

Bazaar Design of Nano and Micro Manufacturing Equipment

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1. Introduction

- ◆ Nanotechnology is rapidly emerging and has tremendous potential in several industries
 - materials
 - medicine/health
 - biotech
 - environment
 - electronics/computing
 - aerospace
 - agriculture
 - energy

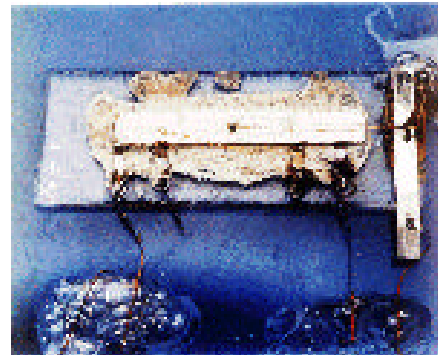
- ◆ Its future depends upon:
 - collaboration in scientific and engineering research -- we need to work together
 - continuous innovation in manufacturing technology

- ◆ This presentation is about ***fostering continuous innovation*** in the manufacture of nano (and micro) scale structures

2. Miniaturization of Semiconductors

- ◆ ICs are a great scientific and engineering achievement

- Transistors (Bell Labs, 1947)
- Silicon Transistors (TI, 1954)
- Integrated Circuits (TI and Fairchild, 1958)
- 40+ years of continuous innovation



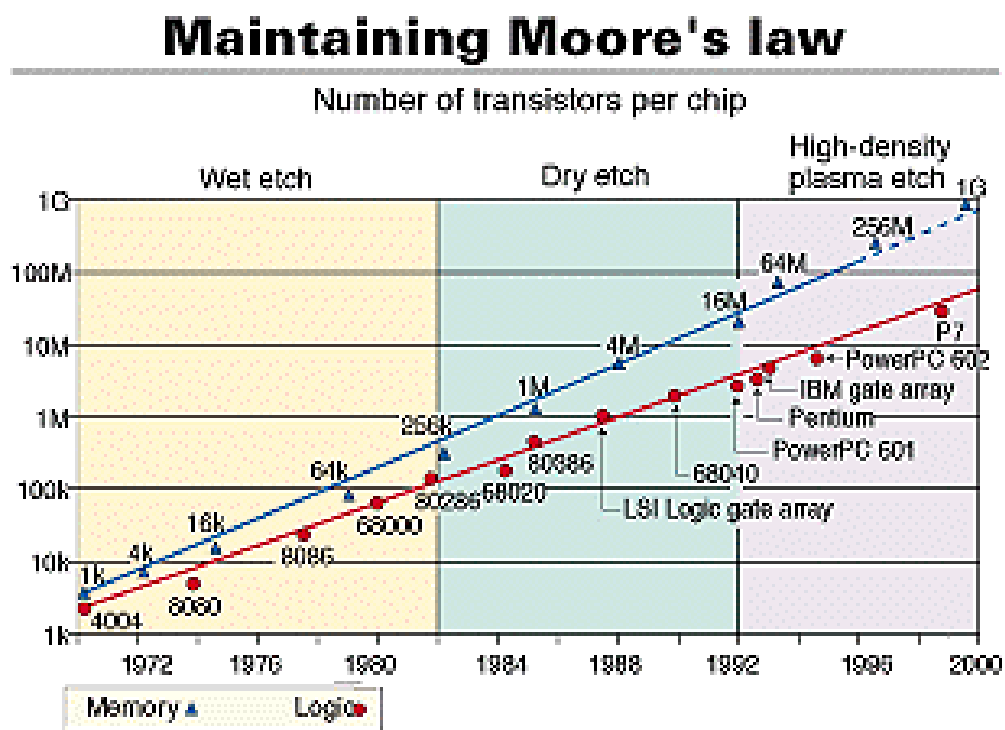
**1st Integrated Circuit,
Jack Kilby, TI, 1958**

- ◆ Continuous performance improvement through manufacturing technology

- Precision \Rightarrow transistor density (millions per IC)
- Batch Mfg \Rightarrow cost per transistor (cents per thousands)
- Process Controls \Rightarrow improved yields

◆ Moore's Law:

Every 18 months, the number of transistors on typical ICs will double (Gordon Moore, 1964).



- ◆ The ability to fit more transistors on a single IC and increase IC size is due to innovation by ***semiconductor equipment manufacturers*** -- the power behind the chips.

DRAM generation	First Mfg. Year	Chip Size (mm ²)	CD (μm)	LW Control (nm)	Overlay Accuracy (nm)
4 Mb	1989	80-90	0.7	70	240
16 Mb	1991	120-140	0.5	50	170
64 Mb	1994	170-200	0.35	35	120
256 Mb	1997	250-300	0.25	25	80
1 Gb	2000	350-400	0.18	18	60

In nanotechnology, how will we match or surpass Moore's Law?

