• It depends on what you mean by ‘title’
WOULD YOU RUN WINDOWS ON YOUR GRANDMOTHER’S PACEMAKER?

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LINUX IS STILL OBSOLETE

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HOW DO WE GET OUT OF THIS MESS?

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COMPUTING ERAS

- Jurassic Era

BRONTIAC  ENIAC  STEGIAC
OUTLINE OF TALK

- Vague generalities
- Mode switch
- Nitty-gritty details of my research and related research
- New stuff
## MORE ERAS OF COMPUTING

<table>
<thead>
<tr>
<th>Era</th>
<th>Example</th>
<th>OS</th>
<th>Goal of OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jurassic</td>
<td>ENIAC</td>
<td>-</td>
<td>(none)</td>
</tr>
<tr>
<td>Mainframe</td>
<td>IBM 360</td>
<td>OS/360</td>
<td>Make it work</td>
</tr>
<tr>
<td>Mini</td>
<td>PDP-11</td>
<td>UNIX</td>
<td>Make it fast</td>
</tr>
<tr>
<td>PC</td>
<td>x86</td>
<td>Windows</td>
<td>Make it pretty</td>
</tr>
<tr>
<td>Embedded</td>
<td>Camera</td>
<td>QNX (?)</td>
<td>Make it invisible</td>
</tr>
<tr>
<td>Ubiquitous</td>
<td>?</td>
<td>?</td>
<td>Make it helpful</td>
</tr>
</tbody>
</table>

Up until now, goal of OS was overcoming hardware limitations (e.g., virtual memory to pretend there was enough memory)
MAKING PREDICTIONS

- Making predictions is hard
- Especially about the future
- People keep trying though
FAMOUS PREDICTIONS

• “Heavier than air flying machines are impossible”
  – Lord Kelvin, President of the Royal Society (1895)

• “The time will come when children will be taught everything by moving pictures. They will never be obliged to read history again”
  – D.W. Griffith, director of Birth of a Nation (1915)

• “There will be only one orchestra left on earth, giving nightly worldwide concerts”
  – Bruce Bliven EiC of The New Republic on radio (1922)
MORE FAMOUS PREDICTIONS

• “The problem with television is that people must sit and keep their eyes glued to the screen; the average American family hasn't time for it.”
  – *New York Times* editorial (1939)

• “I think there is a world market for five computers”
  – T.J. Watson, Chairman of IBM (1945)

• “In the future, computers may weigh only 1.5 tons”
  – *Popular Mechanics* magazine (1949)
YET MORE FAMOUS PREDICTIONS

• “Nobody needs a computer in their house”
  – Ken Olson, President of DEC (1957)
  – (DEC no longer exists. Watch out when the boss says something really dumb)

• “640K ought to be enough for anyone”
  – Bill Gates, CEO of Microsoft (1981)

• “In 5 years, everyone will be running GNU”
  – Andy Tanenbaum, village idiot (1992)
MOORE’S LAW

• Conservative approach: Use Moore’s Law
THE VRIJE UNIVERSITEIT IN 1973

- PDP-11/45
# OUR PDP-11/45 IN 1973

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>PDP-11/45</td>
</tr>
<tr>
<td>Clock</td>
<td>1 MHz</td>
</tr>
<tr>
<td>RAM</td>
<td>16 KB (1 byte = $1)</td>
</tr>
<tr>
<td>Size</td>
<td>2 m³</td>
</tr>
<tr>
<td>Disk</td>
<td>2.5 MB (14-inch RK05)</td>
</tr>
<tr>
<td>Modem</td>
<td>300 bps (via acoustic couplers)</td>
</tr>
<tr>
<td>Wireless</td>
<td>-</td>
</tr>
<tr>
<td>Price</td>
<td>$80,000</td>
</tr>
</tbody>
</table>
MY HOME PC IN 2003

