IPADS INSTITUTE OF PARALLEL AND DISTRIBUTED SYSTEMS

上海交通大學 SHANGHAI JIAO TONG UNIVERSITY

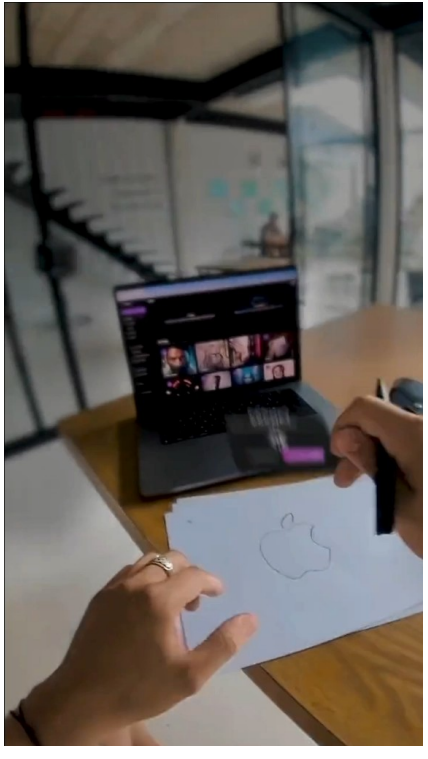
Introduction to CSE: Coping with Complexity

Yubin Xia

IPADS, Shanghai Jiao Tong University

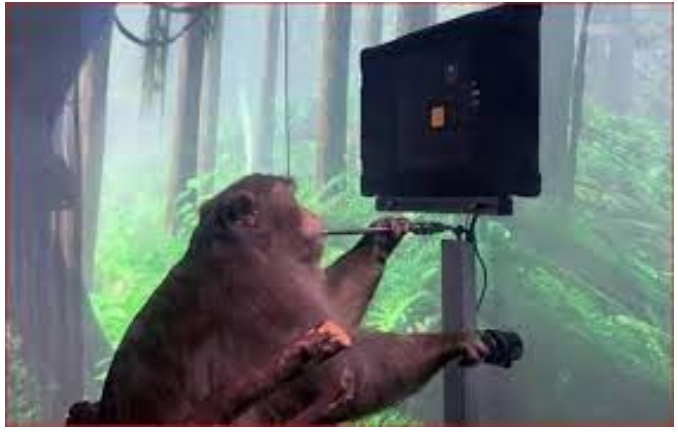
https://www.sjtu.edu.cn

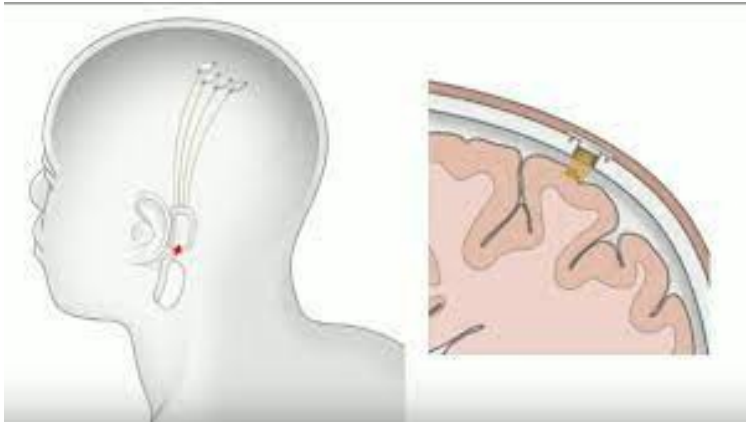
Digital-world VS. Real-world



Digital-world VS. Real-world

Human Computer Interface…






Windows
A fatal exception 0E has ocurred at 0028:C0011E36 in VXD VMM(01) +
00010E36. The current application will be terminated.
* Press any key to terminate the current application.
* Press CTRL+ALT+DEL again to restart your computer. You will
lose any unsaved information in all applications.
Press any key to continue _

钉钉回应黑屏、崩溃 Bug：扛到最后，没想到还是摔了一跤

2020年03月10日 12:05 IT之家

5·27支付宝大规模宕机事故

2015年5月27日下午，部分用户反映其支付宝出现网络故障，账号无法登录或支付。支付宝官方表示，该故障是由于杭州市萧山区某地光纤被挖断导致，这一事件造成部分用户无法使用支付宝。随后支付宝工程师紧急将用户请求切换至其他机房，受影响的用户逐步恢复。到晚上7点20分，支付宝方面宣布用户服务已经恢复正常。

中文名	5·27支付宝大规模宕机事故	恢复时间	2015年5月27日20时左右
发生时间	2015年5月27日下午4点半左右	事件影响	全国大面积支付宝瘫痪

目录

事故背景

支付宝拥有超过4万亿年交易总额，是中国第一大第三方交易平台，约占中国整体社会消费金额的六分之一。

2014年年11月，就有用户反映，支付宝钱包目前无法转账和提现，当用户使用这两项功能时会提示出现未知错误或创建交易失败，该问题在移动客户端以及电脑网页端均存在。 [1]

PATIENT NAME: John
TREATMENT MODE: FIX

Therac-25 (radiation therapy machine) accidents (1985-1987), the injured patients died from lethal dosage of radiation caused by a software bug

	UNIT RATE/MINUTE		
	MONITOR UNITS		
	TIME(MIN)		
GANTRY ROTATION (DEG)	0.000000	0.000000	VERIFIED
COLLIMATOR ROTATION (DEG)	359.200000	359.200000	VERIFIED
COLLIMATOR X (CM)	14.200000	14.200000	VERIFIED
COLLIMATOR Y (CM)	27.200000	27.200000	VERIFIED
WEDGE NUMBER	1.000000	1.000000	VERIFIED
ACCESSORY NUMBER	0.000000	0.000000	VERIFIED

DATE: 2012-04-16 SYSTEM: BEAM READY OP.MODE: TREAT AUTO
TIME: 11:48:58 TREAT: TREAT PAUSE X-RAY 173777
OPR ID: 033-tfs3p REASON: OPERATOR COMMAND:

Ariane 5 explosion due to a floating point bug

Jeep 自由光系统存在入侵风险，菲亚特克莱斯勒汽车公司**召回 140 万辆**汽车

SYSTEM & COMPLEXITY

What is a System?

System =

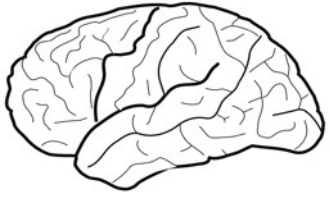
- Interacting set of components with a specified behavior at the interface with its environment

Examples

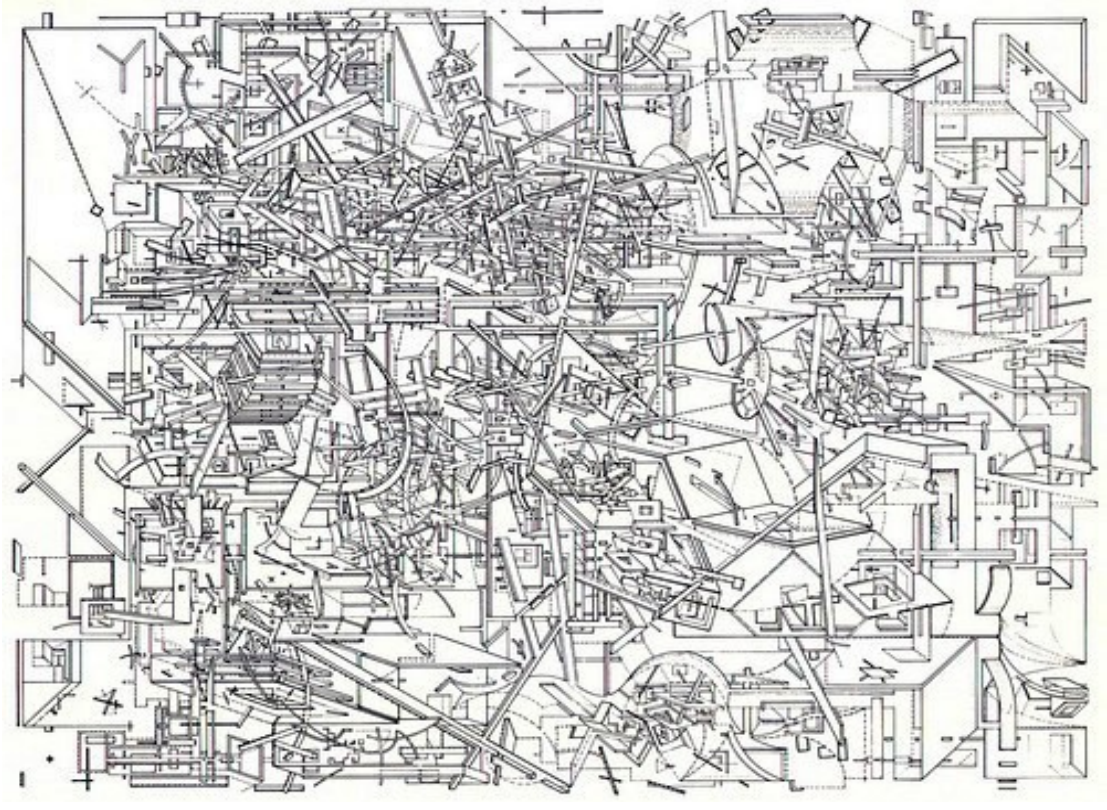
- A web server, an Android phone, file systems, Linux, …

