

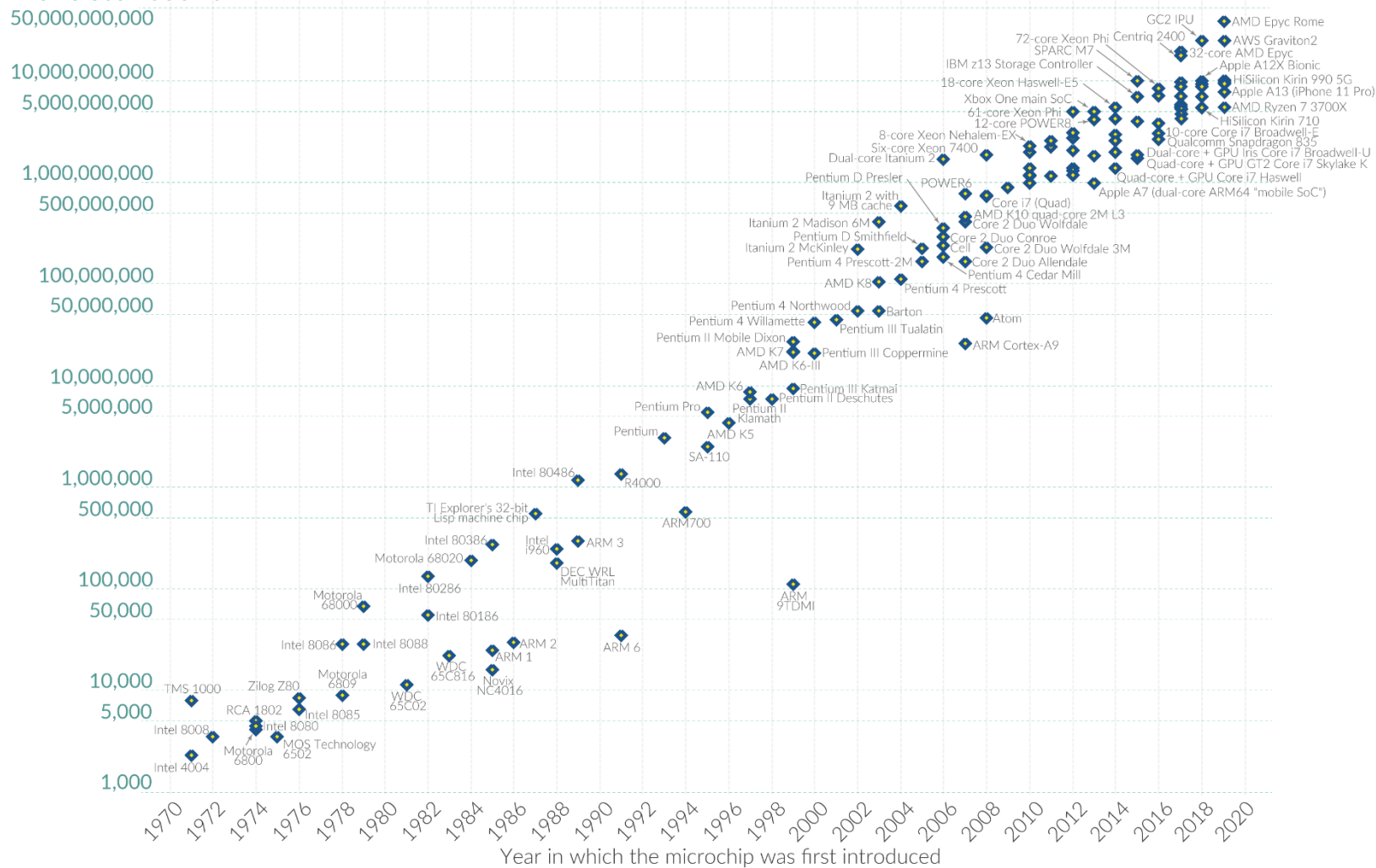
The Future? of Computing

15-213: Introduction to Computer Systems

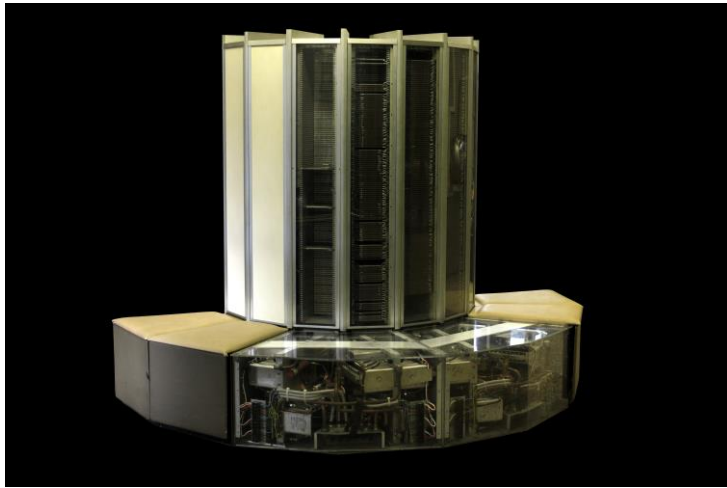
Last Lecture, Aug. 10, 2022

50 Years of “Moore’s Law”

Transistor count



What Moore's Law Has Meant



■ 1976 Cray 1

- 250 M Ops/second
- ~170,000 chips
- 0.5B transistors
- 5,000 kg, 115 KW
- \$9M
- 80 manufactured



■ 2014 iPhone 6

- > 4 B Ops/second
- ~10 chips
- > 3B transistors
- 120 g, < 5 W
- \$649
- 10 million sold in first 3 days