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>2003/1973</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Pentium 4</td>
<td></td>
</tr>
<tr>
<td>Clock</td>
<td>3 GHz</td>
<td>3,000x faster</td>
</tr>
<tr>
<td>RAM</td>
<td>1 GB</td>
<td>60,000x bigger</td>
</tr>
<tr>
<td>Size</td>
<td>0.2 m$^3$</td>
<td></td>
</tr>
<tr>
<td>Disk</td>
<td>1.2 TB</td>
<td>500,000x bigger</td>
</tr>
<tr>
<td>Modem</td>
<td>8 Mbps (ADSL)</td>
<td>30,000x faster</td>
</tr>
<tr>
<td>Wireless</td>
<td>54 Mbps</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>$3000</td>
<td>30x cheaper</td>
</tr>
</tbody>
</table>

$3000 \times 60,000 \times 500,000 \times 30,000 \times 30 = 10^{20}$
MOORE’S LAW FOR AIRCRAFT

• Suppose aircraft obeyed Moore’s law 1973-2003
• Range, seating capacity, speed, cost each $10^5 \times$ better

• In 2003 a high-end plane would have
  - Range: fly nonstop around the world 20,000 times
  - Seating capacity: 2 million people
  - Speed: fly from San Francisco to London in 400 msec
  - Cost: San Francisco-London ticket would be 5 cents
  - Probably have to wait six months for your baggage in London
  - One out of every 500 flights would crash
  - Aircraft engineers would be proud of this safety record
# THE WORLD ACCORDING TO MOORE (IN 2033)

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>2033/2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Pentium 12</td>
<td></td>
</tr>
<tr>
<td>Clock</td>
<td>10 THz</td>
<td>3,000x faster</td>
</tr>
<tr>
<td>RAM</td>
<td>16 PB</td>
<td>60,000x bigger</td>
</tr>
<tr>
<td>Size</td>
<td>Book</td>
<td></td>
</tr>
<tr>
<td>Disk</td>
<td>600 PB</td>
<td>500,000x bigger</td>
</tr>
<tr>
<td>Modem</td>
<td>160 Gbps</td>
<td>30,000x faster</td>
</tr>
<tr>
<td>Wireless</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>$100</td>
<td>30 x cheaper</td>
</tr>
</tbody>
</table>
REALITY CHECK

- Heat problem: Pentium 4 uses ca. 100 watts
- Consequence: Can’t improve clock speed much
- Memory access time is not improving much
- Likely scenario: multicore chips
• I just bought a new mouse
• It came with a CD-ROM containing four programs
• I installed the first one: it was 22 MB
• I didn’t dare install the rest
• Who needs a 90-MB mouse?
SOFTWARE BLOAT

- Put 50 lines/page, 800-page books, 25 to a shelf

NT 3.1
1993
6M LoC
SOFTWARE BLOAT

- Put 50 lines/page, 800-page books, 25 to a shelf

NT 3.5
1994
10M LoC
SOFTWARE BLOAT

- Put 50 lines/page, 800-page books, 25 to a shelf

NT 4
1996
16M LoC
SOFTWARE BLOAT

- Put 50 lines/page, 800-page books, 25 to a shelf

W2000
2000
29M LoC
SOFTWARE BLOAT

- Put 50 lines/page, 800-page books, 25 to a shelf

XP
2002
50M LoC
## MOORE MEETS SOFTWARE

<table>
<thead>
<tr>
<th>Year</th>
<th>1973</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>UNIX V6</td>
<td></td>
</tr>
<tr>
<td>Lines of code</td>
<td>13,000</td>
<td></td>
</tr>
<tr>
<td>Boot time</td>
<td>10 sec</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>30 years later</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>Windows XP</td>
<td></td>
</tr>
<tr>
<td>Lines of code</td>
<td>50 million</td>
<td>4000x bigger</td>
</tr>
<tr>
<td>Boot time</td>
<td>2 min</td>
<td>12x slower</td>
</tr>
</tbody>
</table>