The Problem: Complexity of the Systems

Hard for human to fully understand



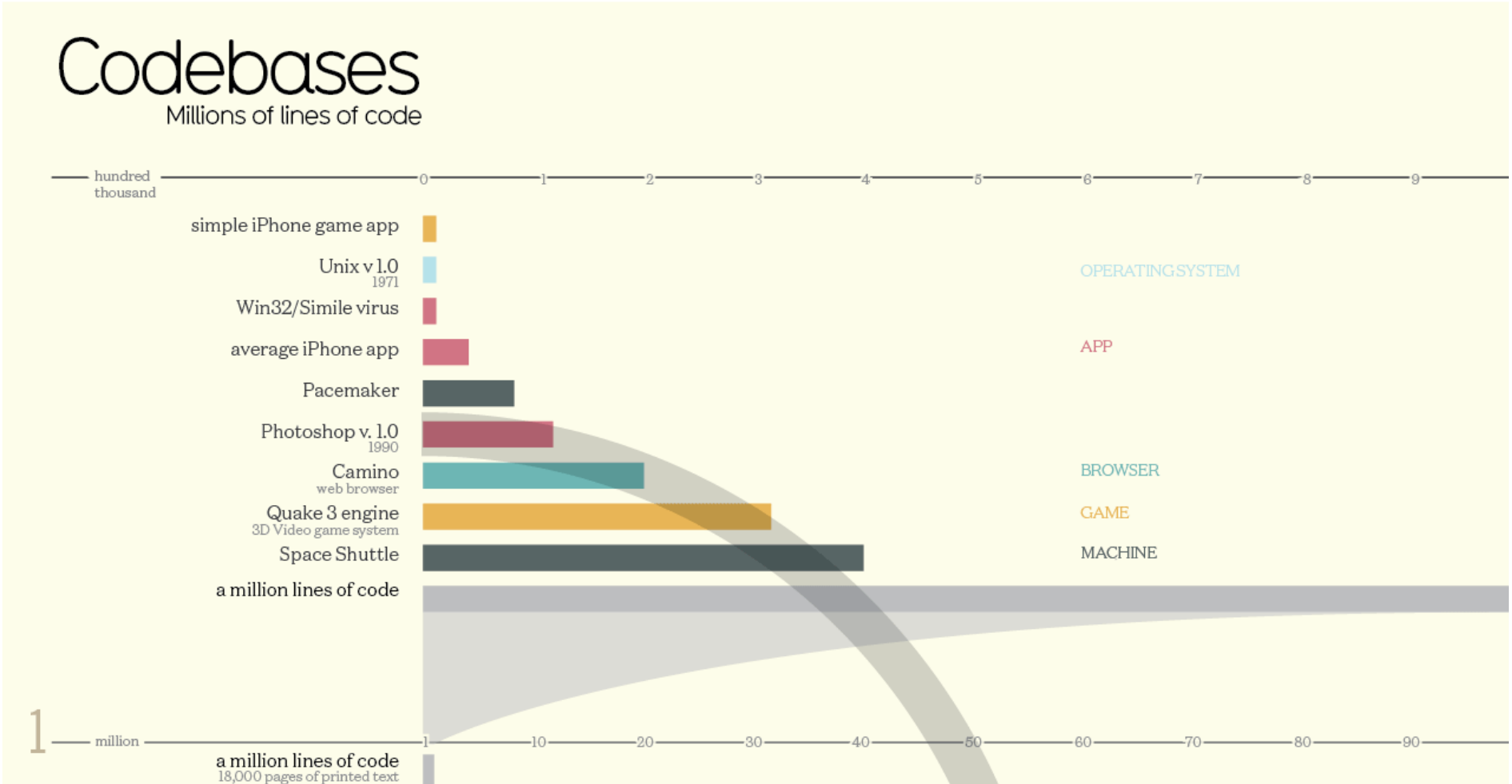
But, we can view from a system's perspective



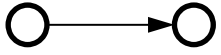
Example of Complex Systems: Linux Kernel

Item	Lines	%
./usr	845	0.0042
./init	5,739	0.0283
./samples	8,758	0.0432
./ipc	8,926	0.0440
./virt	10,701	0.0527
./block	37,845	0.1865
./security	74,844	0.3688
./crypto	90,327	0.4451
./scripts	91,474	0.4507
./lib	109,466	0.5394
./mm	110,035	0.5422
./firmware	129,084	0.6361
./tools	232,123	1.1438
./kernel	246,369	1.2140
./Documentation	569,944	2.8085
./include	715,349	3.5250
./sound	886,892	4.3703
./net	899,167	4.4307
./fs	1,179,220	5.8107
./arch	3,398,176	16.7449
./drivers	11,488,536	56.6110

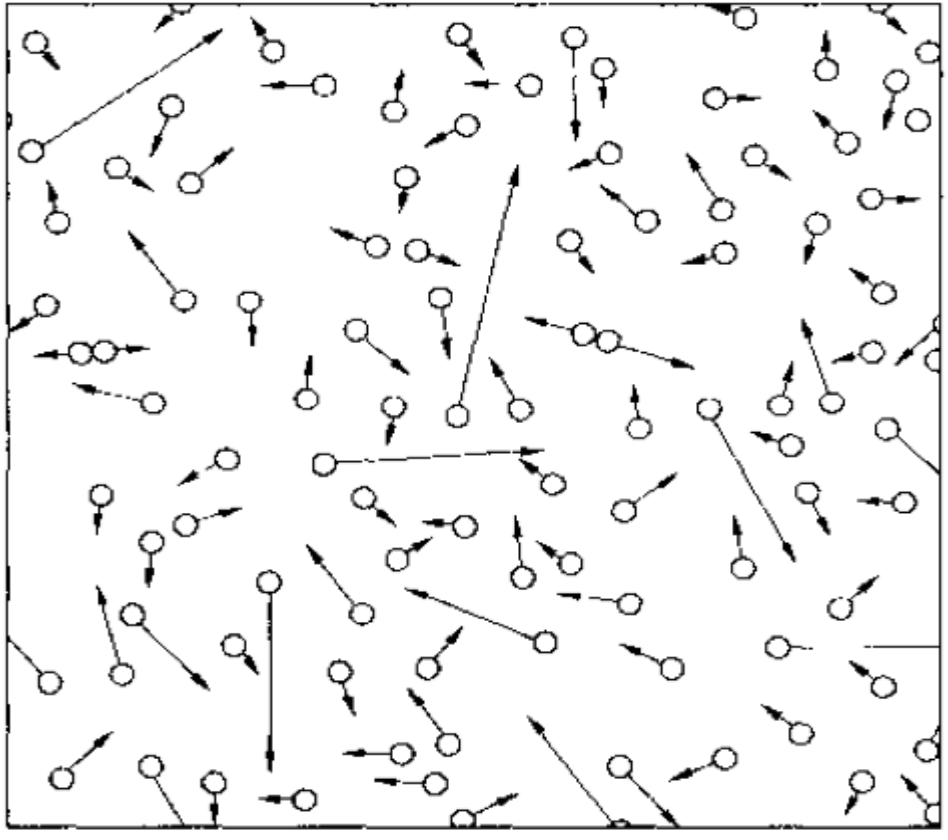
LOC (Lines Of Code)



An Example: The Gas System



A systematical way to understand a complex system is needed



Compare with the Computer Systems

Programming / Data Structure

- LoC (Lines of Code): From hundreds to millions

Operating System / Architecture

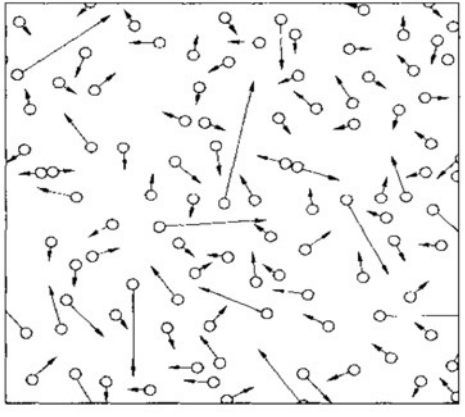
- CPU cores: from one to hundreds

Network

- Nodes: from two to millions

Web Service

- Clients: from tens to millions



14 PROPERTIES

14 Properties of Computer Systems

1. Correctness
2. Latency
3. Throughput
4. Scalability
5. Utilization
6. Performance Isolation
7. Energy Efficiency
8. Consistency
9. Fault Tolerance
10. Security
11. Privacy
12. Trust
13. Compatibility
14. Usability

Property-1: Correctness

Correctness is hard to define

- How to describe the functionalities of your code?

'It's Not a Bug, It's a Feature.'

Who can really say? In a 2013 study, a group of scholars at a German university sifted through the records of five software projects and evaluated thousands of reported coding errors. They discovered that the bug reports were themselves thoroughly buggy. "Every third bug is not a bug," they concluded. The title of their paper will surprise no one: "It's Not a Bug, It's a Feature."

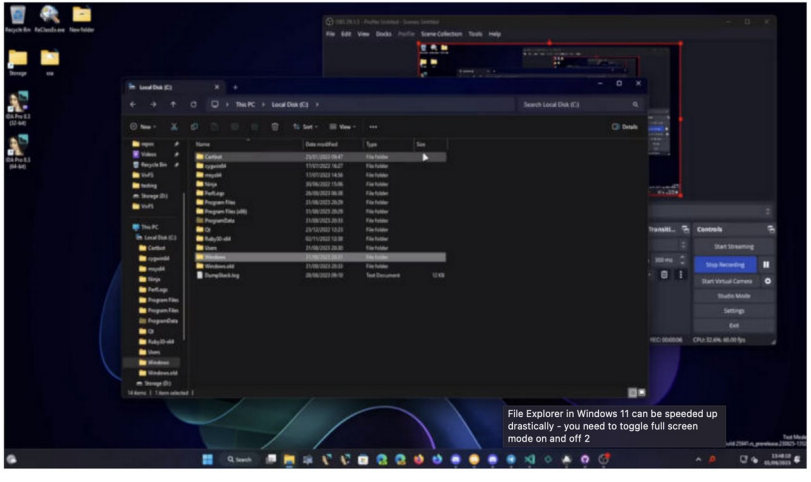
https://www.wired.com/story/its-not-a-bug-its-a-feature/

Property-1: Correctness

File Explorer in Windows 11 can be speeded up drastically – you need to toggle full screen mode on and off

6 days ago Robbie Elmers Add Comment

File Explorer in Windows 11 is not particularly fast, but thanks to an unknown feature of the program, a way was found to speed it up drastically – you need to enable and disable full screen mode. This method was reported by the user of the social network X under the nickname Vivi .



