Intro to Supercomputing and How It Can Help You

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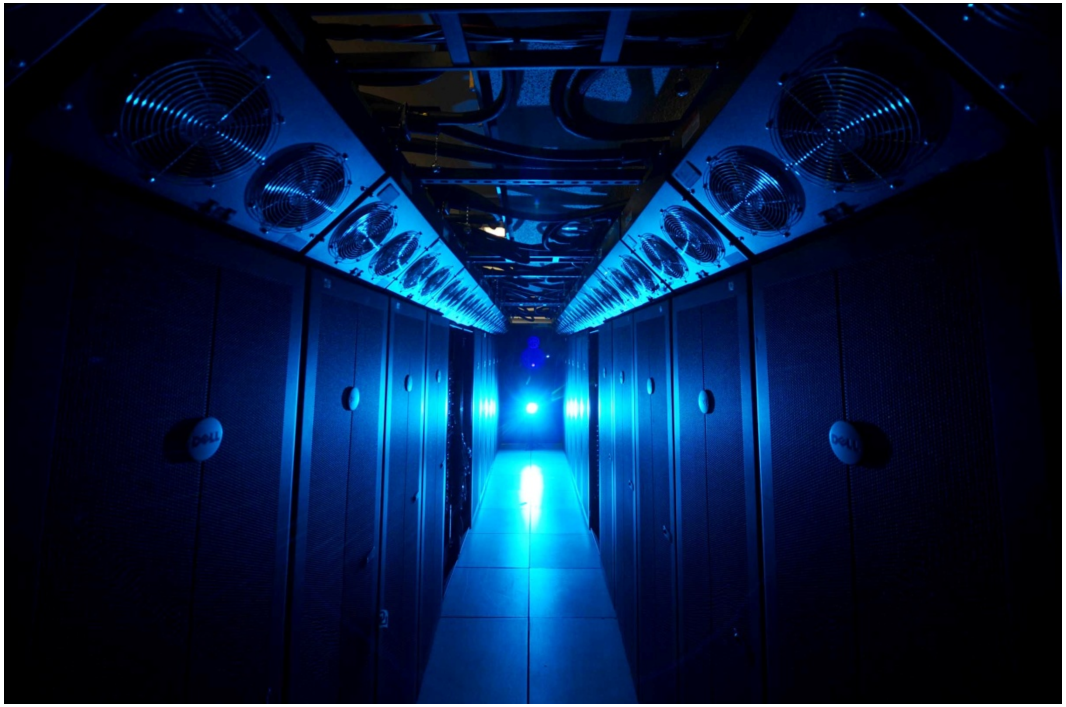
People


EXIT
CHE5480 : A Course in Chemical Engineering & Computer Science
Fall Semester 2003
Integration of HPC in Nanotechnology
National Science Foundation

Things



Thanks for your attention!

Questions?

www.oscer.ou.edu

What is Supercomputing?

Supercomputing is the **biggest, fastest computing right this minute**.

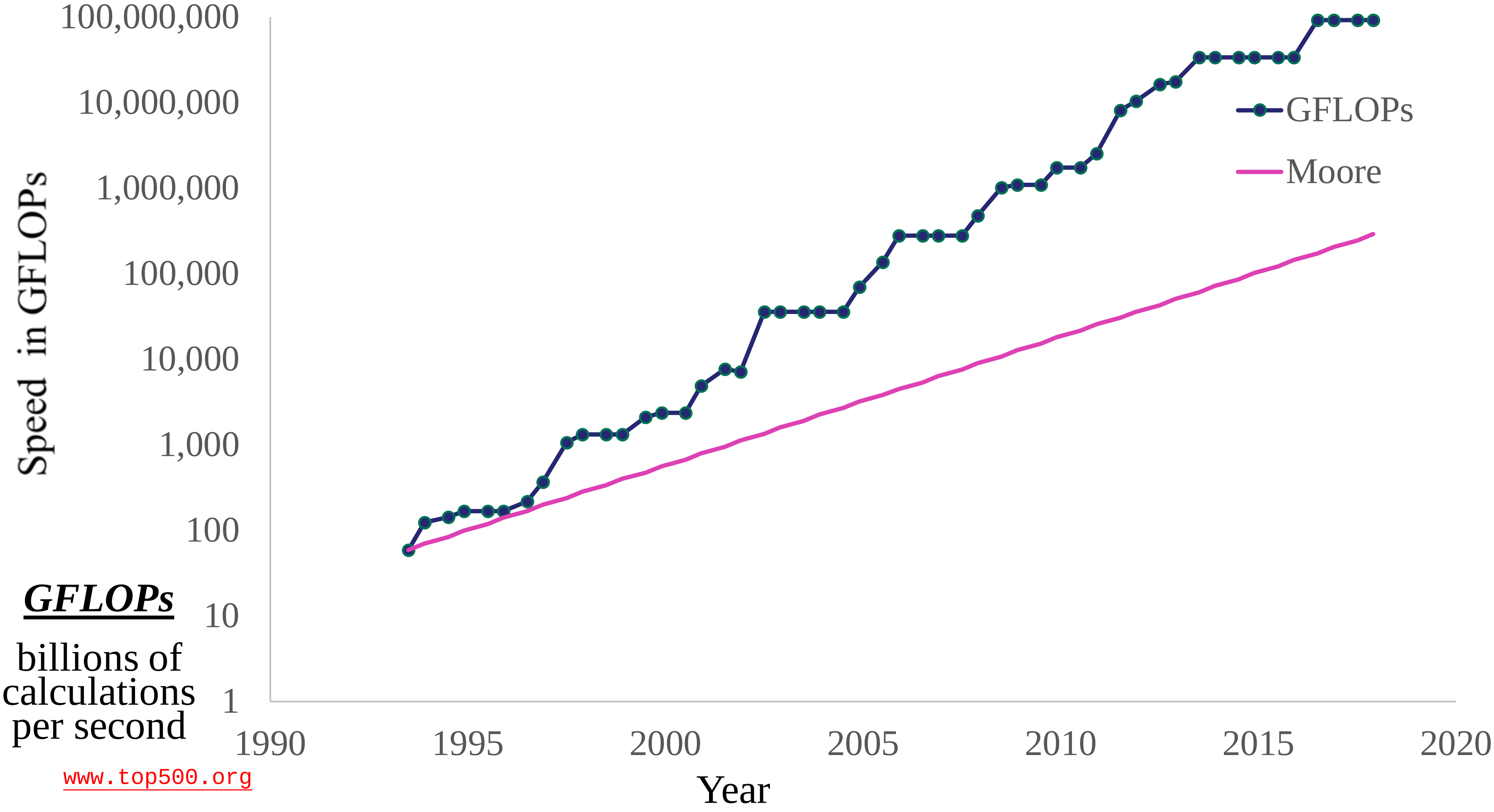
Likewise, a ***supercomputer*** is one of the biggest, fastest computers right this minute.

So, the definition of supercomputing is **constantly changing**.

Rule of Thumb: A supercomputer is typically at least 100 times as powerful as a PC.

Jargon: Supercomputing is also known as ***High Performance Computing*** **(HPC)** or ***Cyberinfrastructure*** **(CI).**

Fastest Supercomputer vs. Moore



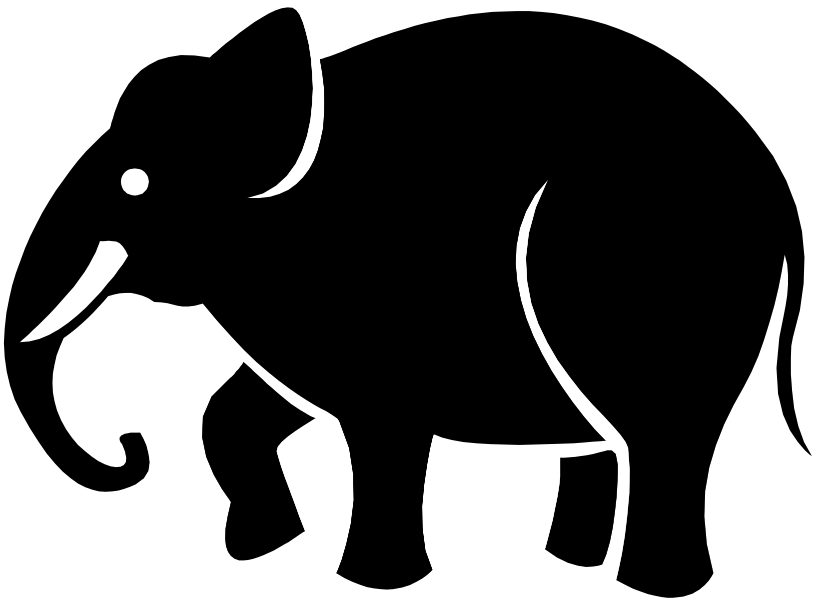
GFLOPs

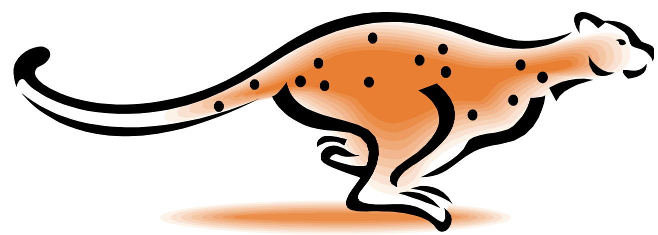
billions of calculations per second

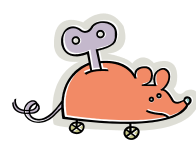
www.top500.org

What is Supercomputing About?

Size **Speed**



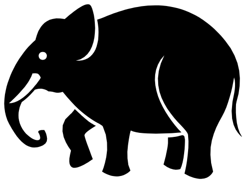




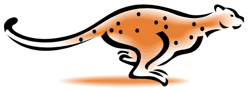
Laptop

What is Supercomputing About?

- **Size**: Many problems that are interesting to scientists and engineers **can't fit on a PC** – usually because they need more than a few GB of RAM, or more than a few 100 GB of disk.

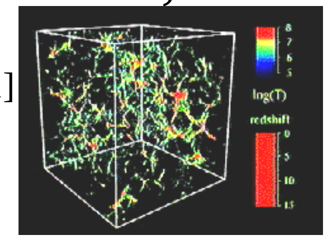


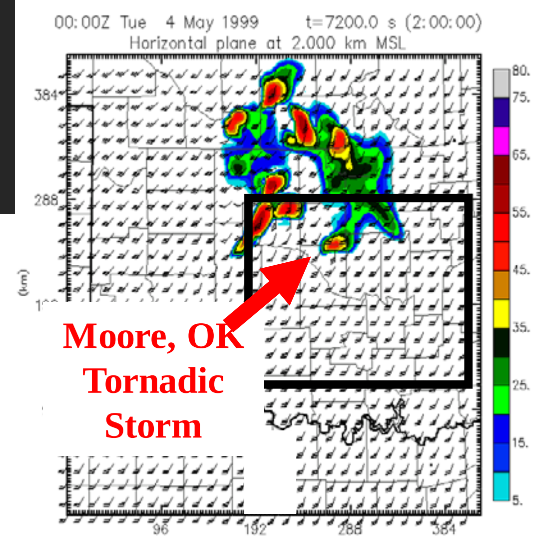
- **Speed**: Many problems that are interesting to scientists and engineers would take a very very long time to run on a PC: months or even years. But a problem that would take **a month on a PC** might take only **an hour on a supercomputer**.



What Is HPC Used For?

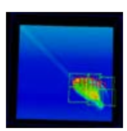
- ***Simulation*** of physical phenomena, such as
  - Weather forecasting
  - Galaxy formation
  - Oil reservoir management

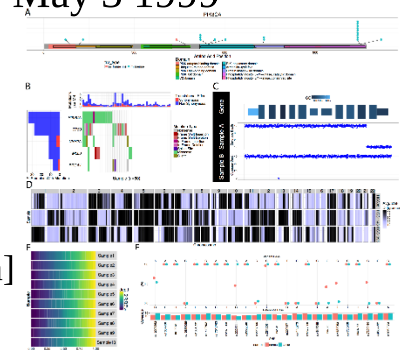
[1] 



May 3 1999[2]

- ***Data mining***: finding **needles** of information in a **haystack** of data, such as
  - Gene sequencing
  - Signal processing
  - Detecting storms that might produce tornados
- ***Visualization***: turning a vast sea of **data** into **pictures** that a scientist can understand

[3] 

[3a] 

Supercomputing Issues

- The tyranny of the ***storage hierarchy***
- ***Parallelism***: doing multiple things at the same time

What is a Cluster Supercomputer?

"… [W]hat a ship is … It's not just a keel and hull and a deck and sails. That's what a ship needs. But what a ship is ... is freedom."

– Captain Jack Sparrow

"Pirates of the Caribbean"

http://lh3.ggpht.com/_6hgSmco4R9M/SfpFA3057zI/AAAAAAAACSg/G-AGCgLrQOk/s1600-h/pirates%5B5%5D.jpg

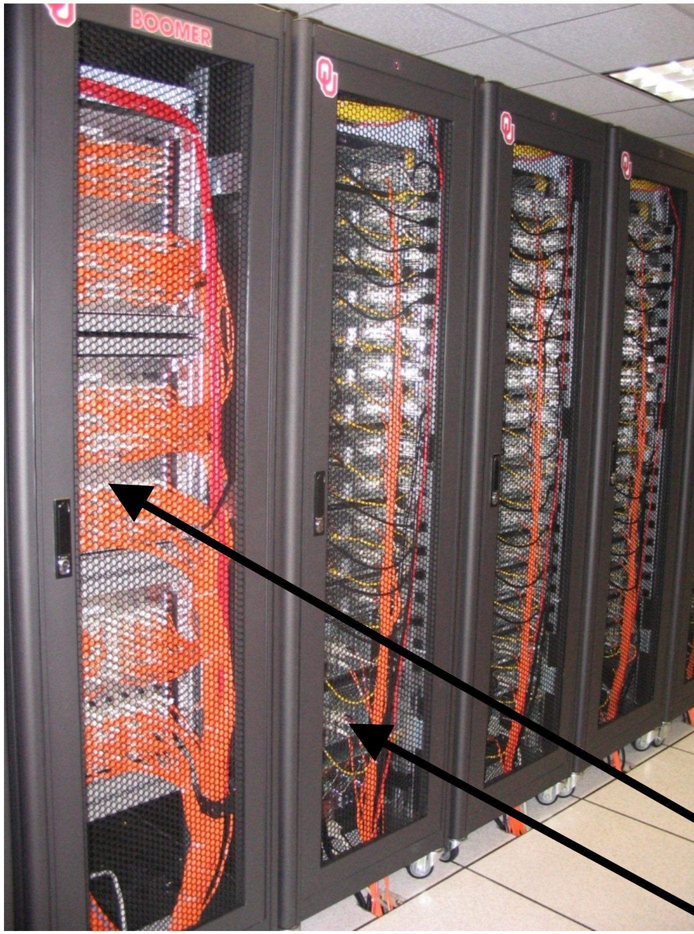
What a Cluster is ….

A cluster **needs** of a collection of small computers, called ***nodes***, hooked together by an ***interconnection network*** (or ***interconnect*** for short).

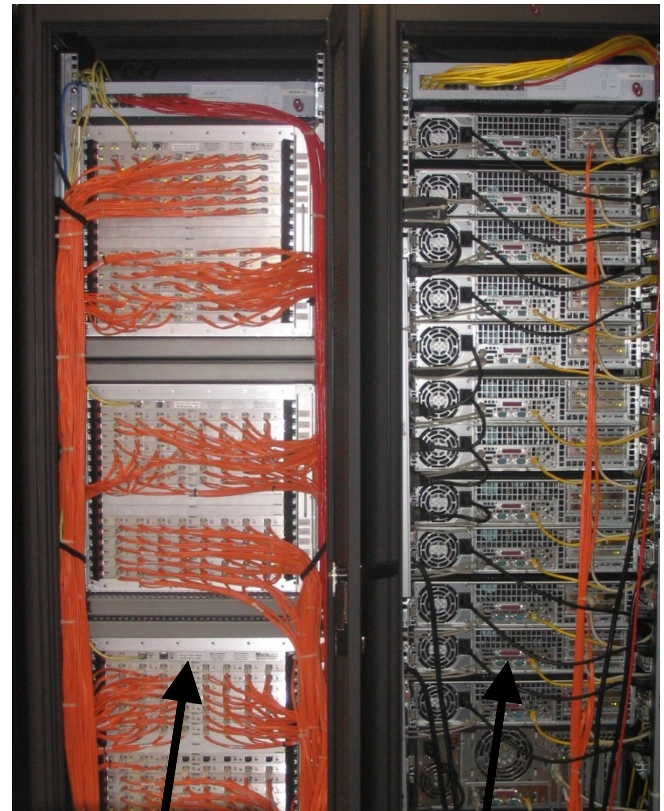
It also **needs** software that allows the nodes to communicate over the interconnect.

But what a cluster **is** … is all of these components working together as if they're one big computer ... a **super** computer.

An Actual Cluster



Boomer, in service 2002-5.



Interconnect

Nodes

OSCER

What is OSCER?

