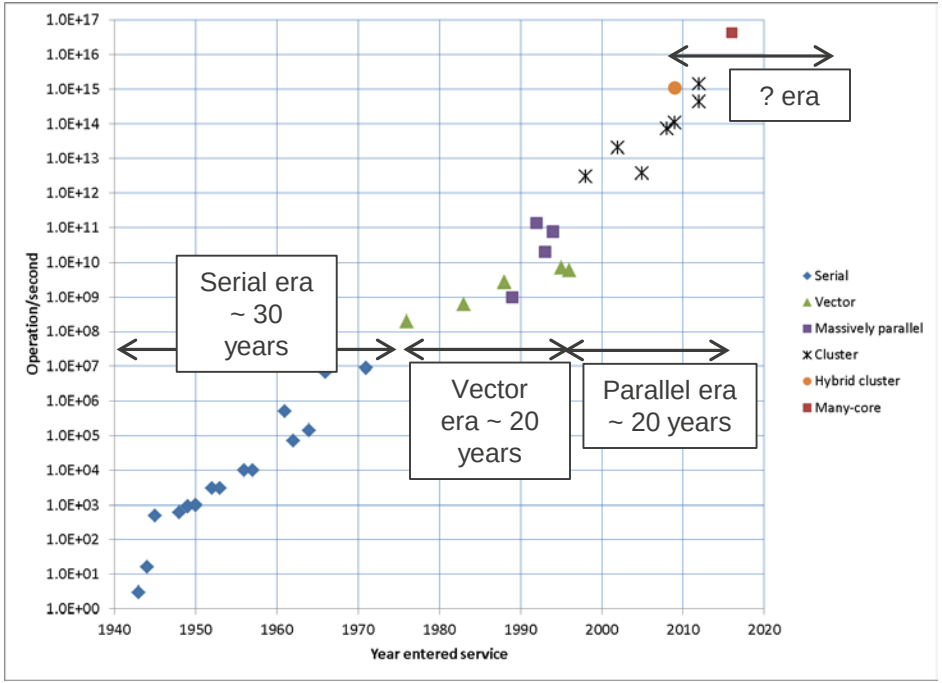
Bill Archer

Advanced Simulation and Computing Program Director

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

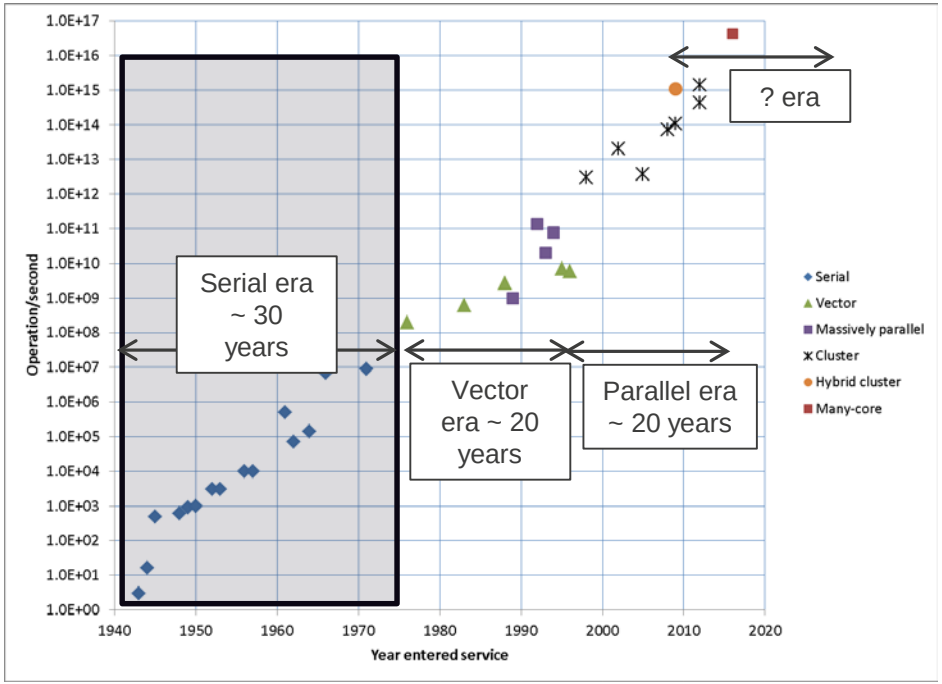
Los Alamos has been at the forefront of computing since 1943

- Los Alamos has both driven, and taken advantage of, increased computing capability
- A 16 order-of-magnitude increase in capability in 70 years!



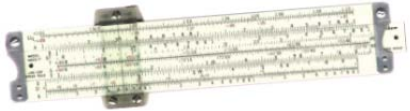
Size of a virus compared to the orbit of the moon!

The serial era began in 1943

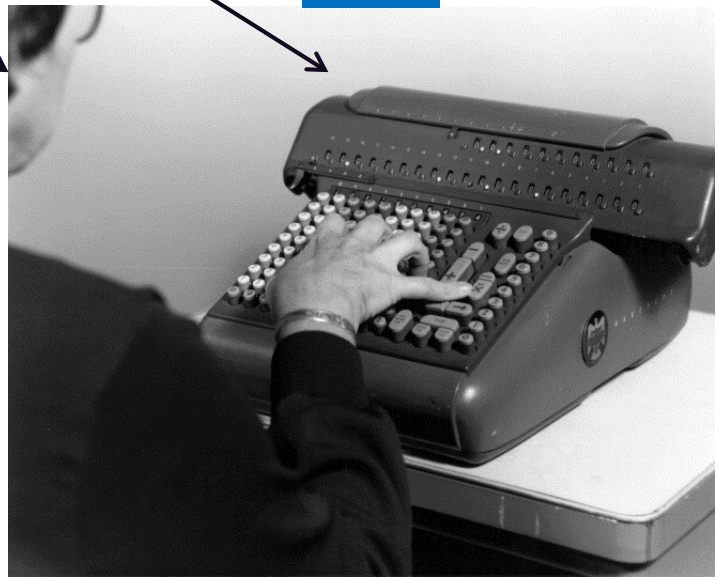


Los Alamos used the best computers of the era for calculating hydrodynamics.