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You can Hack into a Linux Computer just by pressing 'Backspace' 28 times

Dec 17, 2015 Swati Khandelwal

A Piece of Code, Seems Normal

```
char *buf = ...;
char *buf_end = ...;
unsigned int len = ...;
if (buf + len >= buf_end)
    return;   /* len too large */
if (buf + len < buf)
    return;   /* overflow, buf+len wrapped around */
/* write to buf[0..len-1] */
```

Undefined Behavior

	Construct	Sufficient condition	Undefined behavior
Language	$p + x$	$p_\infty + x_\infty \notin [0, 2^n - 1]$	pointer overflow
	$*p$	$p = \texttt{NULL}$	null pointer dereference
	$x\ \mathrm{op}_s\ y$	$x_\infty\ \mathrm{op}_s\ y_\infty \notin [-2^{n-1}, 2^{n-1} - 1]$	signed integer overflow
	$x\ /\ y, x\ \%\ y$	$y = 0$	division by zero
	$x << y, x >> y$	$y < 0 \vee y \geq n$	oversized shift
	$a[x]$	$x < 0 \vee x \geq \texttt{ARRAY\_SIZE}(a)$	buffer overflow
Library	$\texttt{abs}(x)$	$x = -2^{n-1}$	absolute value overflow
	$\texttt{memcpy}(\texttt{dst}, \texttt{src}, \texttt{len})$	$\lvert\texttt{dst} - \texttt{src}\rvert < \texttt{len}$	overlapping memory copy
	use q after $\texttt{free}(p)$	$\mathrm{alias}(p, q)$	use after free
	use q after $p' := \texttt{realloc}(p, \ldots)$	$\mathrm{alias}(p, q) \wedge p' \neq \texttt{NULL}$	use after realloc

Is This Compilers' Bug?

A true story: GCC bug #30475 (2007/01/15)

A GCC user:

- *"This will create MAJOR SECURITY ISSUES in ALL MANNER OF CODE. I don't care if your language lawyers tell you gcc is right. . . . FIX THIS! NOW!"*

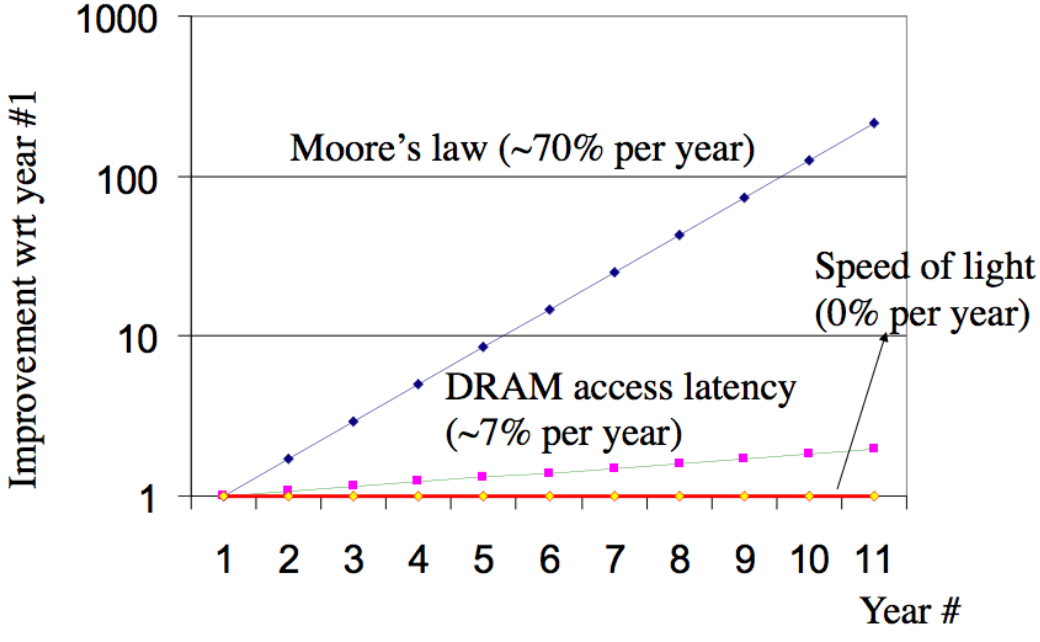
A GCC developer:

- *"I am not joking, the C standard explicitly says signed integer overflow is undefined behavior. . . . GCC is not going to change."*

http://gcc.gnu.org/bugzilla/show_bug.cgi?id=30475

Property-2: Latency

Latency is hard to optimize, it has physical limitations



Property-3: Throughput / Capacity

Throughput: a number of transactions / transferred-data per second

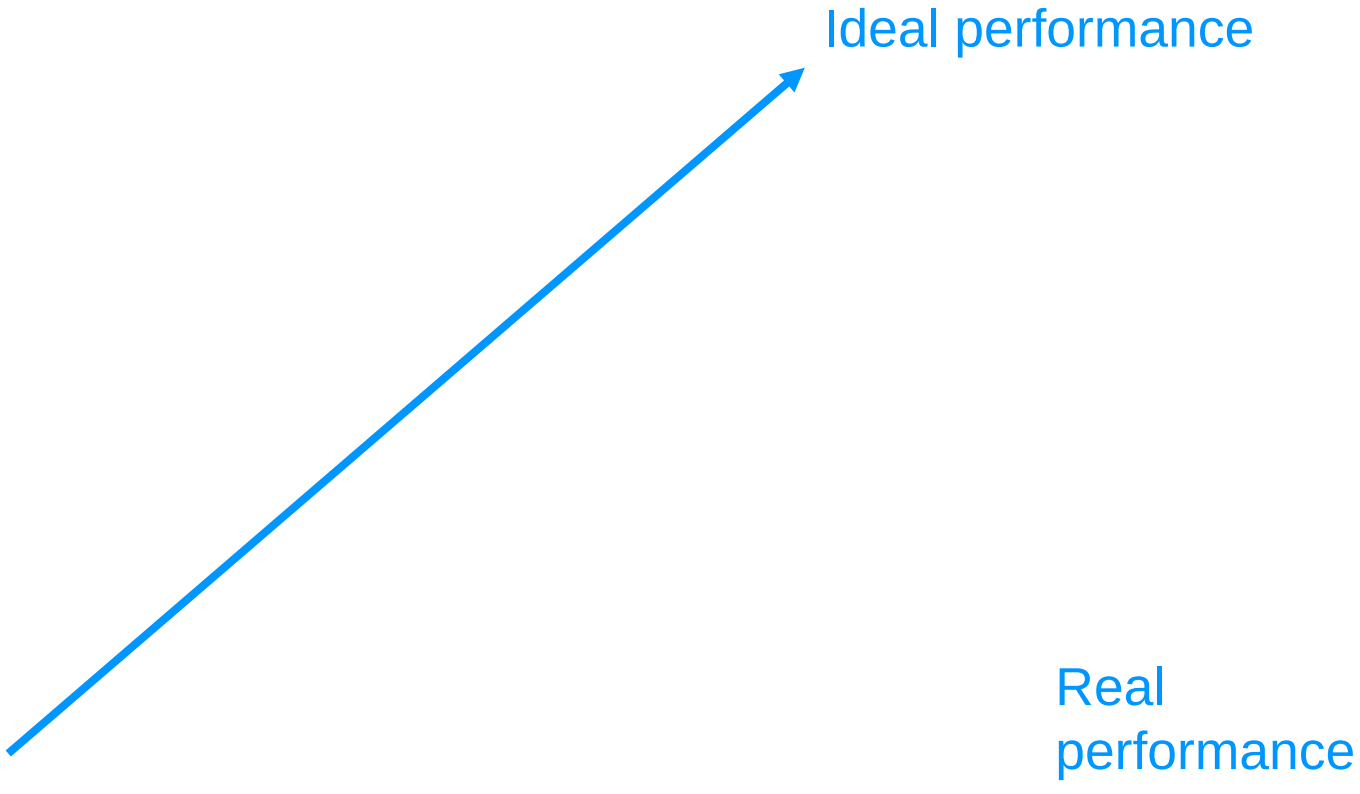
7nm → 5nm → 3nm → 2nm... what's next?

Once stop getting smaller, it has to go bigger

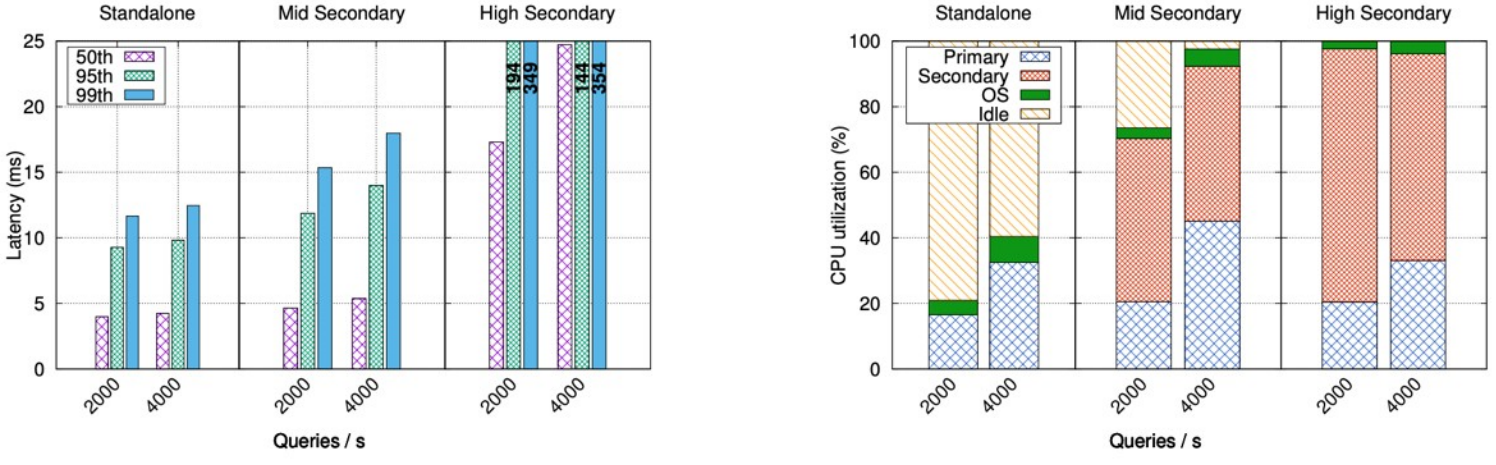
CES 2019: Moore's Law is dead, says Nvidia's CEO

The long-held notion that the processing power of computers increases exponentially every couple of years has hit its limit, according to Jensen Huang.

Property-4: Scalability



Property-5: Performance Isolation



(a) Query response latency

(b) CPU utilization

Figure 4: Single machine run of IndexServe standalone (no colocation) vs. colocated with an unrestricted secondary. A *mid* secondary increases the 99th percentile query latency by up to 42%, while a *high* increases same by up to 29×.