What Moore's Law Has Meant

- 1965 Consumer Product

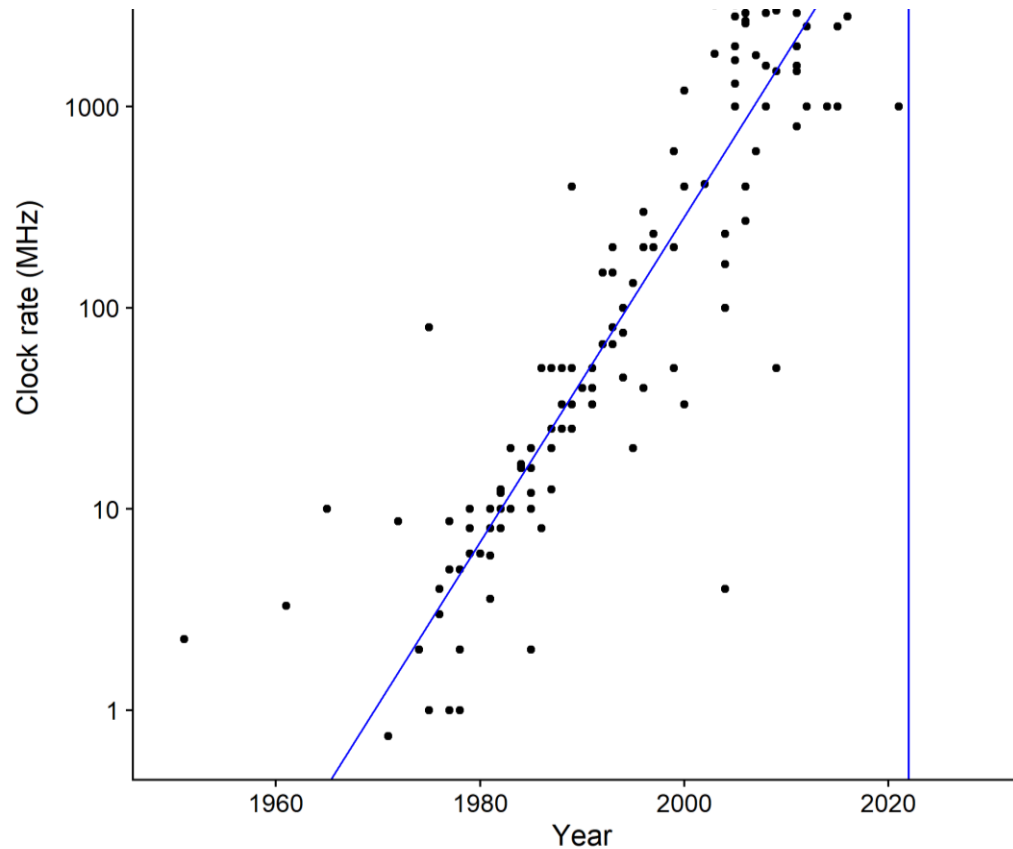


- 2015 Consumer Product

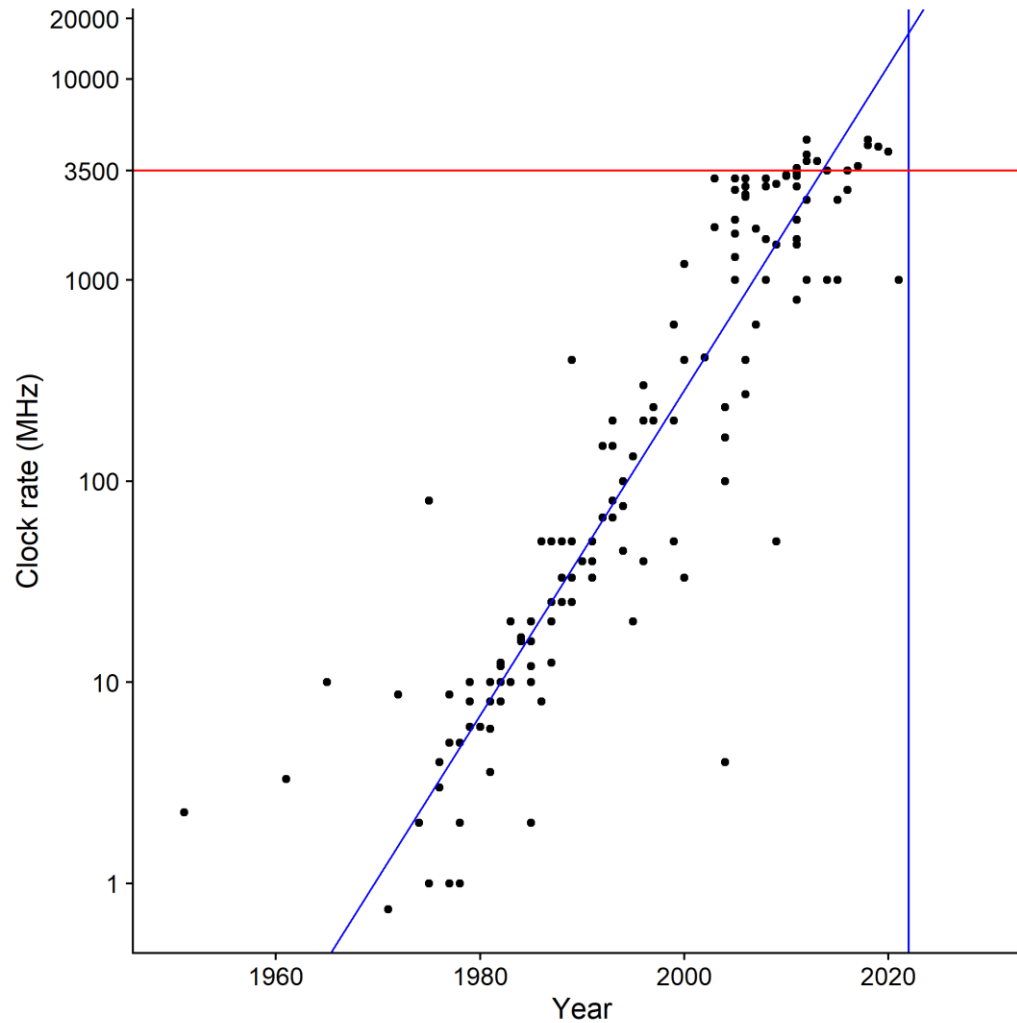


Apple A8 Processor
2 B transistors

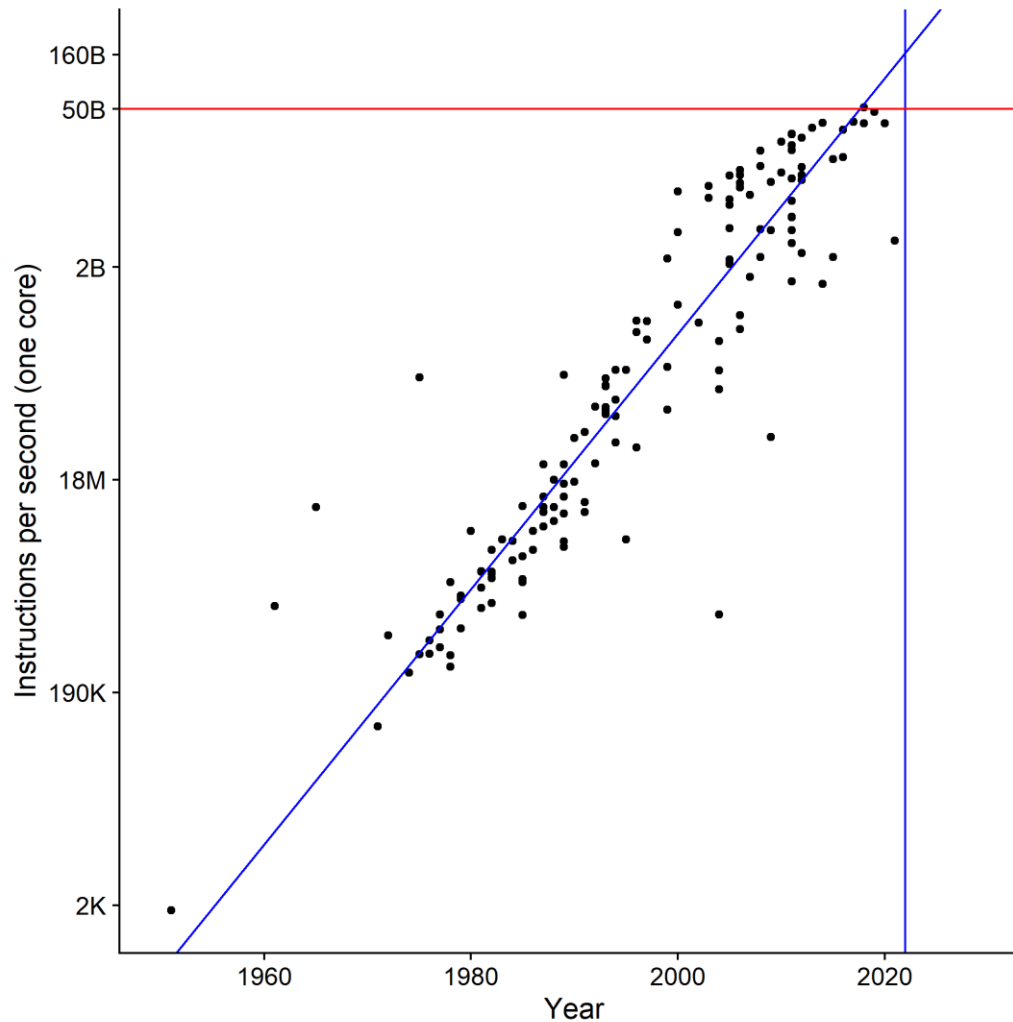
Exponential trends can't continue forever