- Marchant calculator
- Computer
- Slide Rule



3 Ops



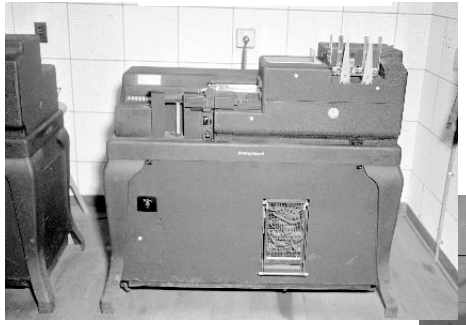
Ops is Operations per second

Serial, Electro-mechanical, 1944-1950

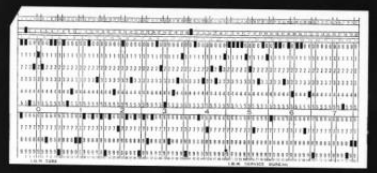
IBM Punch Card Accounting Machines (PCAM) were used for hydrodynamic calculations, 1944 to 1950

16 Ops

IBM 601 Multiplier



IBM Punch Card



IBM 405 Accounting Machine

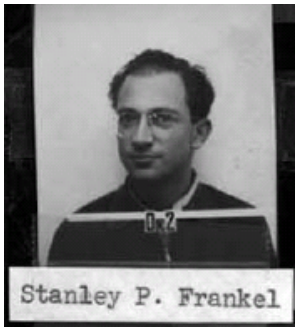
IBM 513 Reproducing / Summary

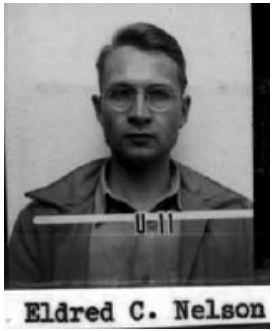
IBM 081 Card Sorter

IBM 031 Key Punch

IBM 077 Collator

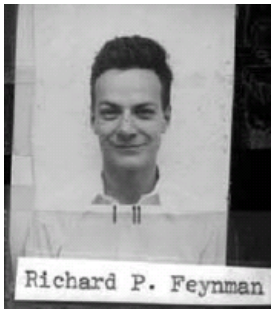
Los Alamos accidentally created the first computer geeks.





- **Stanley Frankel and Eldred Nelson developed the PCAM for scientific computing**

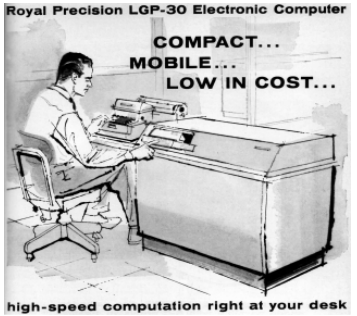
- They became enamored with discovering what could be done … and forgot what must be done
- Nick Metropolis and Richard Feynman took over the computing center



“Well, Mr. Frankel, who started this program, began to suffer from the computer disease”, R. Feynman

Nelson and Frankel were drivers of the early West Coast computer industry.

- **With Serber, in 1942 they worked out the neutronics equations in LA-1 (The Los Alamos Primer)**
- **They formed the first computer consulting firm in 1947 in Los Angles, California**
  - Developed foundations for missile navigation systems in the Northrop Snark cruise missile
- **Frankel lost his clearance in 1949, his father was a communist**
  - Designed the first personnel computer while at CalTech
  - Sold by Librascope as the LGP-30 in 1956
  - LGP-30 strongly influenced the first HP desktop calculator
- **Nelson lead the development of**
  - The first airborne digital computer at Hughes Aircraft
  - The first process control computer at TRW for a refinery
- **And much more!**

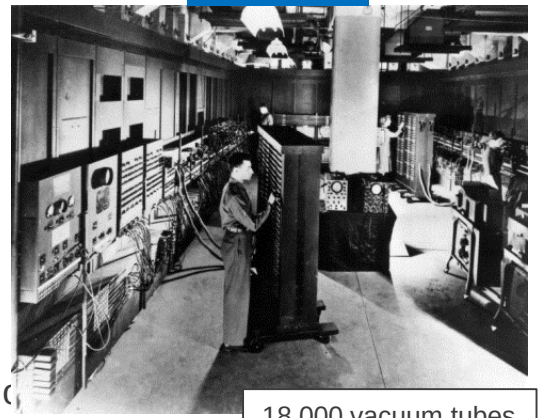


Ad in Proceedings of the IRE in May, 1957

The first calculation on ENIAC, one of the first electronic computers, was by Los Alamos

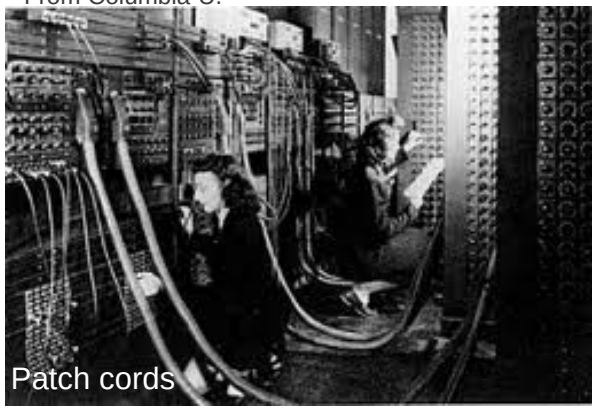
- **The first calculation on ENIAC, 1945**
  - First thermonuclear calculation, for the Super bomb
  - John von Neumann, Stan Frankel, Anthony Turkevich
- **Monte Carlo method developed at Los Alamos, 1947**
  - Uses random particle method to solve nuclear problems
  - By Stan Ulam and John von Neumann
- **First ever Monte Carlo calculation, on ENIAC in 1948**
  - John von Neumann, Klara von Neumann, Herman Goldstine, Adele Go

500 Ops

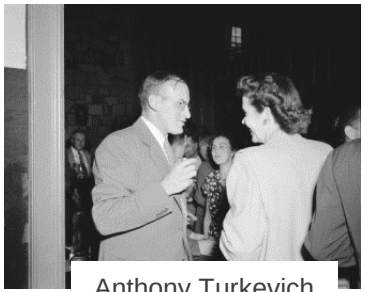


18,000 vacuum tubes

From Columbia U.