Iorgulescu, Călin, et al. "Perfiso: Performance isolation for commercial latency-sensitive services." *USENIX ATC'18.*

Property-6: Utilization

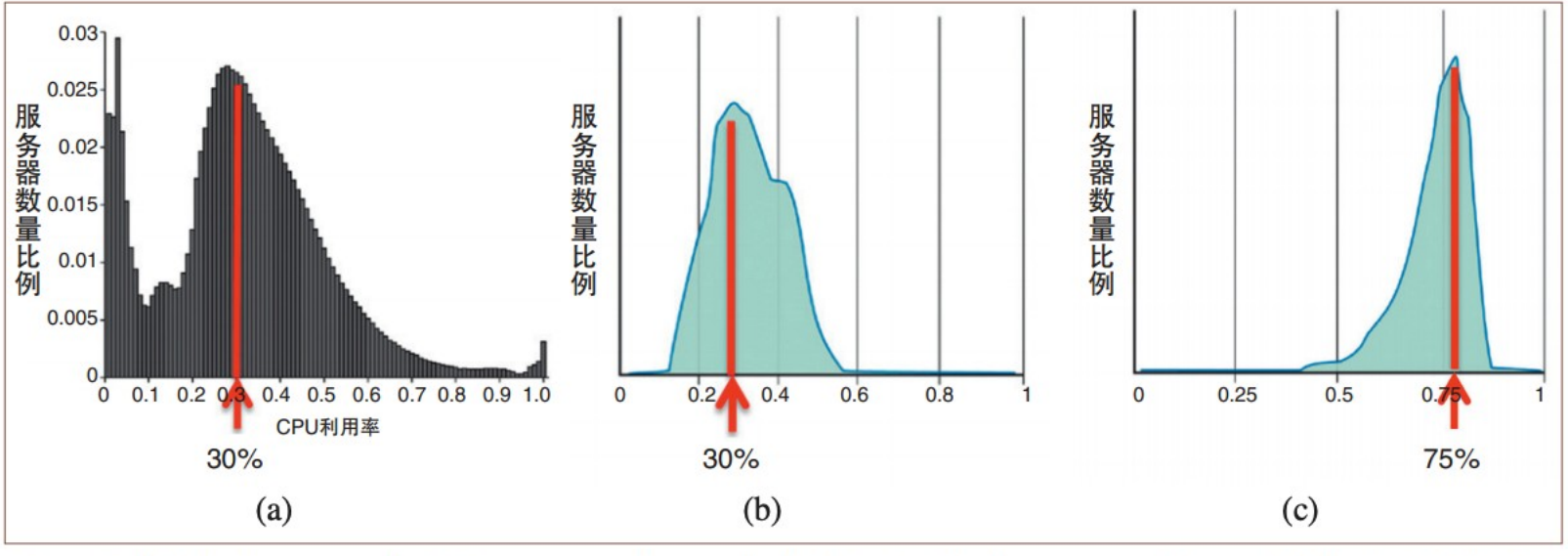
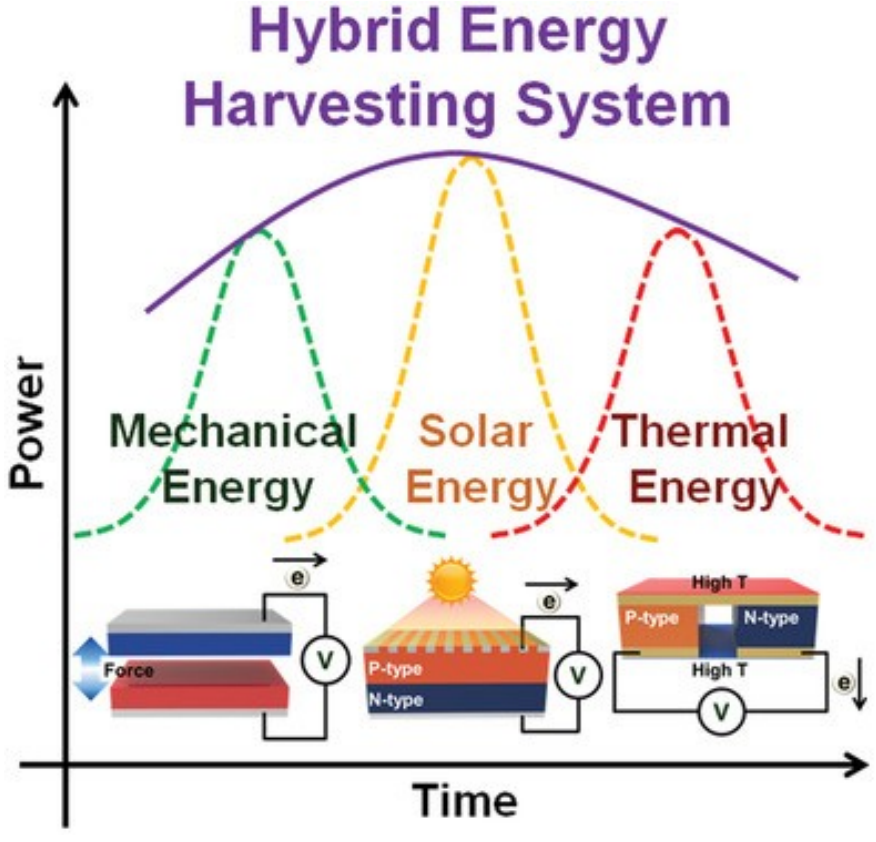


图2　谷歌数据中心CPU利用率：(a)2006年5000台在线应用服务器；(b)2013年2万台在线应用服务器；(c)2013年2万台批处理应用服务器[4]

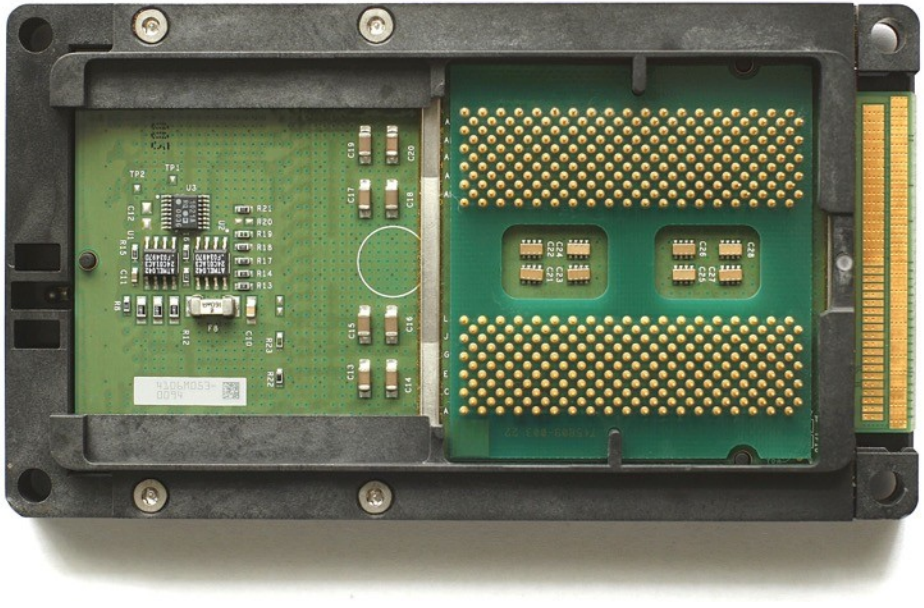
数据来源：“数据中心成本与利用率现状分析”，中国计算机学会通讯，2015.

Property-7: Energy Efficiency



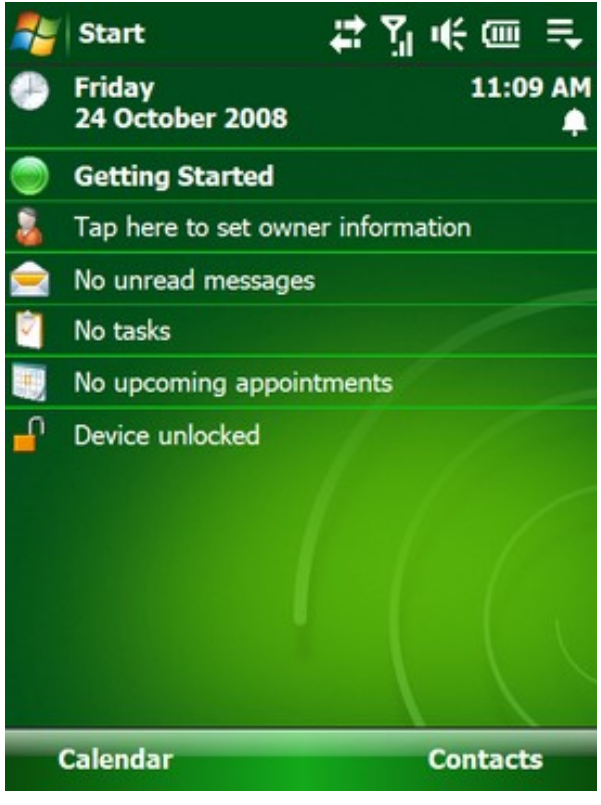
Property-8: Compatibility

Intel's Itanium, 64-bit, not compatible to x86, died.



Itanium Process, from Wikipedia

Property-9: Usability



Property-10: Consistency

在12306买到相同高铁票怎么办?

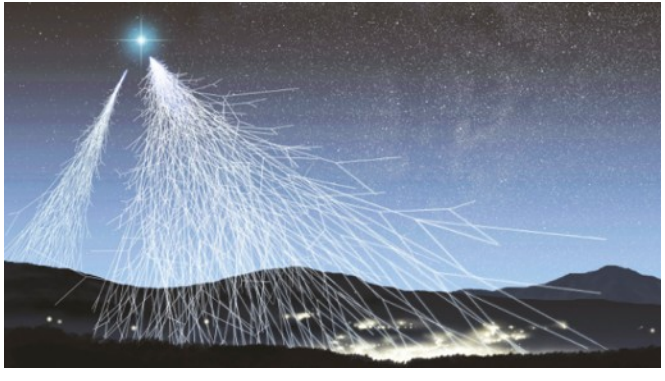
2019-06-10 17:12

据时间视频消息， 6 月 8 日，北京南站，庞女士和丈夫乘坐 G497 列车，上车后发现票面上的座位坐了人。庞女士和在座位上的乘客交涉后，发现除了身份证和姓名不一样之外，她们的票和自己手上的票一模一样。两人均是在窗口购票，双方购票相差时间三分钟左右。双方在找到列车长之后，庞女士被安排到了另一个车厢。

针对此事， 12306 客服回应称这种情况很少见，可能是由于机器故障所致。

Property-11: Fault Tolerance

A bug of Cisco router is caused by cosmic radiation



Cisco Bug: CSCuz62750 - Incremental drops on counter DROP_FRM_CRC_ERR_SGMII0 causes traffic loss

Last Modified
Sep 20, 2016

Product
Cisco ASR 9000 Series Aggregation Services Routers

Known Affected Releases
all

Description (partial)
Symptom:
Partial data traffic loss can be observed. Below list counters need to focus to determine the issue:-

"show controller np counters all loc <location>" could indicate FRM_FRM or CRC drop counts.