- Multidisciplinary center
- Division of OU Information Technology
- Provides:
  - Supercomputing **education**
  - Supercomputing **expertise**
  - Supercomputing **resources**: hardware, storage, software
- For:
  - Undergrad students
  - Grad students
  - Staff
  - Faculty
  - Their collaborators (including **off campus**)

Who is OSCER? Academic Depts

- Aerospace & Mechanical Engineering
- Anthropology
- **Biochemistry & Molecular Biology**
- Biological Survey
- Biology
- Biomedical Engineering
- **Biostatistics & Epidemiology**
- Chemical, Biological & Materials Engr
- Chemistry & Biochemistry
- Civil Engineering & Environmental Science
- Computer Science
- Economics
- Educational Psychology
- Electrical & Computer Engineering
- Finance
- Geography & Environmental Sustainability
- Geology & Geophysics
- Industrial & Systems Engineering
- Mathematics
- Meteorology
- **Microbiology & Immunology**
- Microbiology & Plant Biology
- **Occupational & Environmental Health**
- **Ophthalmology**
- Petroleum & Geological Engr
- Physics & Astronomy
- **Physiology**
- Psychology
- **Radiology**
- South Central Climate Science Center
- Sociology

More than 150 faculty & staff in **29 depts** in Colleges of Arts & Sciences, Atmospheric & Geographic Sciences, Business, Earth & Energy, Education, Engineering, Medicine and Public Health – with **more to come**!

Who is OSCER? Groups

- Advanced Radar Research Center
- Biocorrosion Center
- Center for Analysis & Prediction of Storms
- Cooperative Institute for Mesoscale Meteorological Studies
- Center for Engineering Optimization
- Institute for Environmental Genomics
- Interaction, Discovery, Exploration, Adaptation Laboratory
- OU Information Technology
- Oklahoma Center for High Energy Physics
- Plains Institute
- Robotics, Evolution, Adaptation, and Learning Laboratory
- South Central Climate Science Center

Who? Oklahoma Institutions

1. Cameron University
2. East Central University
3. Langston University
4. Northeastern State University
5. Northwestern Oklahoma State University
6. Oklahoma Baptist University
7. Oklahoma City University
8. Oklahoma School of Science & Mathematics
9. Oklahoma State University
10. Rogers State University
11. Southeastern Oklahoma State University
12. Southwestern Oklahoma State University
13. University of Central Oklahoma
14. University of Oklahoma (Norman, HSC, Tulsa)
15. University of Science & Arts of Oklahoma
16. University of Tulsa

1. NOAA National Severe Storms Laboratory
2. NOAA Storm Prediction Center
3. Noble Research Institute
4. Oklahoma Climatological Survey
5. Oklahoma Medical Research Foundation
6. OneNet
7. Tinker Air Force Base

OSCER has supercomputer users at <u>every Oklahoma public university but one</u>, plus at many private universities and one high school.

E m ∃ w

Who Are the Users?

Over 800 users so far, including:

- Roughly equal split between students vs faculty/staff (students are the bulk of the active users);
- many off campus users (roughly 20%);
- … more being added **every month**.

What Does OSCER Do? Teaching

Science and engineering faculty from all over America learn supercomputing at OU by playing with a jigsaw puzzle (NCSI @ OU 2004).

What Does OSCER Do? Facilitation

OU undergrads, grad students, staff and faculty learn
how to use supercomputing in their specific research.

OSCER Resources

OSCER's Current Supercomputer

Peak speed: 400 TFLOPs*

*TFLOPs: trillion calculations per second (double precision floating point)

645 compute servers

~1300 Intel Xeon Haswell, Broadwell, Sandy Bridge and Skylake CPU chips

13,000+ CPU cores

33 TB RAM

400 TB public disk

1.4 PB "condominium" disk

Mellanox 40 Gbps FDR10 Infiniband (3:1 oversubscribed, 13.33 Gbps, ~1 microsec latency)

Dell N-series Gigabit/10G Ethernet

CentOS 7 Linux

298 (46%) of compute servers are "condominium" (owned by individual research teams).

schooner.oscer.ou.edu

Photo: Jawanza Bassue

Internal Research Cloud

OU Research Cloud ("OURcloud")

This provides server replacement, so charged per virtual server per month, not per server per hour.

Oklahoma PetaStore

- Tape archive available to researchers at OU (and statewide), with a unique business model that makes long term archival storage affordable for our researchers, who pay about **half** as much per TB per copy as USB disk drives from Walmart, and **far less** than cloud or enterprise-quality disk.
- Funded by an NSF grant.
- Currently 1.8 PB content (2859 tape cartridge slots, all filled)
- OU IT's cost: space, power, cooling, labor, maintenance
- OU researchers' cost: tape cartridges (much cheaper)
- We now have a new NSF grant for the next archive (OURRstore).

OURRstore: Coming Soon!

- Successor to the PetaStore
- Funded by a new NSF grant
- ~11,000 tape cartridge slots
- File sharing: A file owner can designate that a file, or a collection of files, is downloadable by specific people, specific groups, or the whole world – with just a few clicks!

Why Tape?

- **<u>NO ONE LIKES TAPE!</u>**
  - <u>Very long latency per file</u>: 1 minute on average, compared to microseconds for SSD and milliseconds for spinning disk.
    - Best solution: a few big files instead of lots of small files.
- But, tape is **<u>much cheaper</u>** than disk.
- At large scale (PB), tape is the only affordable option.
  - The alternative to 100 PB of tape isn't 100 PB of disk; the alternative to tape is deleting your 100 PB of data.
- And, tape can be bought up front, then not re-bought for a decade or more – you don't need more grant money for your old files.
- Tape is like democracy and old age: it sucks except compared to the alternative.

Large Scale, Long Term Storage

Example: 1 PB of content:

- IBM enterp: 8 years, 1 PB, 2 copies = ~$2,000,000 at current pricing: **111x**
- Google: 8 years, 1 PB, N copies = ~$400,000 at current pricing: **22x**
- Dell: 8 years, 1 PB, 2 copies = ~$380,000 at current pricing: **21x**
- Amazon: 8 years, 1 PB, N copies = ~$230,000 at current pricing: **13x**
- Backblaze: 8 years, 1 PB, 2 copies = ~$158,000 at current pricing: **8.8x**
- Microsoft: 8 years, 1 PB, N copies = ~$115,000 at current pricing: **6.4x**
- USB disks: 8 years, 1 PB, 2 copies = ~$79,000 at current pricing: **4.4x**
- OURRstore: 8 years, 1 PB, 2 copies = ~$18,000 at current pricing: **base**
  (assumes dual copies for all non-cloud solutions; many include IDC; equipment gets bought again at start of year 6)

Batch Computing

- Batch computing: Submit a description of what you want to run, how, and what resources it'll need.
- It might start quickly, but it might wait quite a while, because the supercomputer is more popular than big.
- **NO ONE LIKES BATCH COMPUTING!**
- At large scale, the alternative to batch computing isn't on-demand interactive computing; at large scale, the alternative to batch computing is **NOT** computing.
- Batch computing is like democracy and old age: it sucks except compared to the alternative.

Supercomputing is Good for Big

- If you can fit a problem on your laptop or desktop PC, do so.
- Supercomputing is good for big problems:
  - Problems that need too much RAM and/or disk.
  - Problems that take too long to run.

HIPAA?

- We're working with OU IT's Information Security group, including OU's HIPAA team, to see what it'd take to make OSCER's resources HIPAA-aligned.
- We've had a preliminary meeting already, and our next meeting – where we hope to map out a plan – is scheduled for mid-April.
- **NO PROMISES** – but we hope to be able to roll this out on OSCER's upcoming supercomputer, and maybe on OURRstore too.

A Quick Primer on Hardware

Henry's Laptop

Dell Latitude 3590[4]

https://i.dell.com/is/image/DellContent//content/dam/global-site-design/product_images/dell_client_products/notebooks/latitude_notebooks/13_3590/global_spi/notebooks-latitude-15-3590-campaign-hero-504x350-ng.psd?fmt=png-alpha&wid=570&hei=400

- Intel Core i5-8250U
  quad core, 1.6 GHz, 6 MB L3 Cache
- 8 GB 2400 MHz DDR4 SDRAM
- 256 + 448 GB SSDs
- 1 Gbps Ethernet Adapter

Typical Computer Hardware

- Central Processing Unit
- Primary storage
- Secondary storage
- Input devices
- Output devices

Central Processing Unit

Also called ***CPU*** or ***processor***: the "brain"

Components

- ***Control Unit***: figures out what to do next – for example, whether to load data from memory, or to add two values together, or to store data into memory, or to decide which of two possible actions to perform (***branching***)
- ***Arithmetic/Logic Unit***: performs calculations – for example, adding, multiplying, checking whether two values are equal
- ***Registers***: where data reside that are **being used right now**

Primary Storage

- ***Main Memory***
  - Also called ***RAM*** (“Random Access Memory”)
  - Where data reside when they’re **being used by a program that’s currently running**
- ***Cache***
  - Small area of much faster memory
  - Where data reside when they’re **about to be used** and/or **have been used recently**
- Primary storage is ***volatile***: values in primary storage disappear when the power is turned off.

Secondary Storage

- Where data and programs reside that are going to be used **in the future**
- Secondary storage is ***non-volatile***: values **don't** disappear when power is turned off.
- Examples: hard disk, CD, DVD, Blu-ray, magnetic tape, floppy disk
- Many are ***portable***: can pop out the CD/DVD/tape/floppy and take it with you

Input/Output

- Input devices – for example, keyboard, mouse, touchpad, joystick, scanner
- Output devices – for example, monitor, printer, speakers

The Tyranny of the Storage Hierarchy

The Storage Hierarchy

Fast, expensive, few

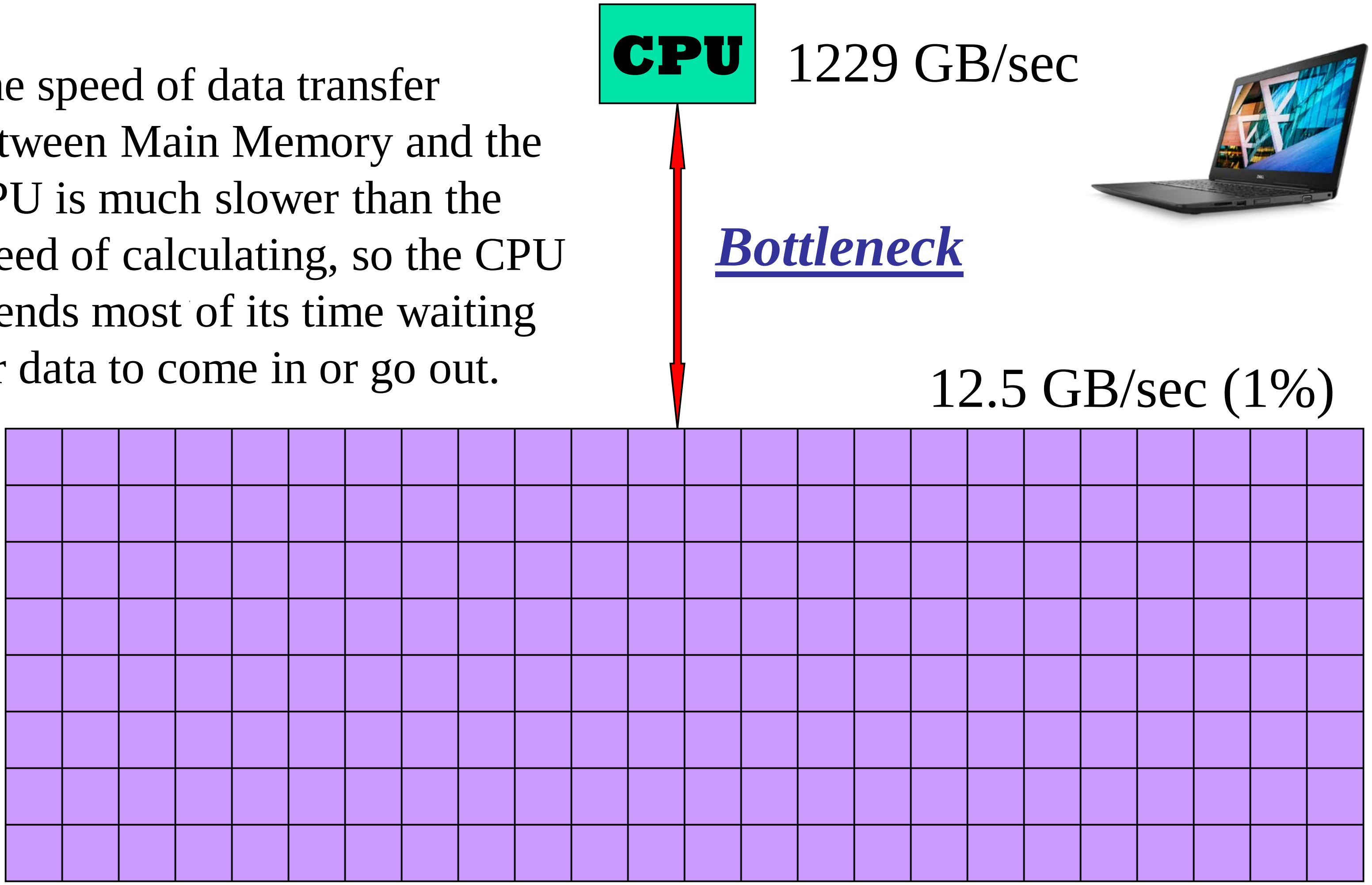
Slow, cheap, a lot

[5]

- Registers
- Cache memory
- Main memory (RAM)
- Hard disk
- Removable media (CD, DVD etc)
- Internet

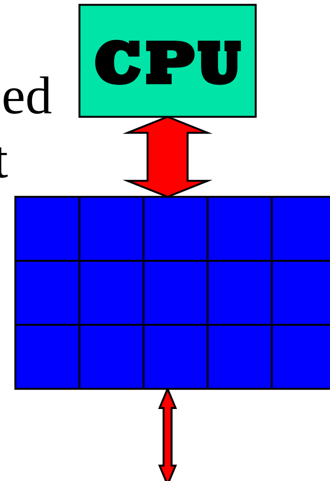
RAM is Slow

The speed of data transfer between Main Memory and the CPU is much slower than the speed of calculating, so the CPU spends most of its time waiting for data to come in or go out.



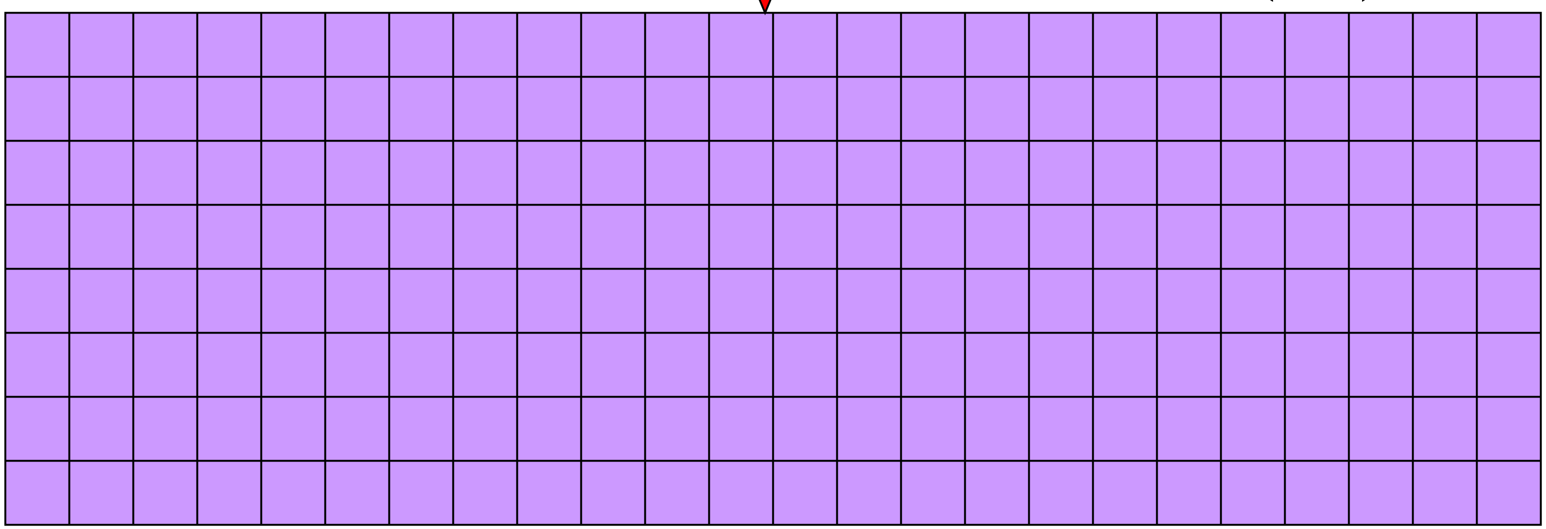
Why Have Cache?

Cache is much closer to the speed of the CPU, so the CPU doesn't have to wait nearly as long for stuff that's already in cache: it can do more operations per second!