Patch cords



Anthony Turkevich

The first shock hydrodynamics code was developed on an IBM prototype

- **Richtmyer and von Neumann, 1947-1951**
- **Was the first shock hydrodynamics code**
  - Used too much memory for ENIAC
  - Developed artificial viscosity for shocks
  - Used Monte Carlo method
- **SSEC was IBM's first electronic computer**
- **Los Alamos hijacked almost every 1st generation machine**
  - National Bureau of Standards, Census Bureau

Robert Richtmyer

Pictures from IBM

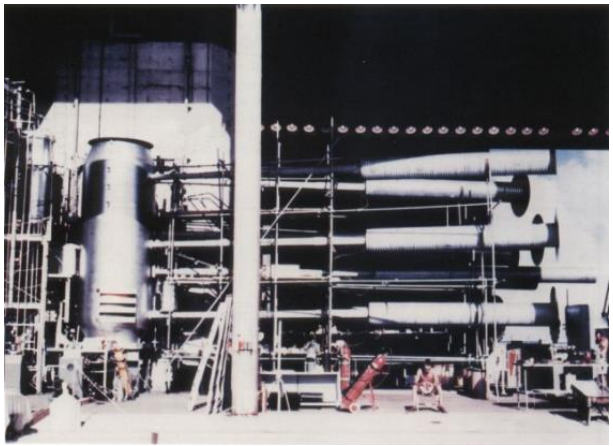
IBM Selective Sequence Electronic Calculator (SSEC), their first large-scale electronic machine,1948 - 1952

600 Ops

13,000 vacuum tubes

Thermonuclear burn calculations were carried out on NBS Standards Electronic Automatic Computer (SEAC) machine

Mike Device and Conrad Longmire



SEAC

Picture from NBS

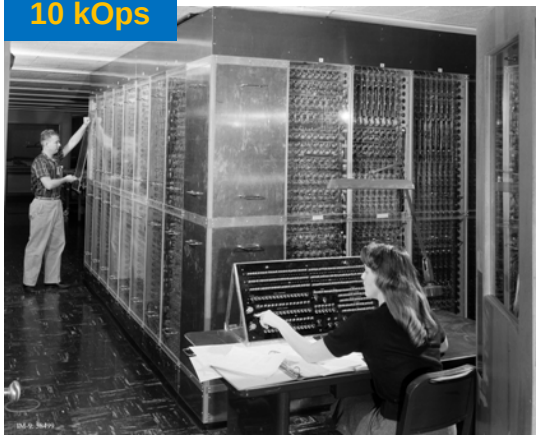
MANIC I & II were the Los Alamos first generation systems

- **Hand built by team lead by Metropolis**
- **MANIAC I in service 1952 to 1957**
  - About 1,000X faster than PCAM
  - Cathode-ray Williamson tubes for memory
  - Used for hydrodynamics & Monte Carlo
- **MANIAC II in service 1957 to 1977**
  - Had floating point
  - Over 5000 vacuum tubes
  - Overcome by the IBM 704
  - Mainly used for computer science research

3 kOps

MANIAC I

10 kOps



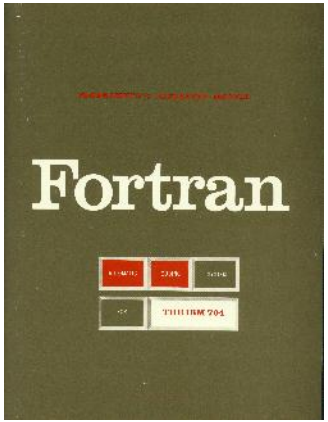
MANIAC II

The IBM 701 and 704 machines were revolutionary

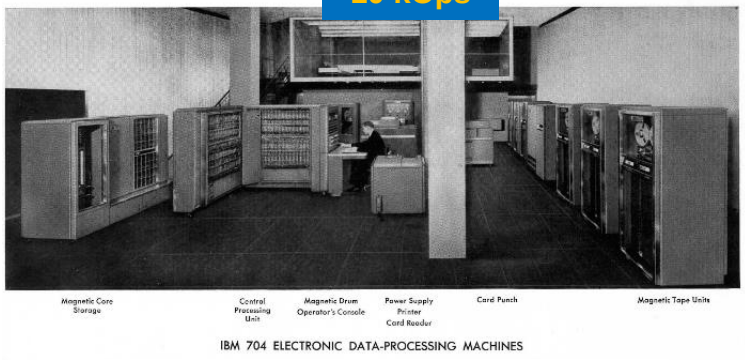
- **First LANL use of commercial computers**
- **Programmed in assembler**
  - A big step forward from patch cords!
- **701 used a cathode-ray for memory**
  - It would crash every time a truck drove by on Trinity
  - Required backups every 10 minutes!
- **704 had floating point hardware and magnetic core memory**
- **First one-point safety calculations, 1955**
- **FORTRAN on 704, 1957**

