Supercomputing Systems

EE685, Fall 2024

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What Is A Supercomputer?

- One of the most expensive computers?
- A very fast computer?
- Really two key characteristics:
  - Computer that solves big problems...
    stuff that wouldn't fit on a PC
    stuff that would take too long to run
  - Performance can scale...
    more money buys a faster machine
- A supercomputer can be cheap!

The Key Is Parallel Processing

- Process *N* "pieces" simultaneously, get up to factor of *N* speedup
- Modular hardware designs:
  - Relatively easy to scale – add modules
  - Higher availability (if not reliability)

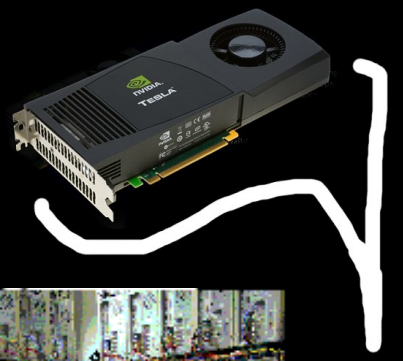
Amdahl's Law

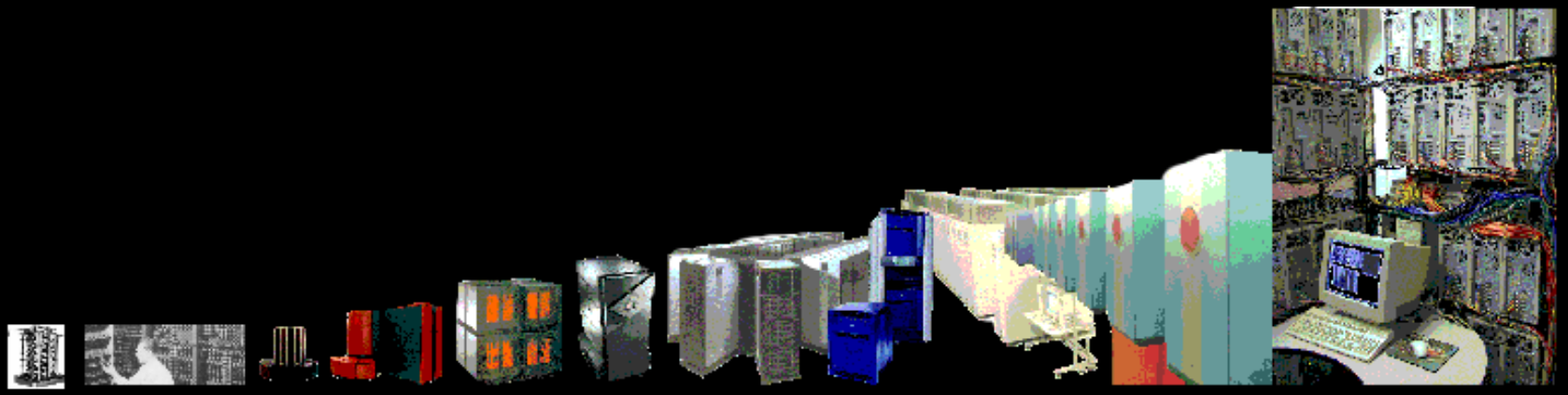
- If 1/N time is not affected by a change, the best possible speedup is only N
- Originally for sequential overhead in parallel code, but applies for any change

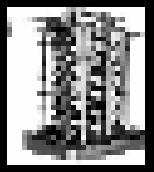
Suppose a program spends 80% of its time doing multiplies... you can't get more than a 5X speedup by improving only multiplies!

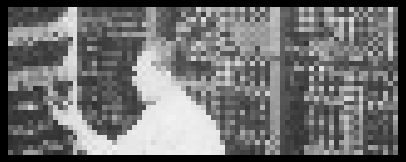
The Evolution Of Supercomputers

- Most fit survives, even if it's ugly
- Rodents outlast dinosaurs...
  and bugs will outlast us all!



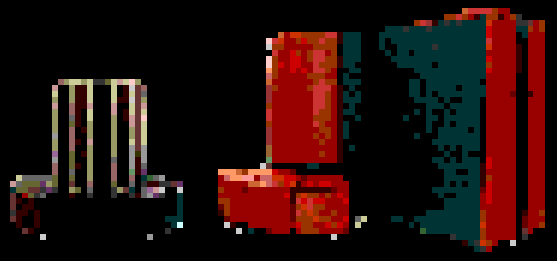






Pre-Siliconian Era

- Before cheap transistors (– 1960s)
- E.g.: ENIAC
- Faster because machines are faster than humans
- Does one operation at a time because circuitry is too expensive to do more

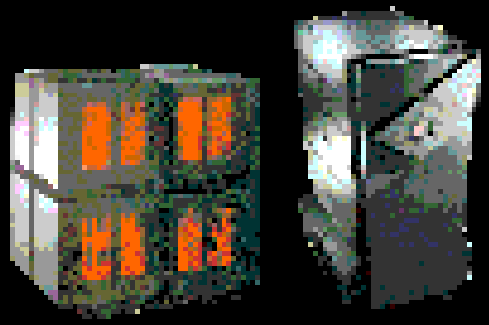


Vectorian Period

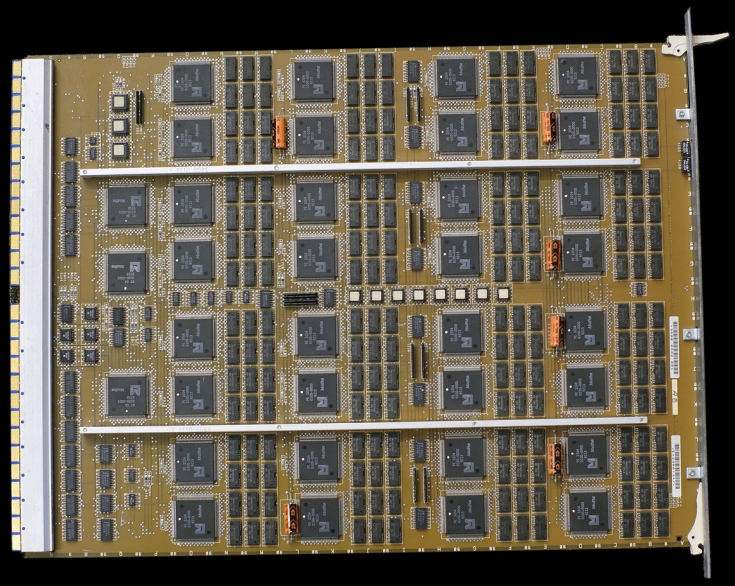
- Cheap transistors (1970s)
- E.g.: Cray 1
- Faster by applying the same operation to a vector of data at a time:

```
A[0..N] = B[0..N] + C[0..N]
```

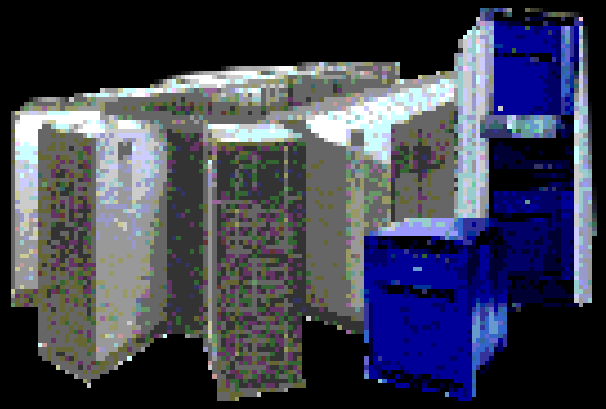
- Can't change parallelism width without changing all register sizes and datapaths



Early Massivian Period



- Cheap chips with many transistors (1980s)
- E.g.: Thinking Machines Connection Machine
- Faster by applying the same operation to a vector of data at a time
- Modularly scalable SIMD (Single Instruction, Multiple Data) – can change parallelism simply by adding modules

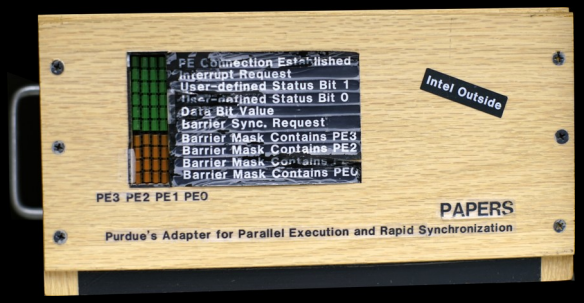


Sharedmemian Period

- Cheap processors with custom memory
- E.g.: SGI Origin
- Faster by executing different code in parallel, using a custom shared memory to interact
- Modularly scalable MIMD (Multiple Instruction, Multiple Data) – can change parallelism simply by adding modules

Late
Massivian
Period

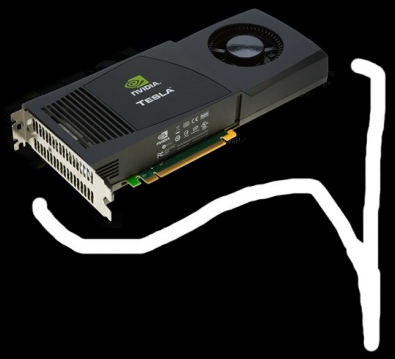
- Cheap processors with custom network (1990s)
- E.g.: ASCI Red
- Faster by executing different code in parallel, using a custom messaging network to interact
- Modularly scalable MIMD (Multiple Instruction, Multiple Data) – can change parallelism simply by adding modules



Clusters!