1082	DROP_FRM_CRC_ERR_SGMII0	1429516994	0
1083	DROP_FRM_FRM_ERR_SGMII0	74455703	0
1084	DROP_FRM_CRC_ERR_SGMII1	1427728248	0
1085	DROP_FRM_FRM_ERR_SGMII1	74942820	0
1086	DROP_FRM_CRC_ERR_SGMII2	1431171380	0
1087	DROP_FRM_FRM_ERR_SGMII2		
1088	DROP_FRM_CRC_ERR_SGMII3		
1089	DROP_FRM_FRM_ERR_SGMII3		

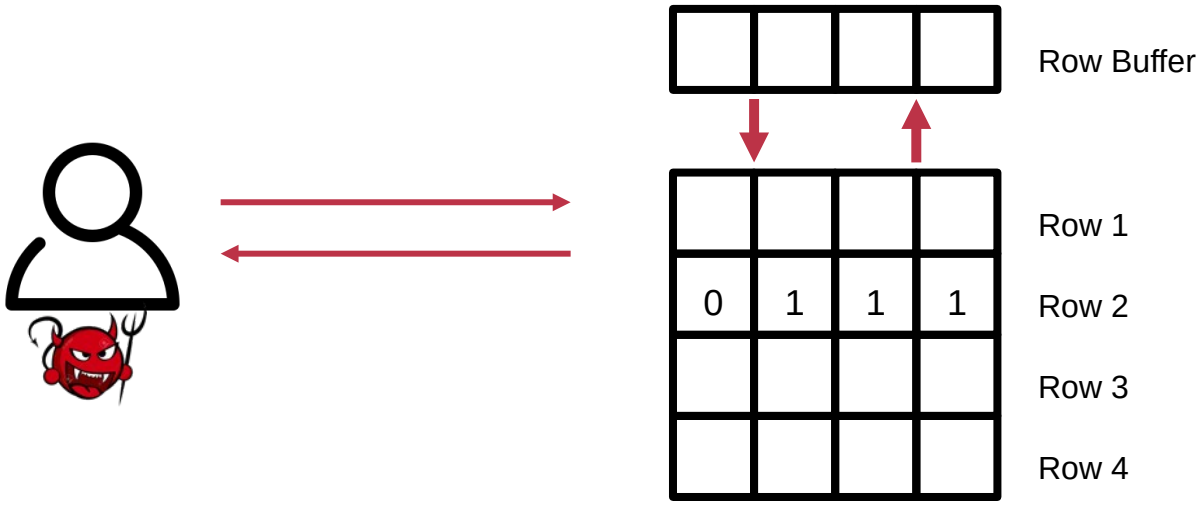
Cosmic radiation

It is also theoretically possible for data corruption to happen after the CRC check, which should then be detected at the higher protocol layers.

Conditions:
Problem observed on operational network. Possible trigger is cosmic radiation causing SEU soft errors.

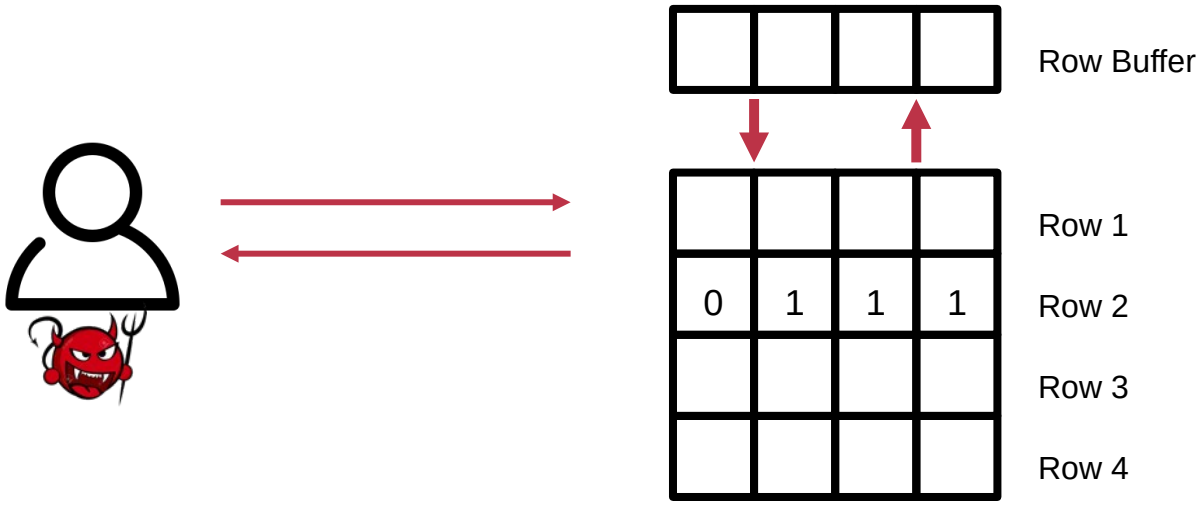
This issue can affect "Juggernaut" LCs (A9K-1X100GE-SE/TR, A9K-2X100GE-SE/TR)

Property-11: Fault Tolerance



Rowhammer Attack: flip memory bits!

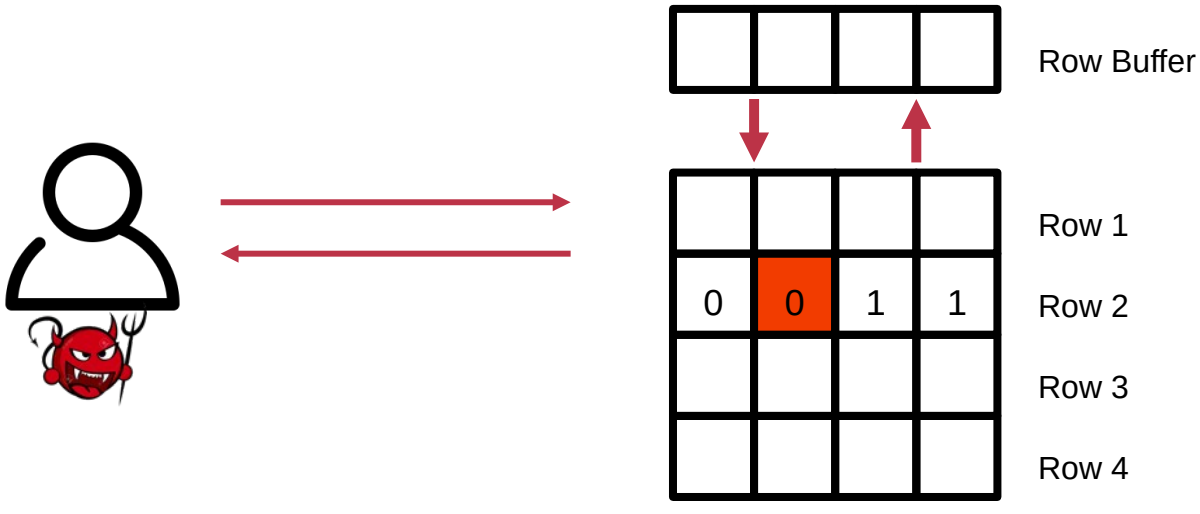
Property-11: Fault Tolerance



Rowhammer Attack: flip memory bits!

Property-11: Fault Tolerance

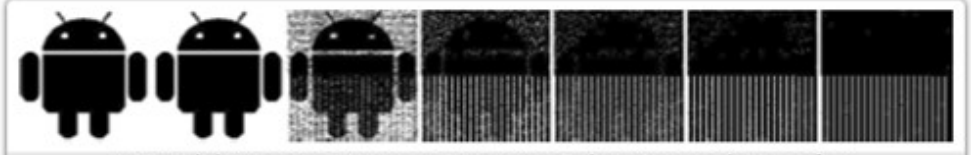
CPU Architecture	Errors	Access-Rate
Intel Haswell (2013)	22.9K	12.3M/sec
Intel Ivy Bridge (2012)	20.7K	11.7M/sec
Intel Sandy Bridge (2011)	16.1K	11.6M/sec
AMD Piledriver (2012)	59	6.1M/sec



Rowhammer Attack: flip memory bits!

Property-12: Security

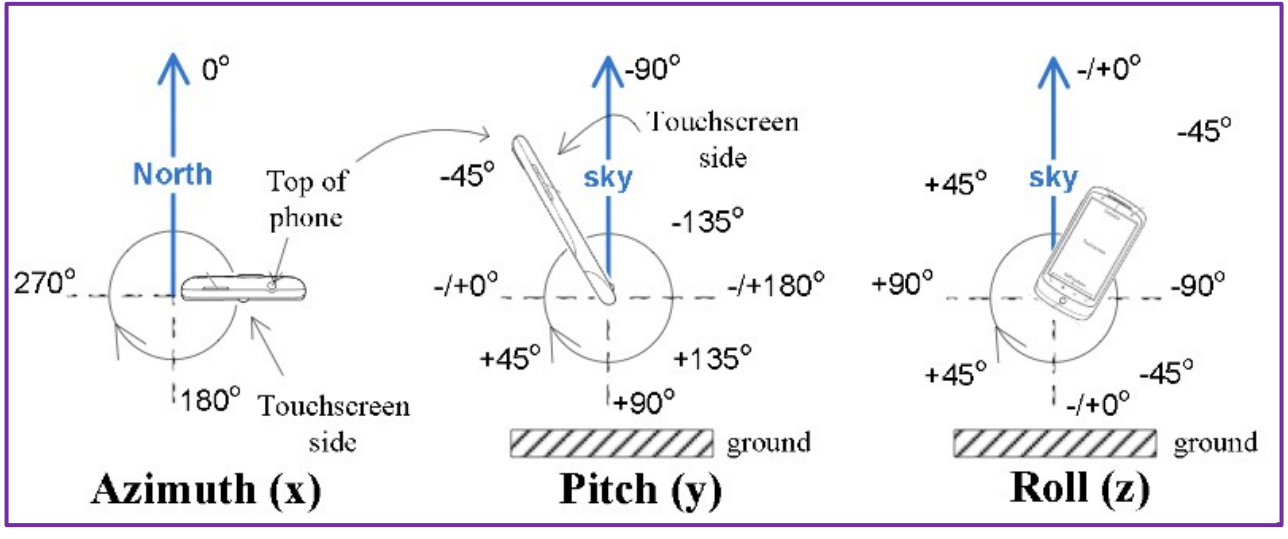
Cold-boot attack: physically attack that can scan memory to get any plaintext



A 'Droid' bitmap in RAM on a Samsung Galaxy Nexus device after 0s, a minuscule time, 0.5s, 1s, 2s, 4s and 6s. Reboot at room temperature.