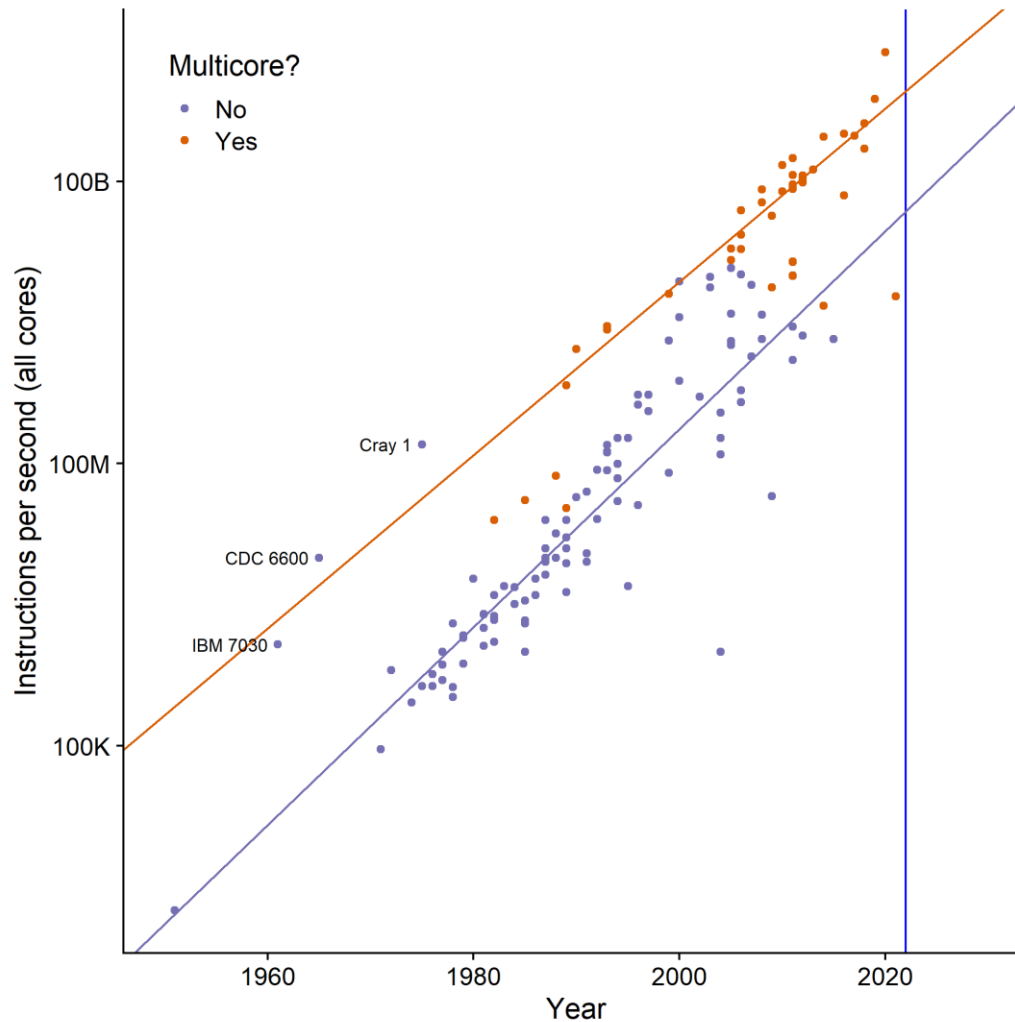
Exponential trends can't continue forever



Clock rate \rightarrow single thread performance



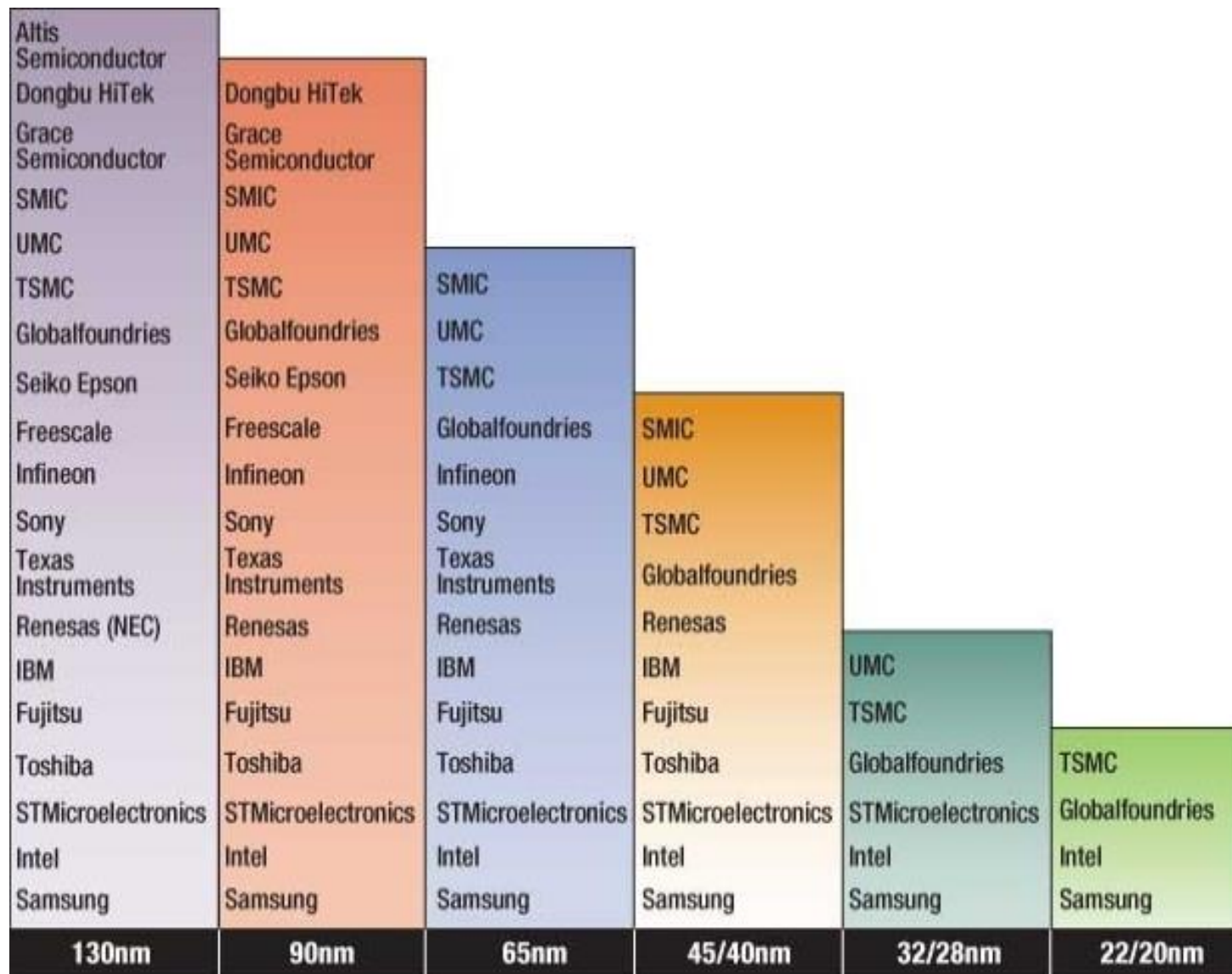
If all else fails, add parallelism...