Are current OSes $10^{20}$x better than UNIX V6? We have VM, GUIs, Web, but is this $10^{20}$x?
SOFTWARE IN 2033

- Windows NT grew from 6 to 50 MLoc in 9 years
- In 2033, Windows-33 will occupy 1.6 million books
- That is 3x the size of the Caltech library
- Windows won’t pass Harvard library until 2043
MYHRVOLD’S LAWS

- “Software is a gas. It expands to fill its container.”
- “Software is getting slower faster than hardware is getting faster”
LIFE IN THE REAL WORLD

My computer is broken
LIFE IN THE REAL WORLD

You are a computer genius

E = mc²
LIFE IN THE REAL WORLD

Please fix it

E = mc²

Mr. Fixit

Note: I didn’t think of E = mc²
It was a guy with much more hair
Besides, I’m not a physicist any more
LIFE IN THE REAL WORLD

Please fix it

P = NP

Mr. Fixit
Of course, it is never a hardware problem. It is always the operating system. And Linux is just almost as bad as Windows.
MY FRIEND

• I taught him about the CONTROL key in Windows
• Has masters in engineering from Cornell
• Has masters from the MIT Sloane School
• Uses computers 8 hours a day for his business
• Not a dummy and not a beginner
• He didn’t know about the CONTROL key
• Imagine what people lacking Ivy League engineering degrees don’t know
MORE COUSINS

• April 2005: My cousin had a computer full of spyware
• It ran in the background, consumed 90% of CPU
• She was about to throw out the computer
• I formatted the disk and reinstalled Windows
• June 2005: Another cousin, same thing
“On a recent Sunday morning when Lew Tucker's Dell desktop computer was overrun by spyware and adware - stealth software that delivers intrusive advertising messages and even gathers data from the user's machine - he did not simply get rid of the offending programs. He threw out the whole computer.”

- Tucker has a Ph.D. in computer science !!!
- NYT article went on to give many more examples
- Nice to know my family is not weird
THE TELEVISION MODEL

1. You buy the television
2. You plug it in
3. It works perfectly for the next 10 years
THE COMPUTER MODEL

1. You buy the computer
2. You plug it in
3. You install service packs 1 through 9f
4. You install 18 new emergency security patches
5. You find and install 7 new device drivers
6. You install antivirus software
7. You install antispyware software
8. You install antihacker software (firewall)
9. You install antispam software
10. You reboot the computer
11. It doesn’t work
12. You call the helpdesk
13. You wait on hold for 30 minutes
14. They tell you to reinstall Windows
The New York Times recently reported that 25% of computer users have gotten so angry at their computer that they physically hit it.

Have you ever punched your car? Spanked your stereo?
A NEED TO RETHINK OPERATING SYSTEMS

• Operating systems research need to be refocused
  – We have nearly infinite hardware on PC-class machines
  – Plenty of CPU cycles, RAM, bandwidth
  – Current software has tons of (useless) features
  – Consequently, the software is slow, bloated, and buggy

• To achieve the TV model, future OSes, must be
  – Small
  – Simple
  – Modular
  – Reliable
  – Secure
THIS TALK IN A NUTSHELL

- Current software is full of useless features
- This makes the code bloated and unreliable
- Future software should be simple, reliable, secure
- Our research should be aimed at achieving this
WHAT AM I DOING ABOUT ALL THIS?