Müller, Tilo, and Michael Spreitzenbarth. "Frost." *Applied Cryptography and Network Security*. Springer Berlin Heidelberg, 2013.

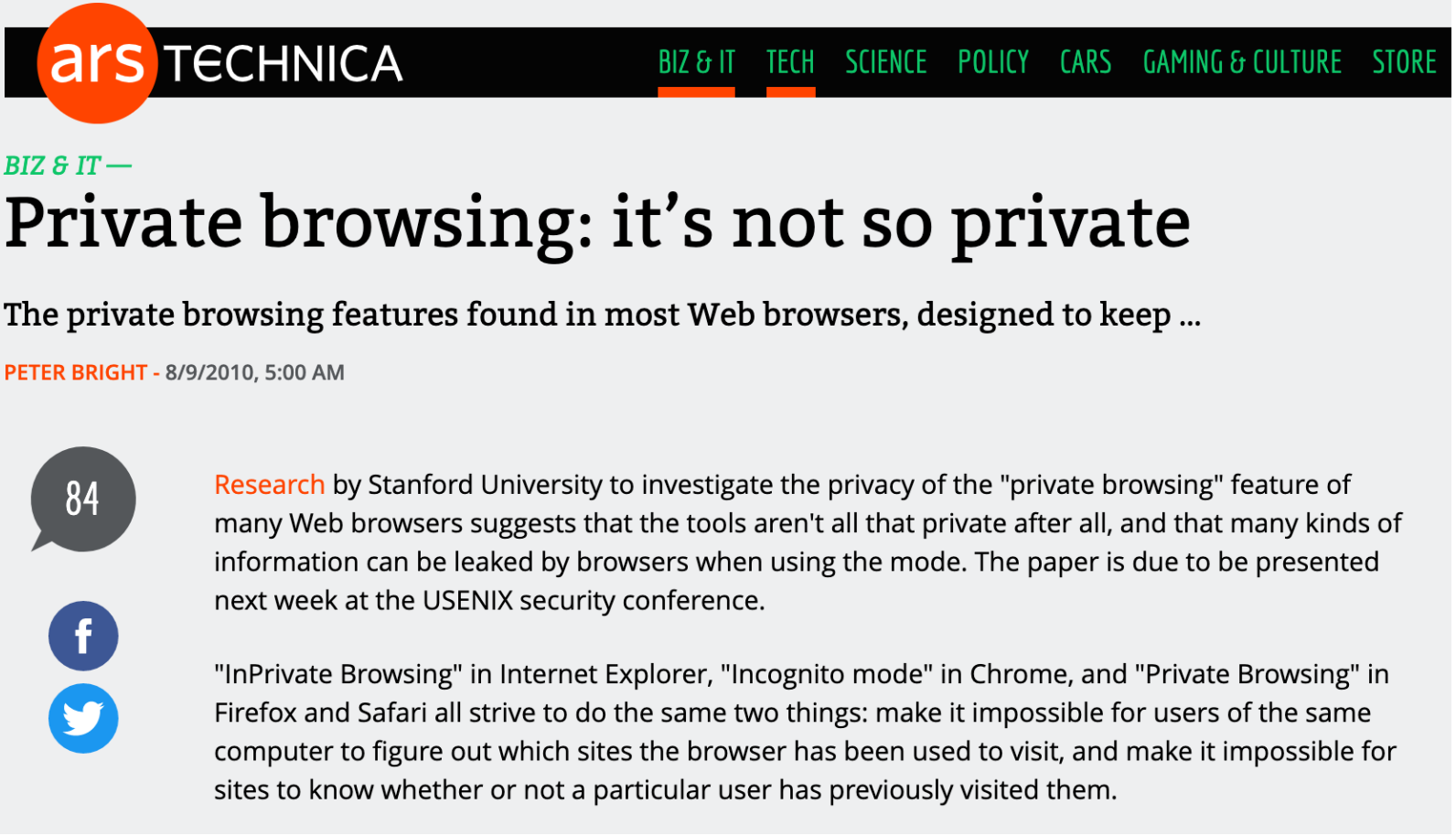
Property-12: Security



Side-Channel: infer PIN code through motion-detector

Cai, Liang, and Hao Chen. "TouchLogger: Inferring Keystrokes on Touch Screen from Smartphone motion." *HotSec*. 2011.

Property-13: Privacy



ars TECHNICA

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BIZ & IT —

Private browsing: it's not so private

The private browsing features found in most Web browsers, designed to keep ...

PETER BRIGHT - 8/9/2010, 5:00 AM

84

Research by Stanford University to investigate the privacy of the "private browsing" feature of many Web browsers suggests that the tools aren't all that private after all, and that many kinds of information can be leaked by browsers when using the mode. The paper is due to be presented next week at the USENIX security conference.

"InPrivate Browsing" in Internet Explorer, "Incognito mode" in Chrome, and "Private Browsing" in Firefox and Safari all strive to do the same two things: make it impossible for users of the same computer to figure out which sites the browser has been used to visit, and make it impossible for sites to know whether or not a particular user has previously visited them.

Property-14: Trust

Fighting Club, 1999

Conflict between these Properties

Usability VS. Privacy

Performance VS. Security

Performance VS. Energy

Fault Tolerance VS. Consistency

...

All these lead to more complexity

SYSTEM COMPLEXITY

Problem Types

Emergent properties (surprise!)

- The properties that are not considered at design time

Propagation of effects (butterfly effort)

- Small change -> big effect

Incommensurate scaling (growing pains)

- Design for small model may not scale

Trade-offs (waterbed effect)

- You cannot sell the cow and drink the milk

1. Emergent Properties

Features

- No evident in the individual components of a system
- But show up when combining those components
- Might also be called surprises
- An unalterable fact of life: some things turn up only when a system is built

1. Emergent Properties

The Millennium Bridge

- For pedestrians over the River Thames in London
- Pedestrians synchronize their footsteps when the bridge sways, causing it to sway even more

- It had to be closed after only a few days

Emergent Property Example: Ethernet

All computers share single cable

Goal is reliable delivery

Listen while sending to detect collisions

- If two nodes sends data at the same time, then both cancel and wait for a random time

Does Collision Detection Work?

What if A finishes sending before data from B arrives?

- 1km at 60% speed of light = 5 ms (microseconds)
- Original Ethernet Spec: 3 Mbit/sec
  - A can send 15 bits before bit 1 arrives at B
  - A must keep sending for 2*5 ms (to detect collision when first bit from B arrives)
- Minimum packet size is 5*2*3 = 30 bits
- The default header is 5 bytes (40 bits), so no problem for now

3 Mbit/s -> 10 Mbit/s, What will Happen?

First Ethernet standard: 10 Mbit/s, 2.5 km wire

- Must send for 2*12.5 µseconds = 250 bits @ 10 Mb/s
- Header was 14 bytes
- Needed to pad packets to at least 250 bits (~32 bytes)

Emergent property: Minimum packet size!

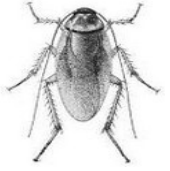
- The 250-bit minimum packet size is a surprise

2. Propagation of Effects [Cole'69]

WHO: tried control malaria in North Borneo

- Sprayed villages with DDT
- Wiped out mosquitoes, but ….
- Roaches collected DDT in tissue
- Lizards ate roaches and became slower
- Easy target for cats
- Cats didn't deal with DDT well and died
- Forest rats moved into villages
- Rats carried the bacillus for the plague

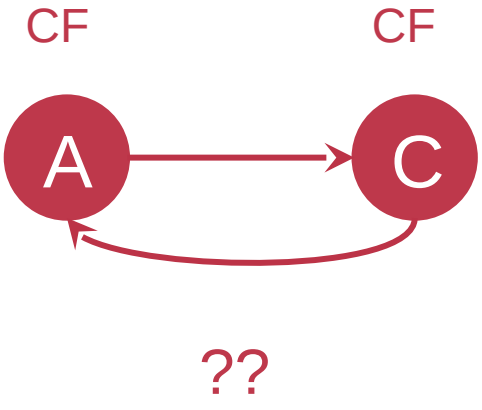
WHO just replaced malaria with the plague

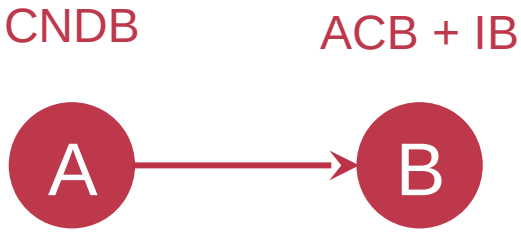


Example: No Small Changes

Phone network features

- CF: Call Forwarding
- CNDB: Call Number Delivery Blocking
  - The caller's number should be hidden
- ACB: Automatic Call Back
- IB: Itemized Billing





- A calls B, B is busy
- Once B is done, B automatically calls A
- A's (caller) number appears on B's bill

3. Incommensurate Scaling

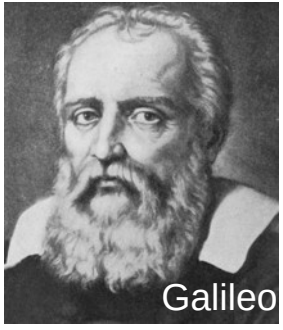
As a system increases in size or speed, not all parts of it follow the same scaling rules

- So things stop working

The mathematical description

- Different parts of the system exhibit different orders of growth

3. Incommensurate Scaling


Galileo

Galileo in 1638

- To illustrate briefly, I have sketched a bone whose natural length has been increased three times and whose thickness has been multiplied until, for a correspondingly large animal, it would perform the same function which the small bone performs for its small animal.
- From the figures here shown you can see how out of pro-portion the enlarged bone appears.