This machine costs 150 million dollars



Exponential capital cost → exponentially fewer manufacturers



Can't outrun Amdahl

■ Moore:

- Most CPU functions got faster simultaneously
- Memory density scaled too!
- I/O (& mem latency) was the primary bottleneck to work around

■ Multicore:

- Parallelization bottleneck

■ GPUs / SIMD

- Only some algorithms can be vectorized

**The future of computing isn't (only)
about speed anymore.**

Four goals for the future of computing

Efficiency

- Wirth's law: Each generation of *software* is *slower* than the previous generation
- Why?
- Can we reverse this trend?

Accessibility

- Using computers to their full potential takes years of training
 - If you don't speak English, can't afford always-on internet, etc. it's hard to get that training
- Can we make it easier?

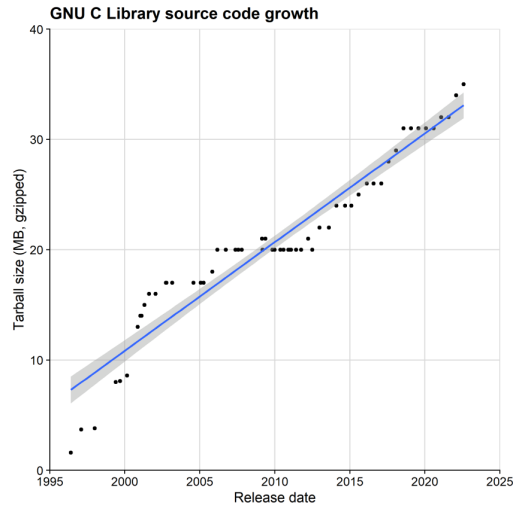
Trustworthiness

- Computers work for us, but...
 - Often they malfunction
 - Sometimes they do what someone *else* wants, against our interests
- Can we fix that?

Customizability

- The most powerful software tools are the ones you can bend to fit the way *you* think
- These tools are really hard to develop
- Can we make *that* easier?

Efficiency's Worst Enemy: Code Bloat



Keep in mind that
one person's bloat
is another person's
essential feature

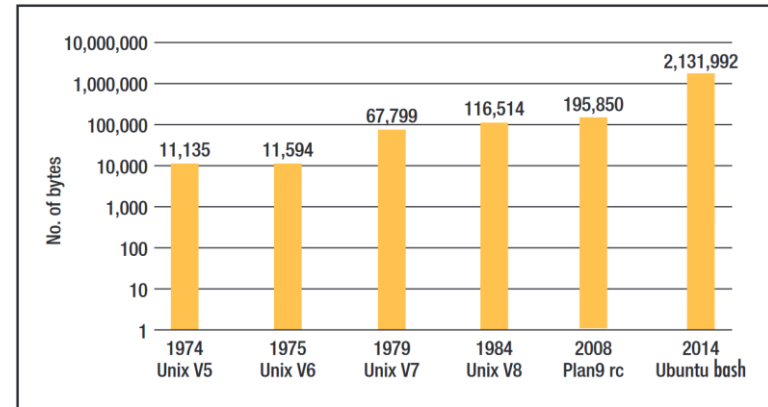
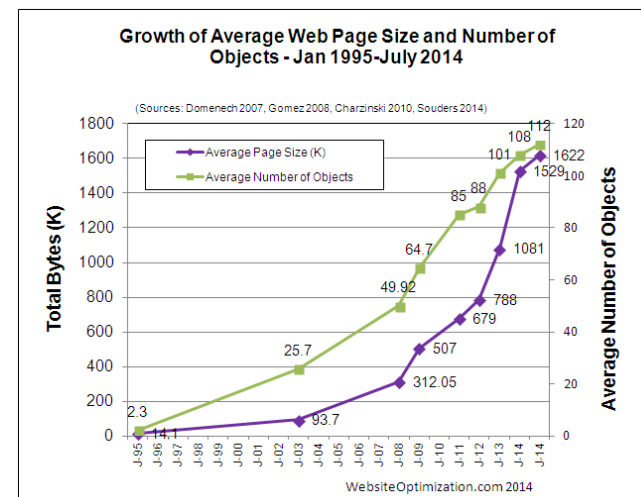


FIGURE 2. The source code size over time for the default command shell on Unix and Unix-like systems. From approximately 11 Kbytes in fifth-edition Unix in 1974 to 2.1 Mbytes for the `bash` shell 40 years later is an increase of 191 times.



Efficiency and Complexity

“Perfection is achieved not when there is nothing more to add, but when there is nothing more to remove.”