3 kOps

IBM 701 – serial #2 to Los Alamos (#1 replaced SSEC); 1953-1956



10 kOps

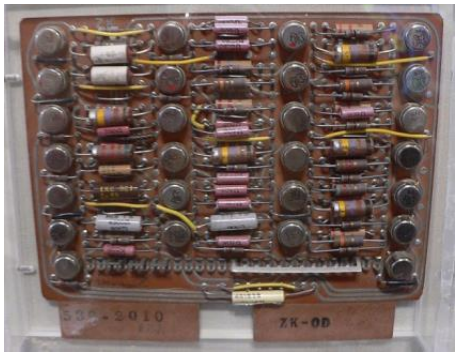


IBM 704 – serial #1 to Los Alamos; 1956-1963

IBM 7030 Stretch was IBM's first computer built of transistors

500 kOps

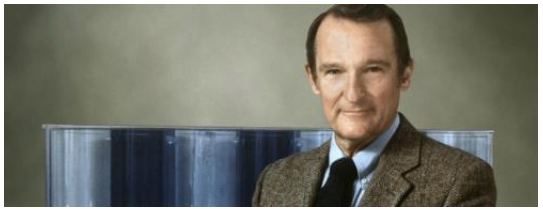
- **A 5-year co-design effort by LANL and IBM**
- **IBM's first transistorized computer**
- **LANL took serial #1**
- **World's fastest computer, 1961 to 1964**
  - Stretch was mainly a computer science research project;
    - IBM used concepts for the IBM 360
- **Weapons work was on the IBM commercial descendants**
  - IBM 7090 (1962-1964)
  - IBM 7094 (1964-1970)
  - About 8X faster than the IBM 704.
- **The first mass archiving system, the IBM 1360 Photo Store, is installed, 1966**



IBM 7030 circuit board

IBM 7030

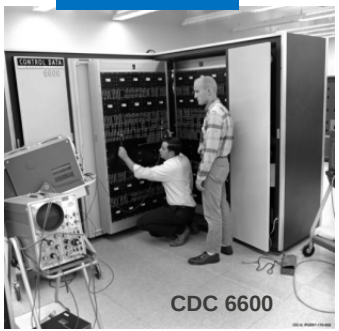
Control Data Corporation (CDC) systems were used for 20 years



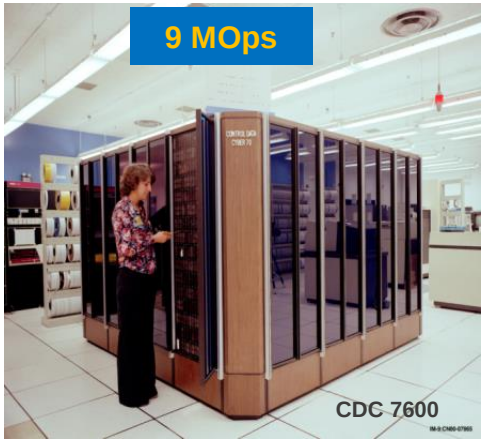
Courtesy of Cray, Inc.

- **CDC 6600: fastest type computer, 1964-1969**
  - – First liquid cooled system at Los Alamos
  - – At LANL, 1966-1981
- **CDC 7600: fastest type computer, 1969-1976**
  - – At LANL, 1971-1985
- **Both were designed by Seymour Cray**

7 MOps



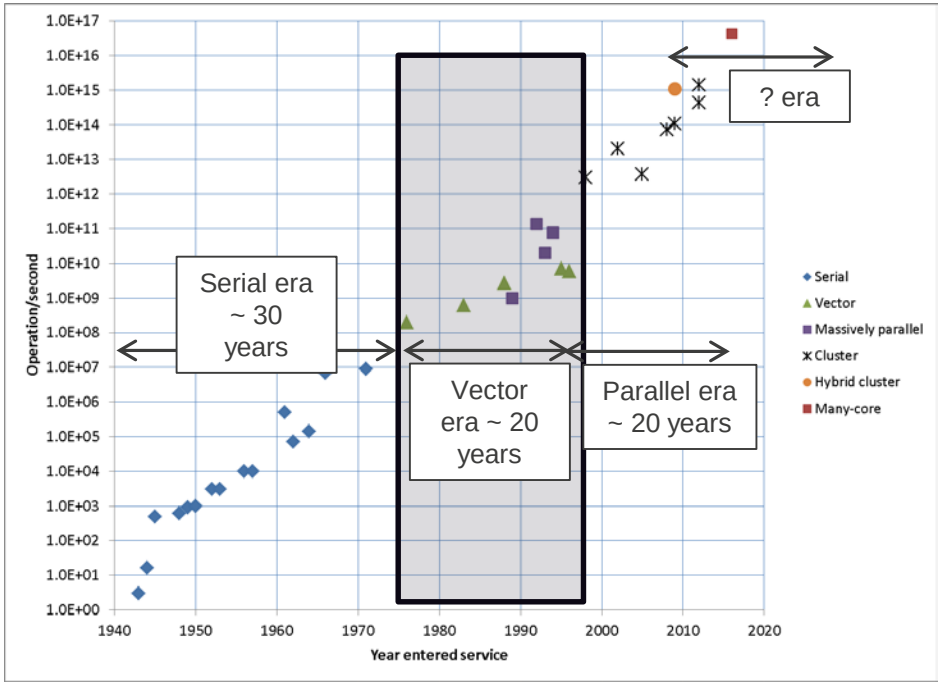
9 MOps



The vector era began in 1976

1981: Los Alamos Scientific Laboratory becomes Los Alamos National Laboratory

- **First parallel type calculations**
  - Same operation on several numbers
- **Vector machines required rewriting the weapon codes**