Clusterian Period

- Commodity parts and interfaces (1994 –)
- E.g.: Spareparticus, Beowulf, KLAT2, NAK
- Faster by executing different code in parallel, leverages commodity processors and network and also standard interfaces for custom parts
- Modularly scalable MIMD (Multiple Instruction, Multiple Data) – can change parallelism simply by adding modules



- GPUs (Graphics Processing Units) as cheap, fast, add-in cards in cluster nodes (2010 –)
- E.g.: NAK (and *most of the Top500*)
- The thing(s) on video cards... SIMDish, but:
  - Lots of little SIMDs (low fanout)
  - Multithreading to hide memory latency
  - Various restrictions to simplify HW
- NVIDIA CUDA and OpenCL...
- Intel's Xeon Phi is *sort-of* a GPU, but MIMDish
- GPU(s) will be on chip with SMP cores

Quantum?

- Uses QuBits rather than Bits
- Superposition allows 0, 1, or *indeterminate*
- Entangled superposed QuBits can hold all possible values simultaneously
  - E.g., 16 QuBits can hold {0, 1, 2, … 65535}
  - Parallel processing without parallel hardware
- Reading a QuBit's value collapses superposition; you get only a single answer
- Could be the next big thing… or not

Clusters And Bigger

- Mostly from interchangeable (PC) parts…
  and mostly running some form of Linux
- Cluster or Beowulf is a *parallel supercomputer*
  with tightly coupled, homogeneous, nodes
- Farm is homogeneous, colocated, machines
  with a common purpose (e.g., a render farm)
- Warehouse Scale Computer is a warehouse full
  of racked clusters used for *throughput*
- Grid is many internet-connected machines
- Cloud is *virtualized* grid/WSCs providing *services*

Types Of Hardware Parallelism

- Pipeline
- Superscalar, VLIW, EPIC
- SWAR (SIMD Within A Register)
- SMP (Symmetric MultiProcessor; multi-core)
- GPU (Graphics Processing Unit)
- Cluster
- Farm / Warehouse Scale Computer
- Grid / Cloud

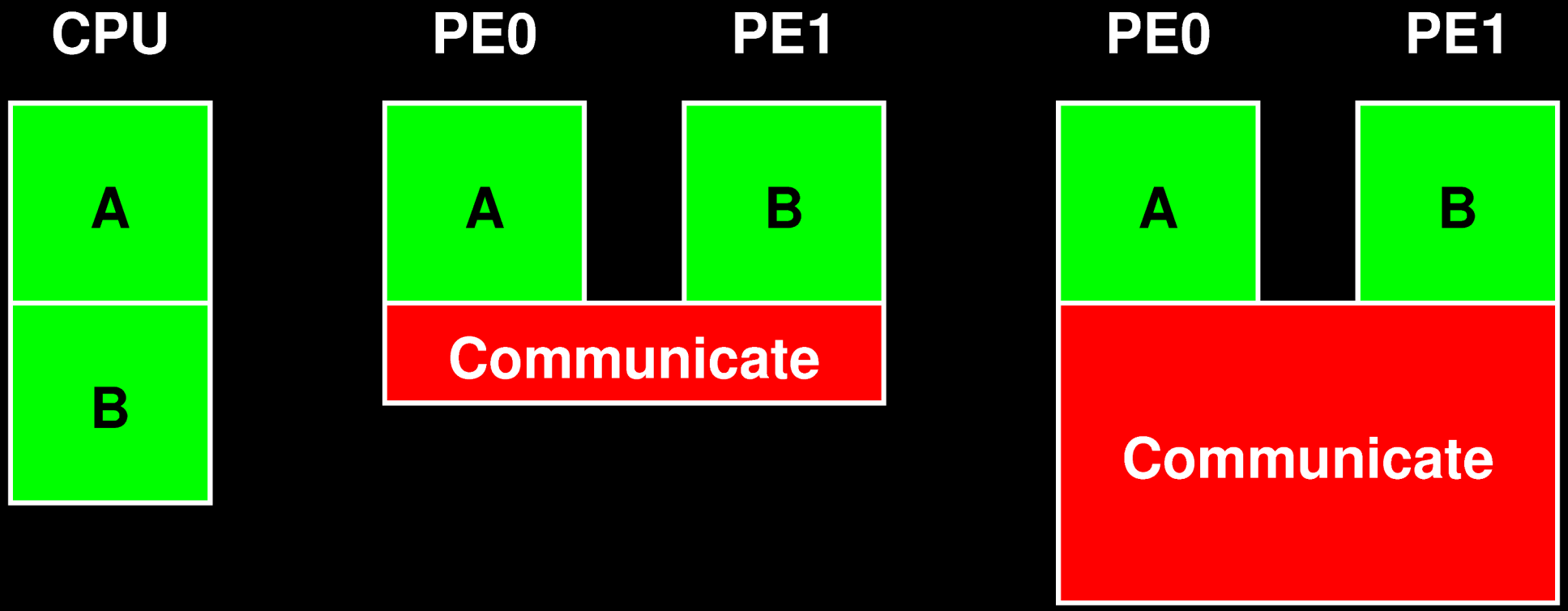
Engineering A Cluster

- This is a ***systems*** problem
- Optimize ***integrated effects*** of:
  - Computer architecture
  - Compiler optimization/parallelization
  - Operating system
  - Application program
- Payoff for good engineering ***can be*** **HUGE!**
  (penalty for bad engineering ***is*** **HUGE!**)

One Aspect: Interconnection Network

- Parallel supercomputer **nodes** interact
- **Bandwidth**
  - Bits transmitted per second
  - **Bisection Bandwidth** most important
- **Latency**
  - Time to send something here to there
  - Harder to improve than bandwidth....