—Antoine de Saint Exupéry

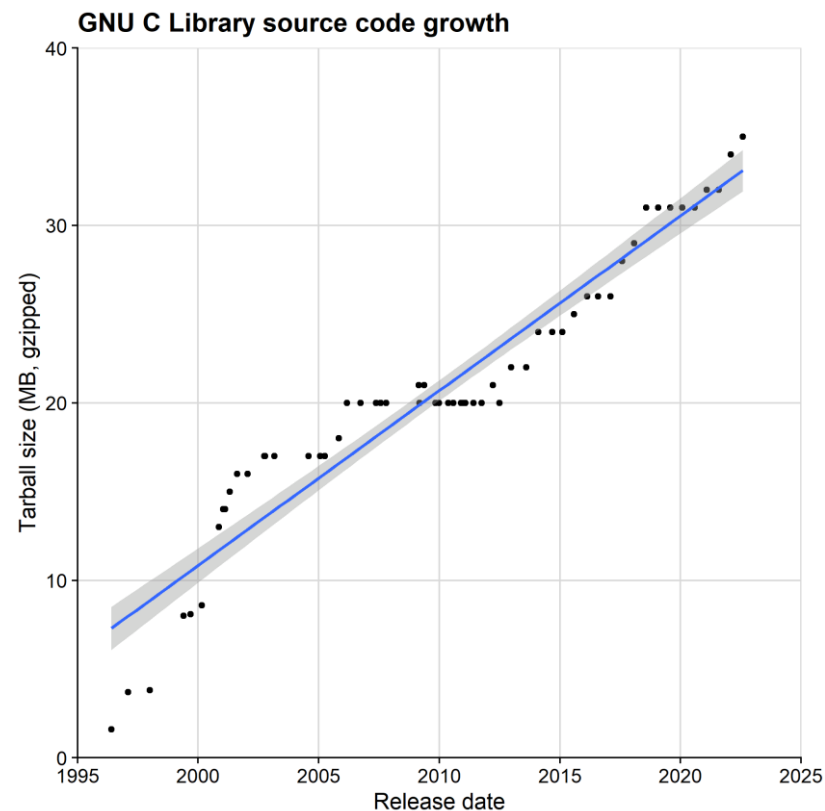
“In order to remain viable, a system needs to generate the same degree of internal complexity as the external complexity it faces in its environment.”

—William Ashby
(as summarized by Boisot and McKelvey)

Challenge for systems designers: remove all of the unnecessary complexity—but none of the necessary complexity

The Curse of Backward Compatibility

- **Consider gets**
 - *Cannot* be used safely
 - Already deprecated in 1989 C standard, formally removed in 1999
 - Every C library still implements it (yes, even musl)
 - Just in case someone needs to run a really old program...



The local newspaper website...

Pittsburgh Post-Gazette

Tuesday, August 09, 2022, 9:59PM | 75°

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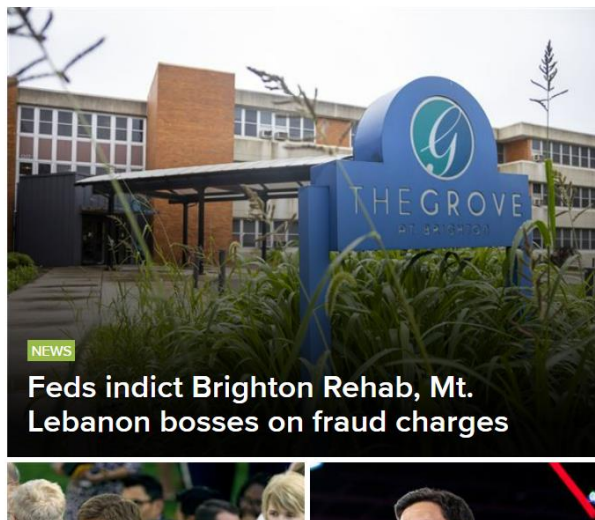
THIS JUST IN

Pirates recall Rodolfo Castro, option Cal Mitchell, make bevy of minor-league moves **1h**

U.S. Rep. Scott Perry, a Pennsylvania Republican, says FBI agents seized his cellphone **2h**

Company sues Steelers wide receiver Diontae Johnson for his no-show at youth camp **3h**

Roger Goodell: NFL appeal of Deshaun Watson suspension 'right thing to do' **3h**



Feds indict Brighton Rehab, Mt. Lebanon bosses on fraud charges

ADVERTISEMENT



STEELERS TRAINING CAMP VIDEOS

Gerry Dulac on Steelers' ...
Steelers beat writer Gerry Dula...

1166 HTTP requests

47 MB of data transferred

Still loading stuff in the background 1 minute after this screen stabilized

... without the ads

Pittsburgh Post-Gazette

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NEWSLETTERS

THIS JUST IN

Pirates recall Rodolfo Castro, option Cal Mitchell, make bevy of minor-league moves **1h**

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Roger Goodell: NFL appeal of Deshaun Watson suspension 'right thing to do' **3h**

Federal judge denies LIV golfers bid for PGA Tour postseason **3h**

Feds indict Brighton Rehab Mt Lebanon



NEWS

Feds indict Brighton Rehab, Mt. Lebanon bosses on fraud charges



NEWS

Wolf, CMU president among Pennsylvanians at Biden's signing of 'CHIPS and Science' bill



NEWS

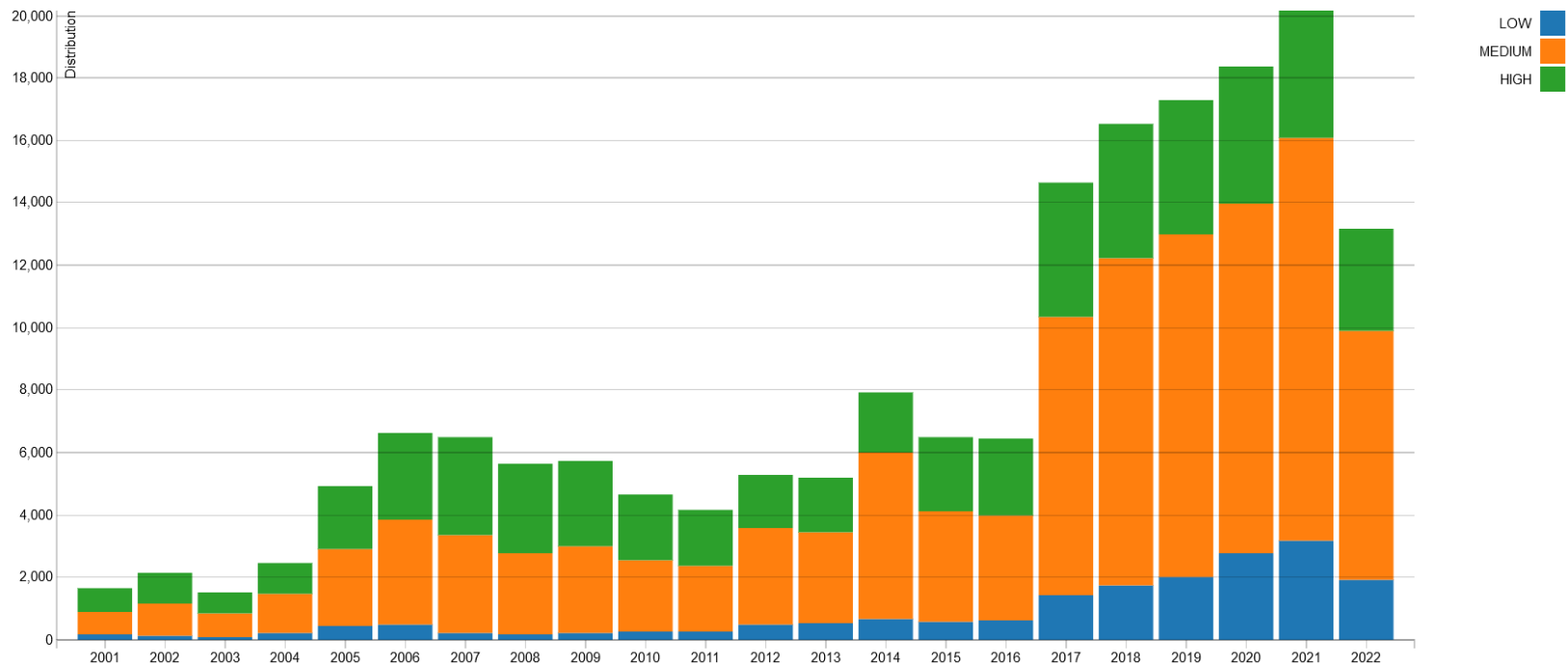
Florida Gov. DeSantis coming to Pittsburgh next week to stump for Mastriano