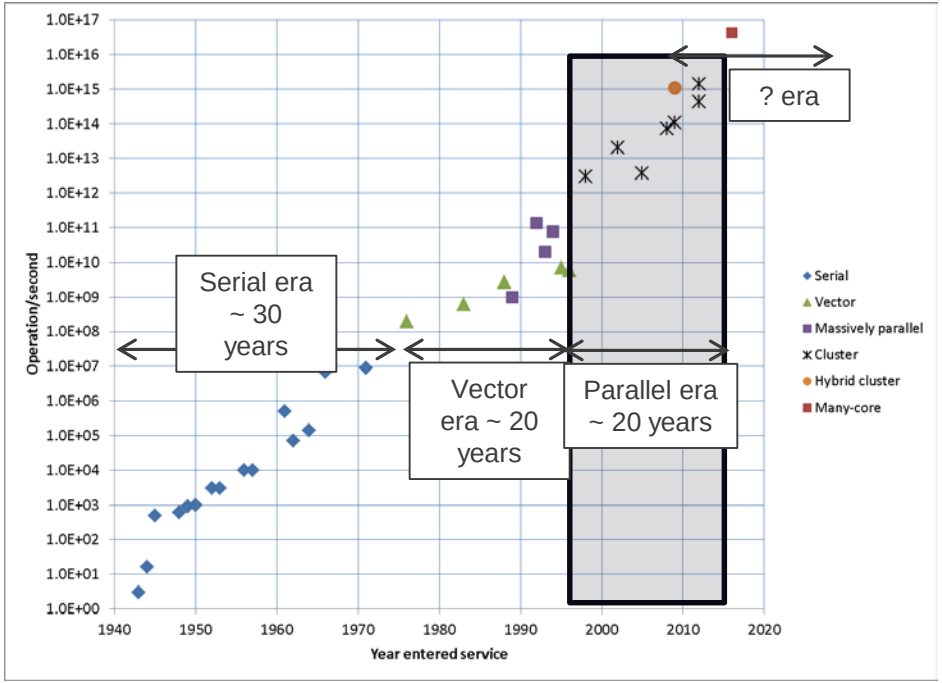
Vector, integrated circuits, 1976-1999

The Cray vector systems were used by the weapons program for about 30 years

- **Cray 1 was co-designed with Los Alamos over a 6 year period**
  - Los Alamos had serial #1
  - Fastest machine, used integrated circuits
  - Bare iron, LLL wrote operating system and LASL wrote compilers, math and graphics libraries
- **Cray XMP arrived in 1983, 4 CPU**
- **Cray YMP arrived in 1988, 8 CPU**
- **LANL kept a T94 until 2003 and a J90 until 2004**

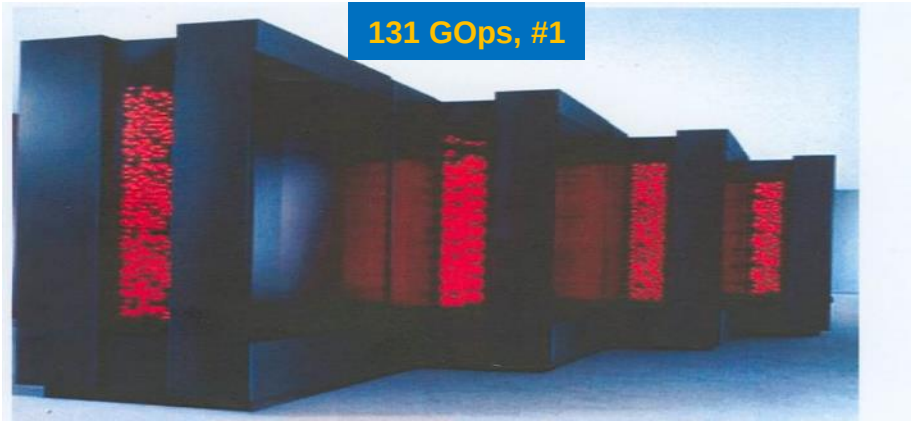
The 1990's was a time of change, resulting in parallel cluster systems

- **End of U.S. nuclear testing in 1992**
- **Change in computing technology**
- **Caused nation to found ASCI, 1995**
  - Accelerated Strategic Computing Initiative
  - Vision was a big leap forward in computing, both machines and codes; focused on 3D



Thinking Machines CM-2 & CM-5; Cray T_3D

- CM-5 was fastest machine
  - CM-2 and CM-5 used C*, a data parallel C, and a data parallel Fortran
- MPI 1.0 standard approved, 1991
  - LANL heavily involved
- UNIX workstations proliferated
- LANL collaborated with IBM and others to develop parallel archiving, the High Performance Storage System (HPSS), in 1992



TM CM-5

TM CM-2

CM-5: 1024 Sparc processors, no vector units, fat tree network, 131 GFs, 1992

CM-2: 65,536 single-bit processors, no vector units, hypercubic network, 2.5 GFs, 1989

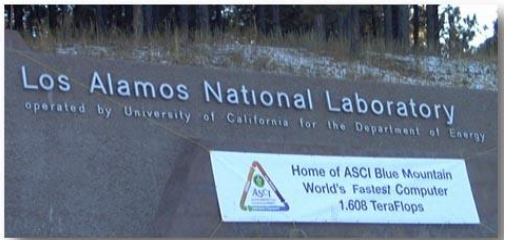
Cray T_3D

T_3D: 2048 Alpha processors, no vector units, 3D torus network, 19 GFs, 1994

ACL had other MPP prototypes such as the Motorola Monsoon, and the Intel iWARP

SGI Blue Mountain

- **Accelerated Strategic Computing Initiative (ASCI) started, 1995**
- SGI bought Cray in 1996
- Showed the need for large parallel file systems
  - ASCI Path Forward that developed the parallel file systems Lustre and Panasas
  - Launched the large, parallel, file system industry which lead to today's global parallel file systems
- System software hardened by ASCI for large scale machine: scheduler, MPI, Totalview, memory tools, compilers
- Jump started multiple software industries that are in widespread use in HPC today
  - Communication libraries, integrated visualization services, run time environments, etc



LANL's first commercial off-the-shelf cluster: 48 SGI Origin 2000 shared memory machines, each with 128 MIPS R10000 CPUs, a total of 6,144 CPUs, integrated as one system using a high performance interconnect (Cray's version of the *High Performance Parallel Interface HIPPI)*

3.1 TOps

- For a short time Blue Mountain was fastest machine at 1.6 TF
- Eventually upgraded to 3.1 TF, then #2