Latency Determines Smallest Useful Parallel Grain Size

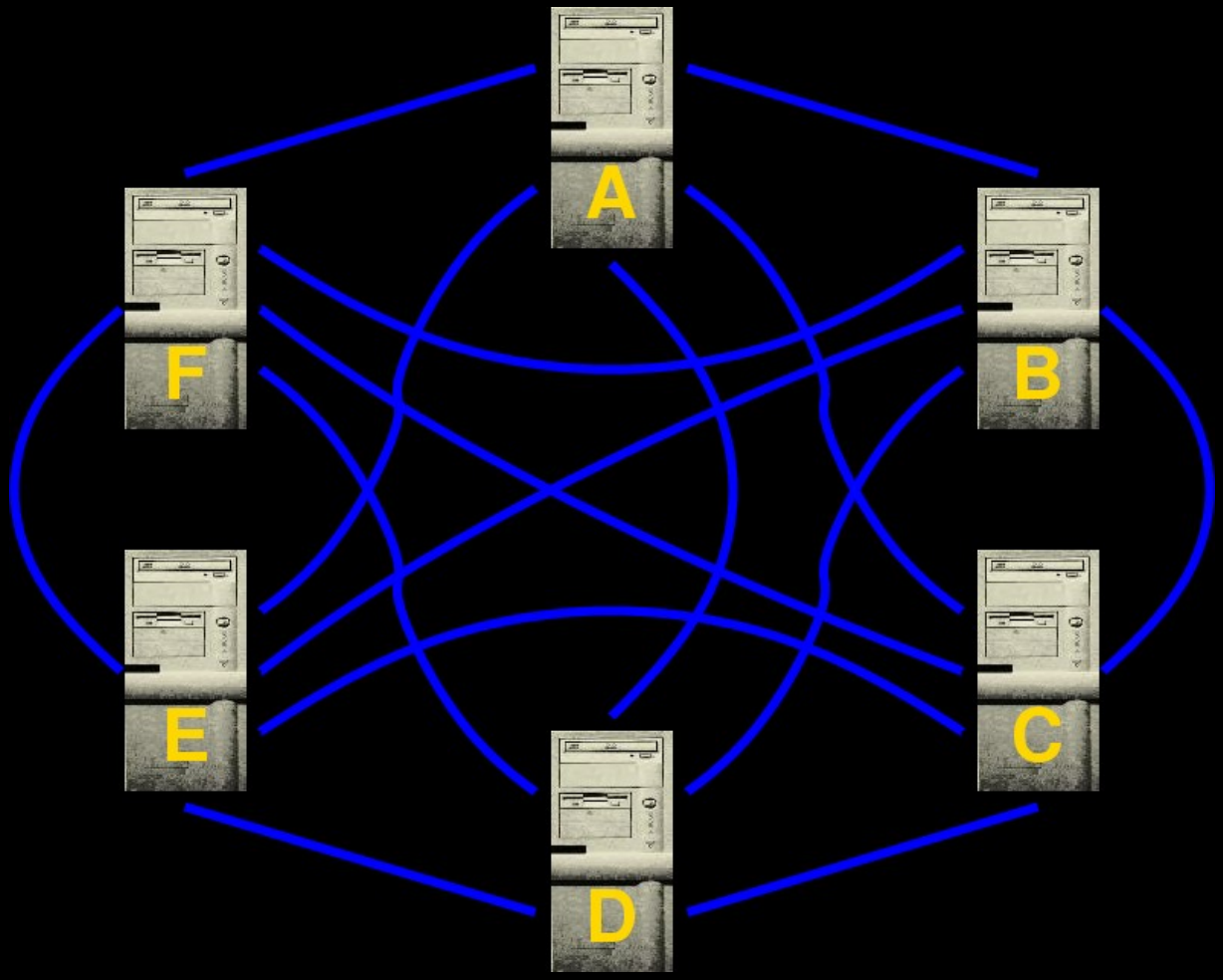


Network Design

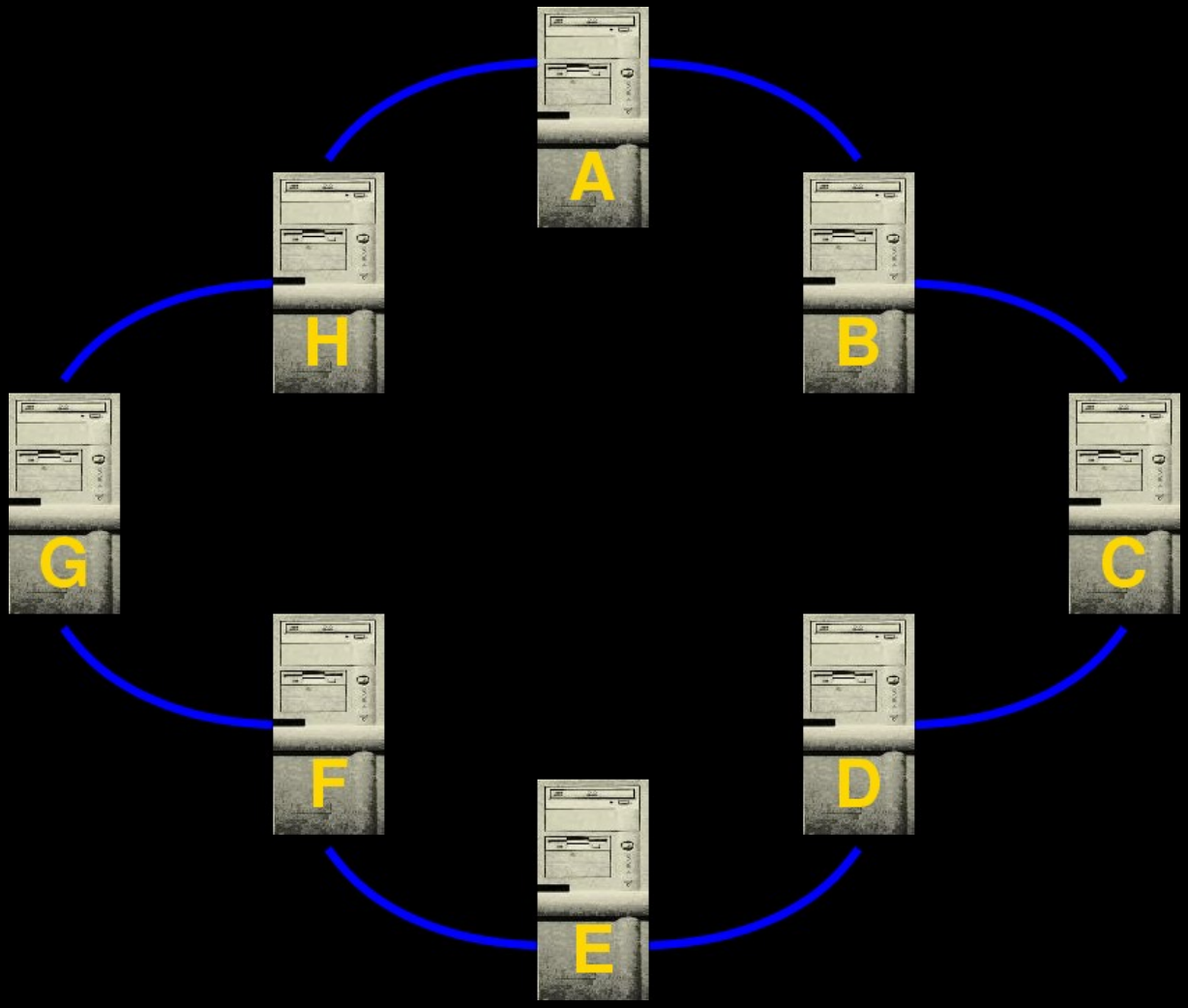
- Assumptions
  - Links are bidirectional
  - Bounded # of network interfaces/node
  - Point-to-point communications
- **Topology**
- Hardware
- Software
- Circuit switching vs. Packet switching vs. Circuit-acquired packet switching
- Routing?

No Network

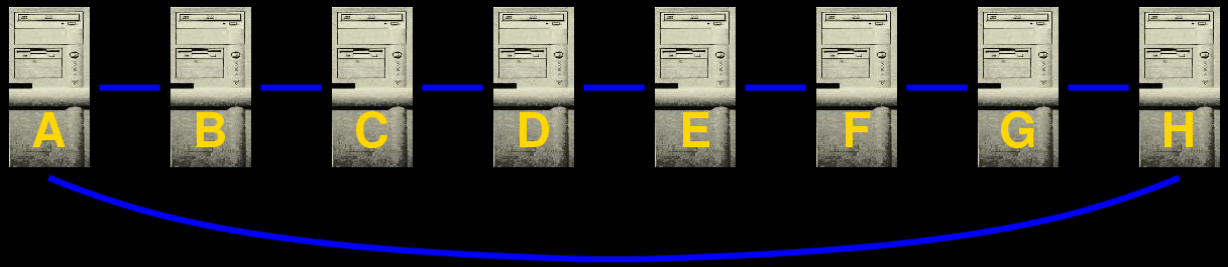
Direct Fully Connected

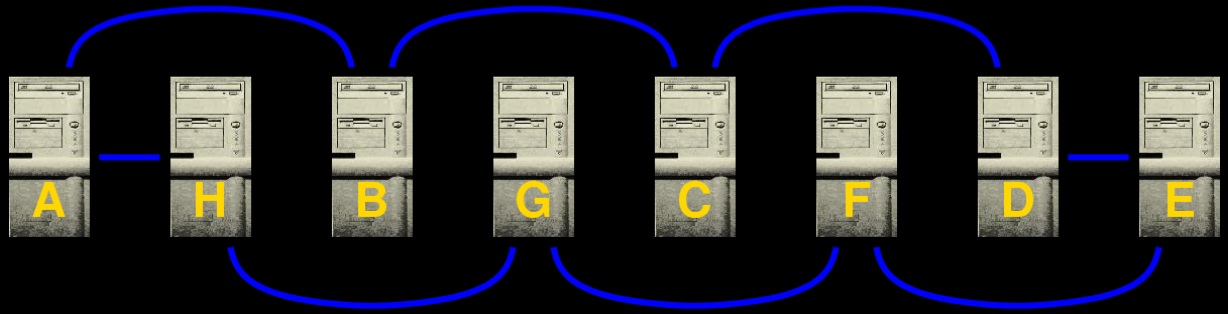


Toroidal 1D Mesh (Ring)