87 HTTP requests

7.4 MB of data transferred

No network activity after 1.5 seconds

Trustworthiness



**Bugs reported to the National Vulnerability Database (USA), 2001–present
(only security-critical bugs are counted)**

Trustworthiness (another angle)

“algorithm???
that thing where
social media sites get money from advertisers
the more shit you click on
so they shove content at you
that is theoretically to your interest
but actually is content that will keep you clicking,
including content that enrages you,
because they don't care about giving you shit you like
just about keeping you engaged as long as possible,
and oh also did we mention this ties into the modern lack of data privacy,
the algorithm is watching everything you interact with
to profile you better for advertising to you,
it's spying on you across platforms whenever possible,”
—Tumblr person @jmtorres

Trustworthiness (another angle)

SYSTEM VIRUS

System May Have Downloaded For Help Rem

WANA DECRYPTOR 2.0

Oops, your files have been encrypted!

What Happened to My Computer?
Your important files are encrypted. Many of your documents, photos, videos, databases and other files are no longer accessible because they have been encrypted. Maybe you are busy looking for a way to recover your files, but do not waste your time. Nobody can recover your files without our decryption service.

Payment will be raised on 5/16/2017 00:47:55
Time Left 02:23:57:37

Your files will be lost on 5/20/2017 00:47:55
Time Left 06:23:57:37

[About bitcoin](#)
[How to buy bitcoins?](#)
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```