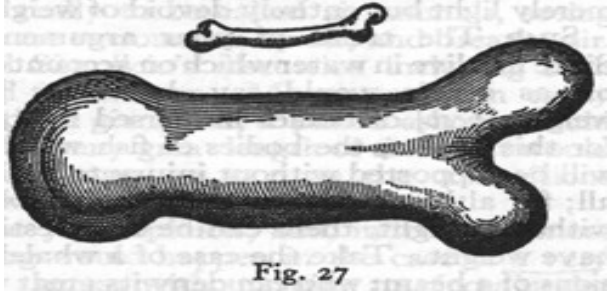
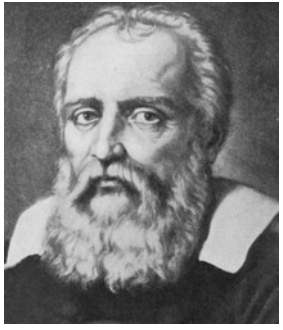


Fig. 27

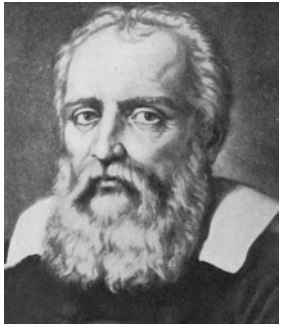
3. Incommensurate Scaling



Galileo in 1638

- Clearly then if one wishes to maintain in a great giant the same proportion of limb as that found in an ordinary man he must either find a harder and stronger material for making the bones, or he must admit a diminution of strength in comparison with men of
  medium stature; for if his height be increased inordinately he will fall and be crushed under his own weight.

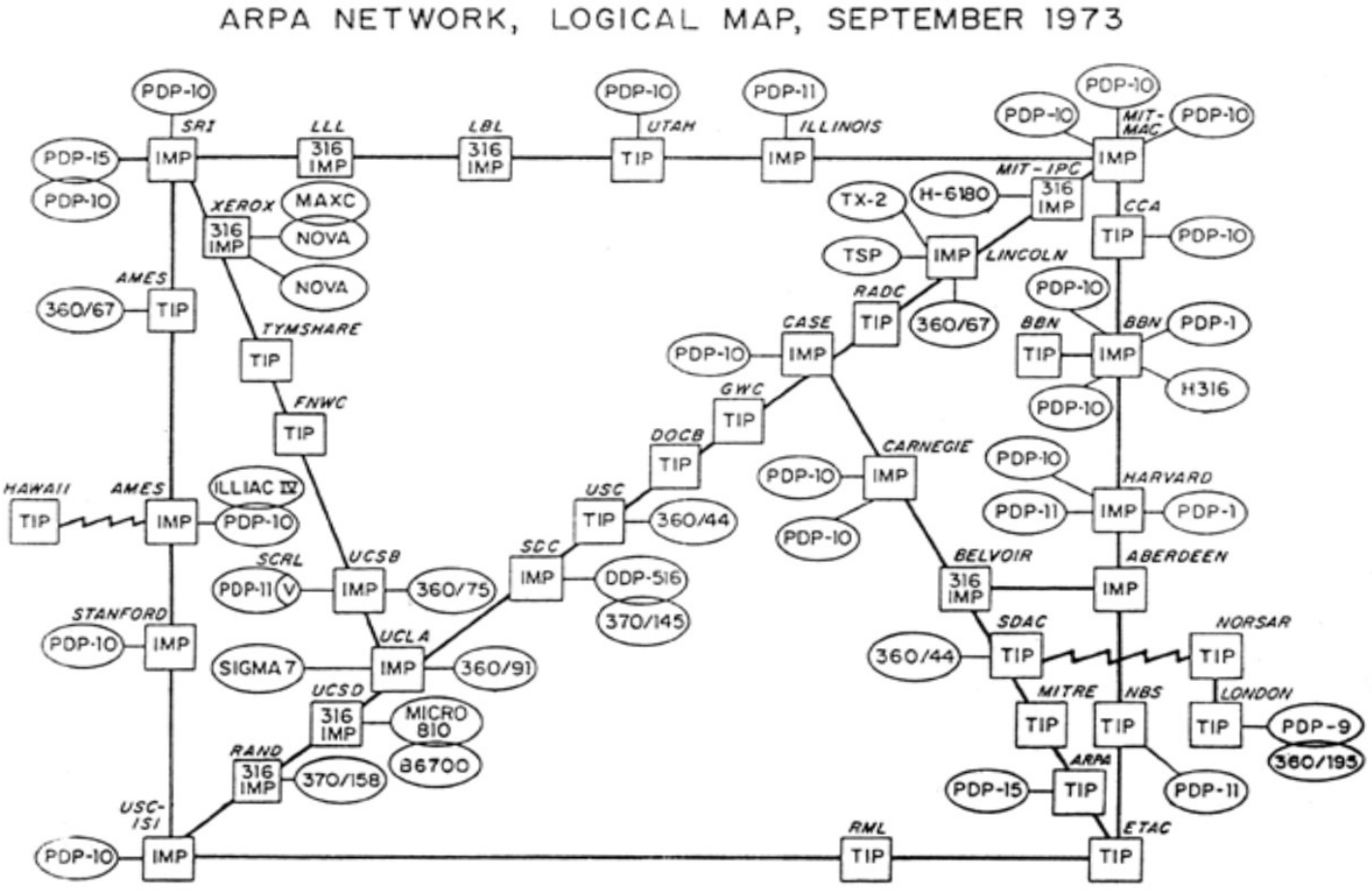
3. Incommensurate Scaling



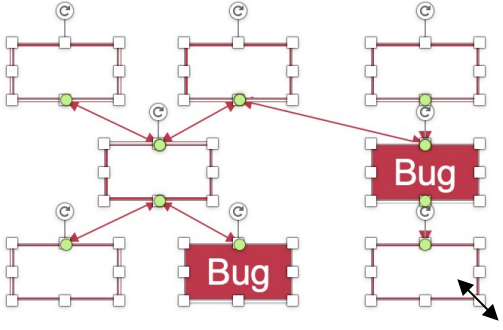
Galileo in 1638

- Whereas, if the size of a body be diminished, the strength of that body is not diminished in the same proportion; indeed the smaller the body the greater its relative strength. Thus a small dog could probably carry on his back two or three dogs of his own size; but I believe that a horse could not carry even one of his own size.

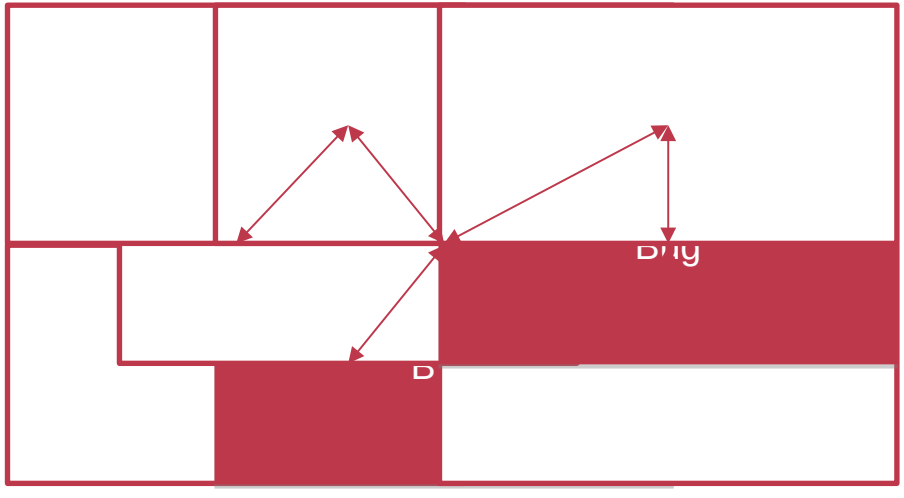
3. Incommensurate Scaling



Example: Scaling Figures in PPT



Original



A mess after scaling

Example: Scaling the Internet

Size routing tables (for shortest paths): $O(n^2)$

- Hierarchical routing on network numbers
- Address: 16-bit network number and 16-bit host number

Limited networks (2^{16})

Solutions:

- NAT (Network Address Translators) and IPv6

4. Trade-offs

General models

- Limited amount of goodness
- Maximize the goodness
- Avoid wasting
- Allocate where helps most

Waterbed effect

- Pushing down on a problem at one point
- Causes another problem to pop up somewhere else

4. Trade-offs

Binary classification

- We wish to classify a set of things into two categories
    - Based on presence or absence of some property
- But we lack a direct measure of that property
- So we identify some indirect measure instead
    - Known as a proxy

4. Trade-offs

Binary classification (Cont.)

- Occasionally this scheme misclassifies something
- By adjusting parameters of the proxy
- The designer may be able to:
    - reduce one class of mistakes
    - but only at the cost of increasing some other class of mistakes

M.A.L.H

COPING WITH COMPLEXITY

How to Handle Complexity?

Ideally, the "Constructive Theory"

- Allows the designer systematically to
  - Synthesize a system from its specifications
  - Make necessary trade-offs with precision
- Works in some fields
  - Communication systems
  - Linear control systems
  - Design of bridge and skyscrapers (to a certain extent)

How to Handle?