Cluster, 2002-2007

DEC/Compaq/HP Q

- **Very painful relationship with vendor**
  - Didn't buy last third of machine
- **First machine with a global parallel file system – we had to learn how to use it**
  - Proved that a global file system was viable
- **Optical interconnects started by ASC**
  - Technology used industry wide now
- **Silent data corruption discovered**
  - Industry wide concern now
- **Further hardening of system software for large scale HPC**
- **Became a very stable workhorse machine for DSW**
  - First LANL supercomputer to support tri-lab users
- **Parallel, 3D, interactive visualization was developed by ASCI**
  - LANL led in parallel visualization with Ensight, Paraview, and Powerwall

2048 HP ES45 servers (4 Alpha CPU SMPs) for 8192 CPU; Quadrics (QSW) dualrail switch interconnect, which uses a fat-tree configuration

Linux Networx Lightening & Cray Cielo

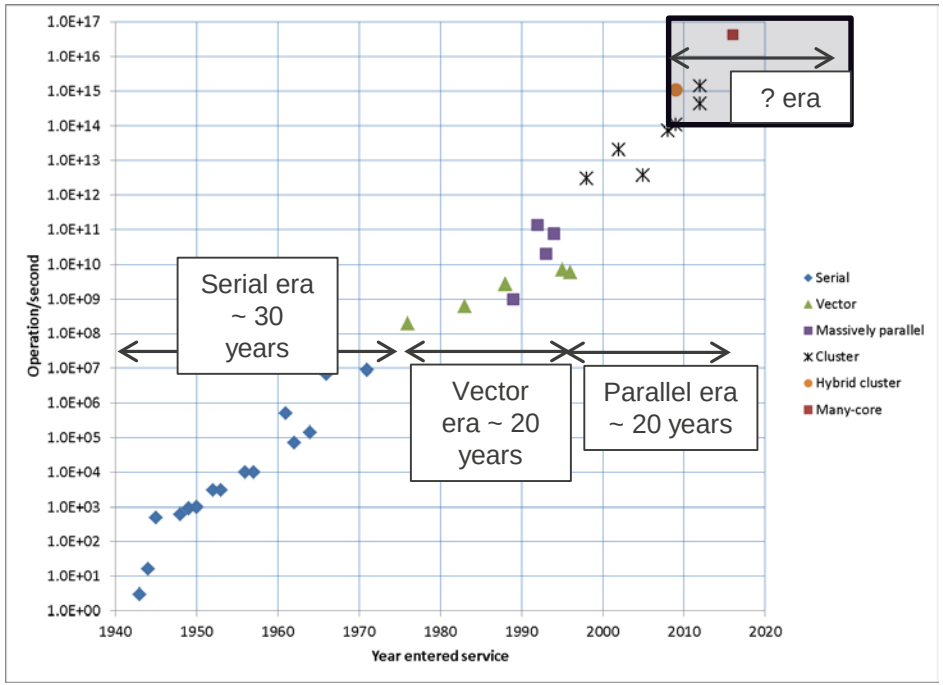
- LANL's first Linux cluster was Pink, a 1,024 node proof-of-concept machine
- Lightening was LANL's first production Linux cluster, 2005
- LANL acted as integrator, the first time in decades!
- Painful stand-up, but became a very solid production machine
- Began a long line of Commodity Technology Systems
  - Typhoon, Hurricane, Luna, Fire, Ice, …

Lightening: 2,816 AMD Opteron CPUs in 1,408 nodes

- Cray Cielo was the last conventional capability cluster
- Operational 2011-2016

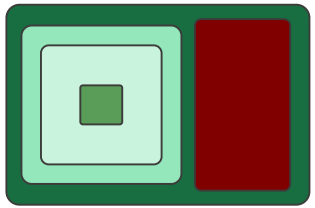
We are entering a new era of computing that is still being defined

- **Los Alamos is one of the leaders of the changes with Roadrunner and Trinity**



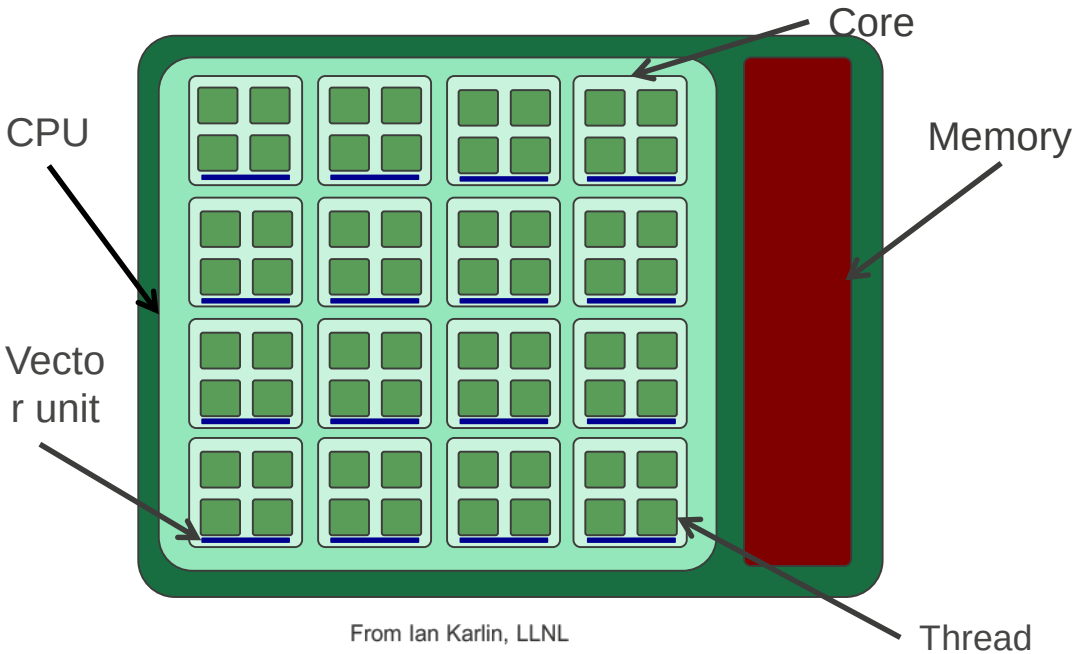
On node parallelism is the challenge on next-generation systems; driven by power usage

2000
1 cores X 1 threads/core
= 1 threads
(no vectorization)



ASCI codes
started with this!