msbl
ast.exe I just w
ant to say LOVE
YOU SAN!! billy
gates why do you
make this possi
ble ? Stop makin
g money and fix
your software!!
♠ δ♥▶ H Δ
ð_ð_ @ @ @
á@ L F
♦ ]êèÙ-π←fb□
+▶H' @ ♠ ♥▶
b♥ ò ð♥ @ ♦
0 00 00-6D 73 62 6C
0 6A 75-73 74 20 77
9 20 4C-4F 56 45 20
0 62 69-6C 6C 79 20
0 64 6F-20 79 6F 75
3 20 70-6F 73 73 69
0 20 6D-61 6B 69 6E
E 64 20-66 69 78 20
7 61 72-65 21 21 00
0 00 00-7F 00 00 00
0 00 00-01 00 01 00
0 00 00-00 00 00 46
C C9 11-9F E8 08 00
0 00 03-10 00 00 00
3 00 00-01 00 04 00
  
```




Your PC ran into a problem that it couldn't handle, and now it needs to restart.

You can search for the error online: `HAL_INITIALIZATION_FAILED`

*** STOP: 0x00000050 (0xFCBFFFF, 0x00000000, 0x00000000, 0x00000000)
PAGE_FAULT_IN_NONPAGED_AREA

p5-0000 irq1:2 SYSUER 0xf0000421

Dll	Base	Date	Stmp	Name	Dll	Base	Date	Stmp	Name
800100000	22f68	65533	7755	ntoskrnl.exe	800400000	22f68	65533	7755	hal.dll
800110000	22f68	65533	7755	atapi.sys	800130000	22f68	65533	7755	SCSIIPORT.SYS
8001b0000	22f68	65533	7755	BusLogic.sys	800010000	22f68	65533	7755	Scsiidisk.sys
800f00000	22f68	65533	7755	Ntfs.sys	fccc00000	22f68	65533	7755	Floppy.SYS
fccc10000	22f68	65533	7755	Scsicdrms.SYS	fccc20000	22f68	65533	7755	Cdaudio.SYS
fccc30000	22f68	65533	7755	Fs_Rec.SYS	fccc40000	22f68	65533	7755	Null.SYS
fccc50000	22f68	65533	7755	Beep.SYS	fccc60000	22f68	65533	7755	snblist.SYS
fccc70000	22f68	65533	7755	i8042prt.SYS	fccc80000	22f68	65533	7755	Mouclass.SYS
fccc90000	22f68	65533	7755	Kbdclass.SYS	fccc90000	22f68	65533	7755	VIDEOPRT.SYS
fccc9a000	22f68	65533	7755	vbmmp.sys	fccc9b000	22f68	65533	7755	vga.sys
fccc9c000	22f68	65533	7755	Msmfs.SYS	fccc9d000	22f68	65533	7755	Npfs.SYS

Address	dword	dump	Build	[1057]	-	Name			
fccc22000	80013b26	b80013b26	b80013b26	b80013b26	fccc22000	80013b26	b80013b26	b80013b26	ntoskrnl.exe
fccc22000	8001022f	d8001022f	d8001022f	d8001022f	fde54c40	80040024	d8001022f	d8001022f	ntoskrnl.exe
fccc22000	8004022f	d8004022f	d8004022f	d8004022f	800155cccc	80040024	d8004022f	d8004022f	hal.dll
fccc22000	800155cccc	800155cccc	800155cccc	800155cccc	fde54c40	800155cccc	800155cccc	800155cccc	ntoskrnl.exe
fccc22000	800155cccc	800155cccc	800155cccc	800155cccc	fde54c40	800155cccc	800155cccc	800155cccc	ntoskrnl.exe
fccc22000	80019220	4d80019220	4d80019220	4d80019220	fccc22000	80019220	4d80019220	4d80019220	ntoskrnl.exe
fccc22000	800134f3	30800134f3	30800134f3	30800134f3	ffffffffff	fccc22000	800134f3	30800134f3	ntoskrnl.exe
fccc22000	800100f6	00800100f6	00800100f6	00800100f6	fccc22000	800100f6	00800100f6	00800100f6	ntoskrnl.exe
fccc22000	800179b0	00800179b0	00800179b0	00800179b0	fde54c40	800179b0	00800179b0	00800179b0	ntoskrnl.exe
fccc22000	800175c0	f6800175c0	f6800175c0	f6800175c0	fccc22000	800175c0	f6800175c0	f6800175c0	ntoskrnl.exe
fccc22000	80010008	0080010008	0080010008	0080010008	e1181030	fde4b020	80010008	0080010008	ntoskrnl.exe
fccc22000	800151e3	33800151e3	33800151e3	33800151e3	c2ce0801	00000000	800151e3	33800151e3	ntoskrnl.exe
fccc22000	80010008	0080010008	0080010008	0080010008	fccc22000	80010008	0080010008	0080010008	ntoskrnl.exe
fccc22000	8001560f	e8001560f	e8001560f	e8001560f	fde48a88	00000000	8001560f	e8001560f	ntoskrnl.exe
fccc22000	8001246c	b8001246c	b8001246c	b8001246c	00000000	8001246c	b8001246c	b8001246c	ntoskrnl.exe
fccc22000	800177c0	08800177c0	08800177c0	08800177c0	800134f3	800100c6	08800177c0	08800177c0	ntoskrnl.exe
fccc22000	800134f3	30800134f3	30800134f3	30800134f3	ffffffffff	fccc22000	800134f3	30800134f3	ntoskrnl.exe
fccc22000	800100c6	60800100c6	60800100c6	60800100c6	fccc22000	800100c6	60800100c6	60800100c6	ntoskrnl.exe
fccc22000	80015612	d80015612	d80015612	d80015612	80015661	2d80015661	d80015612	d80015612	ntoskrnl.exe
fccc22000	80010008	0080010008	0080010008	0080010008	0021f378	80010008	0080010008	0080010008	ntoskrnl.exe
fccc22000	800137fb	5800137fb	5800137fb	5800137fb	0021f3b8	80010008	00800137fb	5800137fb	ntoskrnl.exe
fccc22000	80010008	0080010008	0080010008	0080010008	0021f378	80010008	0080010008	0080010008	ntoskrnl.exe

Riavviare e impostare le opzioni di ripristino nel pannello di controllo del sistema o l'opzione di avvio del sistema /CRASHDEBUG. Se il messaggio riappare rivolgersi all'amministratore del sistema o al gruppo di supporto tecnico.

No trust without comprehension

The screenshot shows the Windows Event Viewer interface. The left pane displays the 'System' log. The main pane shows a list of events, with the following data extracted from the visible rows:

Level	Date and Time	Source	Event ID	Task Ca...
Warning	2022-08-09 10:11:57 PM	DNS Cli...	1014	(1014)
Information	2022-08-09 10:11:47 PM	GroupP...	1500	None
Error	2022-08-09 10:11:47 PM	GroupP...	1129	None
Warning	2022-08-09 10:09:18 PM	Distrib...	10016	None
Warning	2022-08-09 10:09:01 PM	Distrib...	10016	None
Warning	2022-08-09 10:08:28 PM	DNS Cli...	8016	(1028)
Warning	2022-08-09 10:08:17 PM	DNS Cli...	8016	(1028)
Information	2022-08-09 10:04:34 PM	Service ...	7040	None
Warning	2022-08-09 10:02:38 PM	Distrib...	10016	None
Warning	2022-08-09 10:02:05 PM	Distrib...	10016	None
Information	2022-08-09 10:00:36 PM	Service ...	7040	None
Warning	2022-08-09 9:59:36 PM	Distrib...	10016	None
Information	2022-08-09 9:35:32 PM	GroupP...	1501	None
Error	2022-08-09 9:35:32 PM	GroupP...	1055	None
Error	2022-08-09 9:35:32 PM	NETLO...	5719	None
Warning	2022-08-09 9:22:19 PM	DNS Cli...	1014	(1014)
Warning	2022-08-09 9:15:17 PM	DNS Cli...	8015	(1028)

The selected event (ID 1129) is expanded, showing the following details:

Event 1129, GroupPolicy (Microsoft-Windows-GroupPolicy)

General | Details

The processing of Group Policy failed because of lack of network connectivity to a domain controller. This may be a transient condition. A success message would be generated once the machine gets connected to the domain controller and Group Policy has successfully processed.

Log Name: System
 Source: GroupPolicy (Microsoft-Winc
 Event ID: 1129
 Level: Error
 Logged: 2022-08-09 10:11:47 PM
 Task Category: None
 Keywords:

People are working on this one!



Accessibility

- **Remember when I had you run the sharks completely out of RAM?**
 - And nothing particularly bad happened?
 - And you learned some interesting things about virtual memory?

- **Raise your hand if you know someone who is afraid to experiment with their computer.**

“Four freedoms” for ~~software~~ programmers

- The freedom to run the program as you wish, for any purpose
- The freedom to study how the program works, and change it so it does your computing as you wish
- The freedom to redistribute copies so you can help others
- The freedom to distribute copies of your modified versions to others

<https://www.gnu.org/philosophy/free-sw.html#four-freedoms>

The first two freedoms for *everyone*

■ Freedom to run the program...

- Fine as is at first glance
- But what about: freedom to *keep* the version of the program that worked the way you were used to?
 - While still receiving bug fixes?

■ Freedom to study and modify the program...

- Assumes you have the skills and the confidence
 - Freedom to experiment without fear of catastrophe?
 - Freedom to ask basic questions without being sneered at?
- Not everyone wants the skills
 - I can hire a handyman to patch a hole in my wall, why is there no equivalent?

People are also working on this one!



The Recurse Center

BUT: These are all special-purpose tools and educational efforts. We don't even have a plan for the general problem.

Customizability

This is what my text editor looks like.

I write *everything* (except PowerPoint decks ;-) in this interface.

The screenshot shows the Emacs editor interface. The left pane displays a directory listing for 'c:/Users/zweinber/Desktop/lecture_activities:'. The right pane shows LaTeX code for a document class and an enumerate environment.

```

emacs@zw-laptop
c:/Users/zweinber/Desktop/lecture_activities:
total used in directory 641 available 360.5 GiB
dr-xr-xr-x  1 zweinber Domain Users  4096 08-10 10:38 ..
drwxrwxrwx  1 zweinber Domain Users  24576 07-12 15:05 .
-rw-rw-rw-  1 zweinber Domain Users  46324 07-12 15:05 arydshln.sty
drwxrwxrwx  1 zweinber Domain Users  4096 07-12 15:05 attacklab
-rw-rw-rw-  1 zweinber Domain Users  26603 07-12 15:05 bits-and-bytes.md
drwxrwxrwx  1 zweinber Domain Users    0 07-12 15:05 cache-memories
-rw-rw-rw-  1 zweinber Domain Users  8126 07-12 15:05 cache-memories.md
-rw-rw-rw-  1 zweinber Domain Users   730 07-12 15:05 .clang-format
-rw-rw-rw-  1 zweinber Domain Users  22048 07-12 15:05 concurrency.tex
-rw-rw-rw-  1 zweinber Domain Users  4523 07-12 15:05 datalab.md
drwxrwxrwx  1 zweinber Domain Users  4096 07-12 15:05 ecf-exceptions
-rw-rw-rw-  1 zweinber Domain Users  12335 07-12 15:05 ecf-exceptions.tex
drwxrwxrwx  1 zweinber Domain Users  4096 07-12 15:05 ecf-signals
-rw-rw-rw-  1 zweinber Domain Users  17237 07-12 15:05 ecf-signals.tex
-rw-rw-rw-  1 zweinber Domain Users   590 07-12 15:05 .editorconfig
-rw-rw-rw-  1 zweinber Domain Users  2553 07-12 15:05 floating-point.md
-rw-rw-rw-  1 zweinber Domain Users  9264 07-12 15:05 floats.md
drwxrwxrwx  1 zweinber Domain Users  4096 07-12 15:05 gdb-and-assembly
-rw-rw-rw-  1 zweinber Domain Users  14783 07-12 15:05 gdb-and-assembly.te
drwxrwxrwx  1 zweinber Domain Users  4096 07-20 14:10 .git
-rw-rw-rw-  1 zweinber Domain Users   369 07-12 15:05 .gitattributes
-rw-rw-rw-  1 zweinber Domain Users   358 07-12 15:05 .gitignore
-rw-rw-rw-  1 zweinber Domain Users  2700 07-12 15:05 GNUmakefile
-rw-rw-rw-  1 zweinber Domain Users  12546 07-12 15:05 integers.md
-rw-rw-rw-  1 zweinber Domain Users   637 07-12 15:05 .latexindent.yaml
-rw-rw-rw-  1 zweinber Domain Users  1019 07-12 15:05 latexmkrc
drwxrwxrwx  1 zweinber Domain Users  4096 07-12 15:05 linking
-rw-rw-rw-  1 zweinber Domain Users  6165 07-12 15:05 linking.tex
-rw-rw-rw-  1 zweinber Domain Users  9556 07-12 15:05 machine-advanced.te
1%%- lecture_activities  Top L11  (Dired by name)