In Computer Systems

- "We find that we were born too soon"
  - In "Principles of Computer System Design: An Introduction"
- The problems
  - We work almost entirely by analyzing ad hoc examples rather than by synthesizing
  - So, in place of a well-organized theory, we use case studies

Limit the Levels of Complexity

All systems are indefinitely

- The deeper one digs, the more signs of complexity turn up
- A computer -> gates -> electrons -> quarks -> …

Abstraction: limits the depth of digging

M.A.L.H

Modularity

- Split up system
- Consider separately

Abstraction

- Interface/Hiding
- Avoid propagation of effects

Layering

- Gradually build up capabilities

Hierarchy

- Reduce connections
- Divide-and-conquer

Modularity

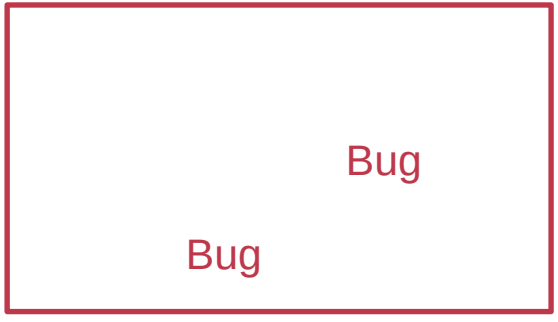
Analyze or design the system as a collection of interacting subsystems

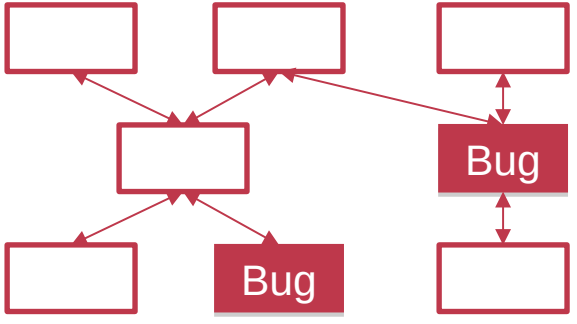
- Subsystems called modules
- "Divide-and-conquer" technique

Modularity is the simplest, most important tool for reducing complexity

- Consider interactions among the components within a module without simultaneously thinking about the components that are inside other modules

Modularity





$$BugCount \sim N$$
$$DebugTime \sim N \times BugCount$$
$$\sim N^2$$

$$DebugTime \sim \left(\frac{N}{K}\right)^2 \times K$$
$$\sim \frac{N^2}{K}$$

Original System

System with Modularity

Assumptions: consider the number of bugs is proportional to its size, and bugs are randomly distributed

Abstraction

Abstraction

- Treat a module based on external specifications, no need for details inside

Principles to divide a module

- Follow natural or effective boundaries
- Fewer interactions among modules (Chap.4 & 5)
- Less propagation of effects

Abstraction

Problem: minimizing interconnections among modules may be defeated

- Unintentional or accidental interconnections, arising from implementation errors
- Well-meaning design attempts to sneak past modular boundaries
    - Improve performance
    - Meet some other requirement

Abstraction

Software is particularly subject to this problem

- The modular boundaries provided by the separately compiled subprograms are actually somewhat soft
- Is easily penetrated by errors in:
    - using pointer;
    - filling buffer;
    - calculating array index;
    - etc.

Abstraction

Failure containment

- When a module does not meet its abstract interface specifications
- Limiting the impact of faults
    - Well-designed and properly enforced modular abstractions
    - Control propagation of effects
- Modules are the units of fault containment

Layering

Goal: Reduce module interconnections even more

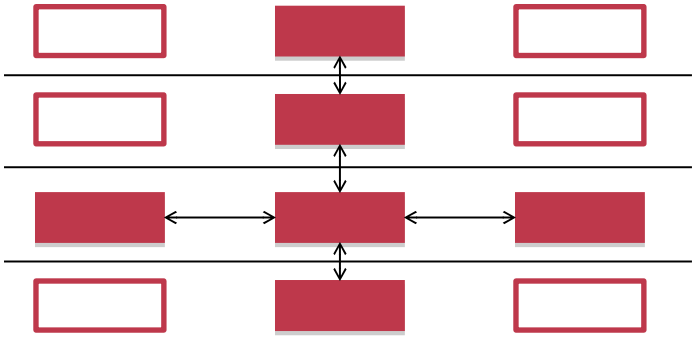
How to do it?

- Build a set of mechanisms first (a lower layer)
- Use them to create a different complete set of mechanisms (an upper layer)

General rule: A module in one layer only interacts with:

- its peers in the same layer, and
- modules in the next lower layer / next higher layer

Layering



House:

- Inner layer of studs, joist, rafter (shape & strength)
- Layer of sheathing and drywall (wind out)
- Layer of siding, flooring and roof tiles (watertight)
- Cosmetic layer of paint (looks good)

Algebra:

- integer, complex number, polynomials, polynomials with polynomial coefficients

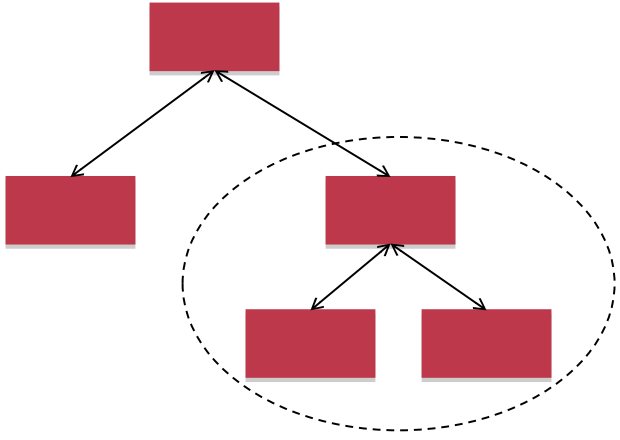
Hierarchy

Hierarchy: another module organization

- Start with a small group of modules
- Assemble them into a stable, self-contained subsystem with well defined interface
- Assemble a group of subsystems to a larger subsystem

Example

- 1 manager leads N employees
- 1 higher manager leads N lower managers



Hierarchy

There are many striking examples of hierarchy

- E.g., microscopic biological systems, assembly of Alexander's empire
- Under evolution, such designs have a better chance of survival

Constrains interactions

- Permit interaction only among the components of a subsystem
- Reduces the number of potential interactions among modules from square-law to linear

COMPUTER SYSTEMS ARE DIFFERENT

Computer Systems are Different

Computer systems are the same as all other systems

- Certain common problems show up in all complex systems
- The techniques that have been devised for coping with complexity are universal

Yet, computer systems are different (sadly)

- The complexity is not limited by physical laws
- The rate of change of technology is unprecedented

Unbounded Composition

Two properties of computer systems

- 1. Mostly digital
- 2. Controlled by software
- Both relax the limits on complexity arising from physical laws in other systems

Computer System: Coping with Complexity

M.A.L.H are NOT enough

- Hard to choose the right modularity
- Hard to choose the right abstraction
- Hard to choose the right layer
- Hard to choose the right hierarchy

COURSE INFO

Scores

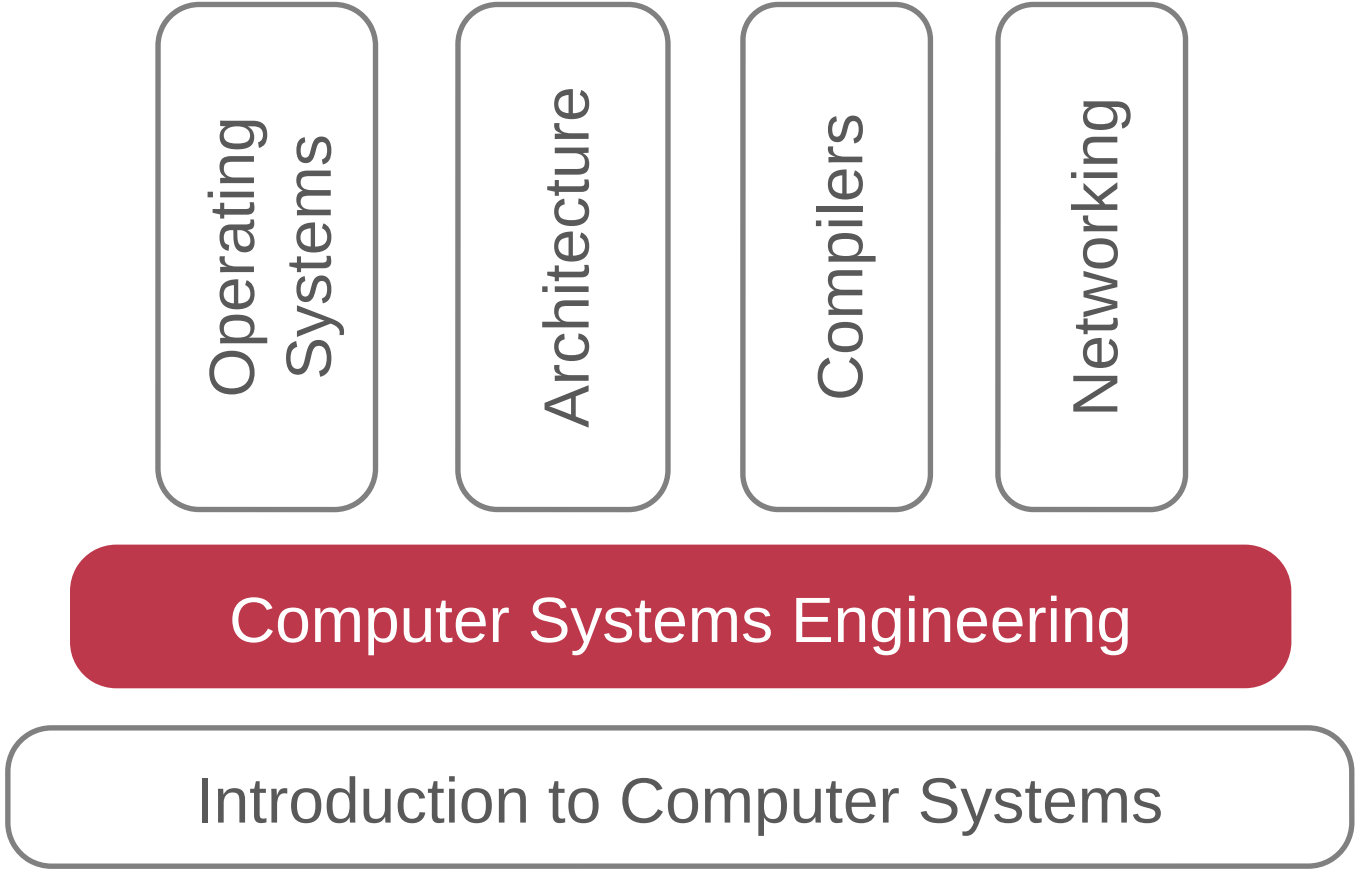
Mid-Exam: 25%

Final-Exam: 35%

Lab: 30%

Homework: 10%

Where is CSE in Courses



Course Info

Instructors

- Yubin Xia: xiayubin@sjtu.edu.cn
- Xingda Wei: wxdwfc@sjtu.edu.cn

TAs

- Le Chen
- Ke Cheng
- Jingkai He
- Yuhan Yang

Website

- https://oc.sjtu.edu.cn/courses/60116