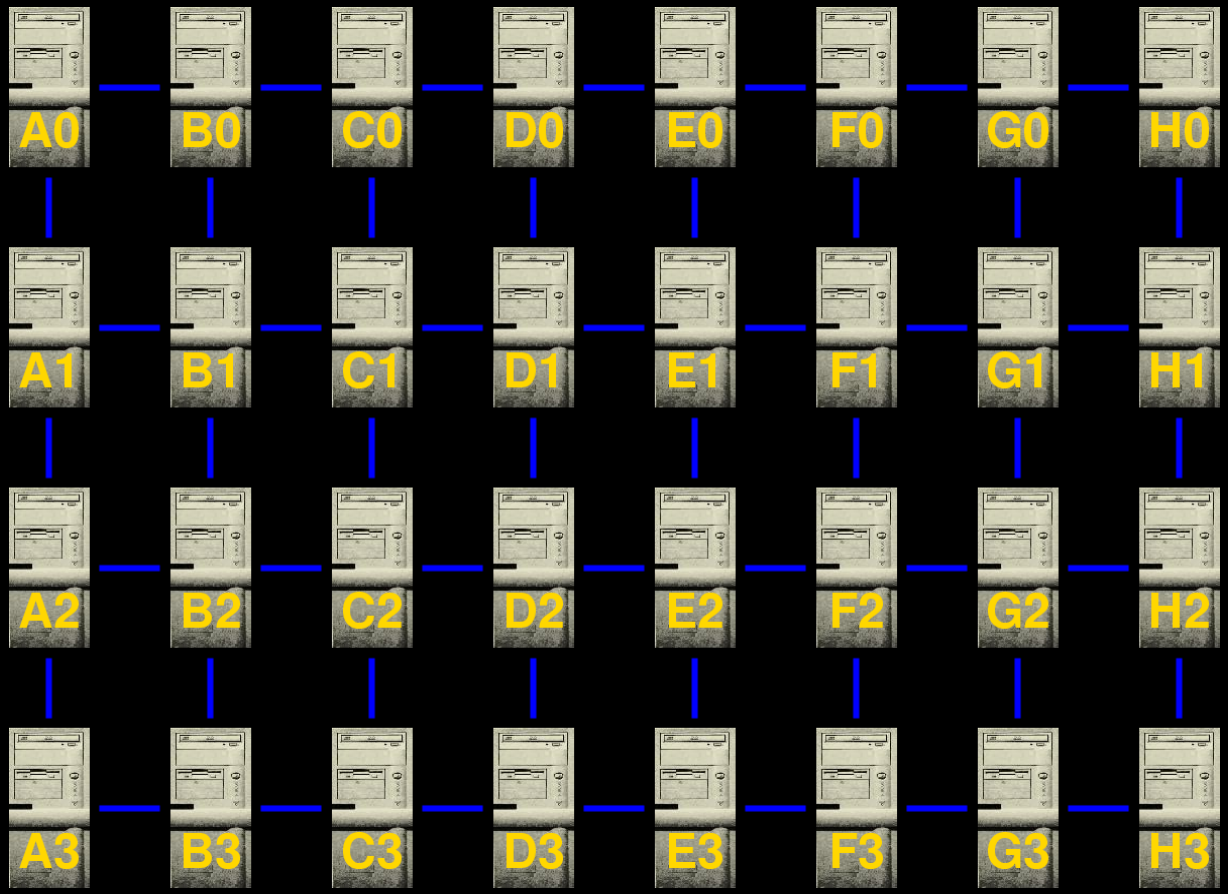


Physical Layout Of Ring

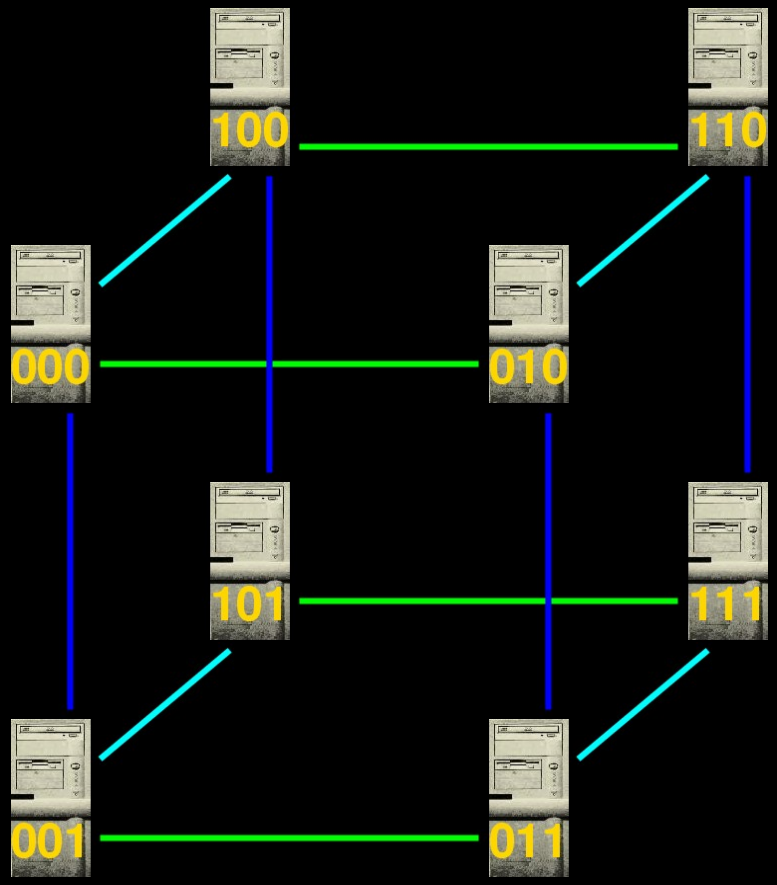




Non-Toroidal 2D Mesh



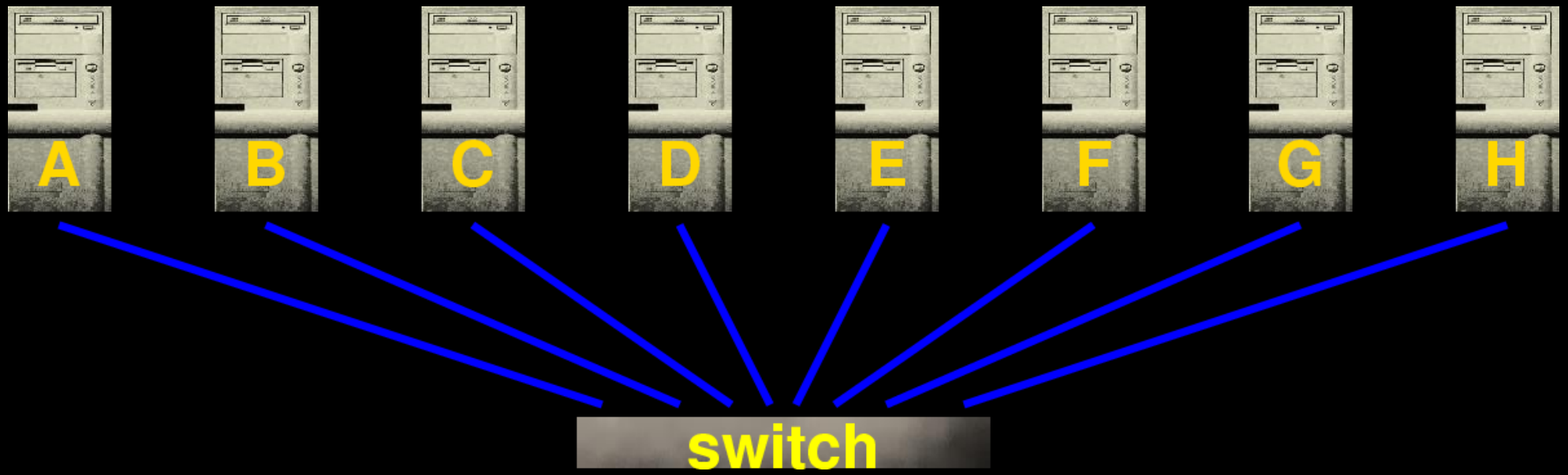
3-Cube (AKA 3D Mesh)