3. The Scientific Method

- ◆ Science evolves models for natural phenomena

Hypothesis \Rightarrow Theory \Rightarrow Law

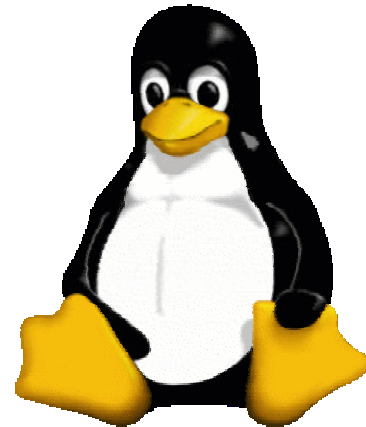
- ◆ The evolution depends upon the ability to **test and refine** hypotheses and theories
- ◆ Its is a collaborative effort, which requires the **open exchange of information**
 - Share hypotheses, theories, and laws
 - Share experimental setups
 - Share experimental results
 - Share the expense
- ◆ The Human Genome project

4. Open Source Software

- ◆ Hackers share source code for scientific benefit
- ◆ Open Source is based on Richard Stallman's notion of "**Free Software**"
 - "as in freedom of speech, not free beer"
 - source code should be freely shared and distributed, like other forms of scientific knowledge
 - Free Software
 - Source code is available **free** (without fee).
 - Anyone is **free** to use or modify the program by changing the source code
 - Anyone is **free** to distribute the original or modified programs (*for fee or for free*)
 - 1984: Stallman starts the GNU Project at MIT's AI Lab to develop Free Software and later founds the Free Software Foundation
- ◆ GNU/Free Software Foundation still alive

- ◆ Then comes along Linus Torvolds, a student at the University of Helsinki (Finland)

- Linus decides to build a new operating system based off Minix, a small UNIX OS
 - Version 0.02 in 1991
 - Version 1.0 in 1994
 - Version 2.2 in 1999



Penguin image by lewing@isc.tamu.edu

- How successful is Linux?
 - Estimated 14,000,000 users world wide
 - So many that some believe it is a giant killer



- ◆ BUT, Linus didn't do it alone!
 - He was helped by thousands of developers
 - Linux is licensed under the GNU GPL
 - Linus coordinated the development

- ◆ Linus's approach to developing the Linux OS:
 - *Delegate everything you can*
 - *Release early and often*
 - *Be open to the point of promiscuity*

◆ **"The Cathedral and the Bazaar"**

Eric Raymond, Linux Kongress 97

<http://www.tuxedo.org/~esr/writings/cathedral-bazaar/cathedral-bazaar.html>

The Cathedral Approach -- "Conventional Method"

" I believed that the most important software needed to be built like cathedrals, carefully crafted by individual wizards or small bands of mages working in splendid isolation, with no beta to be released before its time."

The Bazaar Approach -- "Linus's Method"

*"No quiet, reverent cathedral-building here -- rather, the Linux community seemed to resemble a great **babbling bazaar** of differing agendas and approaches out of which a coherent and stable system could seemingly emerge only by a succession of miracles."*

- ◆ Raymond postulated that 19 aphorisms made Linus's approach successful. Here's a sampling:

"Every good work of software starts by scratching a developer's personal itch."

"Good programmers know what to write. Great ones know what to rewrite (and reuse)."

"Plan to throw one away; you will, anyhow."

"When you lose interest in a program, your last duty to it is to hand it off to a competent successor."

"Treating your users as co-developers is your least-hassle route to rapid code improvement and effective debugging."

"Release early. Release often. And listen to your customers."

"Given a large enough beta-tester and co-developer base, almost every problem will be characterized quickly and the fix obvious to someone."

"The next best thing to having good ideas is recognizing good ideas from your users. Sometimes the latter is better."

- ◆ In 1997: Raymond, O'Reilly and Augustin established "**Open Source**" as an alternative expression of the "Free Software"
- ◆ In 1997, Bruce Perens published the Open Source Definition
 - Established requirements for Open Source license agreements
 - Examples of current OSI Certified licenses:
 1. GNU General Public License
 2. GNU Library Public License
 3. BSD License
 4. Artistic License
 5. MIT License
 6. Mozilla License
 7. Qt Public License
 8. IBM Public License
 9. Python License
- ◆ Linux isn't the only commercial endeavor with an Open Source strategy

5. Open Design -- A Bazaar Design Method

- Late 1998, Dr. Sepehr Kiani realized that designers could benefit from Open Source policies for sharing design information
- Early 1999, Kiani convinces Dr. Ryan Vallance and Dr. Samir Nayfeh of Open Design benefits, especially in machine design applications
- Dr. Nayfeh, having recently joined Mechanical Engineering faculty at MIT, initiated the Open Manufacturing Equipment project (OME project) in mid-1999
 - <http://www.opendesign.mit.edu>
- Dr. Vallance, joined the Mechanical Engineering faculty at the Univ. Kentucky and started the Open Microfabrication and Nanofabrication Equipment project (The OMNE Project) in early-2000
 - <http://www.engr.uky.edu/psl/omne>

- ◆ 2000, Kiani, Vallance, and Nayfeh found the **Open Design Foundation** (non-profit organization):
 - to promote Open Design methods
 - develop and maintain an Open Design Definition -- standards for licenses
 - certify Open Design license agreements
 - distribute (for free) information on licensed Open Design projects

<http://www.opendesign.org>

6. The Open Design Definition

- ◆ ODF is currently writing the Open Design Definition -- a standard for Open Design licenses
- ◆ Draft 0.2 is being discussed in the ODF email list odf-list@opendesign.mit.edu, subscribe at ODF web site
- ◆ Based on principles in the Open Source Definition (Perens, 1997)

7. The Open Design Definition, V 0.2

Free Redistribution

Licenses may not restrict any party from selling or giving away an embodiment as a component within an aggregate embodiment.