40 GB/sec (3.3%)
https://www.softpedia.com/get/System/Benchmarks/BenchMem.shtml

12.5 GB/sec (1%)



Henry's Laptop

Dell Latitude 3590[4]

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- Intel Core i5-8250U
  quad core, 1.6 GHz, 6 MB L3 Cache
- 8 GB 2400 MHz DDR4 SDRAM
- 256 + 448 GB SSDs
- 1 Gbps Ethernet Adapter

Storage Speed, Size, Cost

Henry's Laptop	Registers (Intel Core2 Duo 1.6 GHz)	Cache Memory (L3)	Main Memory (2400MHz DDR4 SDRAM)	Solid State Drive	Hard Drive [none on Henry's laptop]	Flash Thumb Drive (USB 3.0)	Ethernet (1 Gbps)
Speed (MB/sec) [peak]	1,258,496[6] (51.2 GFLOP/s*)	40,000 1/31 as fast as registers	12,500[7] 1/3 as fast as cache	530[9a] 1/24 as fast as RAM	100[9] 1/5 as fast as SSD	221[9b]	125
Size (MB)	10,752 bytes** [11]	6	8192 1365 times as much as cache	448,000 54 times as much as RAM	15,000,000 33 times as much as SSD	524,288	unlimited
Cost ($/MB)	–	$20 [12]	$0.008 [12] ~1/2500 as much as cache	$0.00015 [12] ~1/50 as much as RAM	$0.00002 [12] ~1 / 7.5 as much as SSD	$0.0002 [12]	charged per month (typically)

* <u>GFLOP/s</u>: billions of floating point operations per second

** 168 256-bit integer vector registers,
168 256-bit floating point vector registers

Why the Storage Hierarchy?

Why does the Storage Hierarchy always work? Why are faster forms of storage more expensive and slower forms cheaper?

Proof by contradiction:

Suppose there were a storage technology that was **slow** and **expensive**.

How much of it would you buy?

Comparison

- Floppy: 1.44 MB each, $0.69 ($0.48 per MB), speed 0.03 MB/sec
- Blu-Ray: 25 GB Disk ~$1 ($0.00006 per MB), speed 72 MB/sec

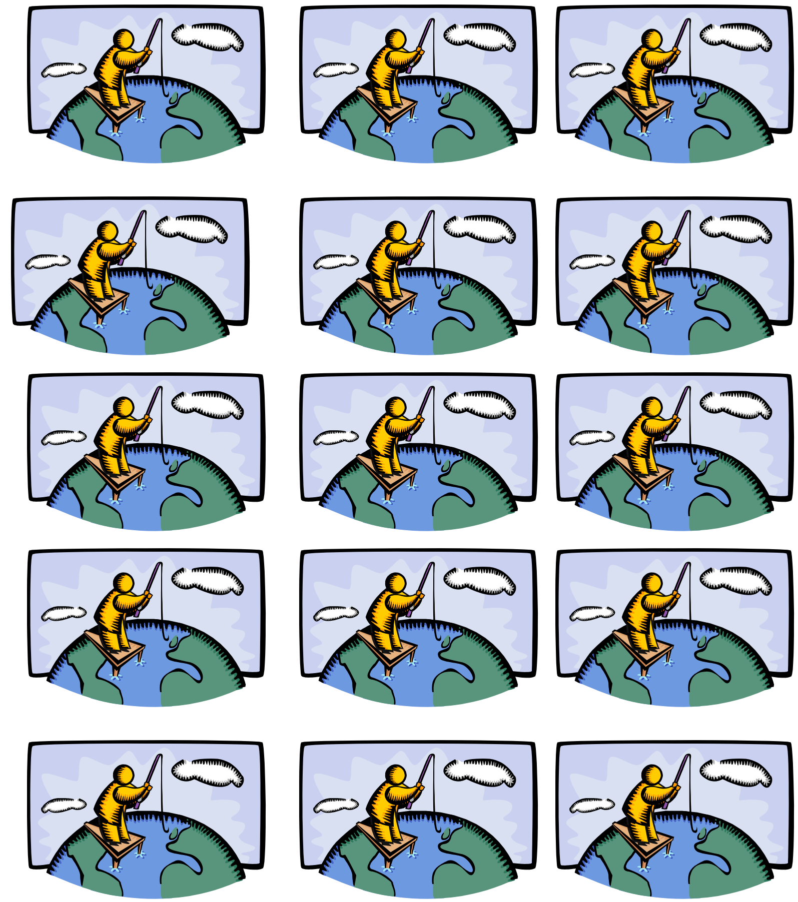
Not surprisingly, no one buys floppy disks any more.

Parallelism

Parallelism

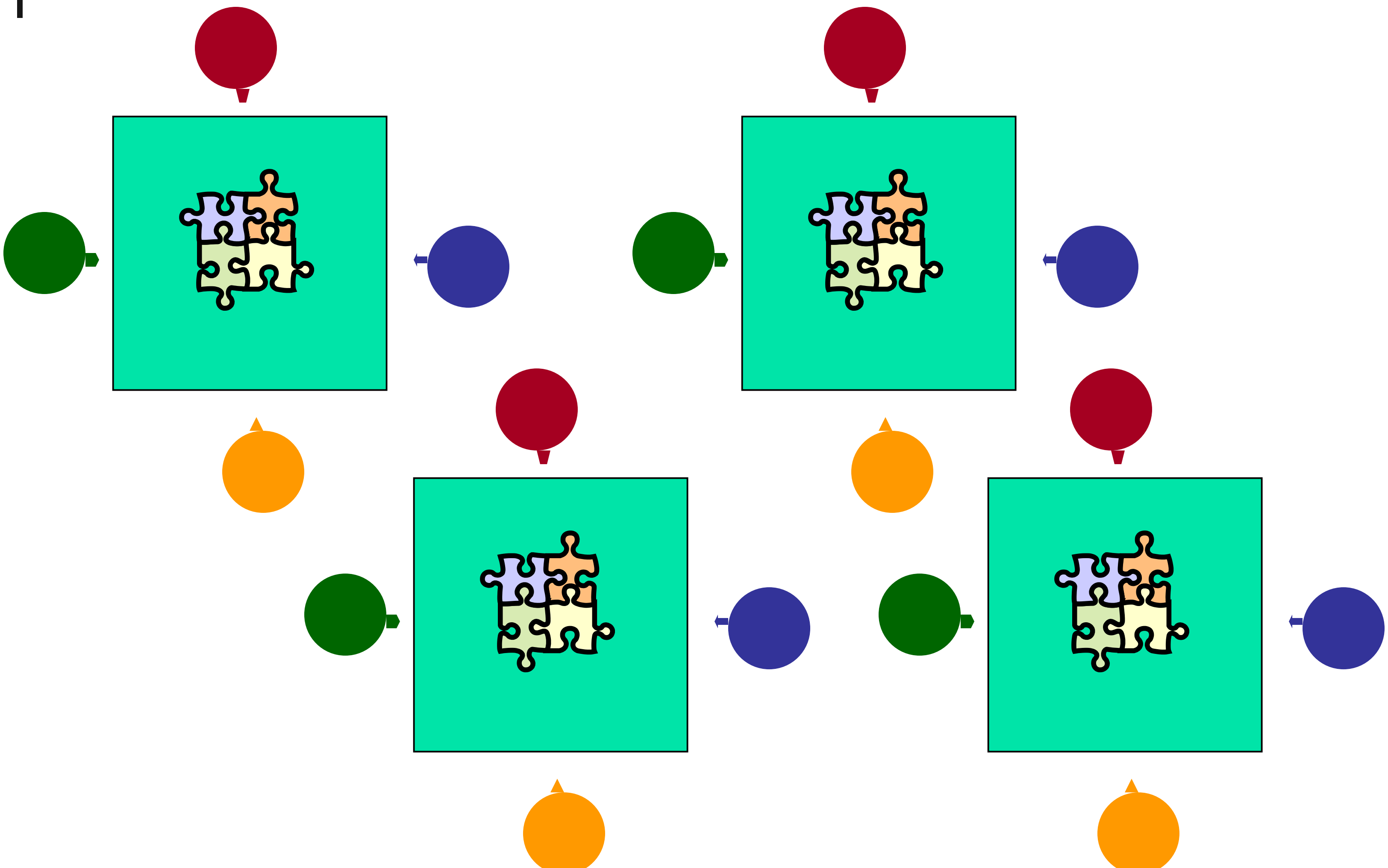
Parallelism means doing multiple things at the same time: you can get more work done in the same time.

Less fish …

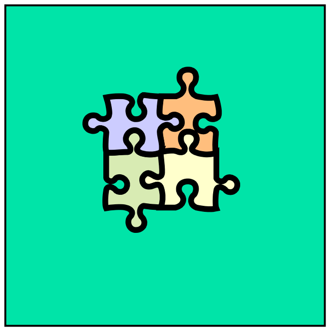


More fish!

The Jigsaw Puzzle Analogy



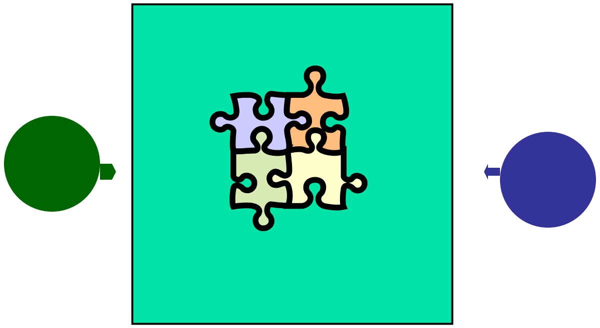
Serial Computing



Suppose you want to do a jigsaw puzzle that has, say, a thousand pieces.

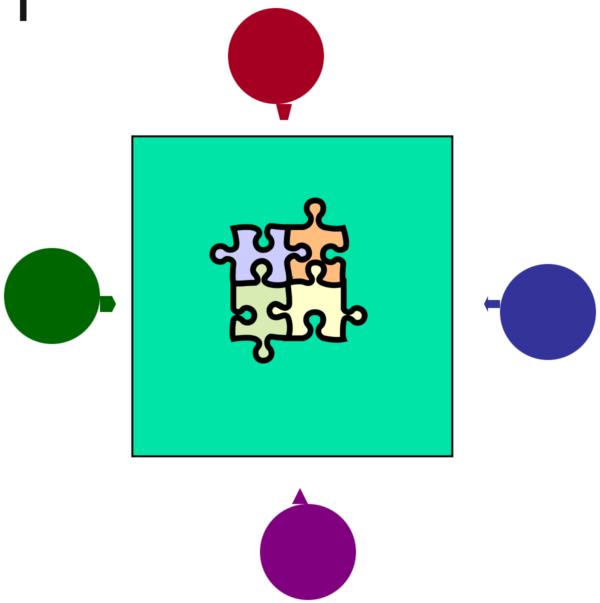
We can imagine that it'll take you a certain amount of time. Let's say that you can put the puzzle together in an hour.

Shared Memory Parallelism



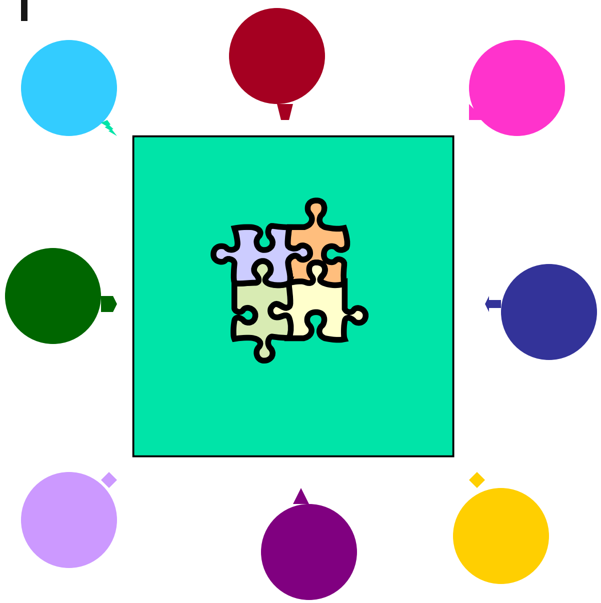
If Janet sits across the table from you, then she can work on her half of the puzzle and you can work on yours. Once in a while, you'll both reach into the pile of pieces at the same time (you'll ***contend*** for the same resource), which will cause a little bit of slowdown. And from time to time you'll have to work together (***communicate***) at the interface between his half and yours. The speedup will be nearly 2-to-1: y'all might take 35 minutes instead of 30.

The More the Merrier?



Now let's put Lee and Kim on the other two sides of the table. Each of you can work on a part of the puzzle, but there'll be a lot more contention for the shared resource (the pile of puzzle pieces) and a lot more communication at the interfaces. So y'all will get noticeably less than a 4-to-1 speedup, but you'll still have an improvement, maybe something like 3-to-1: the four of you can get it done in 20 minutes instead of an hour.

Diminishing Returns



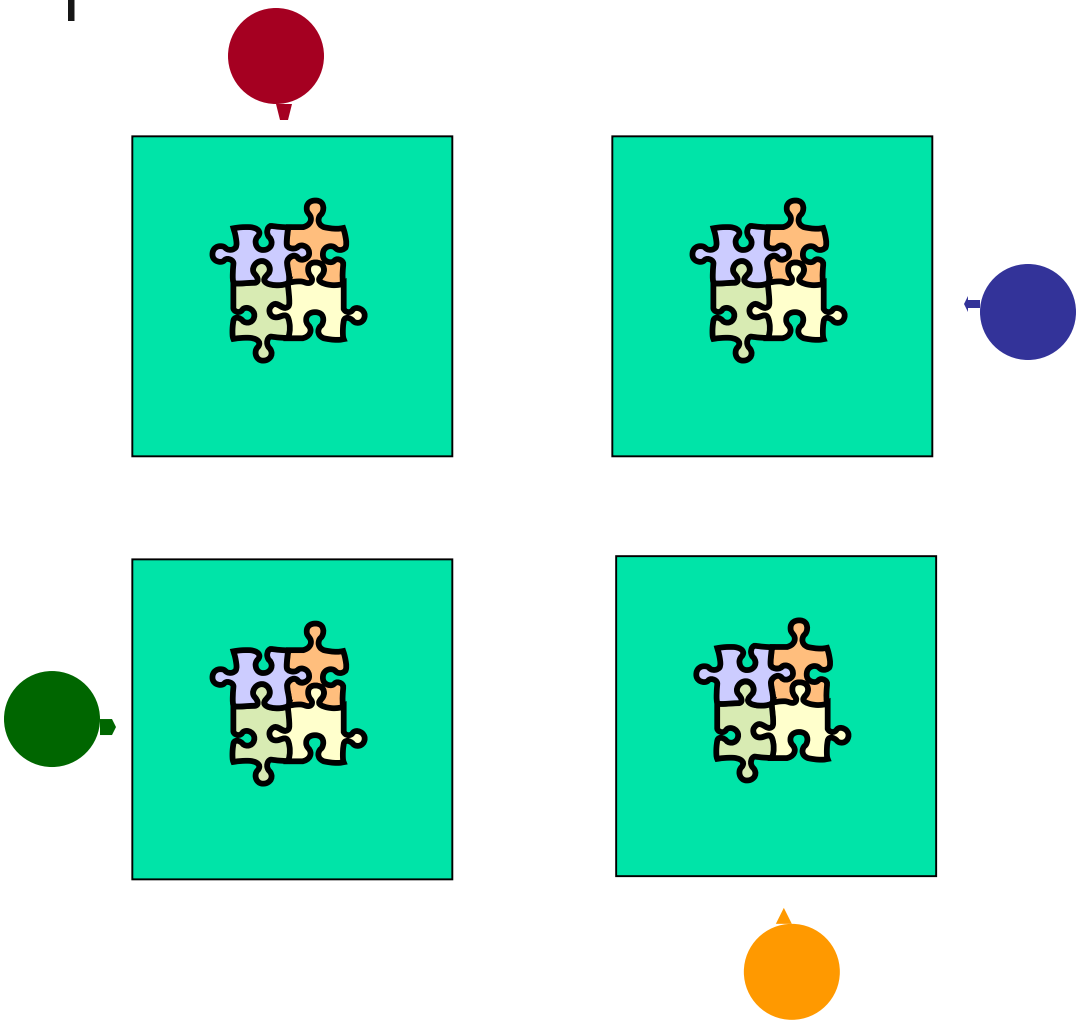
If we now put Dave and Debi and Horst and Kali on the corners of the table, there's going to be a whole lot of contention for the shared resource, and a lot of communication at the many interfaces. So the speedup y'all get will be much less than we'd like; you'll be lucky to get 5-to-1.

So we can see that adding more and more workers onto a shared resource is eventually going to have a diminishing return.