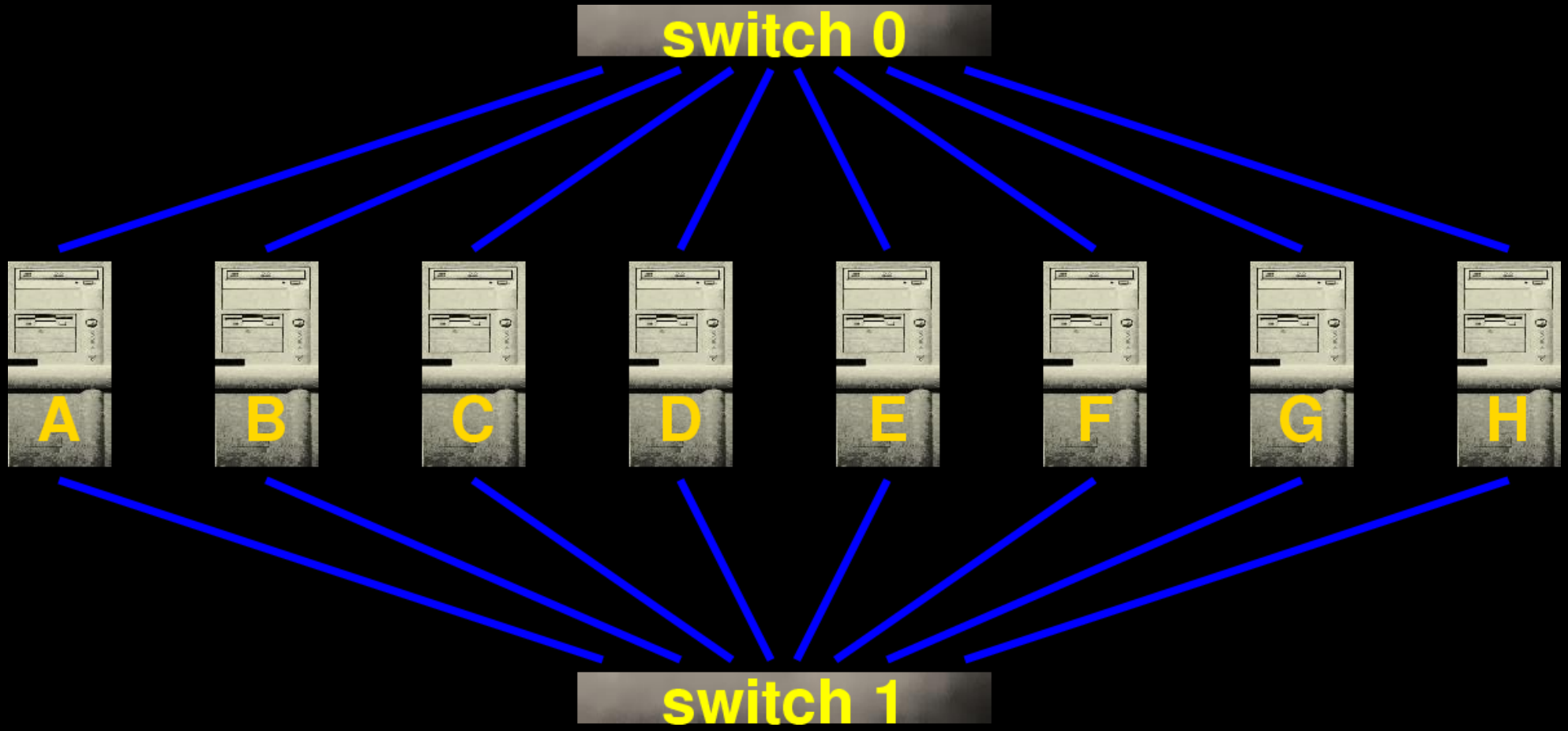
Switch Networks

- Ideal switch connects *N* things such that:
  - Bisection bandwidth = # ports
  - Latency is low (~30us for Ethernet)
- Other switch-like units:
  - Hubs, FDRs (Full Duplex Repeaters)
  - Managed Switches, Routers
- Not enough ports, build a Switch Fabric

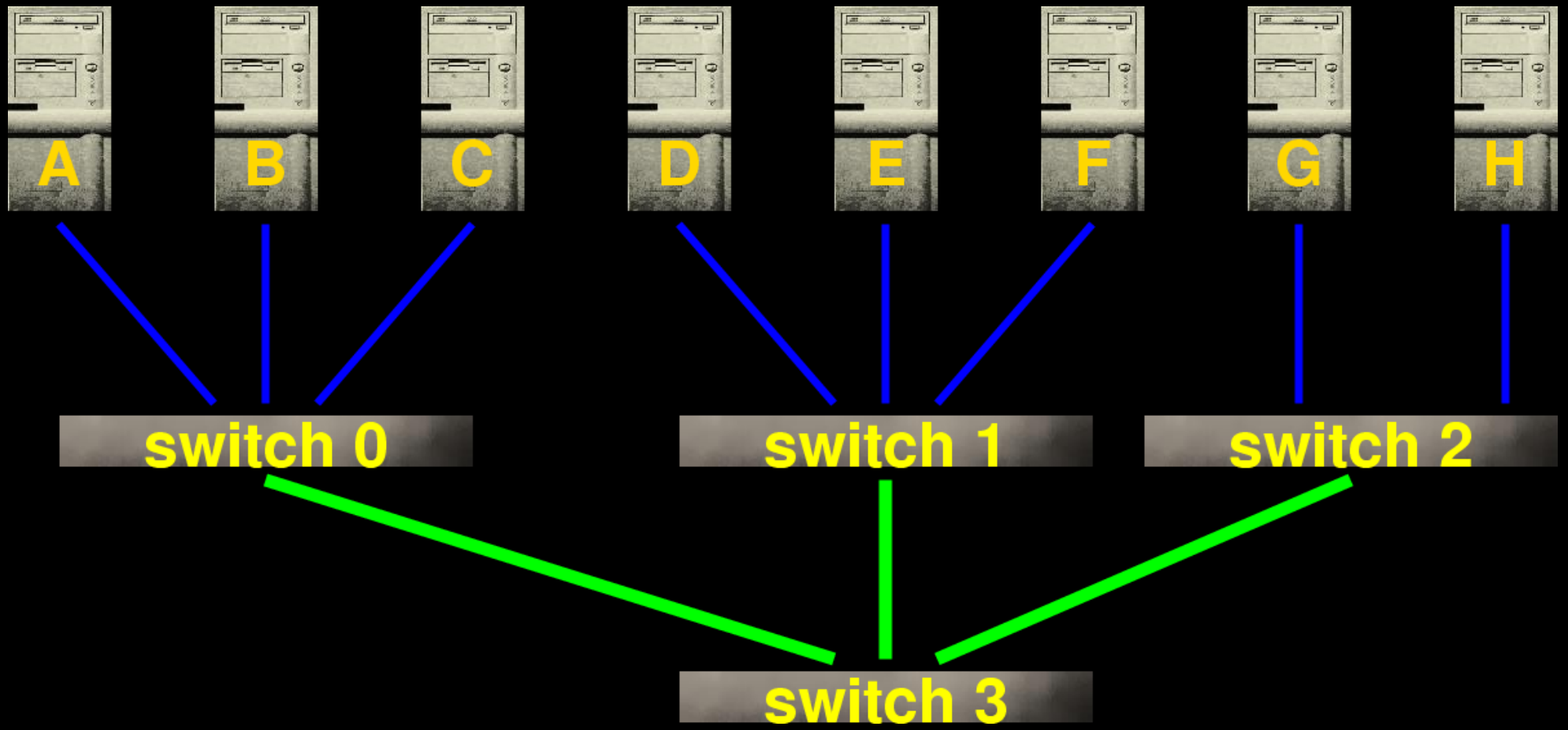
Simple Switch (8-Port)