- Royal Dutch Academy of Sciences thinks there are too many old fogies wandering the halls of academia
- Every year 5 fogies are targeted for garbage collection
- Last year I was one of them
- Told: go off in a corner and stop blocking youngsters
- Consolation prize: grant of $2.5 million for research
- So I am not accountable to anyone now
MODE SWITCH
MY RESEARCH TO ACHIEVE THESE GOALS

- Remember MINIX?
- Released in 1987
- Everyone was bugging me to add more features
- I wanted to keep it simple while waiting for the messiah

Richard Stallman
MINIX 3 DESIGN

• Modularity is the most important idea
• Kernel is tiny (3800 LoC vs. 2½ million for Linux)
• Bug rates: 5-16 bugs per 1000 LoC
• Low interrupt latency (10 microsec) for real time
• Each driver & server is a separate user process
• API of 35 kernel calls (e.g., I/O) for drivers, servers

Jorrit Herder
ARCHITECTURE OF MINIX 3

Microkernel handles interrupts, processes, scheduling, IPC

User mode

Process

Servers

Drivers
SOME MINIX 3 RELIABILITY PRINCIPLES

- Small kernel means fewer kernel bugs
- Put the bugs in cages
- Drivers cannot touch kernel data structures
- Bit map to restrict driver’s use of kernel API calls
- Bit map to restrict driver’s use of I/O ports
- Bad pointers/infinite loops affect only 1 user module
- Reincarnation server for (transparent) driver restarts
- Buffer overruns: fixed messages and I & D space
PERFORMANCE OVERHEAD

- Disk intensive tests: 5-10%
- Network intensive tests: 0% with Fast Ethernet
- CPU intensive tests: 0%
- Boot time from multiboot loader: 5 sec
- Time to build kernel, servers and drivers: 7 sec.
- Time to build 300 /usr/bin programs: 2½ min
POSITIONING OF MINIX

• Show that microkernel-based systems are reliable
• Demonstrate that drivers belong in user mode
• High-reliability and fault-tolerant applications
• $100 single-chip, small-RAM laptops for 3rd world
• Embedded systems:
  – DVD players, cell phones, digital cameras, TVs, etc.

MINIX 3 is available: www.minix3.org
MINIX 3 CD-ROMS

- I have MINIX 3 CD-ROMs with me
- Get one after my talk (saves a 25-MB download)
- Two versions: IDE CD-ROM and USB CD-ROM

If you want to be the first person to tell Slashdot, move fast
Why a raccoon?

- Small
- Cute
- Clever
- Agile
- Eats bugs
- More likely to visit your house than a penguin
WEBSITE DEMO ALMOST DIDN’T MAKE IT

- Would it be possible to have the wireless network turned on during my keynote talk so I can use it to show something live from the web?

- <Your e-mail was rejected by an anti-spam content filter on gateway ... Reasons for rejection may be: obscene language, graphics, or spam-like characteristics.>
OTHER APPROACH TO RELIABILITY: L⁴LINUX

- L4: microkernel written by the late Jochen Liedtke
- L⁴Linux is from Tech. Univ. of Dresden (Härtig)
- Linux runs as a big user process
- However, any bug in Linux still crashes it
- Reboot is faster
OTHER APPROACH: NOOKS

- Research project at UW (Levy, Bershad, students)
- Nooks wraps device drivers inside Linux
- Shadow drivers (U. of Washington)
- Practical: improves reliability of legacy drivers
OTHER APPROACH: VIRTUAL MACHINES

- Research at Univ. of Karlsruhe (LeVasseur et al.)
- Run each driver in a different VM
- If a driver crashes, only its VM dies
OTHER MICROKERNEL APPROACHES

- Mach
- Chorus
- EROS
- QNX Neutrino
- VxWorks
- Exokernel
- GNU Hurd (Mach/L4)
- Darwin (Apple Mac OS X)
- Nexus (Microsoft)
LINUX IS STILL OBSOLETE

• Big bloated monolithic kernel
• Not as bloated as Windows
• Trying hard to correct this deficiency
• It is the wrong way to go
NEXT COMPUTER ERA

• Key areas of next era computing are merging
  – Embedded
  – Sensor
  – Ubiquitous

• 26 Billion CPUs sold in 2001
• Most of them were Intel 8051s and similar chips
“NORMAL” EMBEDDED SYSTEMS