Distributed Parallelism

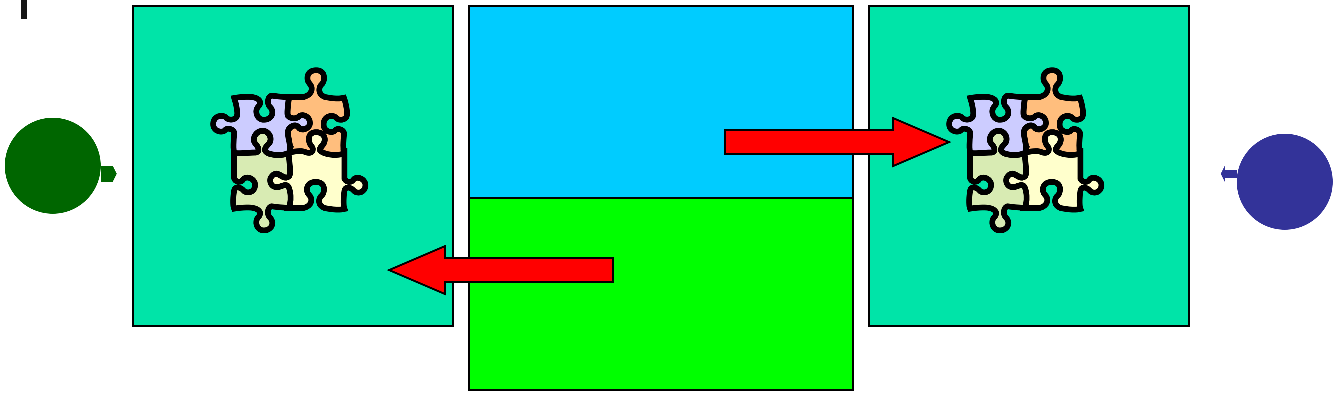
Now let’s try something a little different. Let’s set up two tables, and let’s put you at one of them and Janet at the other. Let’s put half of the puzzle pieces on your table and the other half of the pieces on Janet’s. Now y’all can work completely independently, without any contention for a shared resource. **BUT**, the cost per communication is **MUCH** higher (you have to scootch your tables together), and you need the ability to split up (***decompose***) the puzzle pieces reasonably evenly, which may be tricky to do for some puzzles.

More Distributed Processors



It's a lot easier to add more processors in distributed parallelism. But, you always have to be aware of the need to decompose the problem and to communicate among the processors. Also, as you add more processors, it may be harder to ***load balance*** the amount of work that each processor gets.

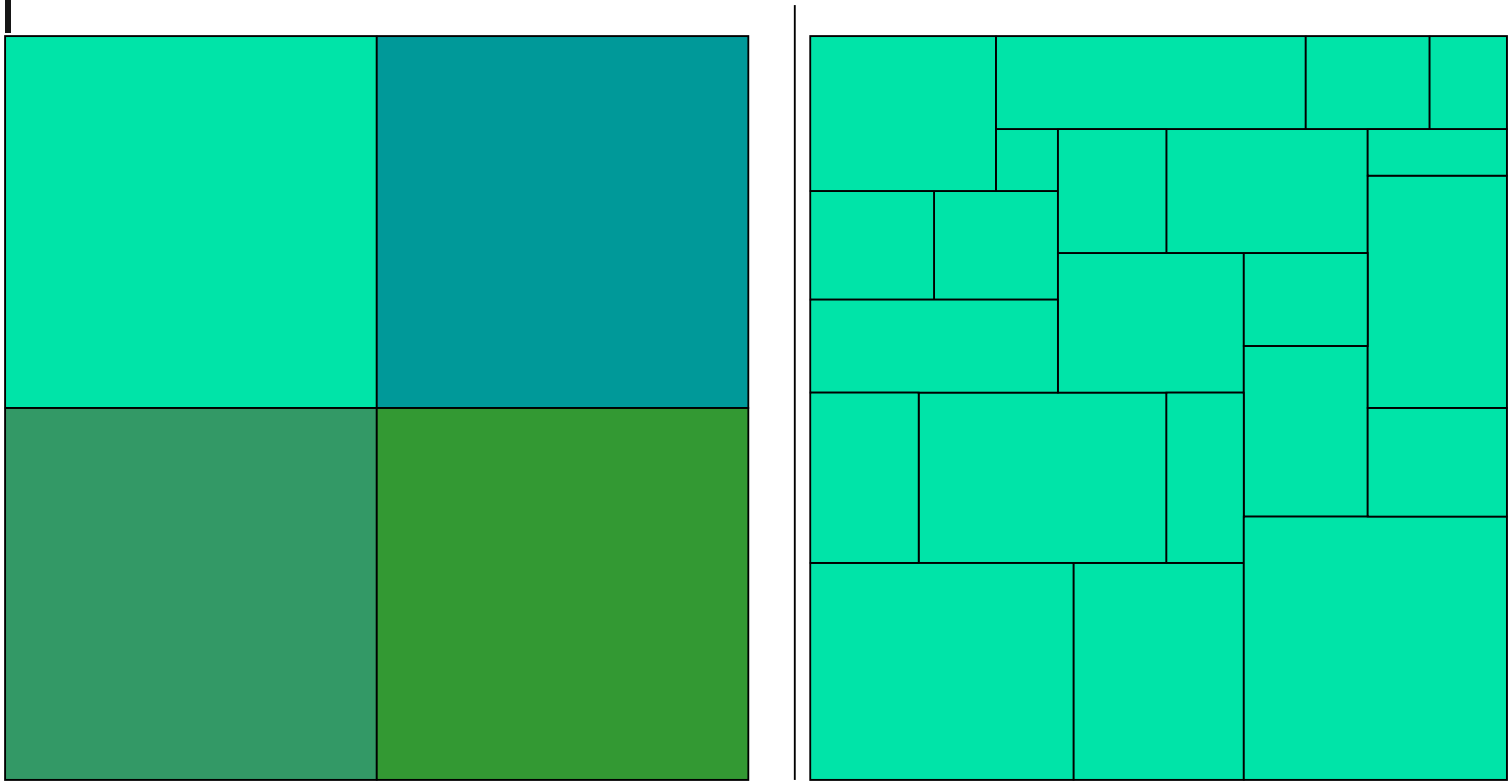
Load Balancing



Load balancing means ensuring that everyone completes their workload at roughly the same time.

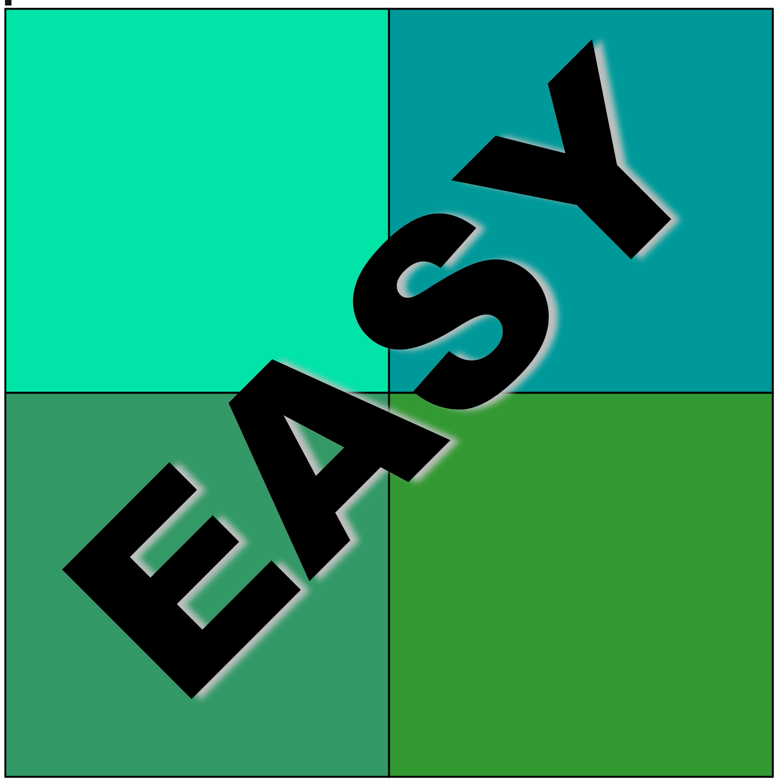
For example, if the jigsaw puzzle is half grass and half sky, then you can do the grass and Janet can do the sky, and then y'all only have to communicate at the horizon – and the amount of work that each of you does on your own is roughly equal. So you'll get pretty good speedup.

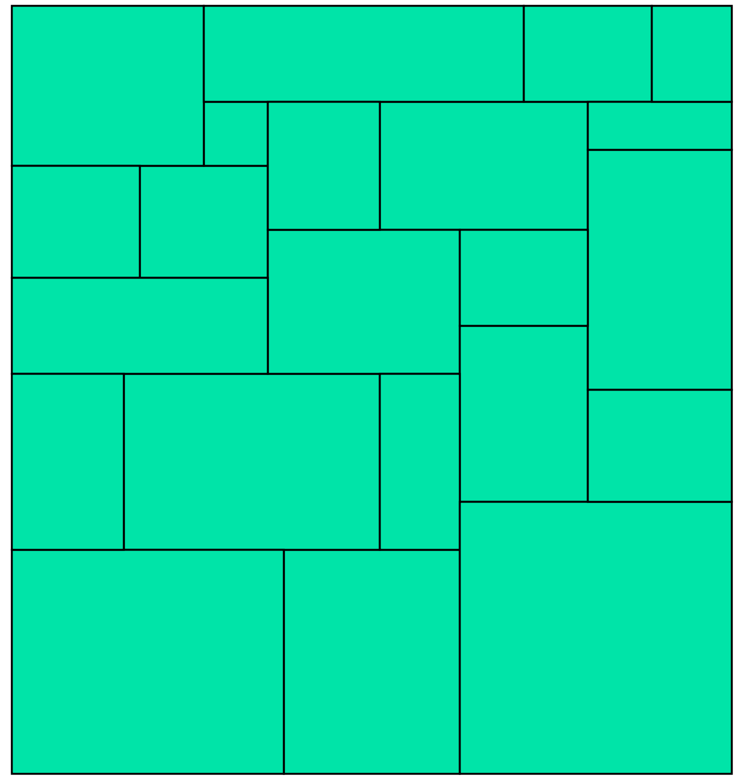
Load Balancing



Load balancing can be easy, if the problem splits up into chunks of roughly equal size, with one chunk per processor. Or load balancing can be very hard.

Load Balancing





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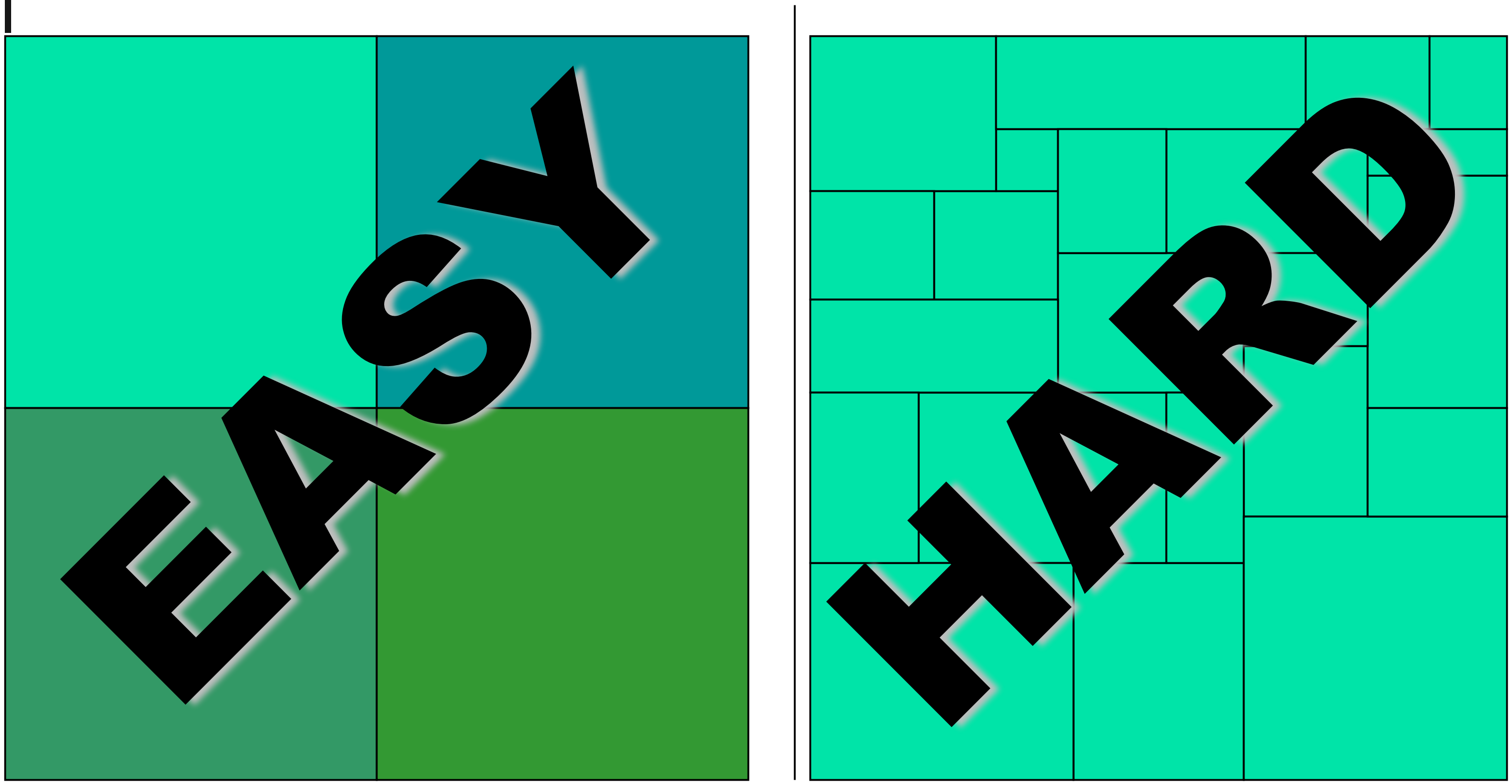
Load Balancing



Load balancing can be easy, if the problem splits up into chunks of roughly equal size, with one chunk per processor. Or load balancing can be very hard.

Moore's Law

Moore's Law

In 1965, Gordon Moore was an engineer at Fairchild Semiconductor.

He noticed that the number of transistors that could be squeezed onto a chip was doubling about every 2 years.

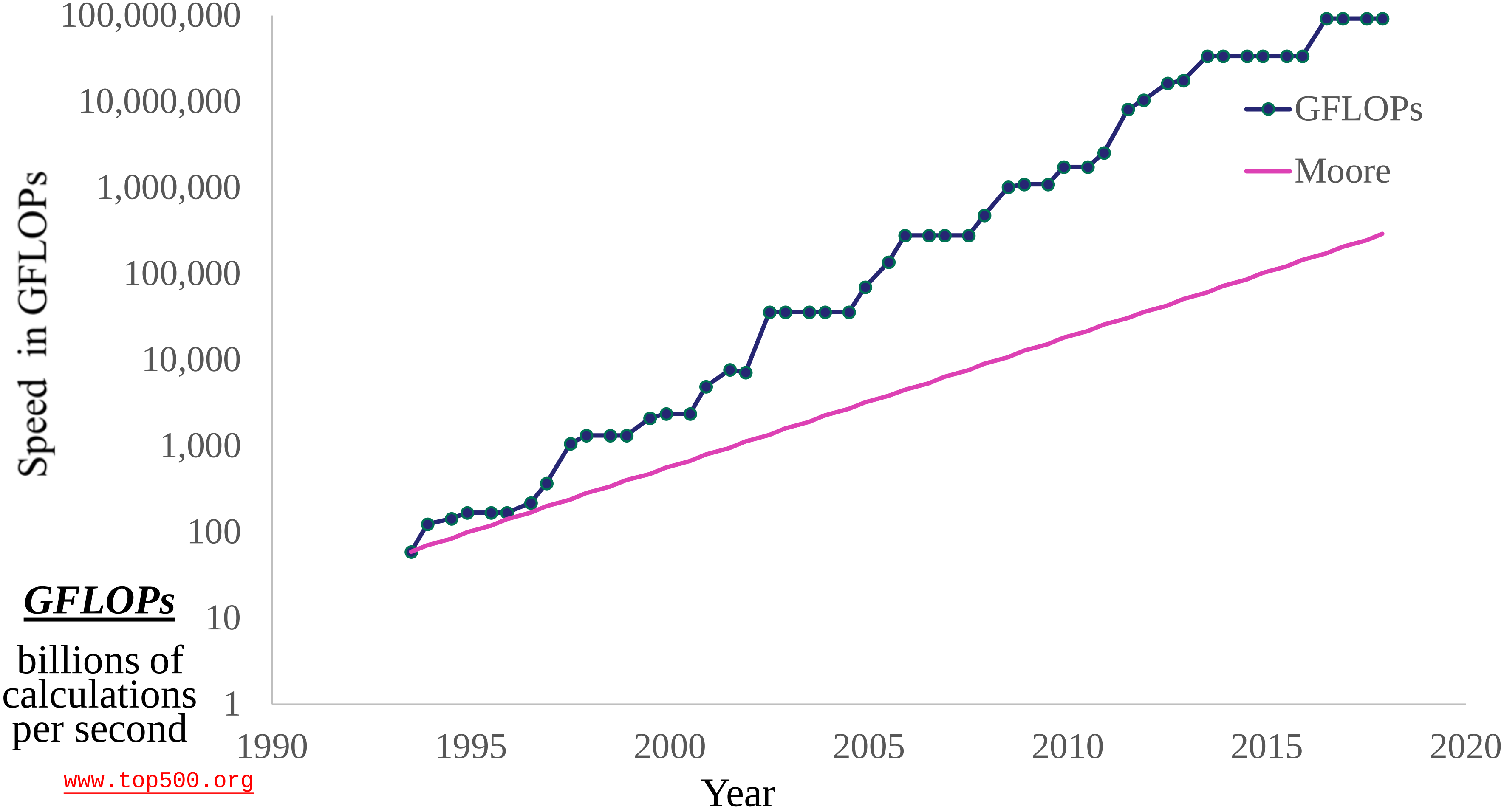
It turns out that computer speed, and storage capacity, is roughly proportional to the number of transistors per unit area.