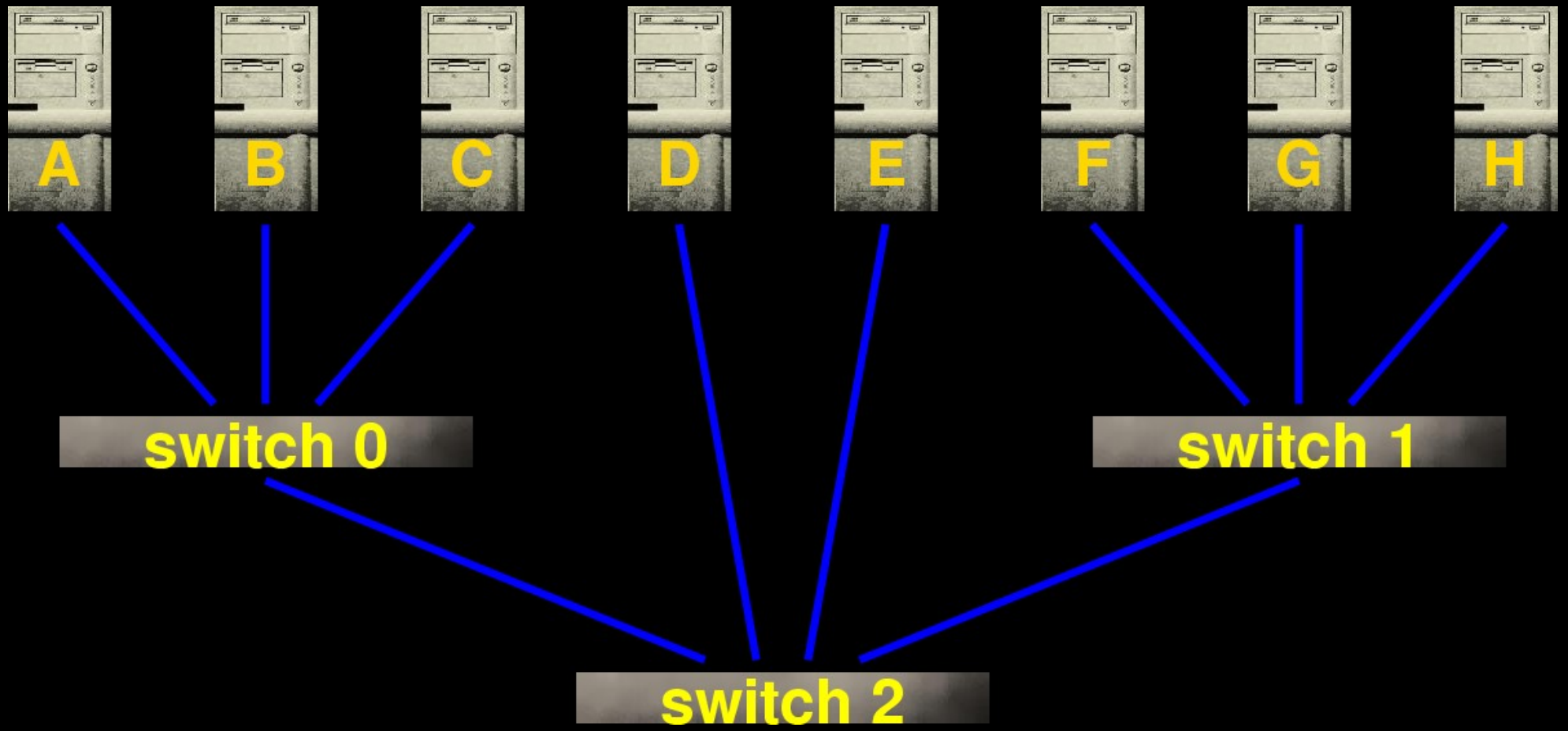
2-Way Channel Bonding



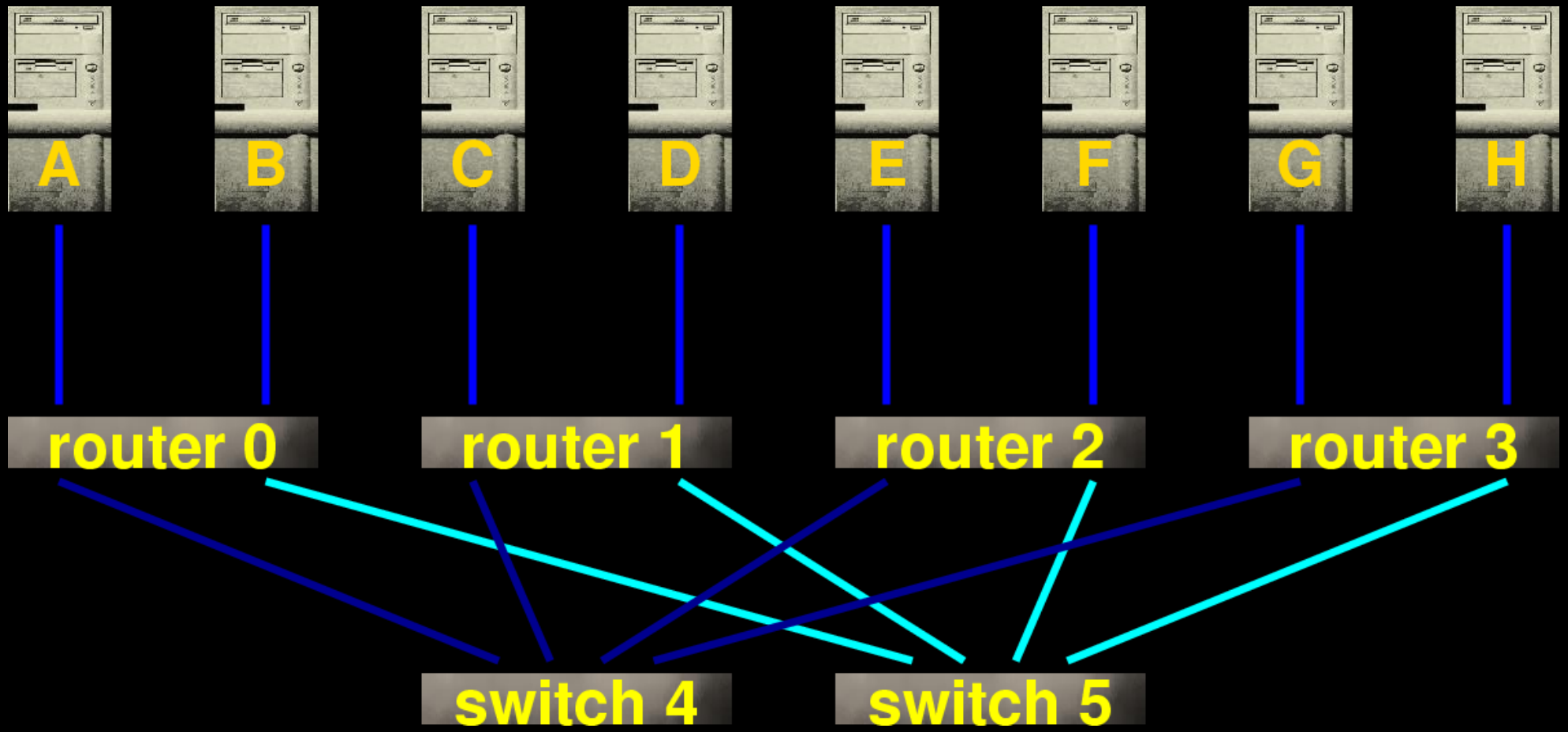
Tree (4-Port Switches)



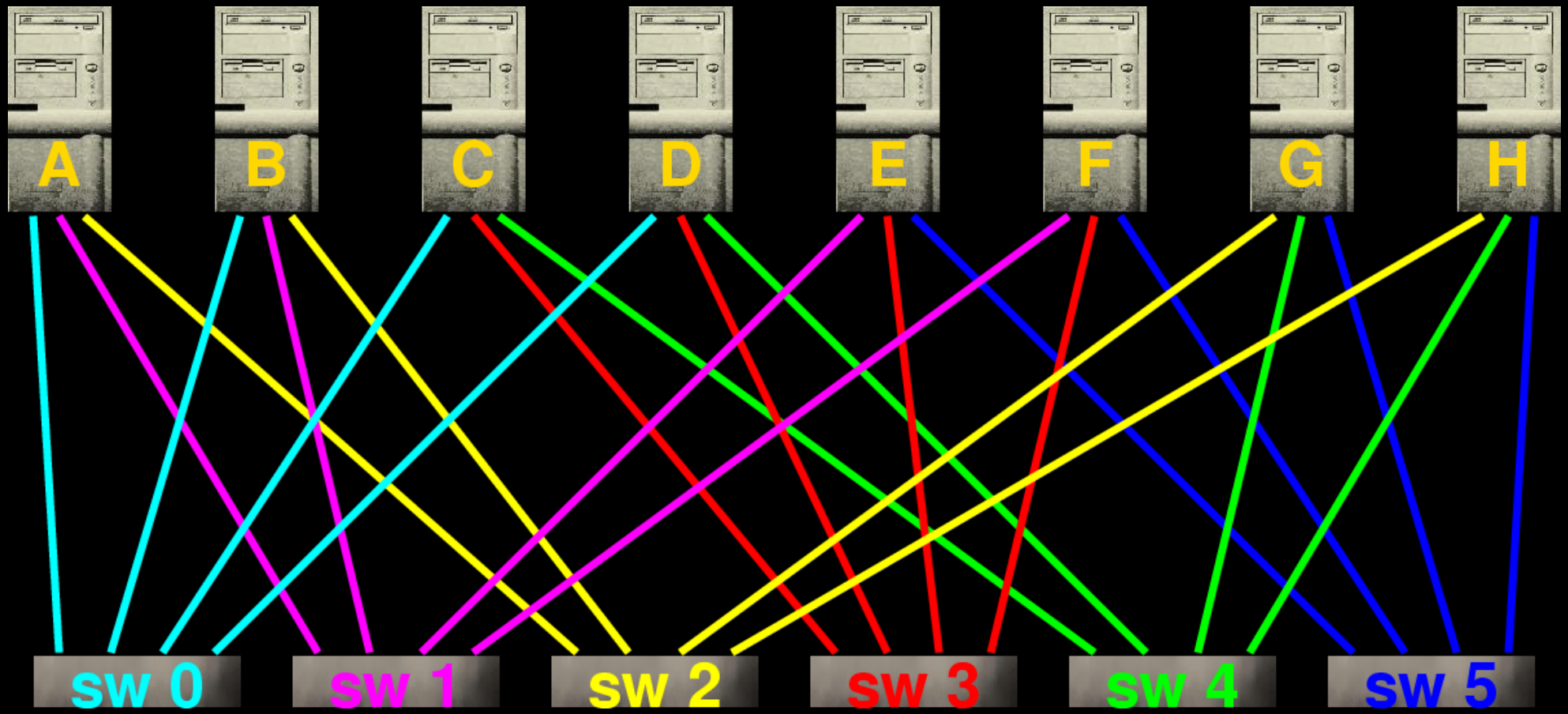
A Better Tree



Fat Tree


A
B
C
D
E
F
G
H
router 0
router 1
router 2
router 3
switch 4
switch 5

Flat Neighborhood Network...
from UK!



