The Crucial Role of Government Funding for IT

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1-Page History of Computers

In the beginning ('40's – '50's) was Eckert, Mauchly and von Neumann

- Needed tables for shell firing angles for the military. Math and physics were understood; just needed faster computation.

In the '60's, large machines like IBM Sys/360 and CDC/Cray

- The supercomputer industry was funded largely by gov't purchases and research $

In the '70's, minicomputers, 1st supercomputers

In the '80's, fast microprocessors, PC's

In the '90's, the internet, browsers, cell phones

In the '00's, search engines, facebook, twitter, smartphones

1. At no point was it obvious what was coming next.
2. We have never been good at predicting what better computers will enable.
3. But it's clear that computers have transformed our world.

Direct Gov't Research Impact on Smartphones

FINFETs

GaAs RF power amp

Siri

The internet

Photo courtesy of Ellen M. Colwell, March 2015

GPS

Embedded antenna

Better batteries

Energy efficient computing

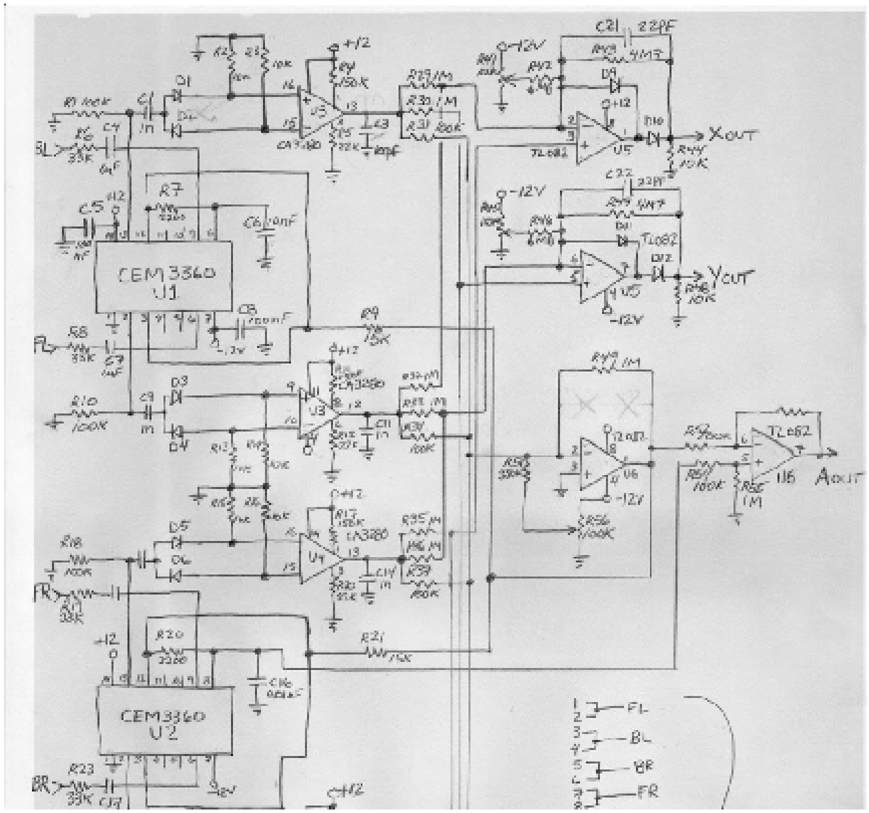
193nm photolithography

MEMS accelerometer/gyro/barometer

Some Previous Gov't Funded Successes

- ü Hardware Description Languages (schematics to programs...see next slide)
- ü Computer aided design (CAD)
- ü Mouse
- ü Graphics
- ü Trusted foundry services for military, intelligence communities
- ü Internet
- ü Client-server
- ü Energy-efficient computing
- ü PhD's to do research & design