Moore wrote a paper about this concept, which became known as ***"Moore's Law."***

(Originally, he predicted a doubling every year, but not long after, he revised that to every other year.)

G. Moore, 1965: "Cramming more components onto integrated circuits." *Electronics*, 38 (8), 114-117.

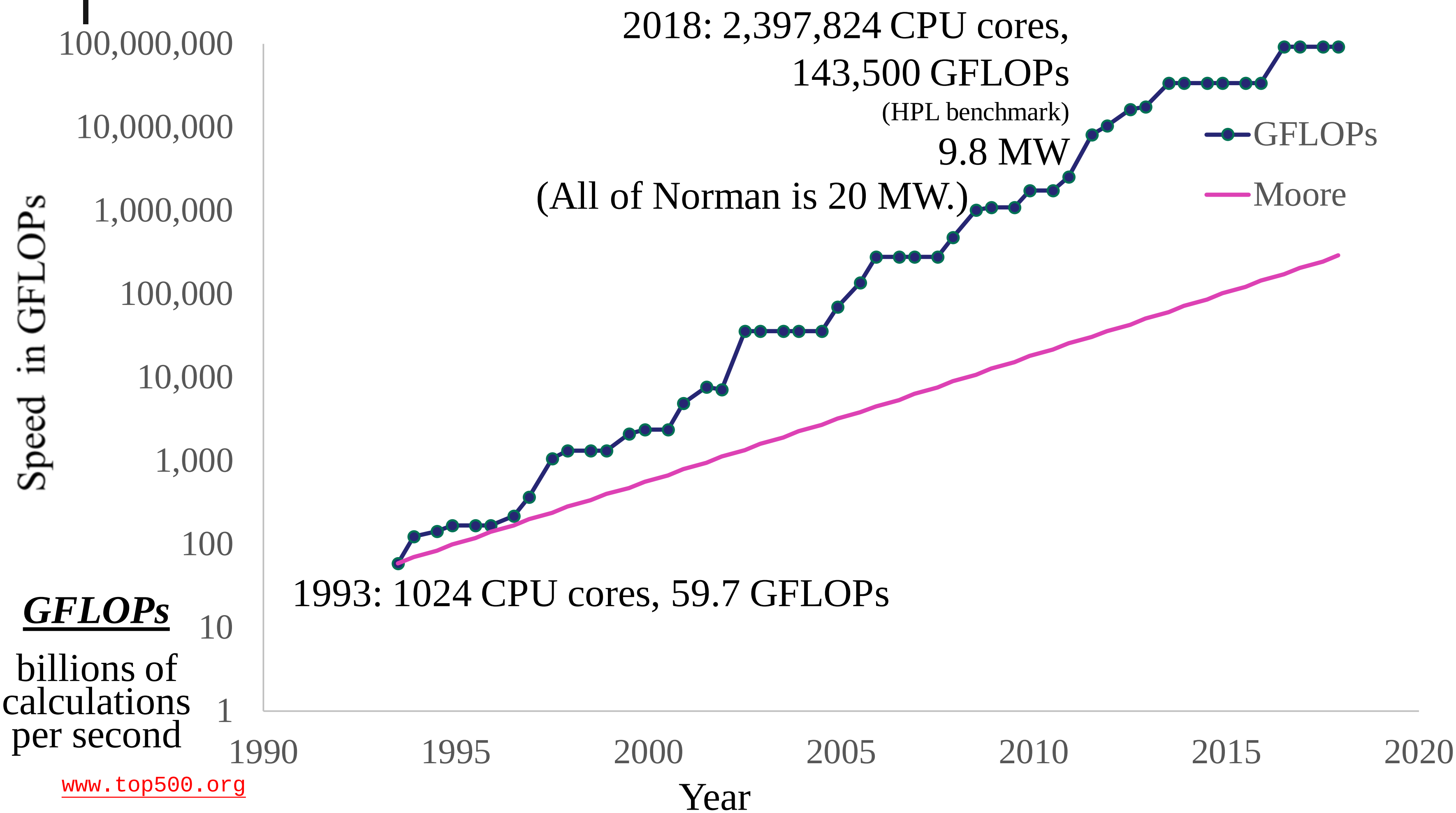
Fastest Supercomputer vs. Moore



GFLOPs
billions of calculations per second

www.top500.org

Fastest Supercomputer vs. Moore



GFLOPs

billions of calculations per second

www.top500.org

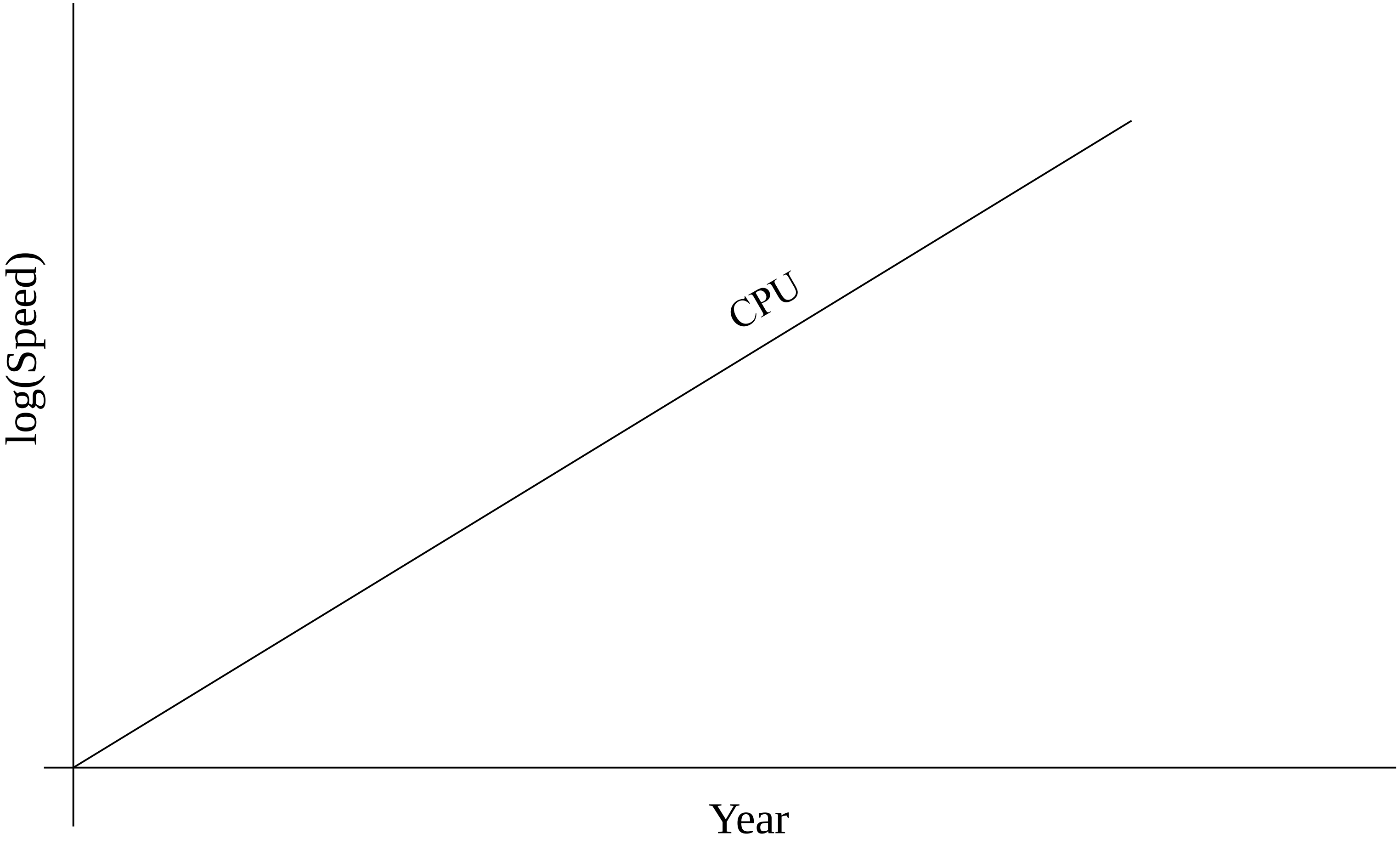
Moore: Uncanny!

- Nov 1971: Intel 4004 – 2300 transistors
- March 2010: Intel Nehalem Beckton – 2.3 billion transistors
- Factor of 1,000,000 improvement in 38 1/3 years
- $2^{(38.33 \text{ years} / 1.9232455)} = 1{,}000{,}000$

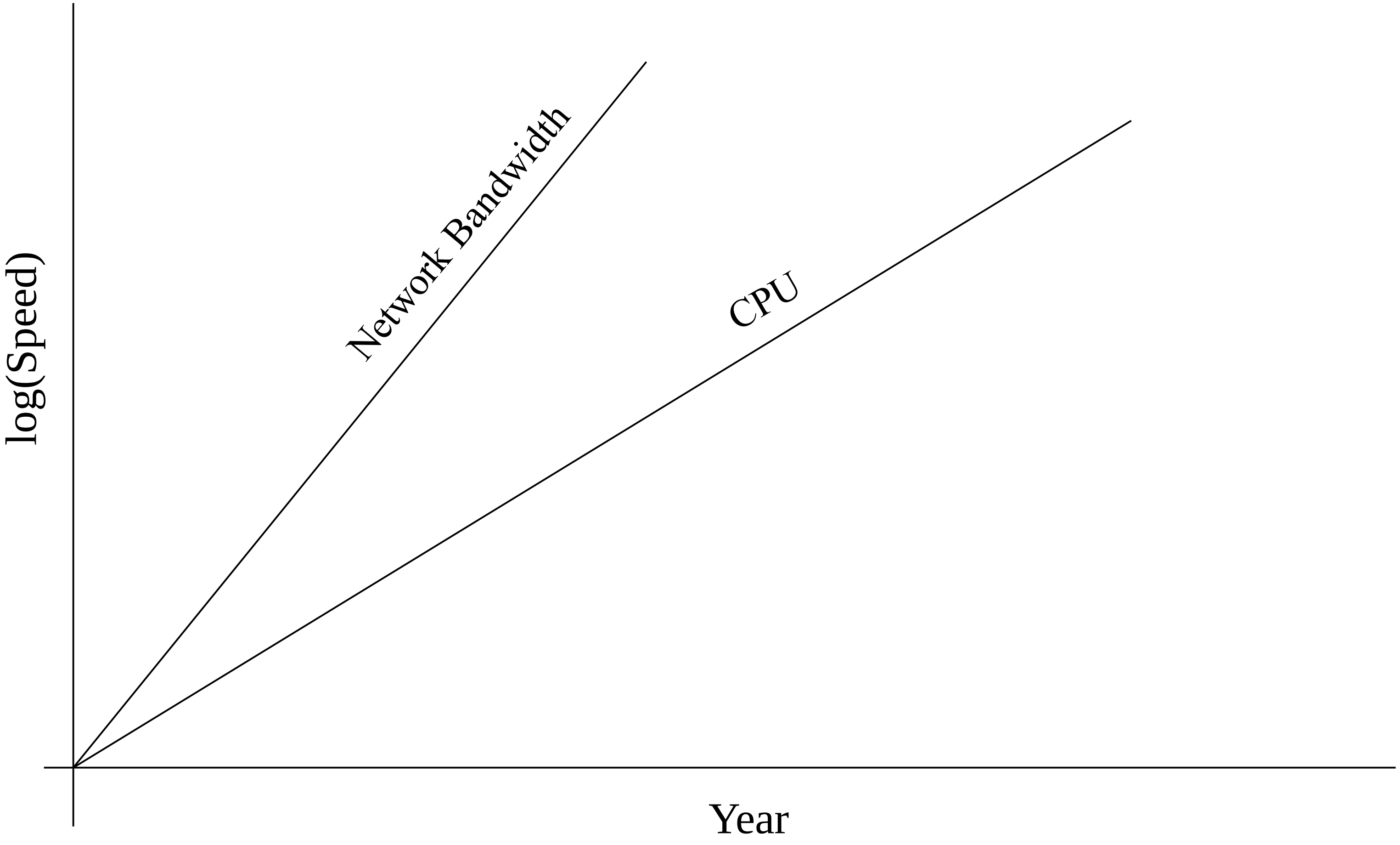
So, transistor density has doubled every 23 months:

UNCANNILY ACCURATE PREDICTION!