Flat Vs. Fat

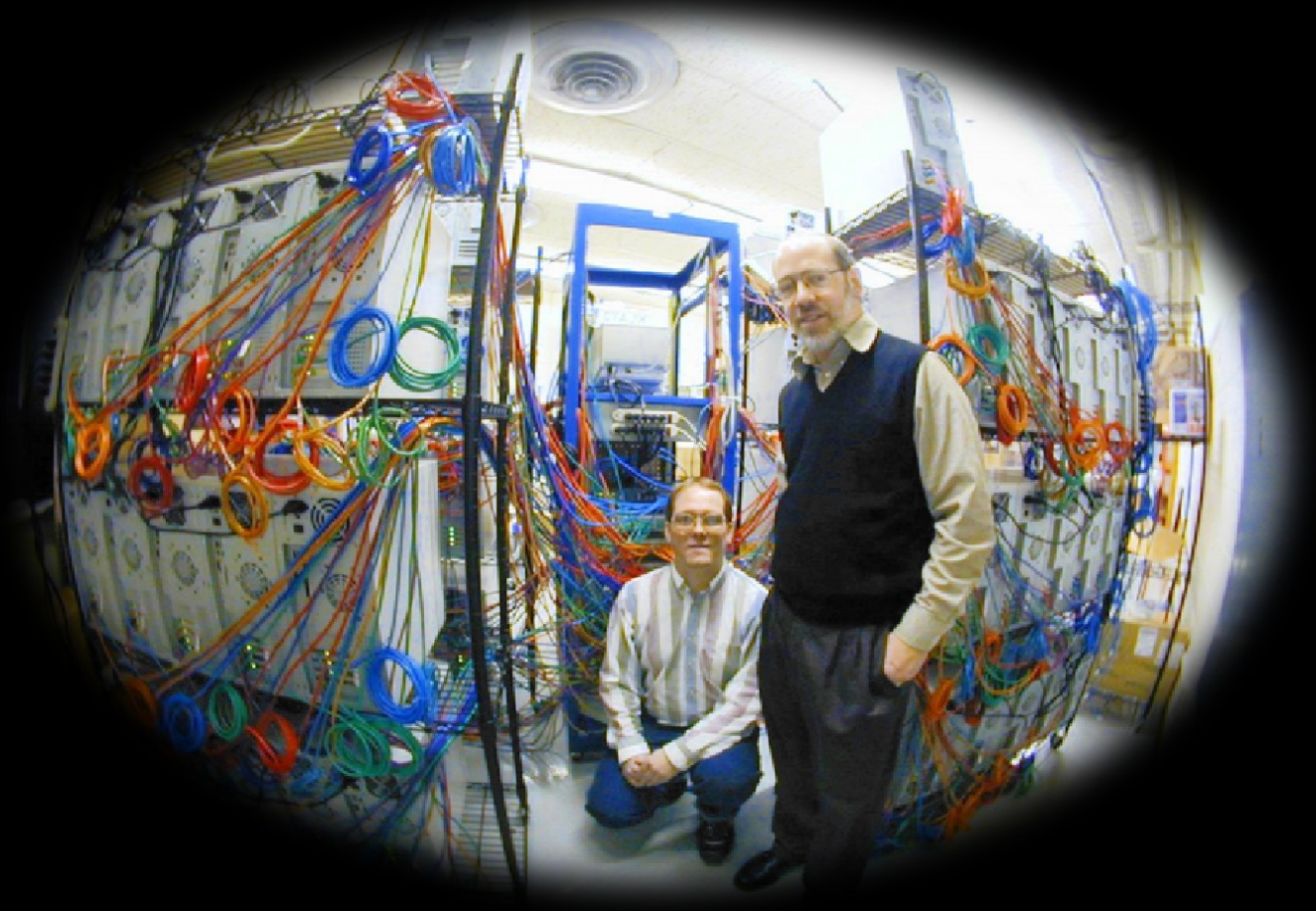
- Latency:
  - 8 node, 4 port: 1.0 vs. 2.7 switch delays
  - 64 node, 32 port: 1.0 vs. 2.5
- Pairwise bisection bandwidth:
  - 8 node, 4port: 1.29 vs. 1.0 units
  - 64 node, 32 port: 1.48 vs. 1.0
- Cost: more interfaces vs. smart routers
- Summary: **Flat Neighborhood wins!**

KLAT2, Gort, & Klaatu

KLAT2 Changed Everything

- KLAT2 (Kentucky Linux Athlon Testbed 2):
  - 1st network designed by computer
  - 1st network deliberately asymmetric
  - 1st supercomputer under $1K/GFLOPS
- 160+ news stories about KLAT2
- Various awards:
  - 2000 Gordon Bell (price/performance)
  - 2001 Computerworld Smithsonian, among 6 Its most advancing science

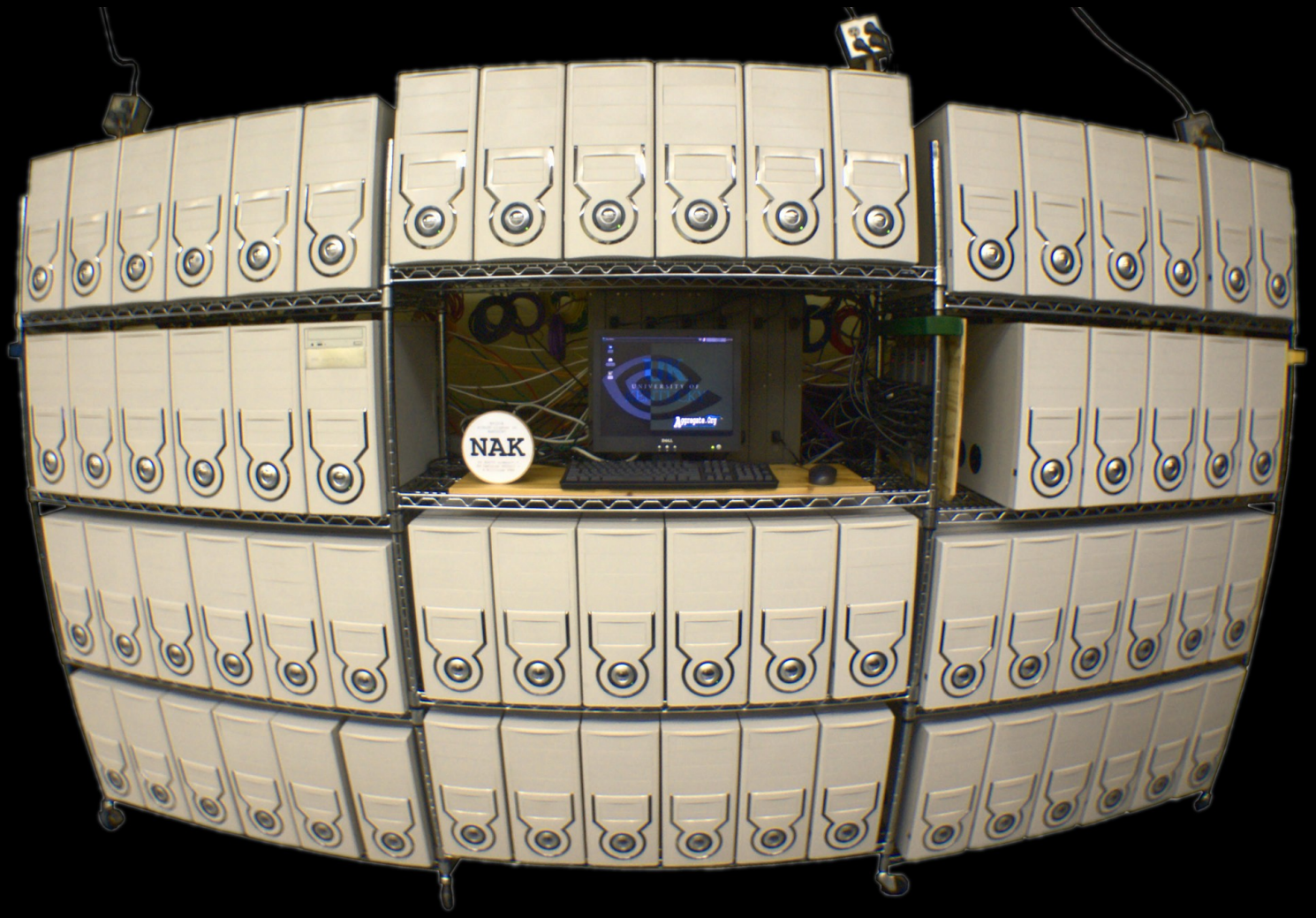
2000, KLAT2



2003, KASY0

2006, ATI GPU

2010, NAK



2012, GPU Clusters

A *Little* Progress…

A GFLOPS is 1 Billion {+,*} per second

1992 MasPar MP1 $1,000,000 / GFLOPS

A *Little* Progress…

A GFLOPS is 1 Billion {+,*} per second

1992	MasPar MP1	$1,000,000 / GFLOPS
2000	KLAT2	$650 / GFLOPS

A *Little* Progress…

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A *Little* Progress...