What Industry Provides Today
16 cores X 4 threads/core = 64 threads **plus** vectorization



From Ian Karlin, LLNL

How do we use all of this?

Roadrunner, LANL/IBM, 1100 TF, 2009

- **First computer to deliver 1 Petaflop**
- **First large deployment of a hierarchical architecture**
  - Cell accelerators + PowerPC + Opteron
  - Very power efficient due to accelerators
  - Debuted #4 on Green500
- **First supercomputer built from non-traditional commodity processor**
- **Demonstrated to industry that hierarchical architecture is the path forward**
  - Power/programmability tradeoffs now crystal clear
  - Now many other machines are using accelerators
- **An example of co-design**
  - At LANL request, Cells were modified for double precision floating point by Sony/Toshiba/IBM

Taught LANL staff about small memory cores, and MPI+X programming model

SCC cooling infrastructure is being increased to accommodate ASC systems through 2030

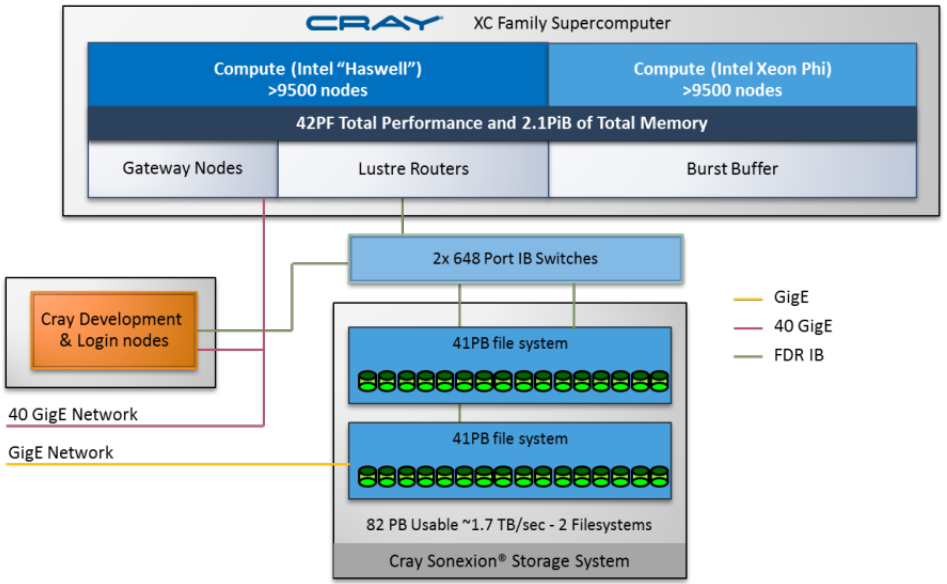
- **Current work will accommodate systems through about 2030**
- **Will have 40 MW power in the SCC and 33 MW of warm water cooling**
  - 75^{o} water to computer

Trinity is designed to support the most demanding stockpile simulations

- **Contract signed In July 2014 with Cray for an XC40 system**
  - 2 PB memory
  - A many-core architecture
- **Trinity Haswell general availability on July 5**
- **Trinity KNL has been merged with the Haswell partition**
- **Will allow 3D full-system simulations**
- **Push transition of weapon codes to next generation architectures**

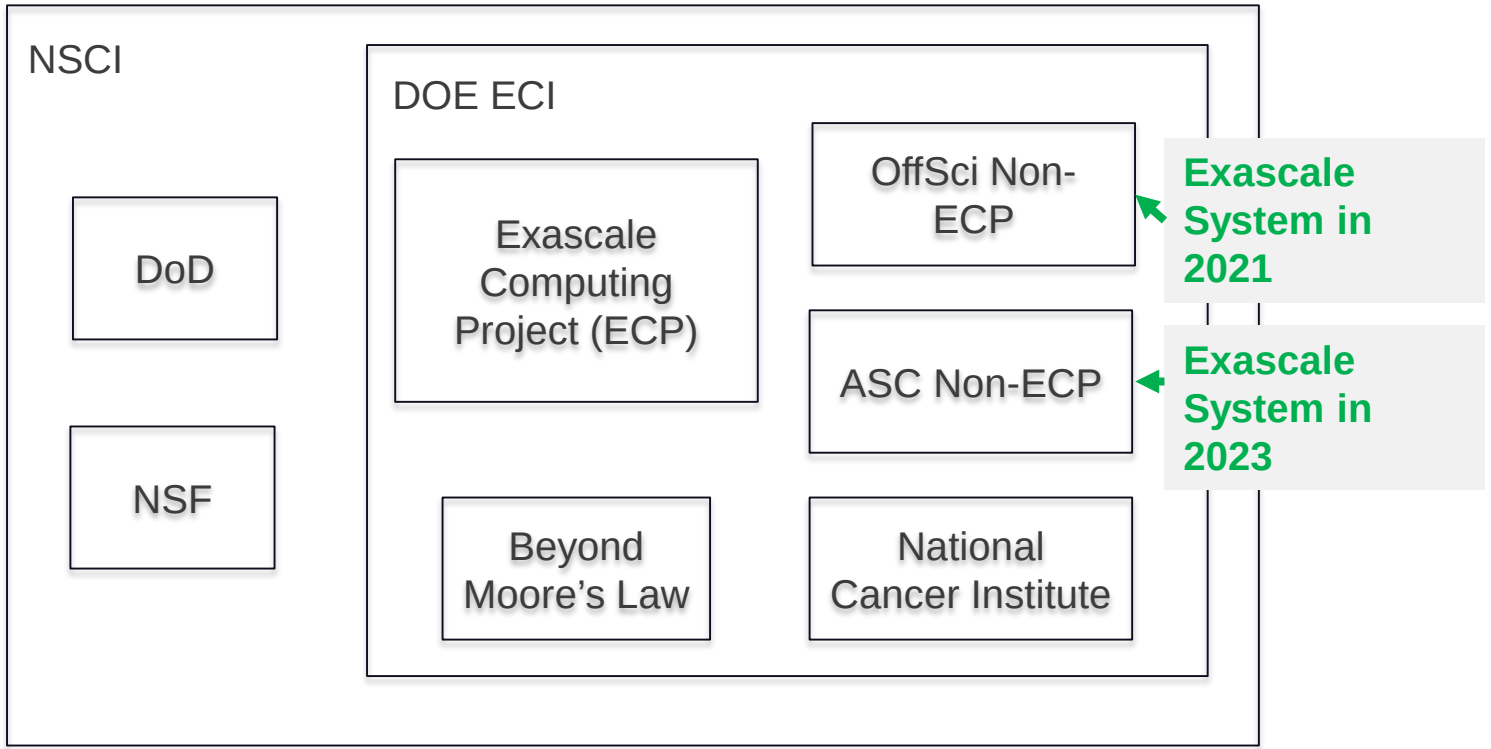
Cray Compute and Storage Infrastructure for "Trinity"