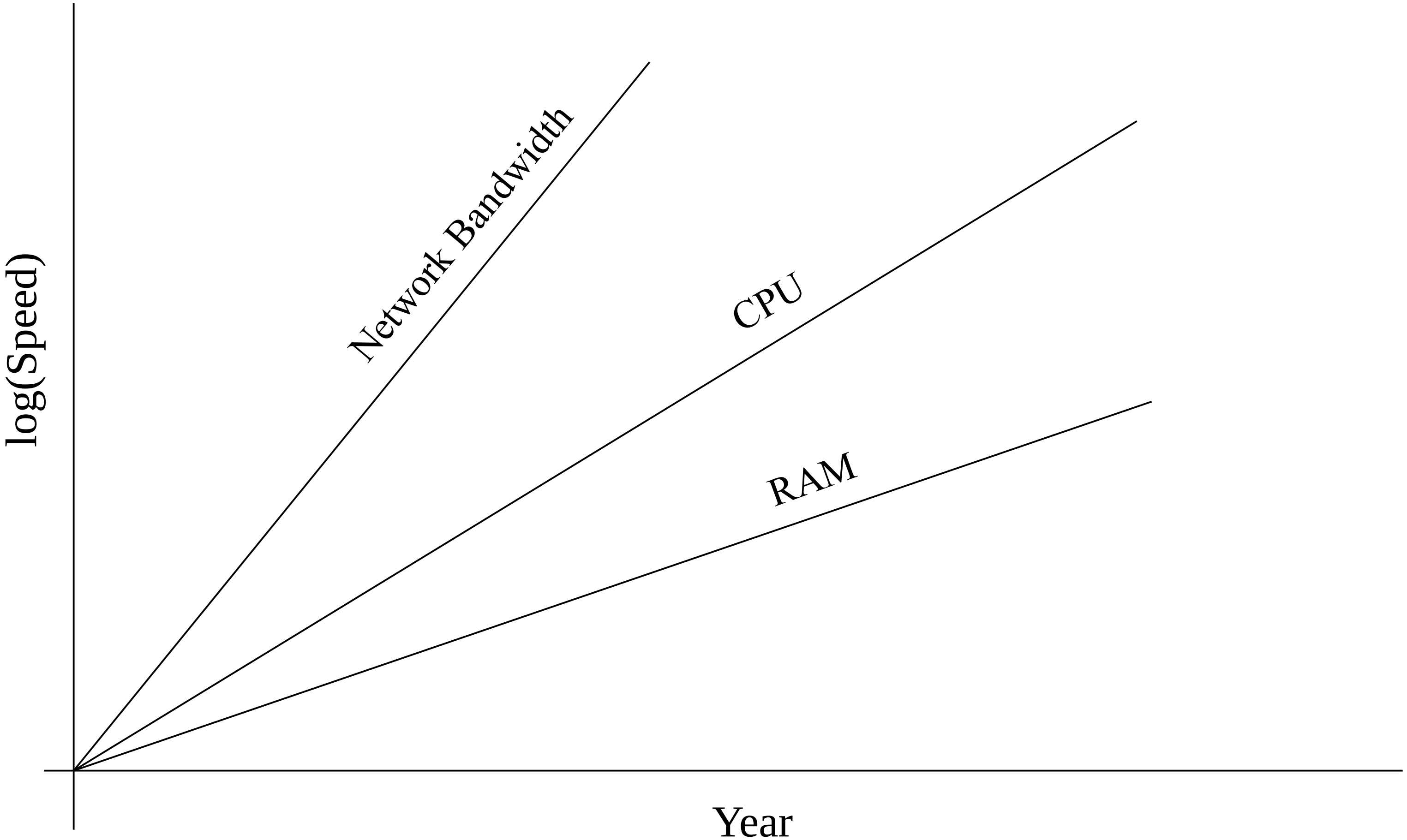
Moore's Law in Practice



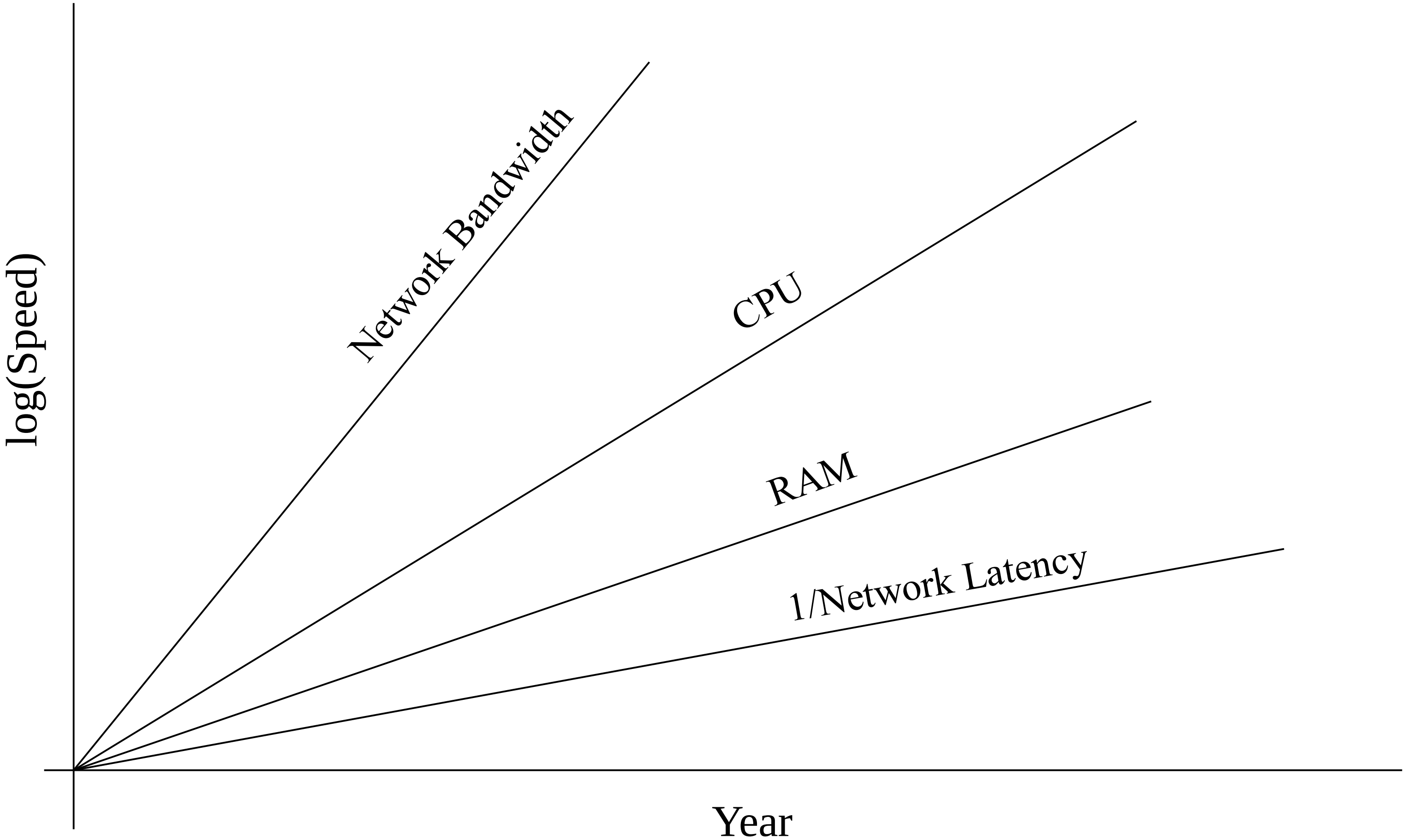
Moore's Law in Practice



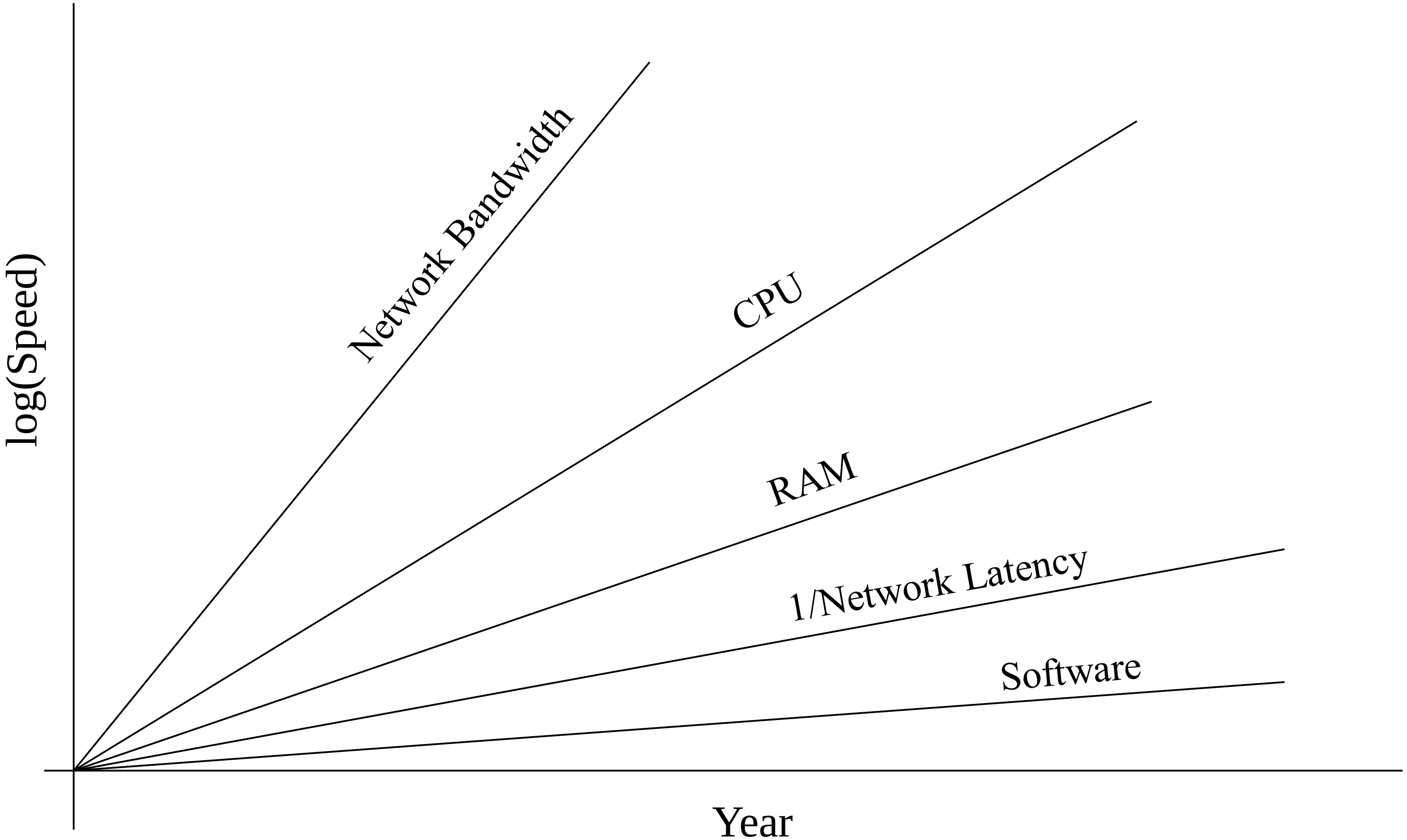
Moore's Law in Practice



Moore's Law in Practice

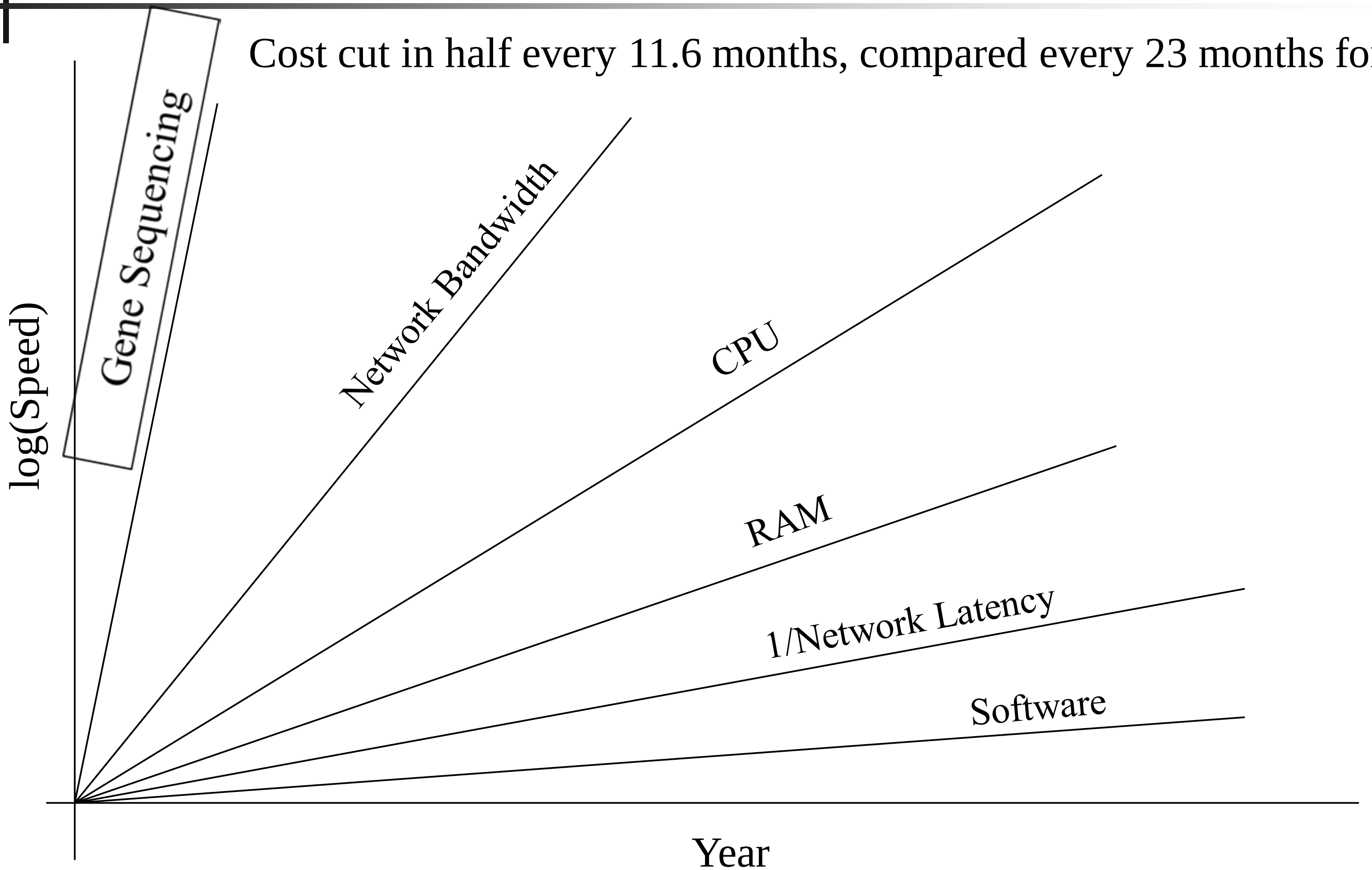


Moore's Law in Practice



Moore's Law on Gene Sequencing

Cost cut in half every 11.6 months, compared every 23 months for CPUs.[18]



Is Moore's Law Dead?

- Moore's Law isn't dead yet:
  - CPU chip speed improved from 53 GFLOPs per socket on Intel Nehalem W5590 in 2009 [13] to 1523 GFLOPs per socket on Intel Skylake 8180 in 2017 [14], a doubling period of 2 years.
  - Memory bandwidth went from, for example, ~37 GB/sec on dual Intel Nehalem W5580 in 2009 [15,16] to ~290 GB/sec in late 2017 on dual AMD EPYC [17], a doubling period of 3 years.

What does 1 TFLOPs Look Like?

1 TFLOPs: trillion calculations per second

1997: Room

ASCI RED[13]
Sandia National Lab

2002: Row

boomer.oscer.ou.edu
In service 2002-5: 11 racks

2012: Card

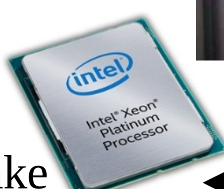
AMD FirePro W9000[14]

NVIDIA Kepler K20[15]

Intel MIC Xeon PHI[16]

CPU Chip 2017

AMD EPYC



Intel Skylake

https://www.top500.org/static/media/uploads/.thumbnails/epyc-vs-xeon.jpg/epyc-vs-xeon-742x382.jpg

Why Bother?

Why Bother with HPC at All?

It's clear that making effective use of HPC takes quite a bit of effort, both learning how and developing software.

That seems like a lot of trouble to go to just to get your code to run faster.

It's nice to have a code that used to take a day, now run in an hour. But if you can afford to wait a day, what's the point of HPC?

Why go to all that trouble just to get your code to run faster?

Why HPC is Worth the Bother

- What HPC gives you that you won't get elsewhere is the ability to do **bigger, better, more exciting science**. If your code can run faster, that means that you can tackle much bigger problems in the same amount of time that you used to need for smaller problems.
- HPC is important not only for its own sake, but also because what happens in HPC today will be on your desktop in about 10 to 15 years and on your cell phone in 25 years: it puts you **ahead of the curve**.

The Future is Now

Historically, this has always been true:

Whatever happens in supercomputing today will be on your desktop in 10 – 15 years.

So, if you have experience with supercomputing, you'll be ahead of the curve when things get to the desktop.

R Demo: Hello world

https://github.com/wibeasley/RAnalysisSkeleton/tree/master/utility/super-computer

https://github.com/wibeasley/RAnalysisSkeleton/blob/master/documentation/oscer-steps.md

R Demo: Reproduce full repository

R Demo: Reproduce full repository

Questions?

References

[1] Image by Greg Bryan, Columbia U.

[2] "Update on the Collaborative Radar Acquisition Field Test (CRAFT): Planning for the Next Steps." Presented to NWS Headquarters August 30 2001.

[3] See http://hneeman.oscer.ou.edu/hamr.html for details.

[3a] https://genviz.org/assets/genvisr_fig_v4.png

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[5] http://www.vw.com/newbeetle/

[6] Richard Gerber, The Software Optimization Cookbook: High-performance Recipes for the Intel Architecture. Intel Press, 2002, pp. 161-168.

[7] RightMark Memory Analyzer. http://cpu.rightmark.org/

[8] ftp://download.intel.com/design/Pentium4/papers/24943801.pdf

[9] http://www.samsungssd.com/meetssd/techspecs

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[9b] https://www.tomshardware.com/reviews/usb-3.0-thumb-drive-review,3477-2.html

[10] http://www.samsung.com/Products/OpticalDiscDrive/SlimDrive/OpticalDiscDrive_SlimDrive_SN_S082D.asp?page=Specifications

[11] https://www.realworldtech.com/haswell-cpu/3/

[12] http://www.pricewatch.com/ , http://www.walmart.com/

[13] Intel® Xeon® Processor W5590. https://ark.intel.com/products/41643/Intel-Xeon-Processor-W5590-8M-Cache-3-33-GHz-6-40-GT-s-Intel-QPI-

[14] Intel Xeon Platinum 8180 Processor. https://ark.intel.com/products/120496/Intel-Xeon-Platinum-8180-Processor-38-5M-Cache-2-50-GHz-

[15] STREAM numbers on nehalem. https://www.cs.virginia.edu/stream/stream_mail/2009/0011.html

[16] Intel® Xeon® Processor W5580. https://ark.intel.com/products/37113/Intel-Xeon-Processor-W5580-8M-Cache-3-20-GHz-6-40-GT-s-Intel-QPI-

[17] AMD EPYC SoC Delivers Exceptional Results on the STREAM Benchmark on 2P Servers. https://www.amd.com/system/files/2017-06/AMD-EPYC-SoC-Delivers-Exceptional-Results.pdf

[18] https://www.genome.gov/sequencingcostsdata/

Supercomputing is Hard

Supercomputing is Hard

Why is Supercomputing hard to use, and getting harder?

- Technology: The machines are getting more and more complicated, with deeper storage hierarchies, hybrid parallelism, and more variation in software technologies (MapReduce, Machine Learning etc).
- Applicability
  - More and more disciplines need research computing – it used to be just physical sciences and engineering, then biosciences, now social sciences and humanities.
  - Within each discipline, a growing fraction of researchers need it.
- Mental Gap: Handhelds are even farther than laptops from Linux, command line, batch, remote, shared computing.

Can’t We Just Make It Easier?

- There are thousands of research software applications. Most of them have small user communities, so very few have commercial potential.
  - OSCER currently supports ~400 on our supercomputer.
  - National centers typically support ~4000.
- Research funding agencies don’t pay for good software, only for exciting new science features – so usability typically isn’t even a consideration.
- “Science Gateways” (web front ends) do help, but only for a very limited subset of popular applications.
  - Ohio Supercomputer Center’s “Open On Demand” software may be a good general solution, and it’s **FREE** (and has active NSF funding).

Supercomputing is Different from Enterprise IT – and That's Good!

Enterprise IT & Research Computing

Enterprise IT: HARDENED

- Secure
- Established technology (mature)
- Best practices
- **5 nines**: 99.999% uptime = **5.25 minutes** of downtime per year

Research Computing: SQUISHY

- Fast and flexible (turn on a dime)
- Cutting edge technology (immature => broken)
- In many cases, there aren't any best practices – too new!
- **1½ nines**: 95% uptime = **18.25 DAYS** of downtime per year
  - This is the National Science Foundation standard, from NSF solicitation 17-558: "… [$60M NSF-funded supercomputer] should be **unavailable** as a result of scheduled and unscheduled maintenance **no more than 5% of the time**."