- My 2-year-old still camera (Nikon D100) has:
  - 3 CPUs
  - LAN
  - 128 MB RAM
  - 1 GB hard disk with a hierarchical file system
  - No WiFi (802.11), but other models do

- These devices need full-blown operating systems including file systems
SOFTWARE BLOAT IS FOLLOWING US

- My camcorder can make videos in sepia
- Who would use this feature twice?
- Sepia mode is only software. What’s the harm?
  - Feature bloat makes the device hard to use
  - More code = more bugs = more product recalls
RELIABILITY IN REAL-WORLD SYSTEMS

- Embedded SW has real-world consequences
- Think about bugs and upgrades
WOULD YOU RUN WINDOWS ON YOUR GRANDMOTHER’S PACEMAKER?

• Straw poll
GRANDMA
GRANDMA
GRANDMA
GRANDMA
GRANDMA
BLUE SCREEN OF DEATH

• The “Blue screen of death” gets a new meaning

Grandma terminated

Press any key to reboot grandma
HACKING GRANDMA

- Next generation pacemakers and other medical appliances will have Internet connectivity
- Doctor will have access to grandma via wireless
- Will people be infected with computer viruses?
- What about worms, spyware, spam?
- DoS attacks may be fatal
- Blackmail (Pay or I will hack into your grandma)
• “The Guidant Corporation said yesterday that it was recalling about 29,000 implanted heart devices because of flaws that might cause them to short-circuit when they are supposed to deliver a potentially life-saving shock.”

• Straw poll
RELIABILITY REQUIREMENT

- Suppose $P($failure in a year$)$ is $1/1,000,000$
- Suppose 10 million pacemakers worldwide
- Then 10 people will die per year due to software
- This sets the bar for SW reliability pretty high
SENSOR RELIABILITY/SECURITY

- Forest fire detection
- Vehicle accident alerting
- DoS attacks trick network into relaying bogus messages, which results in battery exhaustion
- One-time sensors (ask Google)
UBIQUITOUS COMPUTING

Mark Weiser

• Computers everywhere
  – Smart rooms, buildings, cars that drive themselves
  – In clothes, toys, blackboards, cameras
  – Refrigerators, TVs, stereos (HomeNets)

• Everything talks to everything by wireless
  – Bluetooth, WiFi, WiMax, GSM, UMTS
RFID TAGS

- Radio Frequency IDentification tags
- Very cheap (10 cents)
- Initially for antitheft
- Passive (no battery)
- Powered by remote reader
- Can contain 1024 unique bits
RFID APPLICATIONS

- Killer App: use in stores
  - Antitheft measure
  - Bar code replacement/automated checkout
  - Transportation payment (e.g., EZ-pass for tolls)
  - Animal tracking (pets, livestock, dolphins at sea)

- Will interact with ubiquitous computers, sensors

- Smart washing machine
  - Guys don’t know this, but you can check; you have to tell w.m. what temp

Fatal error: Red sock detected with white shirts
Press any key to reboot washing machine
RFID IS A MASSIVE PARADIGM SHIFT

• By adding an RFID to any object, it can communicate with computers, even be on the Web.

• This merges the real-world with cyberspace.

• Putting real-world (physical) objects online is as revolutionary as the idea of a personal computer.
RFID THREATS

find( product="bra",
     mfg="Victoria’s Secret",
     size >= "38DD",
     event="beep" );

- RFID tags will be in: clothes, passports, money
RFID GUARDIAN

• Monitors existing and new tags within range
• Checks for scans
• Manages your privacy according to your profile
• It can alert you to new tags suddenly present
• It can reply to or block scans of your tags
• www.rfidguardian.org

Melanie Rieback
SUMMARY

• We are moving from PC era to embedded era
• Key issues are reliability and security
• Less emphasis on performance and tricks
• To achieve reliability, need smaller, simpler code
• The future lies at the low-end (sensors, RFID, etc)
THE END

To get MINIX, get the CD-ROM from me now

or go to:   www.minix3.org