Free Design Documentation

Licenses must require that an embodiment include design documentation or ensure that documentation is available for no more than a reasonable reproduction cost (preferably via Internet download). Documentation must be in a preferred format for modifications.

Derived Works

Licenses must allow modifications and derived works, and they must allow them to be redistributed under the terms of the original license.

Integrity of the Designer's Documentation

Licenses may restrict documentation from being distributed in modified form only if the license allows distribution of "retrofit documentation". Licenses must require derived works to carry a different name or version number than the original design.

Open Design Definition V. 0.2, continued

Discrimination Against Persons, Groups, or Fields of Endeavor

Licenses must not discriminate against any person, group of persons, or any specific field of endeavor.

Distribution of Licenses

The rights attached to an embodiment must apply to all to which the embodiment is redistributed without the need for executing additional licenses.

License Must Not Be Product Specific

If a subset of an open design is extracted from an aggregate open design, then all rights from the aggregate design must be maintained with the subset design.

License Must Not contaminate Other Designs

Licenses must not restrict other embodiments that are distributed along with an Open Design embodiment.

8. Necessary Preconditions?

- ◆ a community of participants,
- ◆ participants are designers and users
- ◆ low economic cost of converting the design to a useful embodiment
- ◆ low cost of an imperfect embodiment
- ◆ projects should be initiated with a pre-existing design
- ◆ the community should perceive some promise to the pre-existing design
- ◆ the project leader must recognize good designs (and also hopefully originate good designs)
- ◆ the participants must possess certain skills
- ◆ a medium for effective information sharing (such as internet)
- ◆ participants should join the effort by self-selection or volunteering

9. Sharing Open Design Information

- ◆ Information must be in a form that is convenient for sharing and "easily" modifiable
 - Raw CAD data will likely be required
- ◆ Information will be revision controlled using Concurrent Versioning Software (CVS)
- ◆ Data will be available for free download/upload via the internet
- ◆ Dr. Sepehr Kiani is architecting the data storage using CVS (skiani@alum.mit.edu)

10. Potential Benefits of Open Designs

- No need to reinvent wheels
- Rapid debugging of processes and equipment
- Develop robust designs
- Share development expenses
- Increase design longevity
- Establish standards
- Reduce the cost of ownership and support
- Increase modularity, reconfigurability, and interchangeability
- Eliminates single-source availability
- Promote 3rd Party Enhancements

11. The OMNE Project

Open Microfabrication and Nanofabrication Equipment

<http://www.engr.uky.edu/psl/omne>

- ◆ Current Projects are in micro machining

1. Open Micro EDM Machine

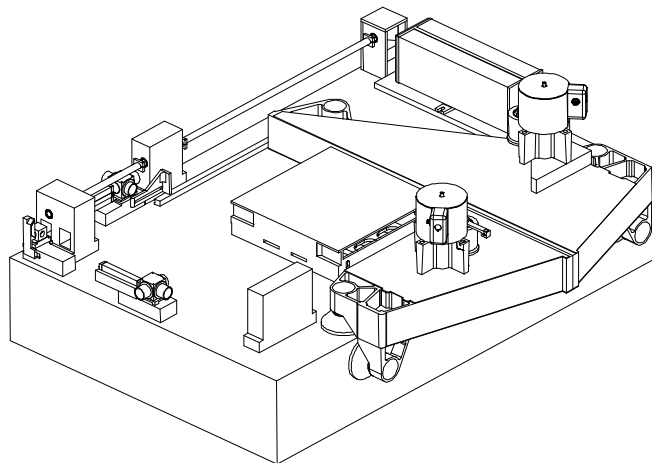


Figure 1: Micro EDM Machine

- Pro/E CAD data will soon be available for free download at the Open Design Foundation web site.
2. Open Controller/Generator for Micro EDM
 3. Open Source Simulation of Micro EDM
- ◆ ***Looking for the first nano-scale project!***

12. Summary

- ◆ Open Design is a potential method for fostering innovation
 - It has similarities to the Scientific Method
 - It is based on the successful principles applied in Open Source software
- ◆ Open Design guarantees that:
 - design documentation is available for *free*
 - anyone is *free* to use or modify an Open Design by changing the design documentation
 - anyone is *free* to distribute the original or modified design, for fee or for free
- ◆ These freedoms yield potential benefits to both manufacturers and equipment manufacturers
- ◆ The OMNE Project at the University of Kentucky is focusing on Open Designs of Microfabrication and Nanofabrication Equipment

13. Contact Information and Reprints

- ◆ PDF file is available at the Precision Systems Laboratory's web site:

<http://www.engr.uky.edu/psl>

- ◆ If you would like discuss in detail, please contact me at:

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