Enterprise vs Research: Incentives

- Suppose paychecks are supposed to going out tomorrow, but the payroll system goes down tonight.
  - On payday, if paychecks don't go out, what happens on the Enterprise IT people who are accountable for the outage?
  - Therefore, what must Enterprise IT people do to stay in business?
  - Another example: Delta's Aug 8 2016 5-hour data center outage cost them $150M ($1M every 2 minutes).
    - https://money.cnn.com/2016/09/07/technology/delta-computer-outage-cost/
- Suppose Research Computing isn't on the cutting edge, and so the institution's grant proposals are less competitive.
  - Eventually, what will happen to the Research Computing team?
  - Therefore, what must Research Computing people do to stay in business?

Enterprise vs Research: How to Resolve?

- **<u>Research Computing can afford some downtime</u>**: A supercomputer that's mostly up but goes down occasionally is **<u>fine</u>**!
  - 24 hours of supercomputer downtime = 10-100 lost grad student days => ~$25K lost research productivity for the downtime
    - 1 grad student = ~$65K/year fully loaded with salary+fringe+tuition+Indirect Costs
      => 1 grad student day = ~$178 productivity loss per grad student per day of downtime
      => 100 grad student days = ~$18K productivity loss for the institution per day of downtime
      => ~$250-2500 productivity loss per research group per day of downtime

OU Meteorology: (((($2208.28 salary/month + 9.7% fringe + $973 tuition/month) × 12 months + 55% IDC) / 2080 biz hours/year) × 8 biz hours/day

- **<u>Cost of 5 Nines vs 1½ Nines</u>**: Cost of 5 nines = 5-10 × 1½ nines. But, budgets are fixed, so the actual cost is a **loss of 80-90% of research productivity** for computing-intensive and data-intensive research.
- **<u>Therefore</u>**: Let the supercomputer go down from time to time, in exchange for having much more capacity (though less resilient), to **maximize research productivity per year**.

Research is the Enterprise Testbed

- Research Computing has only limited best practices; **outages are baked into the business model**.
- In general, some technologies currently being adopted by Research Computing are likely to become Enterprise requirements in a few to several years.
- So, Enterprise IT can watch Research Computing's outages, and use those observations to develop Enterprise best practices.
- <u>Example</u>: When the OU's newest data center opened in 2012, the supercomputer was the first system deployed there, because (a) the supercomputer could afford to be offline for a few days, and (b) the supercomputer isn't "intertwingled" with Enterprise IT systems, and therefore was low risk to use as a data center testbed.

Supercomputing’s Contribution to OU: Summary

OSCER-Facilitated External Funding

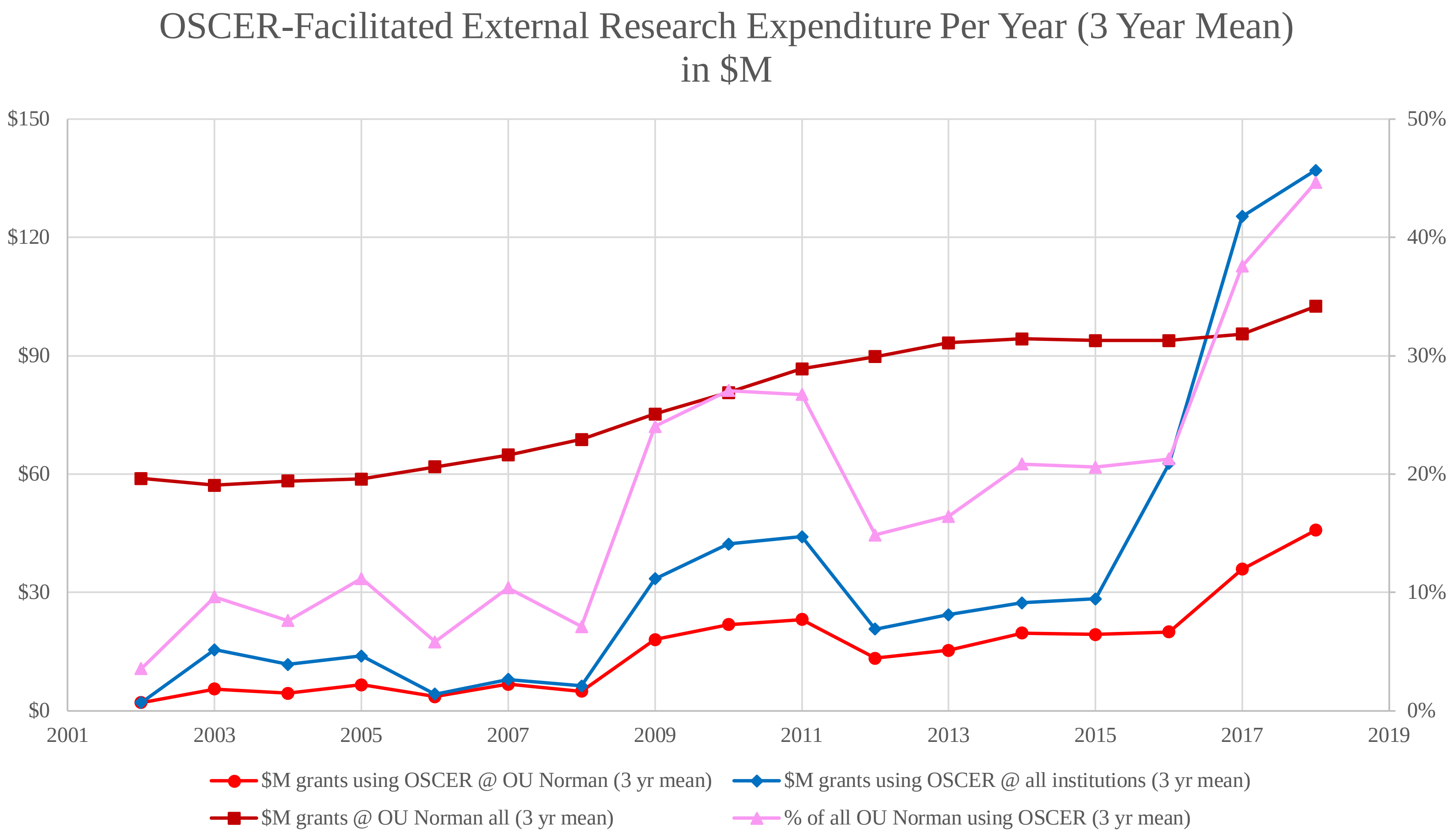
As of Sep 2018:

- External research funding facilitated by OSCER (Fall 2001- Fall 2018): **$317M to OU, $385M to OU's collabs**
- Funded projects: **540**
- **230+** OU faculty and staff in **29** academic departments and **11** non-academic units
- Comparison: Fiscal Year 2002-18 (July 2001 – June 2018): OU Norman externally funded research expenditure: $1.38B

Over the past 3 fiscal years, OSCER has facilitated an average of **44%** of OU Norman's external research expenditure.

(We collect OSCER-facilitated grant and publication info from faculty every Sep.)

OSCER-Facilitated/Yr (3 Yr Mean)



OSCER-Facilitated Publications

- Publications facilitated by OSCER
  - 2019: 1 (as of Sep 2018 – accepted in 2018 but will appear in print in 2019)
  - 2018: 255 (as of Sep 2018)
  - 2017: 219
  - 2016: 331
  - 2015: 266
  - 2014: 253
  - 2013: 275
  - 2012: 356
  - 2011: 223
  - 2010: 159
  - 2009: 115
  - 2008: 116
  - 2007: 85
  - 2006: 109
  - 2005: 84
  - 2004: 50
  - 2003: 26
  - 2002: 10
  - 2001: 3

TOTAL SO FAR: 2936 publications

http://www.oscer.ou.edu/publications/

Includes 56 PhD dissertations, 40 MS theses.
(As of Sep 2018.)

OU Compared to Other Institutions

Do Other Institutions Have HPC Centers?

Do other peer academic institutions have their own supercomputing centers?

- Association of American Universities: **100%** https://www.aau.edu/who-we-are/our-members
- Carnegie Classification
  - R1 (Doctoral Very High Research Activity): **98%**
  - R2 (Doctoral High Research Activity): **60%** http://carnegieclassifications.iu.edu/
- US News National Universities
  - Top 50: **98%**
  - Top 100: **94%**
  - Top 150: **89%**
  - Top 200: **83%**
  - Top 300: **71%**

  https://www.usnews.com/best-colleges/rankings/national-universities
- By top research expenditures
  - Top 50: **98%** (1)
  - Top 100: **97%** (3)
  - Top 150: **96%** (6)

  https://ncsesdata.nsf.gov/profiles/site?method=rankingBySource&ds=herd

OneOklahoma Cyberinfrastructure Initiative

What is OneOCII?

- OneOCII is a collaboration among institutions across Oklahoma to increase uptake of research computing, not just PhD-granting institutions, but also non-PhD-granting.
- OneOCII currently has 5 resource provider sites (OU, Oklahoma State U, U Tulsa, U Central Oklahoma, Langston U), plus another 4 sites on the OneOklahoma Friction Free Network (OFFN), and 3 more in a new proposal.
- OneOCII has been **mission critical** to computing-intensive grant proposals across Oklahoma, totaling **~$45M** since 2008 that wouldn't have gotten funded without OneOCII.
  - This is both because of (a) the need for research computing across Oklahoma, and because (b) grant proposals (especially to the NSF) need Broader Impact items to get funded, which OneOCII provides very effectively.

OneOCII Outcomes: Research

- Grants that specifically needed OneOCII to be funded: **$45M ($4.3M to OU IT, $16.5M to OU researchers, $24M to other institutions)**

  (OneOCII was necessary but not sufficient)
  - NSF EPSCoR RII Track-1 (2008-13, OU+OSU): $15M
  - NSF EPSCoR RII Track-1 (2013-18, OU+OSU+Noble): $20M
  - NSF EPSCoR RII Track-2 (OU+OSU+KU+KSU): $6M ($3M to OU+OSU)
  - NSF EPSCoR RII C2 (OU+OSU+TU+LU+Noble+OneNet): $1.17M
  - NSF CC-NIE (OU+OSU+LU+OII+UCO+OneNet): $500K
  - NSF CC*IIE (OU): $400K
  - NSF CC*IIE (OneNet+GPN): $350K
  - NSF MRI (OU): $968K
  - NSF MRI (OU): $793K
  - NSF MRI (OSU): $908K
  - NSF MRI (OSU): $950K
  - NSF MRI (Langston U): $250K
  - NSF MRI (UCO): $304K
  - NSF MRI (TU): $180K
  - DOD DURIP (TU): $200K
  - NSF CC* (NSU/SWOSU/SE/RSU): $334K

OneOCII Research Computing Grants

COMPLETED

1. Grant No. EPS-0919466, "A cyberCommons for Ecological Forecasting," OU+OSU+KU+KSU, $6M, **COMPLETED**
2. Grant No. EPS-1006919, "Oklahoma Optical Initiative," OU+OSU+Noble+TU+LU+OneNet, $1.17M, **COMPLETED**
3. Grant No. OCI-10310029, "MRI: Acquisition of Extensible Petascale Storage for Data Intensive Research," OU, $793K
4. Grant No. OCI-1126330, "Acquisition of a High Performance Compute Cluster for Multidisciplinary Research," OSU, $908K
5. Grant No. ACI- 1229107, "Acquisition of a High Performance Computing Cluster for Research and Education," LU, $250
6. Grant No. ACI-1440774, "ENCITE: ENabling CyberInfrastructure via Training and Engagement," OneNet+GPN, $130K
7. Grant No. ACI-1341028, "OneOklahoma Friction Free Network," OU+OSU+LU+OII+UCO+OneNet, $500K
8. Grant No. ACI-1440783, "A Model for Advanced Cyberinfrastructure Research and Education Facilitators," OU, $400K

ONGOING

1. Grant No. ACI-1429702, "MRI: Acquisition of a High Performance Computing Cluster for Research at a Predominantly Undergraduate Institution," UCO, $304K
2. Grant No. ACI-1531128, "MRI: Acquisition of Shared High Performance Compute Cluster for Multidisciplinary Computational and Data-Intensive Research," OSU, $950K
3. Grant No. ?, "DURIP-ARO: Heterogeneous Cluster for Cyber-Physical System Security Analytics," TU, $200K
4. Grant No. CNS-1531270, "MRI: Development of Heterogeneous Cluster for Cyber-Physical System Hybrid Analytics," TU, $180K
5. Grant No. OAC-1659235, "CC* Network Design: Multiple Organization Regional One Oklahoma Friction Free Network (MORe OFFN)", NSU/SWOSU/SE/RSU, $334K
6. Grant No. OAC-1828567, "MRI: Acquisition of a Regional Resource for Long-term Archiving of Large Scale Research Data Collections," OU, $968K

<u>TOTAL to OK under OCII/OneOCII</u>: Sep 2008-Sep 2018:

$10M in 14 research computing grants to 12 OK institutions

(OU, OSU, TU, LU, UCO, OII, Noble, OneNet, NSU, SWOSU, SE, RSU)

Average of $1M per year in new research computing grants to OK institutions

Comparison: 2001-2008: $722K (3 grants) TOTAL (10% as much per year)

OneOCII Outcomes: Education

Teaching: 10 institutions including 3 Minority Serving

- Plenty of courses at OU & OSU, both supercomputing and STEM.
- Taught parallel computing using OSCER resources:
  - Cameron U – multiple times
  - East Central U (NASNI) – multiple times including **this semester**
  - Oklahoma City U – multiple times
- Taught parallel computing via LittleFe baby supercomputer and OSCER resources:
  - Southeastern Oklahoma State U (NASNI) – 3 semester sequence, multiple times
- Taught computational chemistry using OSCER resources:
  - Northeastern State U (NASNI) – multiple times
  - Southern Nazarene U
  - Rogers State U – multiple times
- Taught Bioinformatics using OSCER resources:
  - U Tulsa – 2 semester sequence

OneOCII Outcomes: Dissemination

Oklahoma Supercomputing Symposium (2002-present)

- Brings major national figures to speak at OU.
  - The goal is not just for us to hear from them, but also for them to hear about us.
- Net cost to OU is zero (other than a modest amount of labor), because costs are covered by vendor sponsorships.
- Attendance is typically 225-325.
- A cheap way to get national, regional and state research leaders to fall in love with OU, OU IT and OSCER.
- 2019: Wed Sep 25
  - Keynote: Manish Parashar, Division Director, NSF Office of Advanced Cyberinfrastructure

OneOCII Cost-Benefit Analysis

- **<u>Cost</u>**: Typically, the cost to OU IT for participating in OneOCII is low to mid 5 figures per year:
  - ~1% of OSCER resources per year (low 5 figures per year);
  - OSCER labor (5 figures per year).
- **<u>Benefit</u>**: **<u>$4.3M</u>** of grant funding to OU IT so far, plus **<u>$16.5M</u>** grant funding to OU researchers.

OneOCII Reviewer Comments #1

- NSF Director France Cordova, on hearing about OneOCII: **“Why don't we ask all our EPSCoR states to do that?”** (April 20 2017)
- NSF EPSCoR RII Track-1 (2013-18), AAAS external review committee report 2016: “From a scientific collaboration/integration perspective, three accomplishments are noted by the Panel. The first is the OneOCII between OU and OSU, and a true ‘**jewel in the EPSCoR crown**.’ It serves as a model for what a highly successful and supportive collaborative effort could produce. It is particularly noteworthy in that it enables the free usage of all OU and OSU centrally owned CI by all Oklahomans. … Another is the training sessions and support … This collaboration and its best practices have **attracted national NSF interest** in terms of **disseminating this success at the national scale**.”

OneOCII Reviewer Comments #2

- NSF MRI OURRstore: "As part of previous projects and initiatives, the PIs have **successfully engaged in community outreach, science dissemination, and broadening participation of underrepresented students**. With the proposed system, the PIs will continue these successful activities."
- NSF CC*IIE ACI-REF: "The proposal also describes the close **collaboration between the OU CI group and minority serving institutions** in Oklahoma, particularly … at Langston University. … The OU CI group has a long track record of excellence in outreach and training on a national scale, and this proposal will contribute to that."
- NSF CC-NIE OFFN: "There is also a **strong, ongoing curriculum development and deployment** project on HPC, and a local workshop series devoted to introducing large user communities to HPC. There is a **strong outreach program for minorities and workforce development** …."

Ongoing, Current and New Initiatives

OURRstore

- Our new NSF MRI grant will fund the OU & Regional Research Store (OURRstore), the successor to the PetaStore.
- It'll be available to everyone at OU, across Oklahoma, and in other EPSCoR jurisdictions.
- The labor cost on the PetaStore is low (well under an FTE), so we anticipate similar for OURRstore.
- The RFP text is ready.

Virtual Residency

- "Everyone complains about the weather, but no one ever does anything about it."
- We created a program to teach people how to be research computing facilitators, and ultimately to be institutional research computing leaders.
- Workshops: Introductory 2015, 2016, 2017; Intermediate 2018
- Biweekly conference calls
- Grant proposal writing apprenticeship
- Paper writing apprenticeship
- These activities are covered under Neeman's 25% salary+fringe from OU IT's NSF XSEDE grant subaward (previously part of one of our NSF networking grants).