40 POps

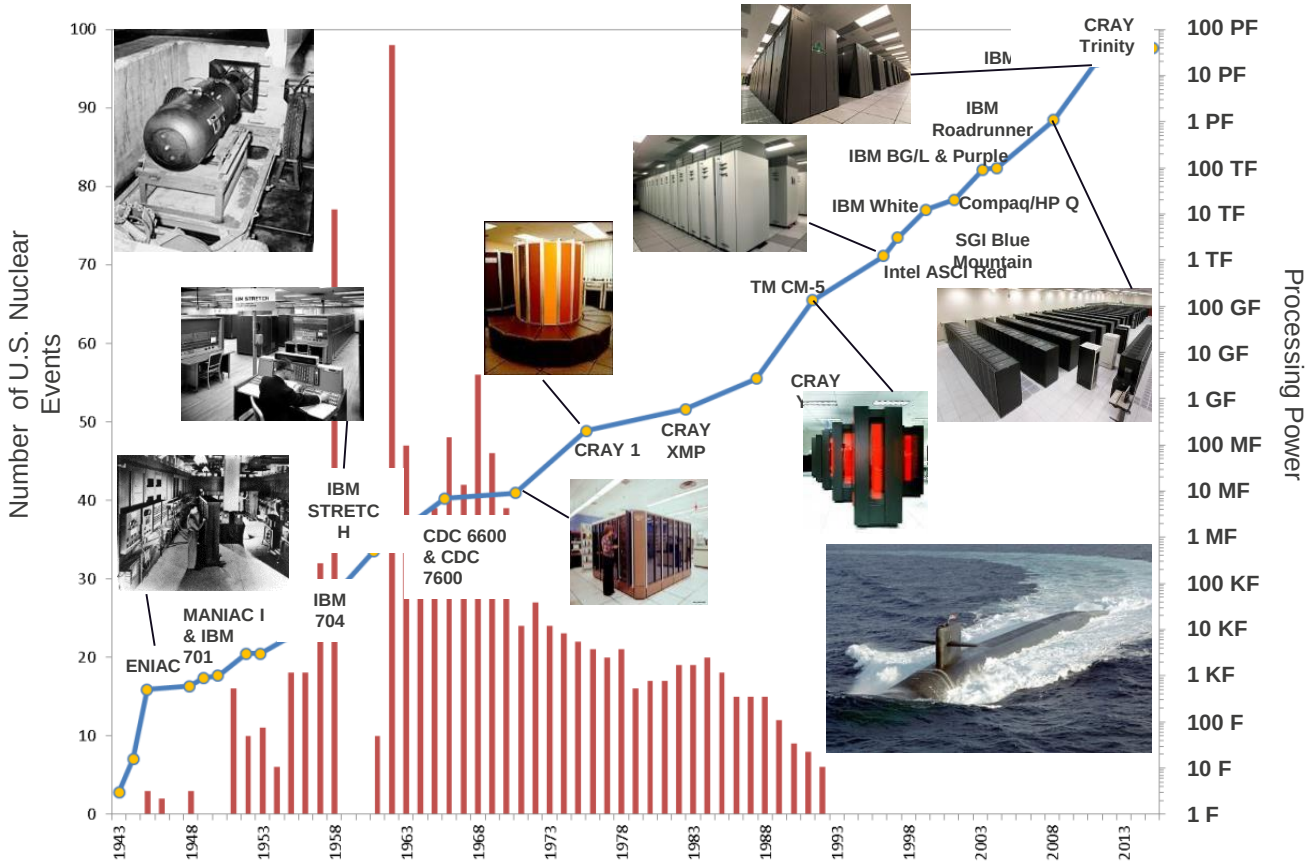


Crossroads contract under negotiation for a 2020 delivery!

National Strategic Computing Initiative (NSCI) and Exascale Computing Initiative (ECI)



Computing has always been a core component of the weapons program



Abstract

Los Alamos has continuously been on the forefront of scientific computing since it helped found the field. This talk will explore the rich history of computing in the Los Alamos weapons program. The current status of computing will be discussed, as will the expectations for the near future.

Biography

Dr. Bill Archer received his doctorate from the University of Oklahoma in 1988 for research on computational quantum chemistry carried out at Los Alamos. He was a post-doc at Rice University, a superconducting magnet designer at the Superconducting Super Collider, and an operations research analyst at the Center for Naval Analyses. While at CNA he was embedded with the Fleet for seven years.

Returning to LANL in 1999 he was project leader for a major integrated design code, studied the history of the weapons program, and has held a variety of line and program management positions in computational physics. He is currently the Program Director for the Advanced Simulation and Computing program that develops the weapon codes and classified high performance computing.