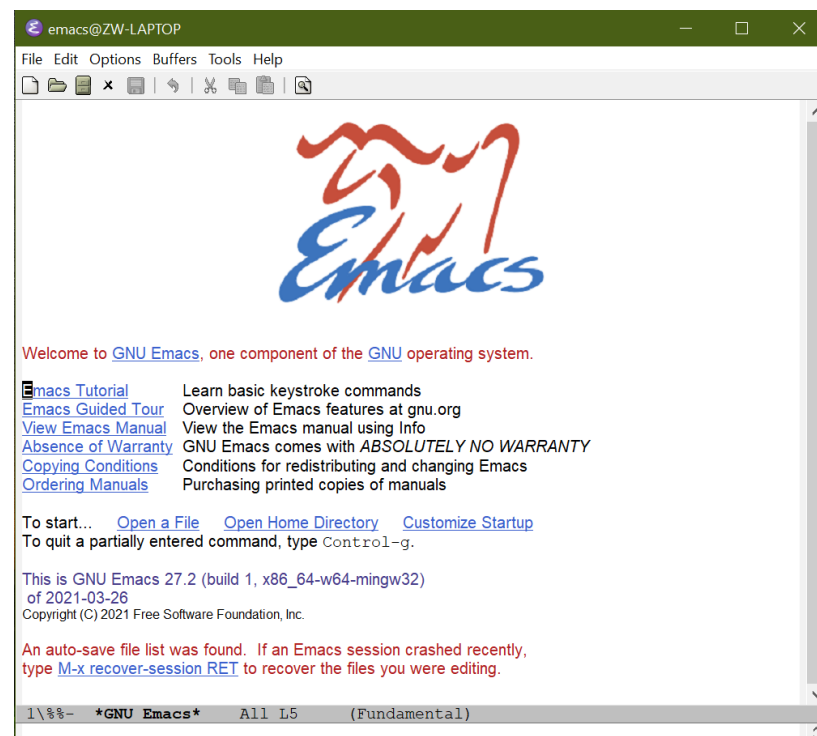
\documentclass[letterpaper]{scrartcl}
\usepackage[T1]{fontenc}
\usepackage[margin=1in]{geometry}
\usepackage{hyperref}
\usepackage{lmodern}
\usepackage{multirow}
\usepackage{fancyvrb}
\usepackage{ulem}
\usepackage{xcolor}

\newcounter{questi}
\newenvironment{quest}{
  \begin{enumerate}
    \setcounter{enumi}{\value{questi}}
    \setlength{\itemsep}{-12pt}
    \ifdefined\solns\else
      \setlength{\itemsep}{36pt}
    \fi
  }{
    \setcounter{questi}{\value{enumi}}
    \vspace{\itemsep}
    \end{enumerate}
}
\ifdefined\solns
  \newcommand{\soln}[1]{{\color{red} #1}}
  \newcommand{\solnblock}[1]{
    \vspace{-3\parskip}
    \parbox[t][30pt]{\textwidth}{\soln{#1}}
    \vspace{2\parskip}
  }
}
U(Unix)--- concurrency.tex  Top L1  Git-master  (LaTeX Fill)

```

Customizability

- This is what the same editor looks like if I start it up without any customization.
- I've written hundreds of lines of Lisp to get this thing exactly the way I want it.
- Most of that is about behavior, not appearance.



Application developers hate customizability

- **With good reason: it can be 10-100x extra testing work for them.**
- **Quotes on the right are only talking about visual tweaks, not Emacs-level “redefine every single keystroke” customizability**

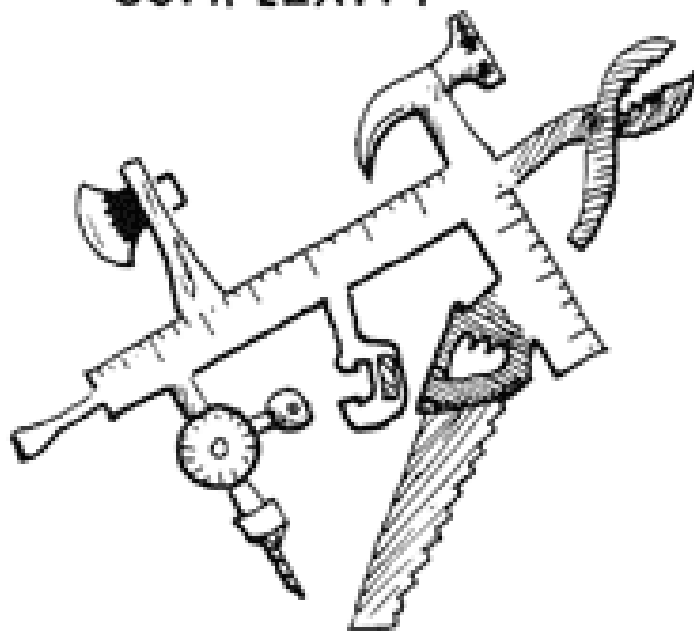
“The basic issue we’re arguing about is whether it’s possible to restyle applications automatically, at scale, without breaking them. In this post I’ll try to explain why I think that it isn’t possible, and why trying to do it is hurting our ecosystem.”

<https://blogs.gnome.org/tbernard/2018/10/15/restyling-apps-at-scale/>

“Over the years FreeDesktop platforms have come a long way in terms of usability and as we strive to make them better platforms for application developers, I think it’s time to shed one more shackle that slows that down: themes.”

<https://samuelhewitt.com/blog/2018-08-05-moving-beyond-themes>

COMPLEXITY



OR SIMPLICITY?