Virtual Residency

- The Virtual Residency has now taught 490 people from 250 institutions in every US state plus 2 US territories and 7 other countries on 5 continents, including:
  - 59 participants from 37 Minority Serving Institutions;
  - 71 participants from 58 non-PhD-granting institutions;
  - 136 participants from 73 institutions in 24 of 26 EPSCoR jurisdictions (all except US Virgin Islands and Guam).

Henry Neeman, PI

Cyberinfrastructure Leadership Academy

University of Oklahoma
Norman, Oklahoma
http://www.oscer.ou.edu/
hneeman@ou.edu

- **Senior Cyberinfrastructure leaders** are retiring and taking their knowledge, experience and wisdom with them. We need to capture this quickly.
- **Emerging midcareer CI leaders** are excellent at responding to national needs and serving their institutions' researchers, but need to learn how to **shape the national CI agenda**.
- **Goals** of this workshop in **bringing these two groups together**:
    - **Transfer knowledge, experience and especially wisdom** from senior CI leaders to emerging CI leaders, in order to enable emerging CI leaders to shape the national research CI landscape.
    - **Initiate mentoring relationships** between senior CI leaders and emerging CI leaders, in order to foster longer term professional development.
    - **Establish peer mentoring** among emerging CI leaders, in order to prepare and position them for national leadership, as senior CI leaders reduce their day to day engagement.
- **National Strategic Computing Initiative**: This workshop focus is a key aspect of the NSF's **workforce development** mission within NSCI.

Taking Leadership

Taking Leadership

- Statewide: OneOCII (already covered)
- Regional
- National

Regional Leadership Examples

- Great Plains Network: Within the Great Plains region, we've been building our leadership across the 6 member states of the GPN (Arkansas, Kansas, Missouri, Nebraska, Oklahoma, South Dakota).
  - That's now culminated with the former OneNet CTO being hired as the Executive Director of the GPN.
- Now, with our new NSF MRI OURRstore grant, we're taking leadership both regionally with the GPN and among EPSCoR jurisdictions.
  - On the OURRstore grant, every EPSCoR jurisdiction is represented among the users and/or on the advisory committee (even US Virgin Islands and Guam).

National Leadership Examples

OSCER personnel have, or have had, the following national leadership roles:

- XSEDE Campus Engagement joint co-managers (the umbrella over Campus Champions)
- Founded the Virtual Residency
  - Trained 493 Research Computing Facilitators so far
  - Proposal writing apprenticeship
  - Paper writing apprenticeship
  - Cyberinfrastructure Leadership Academy
- Linux Clusters Institute steering committee
- SC10-11 Education Program leadership
- NSF Advisory Committee for Cyberinfrastructure (2013-17)

National Events

In 2019, we're scheduled to host the following national events:

- Cyberinfrastructure Leadership Academy Feb 26-28 2019
- Linux Clusters Institute workshop May 13-17 2019
- Virtual Residency workshop June 2-7 2019

(And of course the Oklahoma Supercomputing Symposium on Sep 25 2019.)

OSCER Executive Summary

OU Supercomputing Center for Education & Research (OSCER):

- **Systems**: **Supercomputer**; multi-petabyte **data archive** (grant-funded).
- **Savings**: **$1.56M** savings to OU in FY2018 vs cloud equivalent.
- **Research Facilitated** to date by OSCER (FY2002-18):
  - **Funding**: **$317M** of OU external research funding (plus $385M for collaborators)
    - **~23%** of OU Norman external research expenditure FY2002-18;
    - **~44%** of OU Norman external research expenditure FY2016-18.
  - **Publications**: **2936**, including 56 PhD dissertations & 40 Masters theses.
  - **Projects**: **540** by 230+ OU faculty & staff in 29 depts & 11 other units.
- **OSCER's grants**: **$1.45M** currently active, $3.58M completed.
- **Oklahoma Collaboration**: **1000% increase in annual research computing grants statewide** via the OneOklahoma Cyberinfrastructure Initiative, with OSU's supercomputing center, TU, Langston U etc.
- **OU needs OSCER to stay on top**: **100% of AAU**, **98.5% of R1**, **94% of US News Top 100** have local research computing resources.

OSCER Resources

OSCER's Current Supercomputer

Peak speed: 400 TFLOPs*

*TFLOPs: trillion calculations per second (double precision floating point)

639 compute servers

1284 Intel Xeon Haswell, Broadwell and Sandy Bridge CPU chips

13,208 CPU cores

32.8 TB RAM

400 TB public disk

1.4 PB "condominium" disk

Mellanox 40 Gbps FDR10 Infiniband (3:1 oversubscribed, 13.33 Gbps, ~1 microsec latency)

Dell N-series Gigabit/10G Ethernet

CentOS 7 Linux

290 (45%) of compute servers are "condominium" (owned by individual research teams).

schooner.oscer.ou.edu

Photo: Jawanza Bassue

Schooner: OU IT-Owned Servers

- Compute servers, non-condominium
  - 266 x R430, dual E5-2650v3 10-core 2.3/2.0 GHz, 32 GB RAM
  - 46 x R430, dual E5-2670v3 12-core 2.3/2.0 GHz, 64 GB RAM
- Accelerator-capable servers, non-condominium
  - 28 x R730, dual E5-2650v3 10-core 2.3/2.0 GHz, 32 GB RAM
  - 8 x R730, dual E5-2670v3 12-core 2.3/2.0 GHz, 64 GB RAM
- Large RAM server, non-condominium
  - 1 x R930, quad E7-4809v3 8-core 2.0/1.8 GHz, 1024 GB RAM
- Accelerators, non-condominium
  - 6 x NVIDIA K20M
  - 24 x Intel Xeon Phi 31S1P
- Subtotal peak CPU speed, non-condominium
  230.0 TFLOPs, 700 CPU chips, 7192 cores, 13.65 TB RAM

Schooner Condominium #1

- Compute servers, condominium, Haswell/Broadwell
  - 7 x R630, dual E5-2640v3 8-core 2.6/2.2 GHz, 32 GB RAM
  - 72 x R430, dual E5-2660v3 10-core 2.6/2.2 GHz, 32 GB RAM
  - 6 x R430, dual E5-2650Lv3 12-core 1.8/1.5 GHz, 64 GB RAM
  - 86 x R430, dual E5-2670v3 12-core 2.3/2.0 GHz, 64 GB RAM
  - 5 x R430, dual E5-2670v3, 12-core 2.3/2.0 GHz, 128 GB RAM
  - 14 x R430, dual E5-2650v4 12-core 2.2/1.8 GHz, 64 GB RAM
- Accelerator-capable servers, condominium, Haswell/Broadwell
  - 1 x R730, dual E5-2650v3 10-core 2.3/2.0 GHz, 32 GB RAM
  - 3 x R730, dual E5-2670v3 12-core 2.3/2.0 GHz, 64 GB RAM
- Large RAM server, Haswell/Broadwell
  - 1 x R930, quad E7-4809v3 8-core 2.0/1.8 GHz, 3072 GB RAM
  - 1 x R930, quad E7-4830v4 14-core 2.0/1.6 GHz, 2048 GB RAM
- Accelerators, NVIDIA Kepler series
  - 8 x NVIDIA K20M
- Subtotal peak CPU speed, new condominium:

  149.7 TFLOPs, 422 CPU chips, 4720 cores, 16.7 TB RAM

Schooner Condominium #2

- Compute servers, condominium, Sandy Bridge
  - 75 x R620, dual E5-2650, oct core, 2.0 GHz, 32 GB RAM
- Accelerator-capable servers, condominium, Sandy Bridge
  - 6 x R720, dual E5-2650, oct core, 2.0 GHz, 32 GB RAM
- Accelerators, condominium, Sandy Bridge
  - 12 x NVIDIA M2075
  - 6 x NVIDIA K20M
- Storage, diskfull servers, condominium, Sandy Bridge
  - 4 x R720xd, 12 x 3 TB = ~19 TB useable each
- Subtotal peak CPU speed, Sandy Bridge condominium: 20.7 TFLOPs, 162 CPU chips, 1296 cores, 2.5 TB RAM

Schooner: non-condominium other

- Interconnects
  - Infiniband: Mellanox FDR10, 3:1 oversubscribed
    (40 Gbps native, 13.33 Gbps oversubscribed)
  - Ethernet: GigE downlinks to servers, 10GE uplinks to core
- Storage (user-accessible): ~400 TB usable
  - DataDirect Networks SFA7700X w/70 x 6 TB =
    ~309 TB useable
  - 6 x home/scratch 12 x 6 TB = ~88 TB useable

Oklahoma PetaStore

- Tape archive available to researchers at OU (and statewide), with a unique business model that makes long term archival storage affordable for our researchers, who pay about **half** as much per TB per copy as USB disk drives from Walmart, and **far less** than cloud or enterprise-quality disk.
- Funded by an NSF grant.
- Currently 1.8 PB content.
- OU IT's cost: labor, maintenance.
- OU researchers' cost: tape cartridges
- We now have a new NSF grant for the next archive (OURRstore).

OSCER Accomplishments: Grants & Publications

Current Active Grants Led By OSCER

TOTAL ACTIVE GRANTS led by OSCER: <u>$1.45M</u>

- NSF OAC-1828567, "MRI: Acquisition of a Regional Resource for Long-term Archiving of Large Scale Research Data Collections," $968K (started Sep 1 2018, for OURRstore archive)
- **<u>SUBCONTRACT</u>**: NSF OAC-1548562, "XSEDE 2.0: Integrating, Enabling and Enhancing National Cyberinfrastructure with Expanding Community Involvement," LOCAL PI H. Neeman, $434K to OU (out of $110M total to 19 institutions)
- NSF OAC-1649475, "Cyberinfrastructure Leadership Academy," $49K
- Also active but not led by OSCER:
  - NSF OAC-1620695, "RCN: Advancing Research and Education Through a National Network of Campus Research Computing Infrastructures – The CaRC Consortium," $748K, led by Clemson U (co-PI H. Neeman)

Completed Grants Led by OSCER

TOTAL COMPLETED GRANTS led by OSCER: $3.58M

- NSF ACI-1440783, “CC*IIE Engineer: A Model for Advanced Cyberinfrastructure Research and Education Facilitators,” PI H. Neeman, $400K, 2014-17
- NSF ACI-1341028 , “CC-NIE Integration: OneOklahoma Friction Free Network,” PI H. Neeman, $500K, 2013-17
- NSF OCI-1039829, “MRI: Acquisition of Extensible Petascale Storage for Data Intensive Research,” PI H. Neeman, $792K, 2010-14
- NSF EPS-1006919, “Oklahoma Optical Initiative,” PI H. Neeman, $1.17M, 2010-13
- NSF OCI-0636427, “CI-TEAM Demonstration: Cyberinfrastructure Education for Bioinformatics and Beyond,” PI H. Neeman, $250K, 2006-10
- NSF OCI-0542020, “SGER: Cyberinfrastructure for Distributed Rapid Response to National Emergencies,” PI H. Neeman, $132K, 2005-7
- NSF EIA-0320895, “MRI: Acquisition of an Itanium Cluster for Grid Computing,” PI H. Neeman, $340K, 2003-6

Papers About Pieces of OSCER

1. **H. Neeman**, H. M. Al-Azzawi, A. Bergstrom, Z. K. Braiterman, D. Brunson, D. Colbry, E. Colmenares, A. N. Fuller, S. Gesing, M. Kalyvaki, C. Mizumoto, J. Park, A. Z. Schwartz, J. L. Simms and R. Vania, 2018: "Progress Update on the Development and Implementation of the Advanced Cyberinfrastructure Research & Education Facilitators Virtual Residency Program." *Proc. PEARC'18*, paper 71. DOI: 10.1145/3219104.3219117.
2. **D. Akin**, M. Belgin, T. A. Bouvet, N. C. Bright, S. Harrell, B. Haymore, M. Jennings, R. Knepper, D. LaPine, F. C. Liu, A. Maji, **H. Neeman**, R. Reynolds, A. H. Sherman, M. Showerman, J. Tillotson, J. Towns, G. Turner and **B. Zimmerman**, 2017: "Linux Clusters Institute Workshops: Building the HPC and Research Computing Systems Professionals Workforce." *HPCSYSPROS'17: Proc. HPC Systems Professionals Workshop 2017*, article 4. DOI: 10.1145/3155105.3155108
3. **S. P. Calhoun**, **D. Akin**, **B. Zimmerman** and **H. Neeman**, 2016: "Large Scale Research Data Archiving: Training for an Inconvenient Technology." *Journal of Computational Science*. DOI: 10.1016/j.jocs.2018.07.005.
4. **H. Neeman**, A. Bergstrom, D. Brunson, C. Ganote, **Z. Gray**, B. Guilfoos, R. Kalescky, E. Lemley, B. G. Moore, S. K. Ramadugu, A. Romanella, J. Rush, A. H. Sherman, B. Stengel and D. Voss, 2016: "The Advanced Cyberinfrastructure Research and Education Facilitators Virtual Residency: Toward a National Cyberinfrastructure Workforce." *Proc. XSEDE'16*, article 57. DOI: 10.1145/2949550.2949584.
5. **H. Neeman**, K. Adams, **J. Alexander**, D. Brunson, **S. P. Calhoun**, J. Deaton, F. Fondjo Fotou, K. Frinkle, **Z. Gray**, E. Lemley, G. Louthan, G. Monaco, M. Morris, J. Snow and **B. Zimmerman**, 2015: "On Fostering a Culture of Supercomputing Grant Proposals within a Community of Service Providers in an EPSCoR State." *Proc. XSEDE'15*, article 19. DOI: 10.1145/2792745.2792764.
6. **H. Neeman**, **D. Akin**, **J. Alexander**, D. Brunson, **S. P. Calhoun**, J. Deaton, F. Fondjo Fotou, **B. George**, **D. Gentis**, **Z. Gray**, **E. Huebsch**, G. Louthan, **M. Runion**, J. Snow and **B. Zimmerman**, 2014: "The OneOklahoma Friction Free Network: Towards a Multi-Institutional Science DMZ in an EPSCoR State." *Proc. XSEDE'14*, article 49. DOI: 10.1145/2616498.2616542.
7. **S. P. Calhoun**, **D. Akin**, **J. Alexander**, **B. Zimmerman**, **F. Keller**, **B. George** and **H. Neeman**, 2014: "The Oklahoma PetaStore: A Business Model for Big Data on a Small Budget." *Proc. XSEDE'14*, article 48. DOI: 10.1145/2616498.2616548.
8. C. Carley, B. McKinney, L. Sells, C. Zhao and **H. Neeman**, 2013: "Using a Shared, Remote Cluster for Teaching HPC." *Proc. IEEE CLUSTER 2013*. DOI: 10.1109/CLUSTER.2013.6702630.
9. **H. Neeman**, D. Brunson, J. Deaton, **Z. Gray**, **E. Huebsch**, **D. Gentis** and **D. Horton**, 2013: "The Oklahoma Cyberinfrastructure Initiative." *Proc. XSEDE'13*, article 70. DOI: 10.1145/2484762.2484793.

How Does OSCER Measure Up?

- **<u>Grants</u>**: NSF national avg 24%, NSF OK avg 16% (FY2018) https://dellweb.bfa.nsf.gov/awdfr3/default.asp
  - Led by OSCER (Neeman as PI): 43%

    (1.8x nat'l avg, 2.7x OK avg)
- **<u>Publications</u>** (peer reviewed): 9 in 6 years (1.5 per year)
  - OU Norman average FY2018: 1.98 publications per year

    https://vpr-norman.ou.edu/rsa/fy2018-research-dashboard-charts
  - Neeman (19% faculty): ~**4x** as productive as OU Norman avg (when adjusted for % faculty)

OSCER NSF MRI Grants

For the NSF's prestigious Major Research Instrumentation (MRI) program (at most 3 proposals per institution per year), since OSCER was founded in fall 2001:

- OU IT has won **<u>$2.1M</u>** of the $11.7M in MRI grant funds to OU (17% of OU's MRI funds).
- OU IT has won 3 of the 21 MRI grants to OU (14% of OU's MRI grants).
- OU IT is OU's #2 department for total MRI grant funds and is tied for OU's #2 department for number of MRI grants.
- Neeman is OU's #2 PI for total MRI grant funds (by $9K), OU's #1 PI for number of MRI grants, and Oklahoma's #3 PI for total MRI grant funds.

OSCER Research Networking Grants

OSCER has also had 3 research network grants, totaling **$2M**:

- NSF ACI-1440783, "CC*IIE Engineer: A Model for Advanced Cyberinfrastructure Research and Education Facilitators," PI H. Neeman, $400K, 2014-17
- NSF ACI-1341028 , "CC-NIE Integration: OneOklahoma Friction Free Network," PI H. Neeman, $500K, 2013-17
- NSF EPS-1006919, "Oklahoma Optical Initiative," PI H. Neeman, $1.17M, 2010-13

Combined with NSF MRI grants, OSCER has gotten **$4.1M** in technology grants! (Avg $241K per year)

(**NOTE**: **NOT** a promise to bring in that much per year ….)