Example: Schematics to HDL's



Schematics

Hardware Description Language

```
library IEEE;
use IEEE.std_logic_1164.all;
use IEEE.numeric_std.all;      -- for the unsigned type

entity COUNTER is
  generic (
    WIDTH : in natural := 32);
  port (
    RST   : in std_logic;
    CLK   : in std_logic;
    LOAD  : in std_logic;
    DATA  : in std_logic_vector(WIDTH-1 downto 0);
    Q     : out std_logic_vector(WIDTH-1 downto 0));
end entity COUNTER;

architecture RTL of COUNTER is
  signal CNT : unsigned(WIDTH-1 downto 0);
begin
  process(RST, CLK) is
  begin
    if RST = '1' then
      CNT <= (others => '0');
    elsif rising_edge(CLK) then
      if LOAD = '1' then
        CNT <= unsigned(DATA); -- type is converted to unsigned
      else
        CNT <= CNT + 1;
      end if;
    end if;
  end process;

  Q <= std_logic_vector(CNT); -- type is converted back to std_logic_vector
end architecture RTL;
```

Schematics are still good for circuit design & analysis, but are wrong level of abstraction for computers

Technologies for Computing’s Future

What’s needed? What’s next?

- Exascale (way too big an undertaking for private companies)
- Extremely energy efficient computing
- New switches beyond CMOS, graphene (see next slide)
- Novel alternative processors (neuro, quantum, bio)
- Extreme PNT
- Direct human interfaces
- EMP resistance
- Security
- Video analytics
- Specialized accelerators
- Nanophotonics
- Nanoscale fabrication
- Nano thermals
- Revolutionary energy sources
- SW, algorithms, tools
- Planning beyond the end of Moore’s Law

Bernstein et. al., “Device and Architecture Outlook for Beyond CMOS Switches”, proc. IEEE, V98, N12, Dec. 2010

Devices Benchmarked	Short	Device	State variable	Input	Output	Clock	Reference
15 nm CMOS	CMOS HP / CMOS LP	CMOS L_G = 15 nm	Q	V	V	–	Augustine 2009
Excitonic FET	ExFET	excitonic FET	Q	V	V		J. Appenzeller, Purdue, unpublished
Magnetic tunnel junction MTJ logic switch	MTJ Logic Switch	Co/MgO/NiFe GMR or Co/Cu/NiFe or TMR	magnetic polarization	I	I	–	C. Ross, MIT unpublished
All-spin logic	All-Spin Logic	semiconductor spin channel with nanomagnet input/output	electron spin	I	I	I	B. Behin-Aein 2010
Graphene PN Junction	Graphene PN Junction	field-controlled graphene p-n junction	electron wave phase	V	V	–	J.-U. Lee, SUNY Albany unpublished
Electronic Ratchet	Electronic Ratchet	backgated graphene structured-nanoribbon	Q	V	V	V	M. Stan, unpublished
Graphene thermal logic	Thermal	graphene thermal transistor 10 nm x 10 nm	T	T	T	–	Y. P. Chen, Purdue, unpublished
Binary decision diagram architecture	BDD Arch	generic	Q	V	V	V	S. Datta and V. Narayanan, Penn
Nanomagnet logic	NML	permalloy nanomagnet chains 40 x 60 x 60 nm	magnetic polarization	magnetic polarization	magnetic polarization	I	A. Dingler 2009
Graphene tunnel FET	Tunnel FET	graphene nanoribbon TFET w = 3 nm, L_G = 20 nm	Q	V	V	–	Q. Zhang 2008
InAs tunnel FET	InAs TFET	nanowire TFET 7 nm diameter, L_G = 30 nm	Q	V	V	–	Y. Lu, Notre Dame, unpublished
e-Struct. Modulation Transistor	e-Struct. Modulation Trans.	edge-gated graphene nanoribbon	Q	V	V	–	Raza, Univ. Iowa unpublished
Reconfigurable array of magnetic automata	RAMA	gated multiferroic CoFeO/ BiFeO(BaTiO) composite	magnetic polarization	V	V	V	S. Wolf, unpublished
Bilayer pseudospin FET	BiSFET	graphene/insulator/graphene bilayer pseudospin FET	pseudospin	V	V	V	S. Banerjee 2009
Resonant-enhanced-injection FET	RIEFET	III-V heterojunction resonant tunneling FET	Q	V	V	–	L. F. Register, Univ. TX Austin, unpublished
Heterobarrier tunnel FET	HeTFET	III-V heterojunctions TFET	Q	V	V	–	L. F. Register, Univ. TX Austin, unpublished
Spin wave phase logic	Spin Wave	spin wave 3-input majority gate in NiFe	spinwave phase	V	V	–	A. Khitun 2008b
Magnetic tunnel junction spin torque transfer	MTJ/STT	Spin torque logic with magnetic tunnel junctions and CMOS	magnetic polarization	V	V	–	D. Markovic, UCLA unpublished
Spin torque amplifer	Spin Torque Amplifiers	MgO tunnel junction	magnetic polarization	V	V	–	A. Krivorotov, UCLA unpublished