A GFLOPS is 1 Billion {+,*} per second

1992	MasPar MP1	$1,000,000 / GFLOPS
2000	KLAT2	$650 / GFLOPS
2003	KASY0	$84 / GFLOPS
2010	NAK	$0.65 / GFLOPS

2022 GeForce RTX3090Ti peak is 40 TFLOPS
@ $2K (not counting host)... $0.05 / GFLOPS

The Future

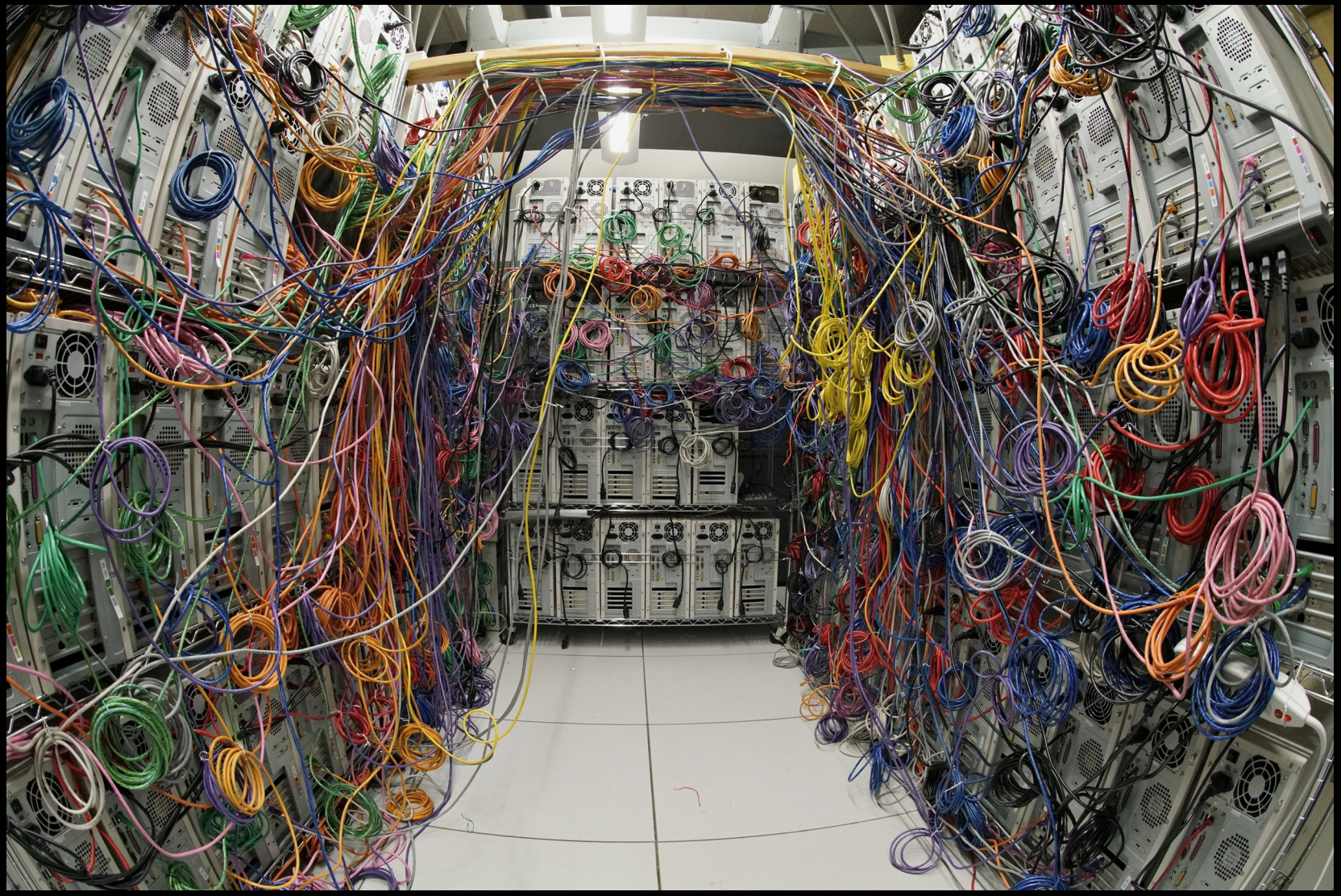
- Everything is moving down...
  Your cell phone outruns the 1992 MasPar MP1; supercomputer today, in your cell phone soon
- More parallelism (and maybe **quantum** too?)
- More heterogeneous (helped by **dark silicon**)
- Everything contains a connected computer (e.g., IoT: Internet of Things)… a good thing?

Dietz's ECE Lab, 108

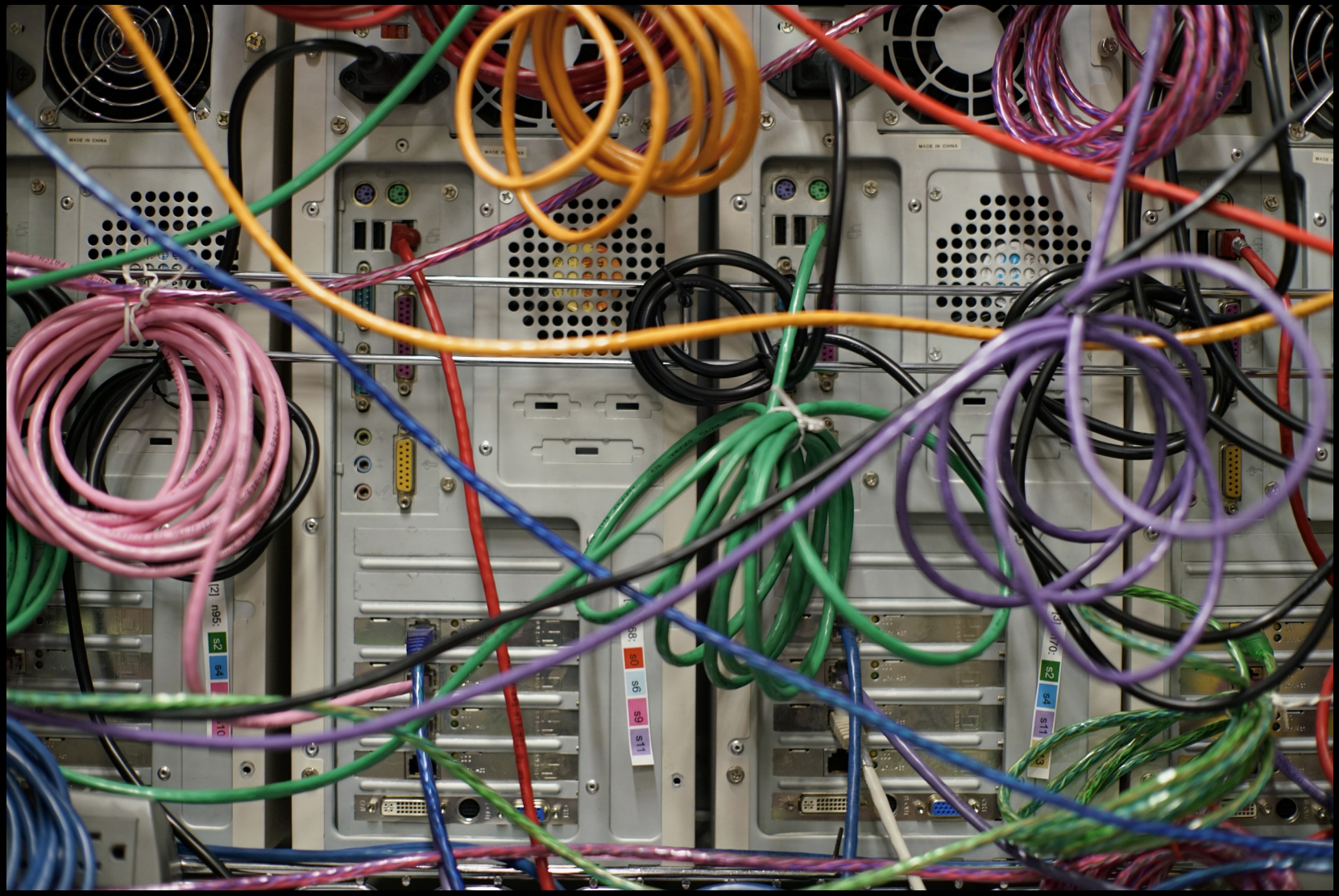
Machine Room, 108A

RAID, Heads, & Rack Cluster

Our “Big” FNN GPU Cluster



How to Wire an FNN



Our Quantum-Inspired Stuff:
Parallel Bit Pattern Computing