Moore’s Law is dying

Lots of CMOS alternatives

None ready to go though

Fig. 1. NRI Research Programs, including NRI-NIST Centers and projects at NSF Nanoscience Centers.

Why gov't funding for IT is right

Why fund industry when
(a) it's rich and
(b) they're going to "do it" anyway?

Hint: They won't.

1. **Capitalism is about *competition***, not cooperation.
   1. Competition fosters innovation primarily towards boosting **immediate profits**, seldom towards long-term payoffs.
      1. Companies don't see opportunities outside of immediate profit
         1. E.g. security, productivity, apps outside their experience
         2. Definitely was my experience at Intel Corp.
      2. New microprocessor + new silicon process + new fab requires **$10B investment. Extremely risky**, not much room for exploration.
         1. I heard this all the time while at DARPA, from Intel, NVIDIA, IBM…
   2. Sometimes competitors should cooperate but need honest broker
      1. **Industry standards** benefit everyone
      2. Organizations like **IEEE** take lead here
      3. But there's a role for **gov't** in **developing right tech to standardize**: GPS, communications, internet protocols, CAD, languages, photolitho, PNT/MEMS

Why gov't funding for IT is right, cont.

COTS Threats & Opportunities

2. The **U.S. military is high-tech**, largely based on commercial off-the-shelf (**COTS**) components.

   a. Allows DoD **to leverage the huge investments** made by the vendors

   b. But opens **vulnerabilities**

      - Counterfeiting
      - Adversaries can buy same components
      - Gov't investments help steer designs towards U.S. needs, returns insights on how best to use components, gives early knowledge, helps us see future more clearly

   c. We have to

      - Leverage COTS where we can
      - Counter it when adversaries wield it against us
      - Transcend COTS when industry won't go where DoD needs to go

Why gov't funding for IT is right, cont.

It isn't just about the IT industry

3. The computer industry directly affects all science, health, manufacturing, entertainment, **communications…are there any fields that are still not heavily leveraging IT?**

   a. The **auto industry has been riding IT's coattails** since the 1970's

      - Dozens of processors, millions of lines of code per modern car

   b. The **entertainment industry has been revolutionized**, from production to distribution to market size opportunities

   c. Large Hadron Collider, new neuro/brain science initiatives, genetic engineering, new drug discovery…**healthcare is now IT-based**

Bottom Line: We Don't Know What's Next, But We'd Better Win!

Nobody can predict the future, not even with Moore's Law as a compass

...and Moore's Law is about to expire**.**

There are **still several years left on Moore's Law**, so computers will get much faster and more capable.

If history is a guide, these **faster computers will enable new applications** in every field of human endeavor.

Our economic system will exploit many of these opportunities but will miss some due to risk, profit-fixation, or habit. **Government funding & direction** has been crucial to leapfrogging these limits in the past.

The U.S. cannot afford to come in second in IT.

END